CAP2

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

Renewal Proposal
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PROJECT SUMMARY
Central Arizona–Phoenix Long-Term Ecological Research: Phase 2

This proposal is to extend to 13 years a long-term study of central Arizona and metropolitan Phoenix, a 6,400-km^2 region of desert, agricultural, and urban/suburban lands that is experiencing rapid urbanization and population increase. CAP1 yielded significant insights into the central question, **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?** CAP LTER findings are contributing to development of an ecological theory that integrates social and ecological variables. Based upon seven years of research on LTER core areas plus study of human drivers and feedbacks of ecological change, CAP2 will be reorganized into five new **Integrative Project Areas (IPAs).** Each area intersects with one or more LTER core areas, but the new research organization aids in explicit inclusion of socioeconomic drivers and feedbacks. The five IPAs are: land-use and land-cover change; climate and ecosystem dynamics; water policy, use, and supply; material flux and socio-ecosystem response; and human control of biodiversity.

The *modus operandi* for long-term monitoring, experiments, information management, site management, network participation, and education/outreach was established during CAP1 pilot projects. Projects continued in CAP2 include: long-term monitoring at 200 sites across CAP; historical analyses of land use; classification of land cover; documentation of change in land cover and use; river monitoring above and below the city; and establishment of intensive sites for in-depth climatic, ecological, and social surveys and experiments. Three long-term experiments will be continued and a fourth initiated (long-term factorial N+P fertilization along a deposition gradient). The recently established North Desert Village "experimental suburb" will be the first ever experimental study (manipulating vegetation types and irrigation methods) of interactions between people and their ecological environment at the neighborhood scale. Acquisition of existing agency databases for analysis (e.g., the distribution of toxic risk in relation to socioeconomic groups) was a major thrust of CAP1 information management and will continue in CAP2 to provide a valuable resource for hypothesis-testing. Modeling research will feature improved simulation models of land-use change and urban-ecosystem functioning and development of scenarios of future growth and change for this urban region.

CAP LTER's **broader impacts** are four: 1) raising the profile and awareness of urban ecology in both science and society; 2) contributing to education and outreach at all levels; 3) producing and maintaining a comprehensive, long-term database of ecological and social variables for a rapidly changing socio-ecosystem; and 4) promoting knowledge exchange with community and governmental decisionmakers. CAP LTER has led the way in demonstrating the need for socioecological integration, both within the LTER network and in the environmental science disciplines (Impact 1). Ecology Explorers, CAP LTER's K-12 education-outreach program, will see continued growth while maintaining its existing diversity of programs and working toward district-wide adoption of the Ecology Explorers curriculum (impact 2). Two new programs are introduced to promote undergraduate involvement: the Communities of Research Scholars and Interns (Impact 2). CAP LTER participants developed the IGERT program in urban ecology and will continue to support graduate participation in research, introducing summer support for independent research in CAP2 (impact 2). Information management will continue to develop innovative new techniques to preserve the long-term integrity and accessibility of the CAP LTER database (Impact 3). Finally, for knowledge exchange (Impact 4), CAP LTER has partnered with several related projects and initiatives in science-policy outreach relating to the urban environment.

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1. RESULTS FROM CAP1

1.1. OVERVIEW

Six years ago, we began a comprehensive study of the rapidly urbanizing central Arizona region, encompassing the Phoenix metropolitan area. Adding to the usual LTER challenges, the study of an urban ecosystem requires us to understand the consequences of intensive human actions, radically altered land cover, accelerated cycling of materials, and ecological impacts of a built environment. As at traditional LTER sites, interdisciplinary collaboration of ecologists, biogeochemists, earth scientists, and climatologists is fundamental but, for a city, sociologists, geographers, economists, urban planners, anthropologists, engineers, and many community partners are also essential. The lessons we learn are helping to frame a new ecology theory that integrates social with ecological variables (Redman 1999; Collins *et al.* 2000; Grimm *et al.* 2000; Kinzig *et al.* 2000; Zipperer *et al.* 2000; Grimm *et al.* 2002; Redman *et al.* 2004).

CAP1 began with several approaches—pilot studies, data-mining and synthesis projects, and short-term experiments—broadly following LTER core areas while integrating human dimensions. In the first three years, we established *long-term research* at a broad spatial extent, to be repeated every five years (Survey200) (Hope *et al.* 2003), along with intensive monitoring at permanent aquatic and terrestrial sites. *Data mining* from local, state, and federal agencies resulted in an extensive urban environmental database, aided by significant leveraged funding (McCartney *et al.*; NSF-BDI, 1999; NSF-ITR, 2002). We used these mined datasets in our primary research and to establish parameters for our *models* of urban ecosystem structure and function. Two *long-term experiments* were established and a third was begun. Finally, we engaged in *cross-site comparisons* and *multiple-site synthesis activities,* including climate studies (Brazel *et al.* 2000; Kinzig & Grove 2001; Brazel & Ellis 2003), a separately funded cross-site project on agrarian landscape change (NSF-BCE, Redman *et al.* 2002), a study of N retention in urban streams (part of LINX-2, NSF-IRCEB, Mulholland *et al.* 2002), and work on bird diversity as a function of socioeconomic setting (Warren *et al. in review*). The following CAP1 findings are organized into the revamped CAP2 structure, organized around interdisciplinary, integrative project areas.

1.2. LAND-USE AND LAND-COVER CHANGE

CAP1 featured three activities associated with land-use and land-cover change (LULCC): 1) classifying, monitoring, and modeling LULCC; 2) examining urban form; and 3) investigating the human drivers of those changes. An Expert Classification System, developed from remotely sensed images (Stefanov *et al.* 2001), offers a vision of the urban patch structure and its changes over the past decade. Analysis of historical land use (since 1912) show agricultural expansion in the first half of the century and urban expansion in the second half (Fig. 3[1]; Knowles-Yanez *et al.* 1999; http://caplter/contributions/); and contributed to our urban growth model (Jenerette & Wu 2001; Berling-Wolff & Wu 2004). This model suggests that, by 2030, urban growth will consume all available agricultural and desert lands. Our ecosystem simulation modeling efforts aim to simulate LULCC and study urbanization's effects on ecological processes. This work also has resolved methodological issues in modeling complex spatial ecological systems (Reynolds & Wu 1999; Wu 1999; Wu & David 2002; Wu *et al.* 2000, 2002, 2004a).

The ASTER Urban Environmental Monitoring (UEM) project (elwood.la.asu.edu/grsl/UEM) characterized regional landscape fragmentation and the spatial variation of the CAP study area

[1] All figures are found at the end of Section 2 (Project Description).

using land-cover classifications derived from ASTER data. We found that 55 urban centers, including Phoenix (studied with leveraged LTER funding), have significant landscape fragmentation and that cities can be ranked according to metrics such as edge and patch density. CAP1 research also shows that urban areas have high patch densities, numbers of patches, and smaller mean patch sizes than either desert or agricultural areas (Luck & Wu 2002). In CAP2, we will enhance our characterizations of urban-development trajectories and predictions of urban-center sustainability and resilience, and have received NASA-Earth Observing System funding to support this project (Stefanov & Christensen 2003).

CAP1 research has updated classic urban-fringe morphology studies, using a much shorter time frame and finer geographic scale (Gober 2000; Gober & Burns 2002). New residential developments resemble a "tidal wave" covering a surprisingly wide geographic area but within a narrow, donut-shaped band of territory. Recent expansion in parts of Phoenix has occurred at a rate of *one mile per year*, compared to one mile per decade for cities in the first half of the twentieth century (Blemenfeld 1954). Land taken out of agriculture is quickly transformed into housing, inspiring CAP LTER ecologists to adapt a model of housing spread borrowed from population-diffusion models (Fagan *et al.* 2001). Recent research includes an international collaboration to compare urban form and growth in four US and French cities (Joliveau *et al. in prep.*).

Urban environments increasingly influence biophysical processes and quality of life for their inhabitants (Baker *et al.* 2002). The Phoenix Area Social Survey (PASS) of eight neighborhoods (302 respondents) captures the spatial variation in human attributes that comprise the social fabric of Phoenix (Harlan *et al.* 2003; http://caplter/contributions/). While most respondents believe in preserving pristine desert lands, paradoxically, half the respondents believe housing density is too high—particularly those on the urban fringe! More than 40% of the respondents are also concerned about the water supply, drinking water safety, accidental releases of industrial chemicals, air pollution, allergens, and soil and groundwater contamination. Half the respondents believe environmental conditions in Phoenix are worsening; only one in five thinks the environment is improving. Expanding the PASS survey with supplemental funding would provide a way of examining human responses to change as Phoenix continues to grow.

1.3. CLIMATE-ECOSYSTEM INTERACTIONS

Data mining of long-term climate records for Phoenix and Baltimore shows that nighttime temperatures have increased for Phoenix, but daytime maximum temperatures are *lower* than the surrounding desert (Fig. 7). The resulting "oasis effect" (Brazel *et al.* 2000) underscores the complex interactions among human preferences and behavior, plants, and local climate. Modeling the urban climate system at the local scale shows the extent to which heat is retained at night, due to local decreases in the sky-view factor and/or the higher thermal admittances of urban surfaces (Brazel & Crewe 2002). Mesoscale MM5 modeling, made possible through special adaptations of the USGS MM-5 land-use code and application of CAP land-cover data (Grossman-Clarke *et al* 2003), provides detailed climate and meteorological information for the entire region, which can be used in atmospheric deposition modeling and other studies.

Local climate and surface-cover feedbacks influence plant size and rate of primary production. For example, five of six landscapes tree species exhibit significant reductions in size owing to adjacency to asphalt parking lots—temperatures on such surfaces are up to 27^{o}C higher than concrete, turf, and other pervious materials (Celestian & Martin *in review*). Meanwhile, pilot work comparing plant growth, gas exchange, and water-use efficiency among six treatments (desert, agricultural and xeriscape or mesiscape residential on former desert or agricultural land), shows that annual primary production (CO_2 uptake) varies with summer heat stress, water status, and land-use type (McDowell & Martin 1999; Martin & Stabler 2002).

Baker *et al.* (2002) investigated the human impacts and feedbacks of the urban heat island (Fig. 7). In the urban core, nighttime minimum temperature has increased by 5°C and the average daily temperature by 3.1°C. Impacts include: 1) increased energy consumption for heating and cooling; 2) increased heat stress (but decreased cold stress) for plants; 3) reduced quality of cotton fiber and reduced dairy production on the urban fringe; and 4) a broadened seasonal thermal window for arthropods. Not least, urban warming has increased the number of "human misery hours per day," which may have important social consequences. Ongoing research is examining these feedbacks at the neighborhood scale.

1.4. WATER POLICY, USE, AND SUPPLY

Although not a specific focus of CAP1, several projects addressed the issues we now consider under this category. Surprisingly, our residential landscape water-use efficiency project show smaller-than-expected differences (Fig. 8) in water application rates between xeriscape and mesiscape designs (Peterson *et al.* 1999)—suggesting that human perceptions rather than plants' physiological needs often dictate water use in urban areas. Water use in Phoenix was contrasted with the 25 largest US cities using a spatially explicit modification of the ecological footprint concept (Luck *et al.* 2001), an approach expanded to compare water footprints between China and the US (Jenerette *et al.* 2004). Retrospective analyses of Phoenix water have focused on geomorphic channel change and historical floods and management in the heavily modified Salt River (Fig. 5). Human activity (largely gravel mining) has profoundly affected the Salt River, but the channel still responds to infrequent flooding (Graf 2000). The need to assure water supply has most greatly determined today's river configuration, rather than to provide protection from flooding or access to gravel (Honker 2002). Dry riverbeds and highly engineered, artificial lakes are the only reminder of the river that once flowed through the metropolis (Grimm *et al.* 2004). Restoration efforts have only begun to focus on streams and riparian areas; we will introduce research in this area in CAP2.

Studies of water policy began more recently, as we established a baseline of information on historical trends (Honker 2002). CAP2 will expand these studies, with the aid of strong partnerships with agencies and projects such as Greater Phoenix 2100 (www.gp2100.org), which envisions the future of metro Phoenix over the long term; Fink *et al.* 2003).

1.5. FLUXES OF MATERIALS AND SOCIO-ECOSYSTEM RESPONSE

Aquatic and terrestrial components of the urban landscape are linked through material fluxes, and CAP1 studies include projects at a range of scales. Our initial focus on a whole system N mass balance (Baker *et al.* 2001) reveals large, human-mediated inputs, both intentional (e.g., fertilizer and food) and inadvertent (e.g., atmospheric deposition), as well as significant retention (Fig. 6). We then worked on quantifying the air-land component of the N budget. Combining results from Models-3/CMAQ and a diagnostic model of NO_x-derived deposition (Fig. 6) confirmed enhanced (~double background) atmospheric N deposition rates for the urban core and downwind sites (Fenn *et al.* 2003; Grossman-Clarke *et al. in revision*). Analyses of metals incorporated by lichens have helped identify spatial variation in air pollution sources (Nash *et al.* 2003; Zschau *et al.* 2003). CAP2 will consider mass balances and deposition of other elements.

Work on the land-water component of materials fluxes has focused on the movement of nutrients during storm events into recipient systems. High concentrations of nutrients (N, P, organic C) and metals are stored on asphalt surfaces, then transported to urban waterways during storms but the N export is not as large as predicted from surface storage (Hope *et al.* 2004). Analysis of a US Geological Survey (USGS) dataset on small urban watersheds reveals that catchment characteristics (e.g., land cover, impervious surface cover, configuration) govern nutrient and metals loads (Lewis & Grimm, *in review*). Retention basins are recipient systems unique to urban areas; CAP soils exhibit high rates of denitrification (Zhu *et al.* 2004). Surface-water channels constitute the other major recipient system. Research in a smaller watershed (IBW) shows that hydrologic management dictates nutrient patterns; when N-enriched groundwater is added to maintain water levels of artificial lakes, P limitation occurs (Goettl 2001; Grimm *et al.* 2004; W.J. Roach, *unpublished data*). Declines in high dissolved organic carbon concentrations downstream of metro Phoenix, owe largely to human manipulations of hydrology (Edmonds 2004). Results from our water-monitoring program show that nutrient concentrations are higher (sometimes by an order of magnitude) downstream of the urban area, but that loads are reduced because little water leaves the city (Baker *et al*. 2001; Edmonds 2004).

The environmental risk study has examined the relationship of spatial distributions of technological hazards to the demographic composition of adjacent neighborhoods (Fig. 13). Researchers have detected clear patterns of social inequities in the distribution of risk burdens, pointing to a pattern of environmental injustice by class and race across a range of technological hazards in the Phoenix area (Bolin *et al.* 2002; Bolin *et al.* in review). CAP2 studies will expand this research to integrate CAP findings and research on toxic materials in air, water, and soil.

1.6. HUMAN CONTROL OF BIODIVERSITY

Biodiversity research, employing both monitoring and experimentation, has focused upon vascular plants, mycorrhizal fungi, arthropods, and birds. Survey200 has revealed that a combination of human-related and non-human predictor variables best explains CAP's spatial variation in plant diversity. Although past and current land use is an important determinant of plant diversity, the most interesting finding to date is a positive plant diversity-income relationship for urban sites. Neighborhoods with a median family-income level above $50,000 per year averaged 2.3 times the plant diversity of less-wealthy areas (Fig. 14). This "luxury effect" suggests that, given sufficient economic means, humans choose to enhance plant diversity (Hope *et al.* 2003). Bird species richness was also strongly correlated with socioeconomic status at the neighborhood scale (Fig. 14; Kinzig *et al.* in review), and distinct human preferences for certain landscape configurations and plant combinations were identified (Martin *et al.* 2003).

Findings by Hope *et al.* (2003) agree with those seen for ground arthropods—the urban landscape has similar levels of diversity to the native landscape it replaced, although community composition differs (McIntyre *et al.* 2001). Spiders exhibit similar spatial diversity patterns to ground arthropods, but productive habitats (agricultural and mesic areas) have high abundance and low diversity, indicating that land-use types modify productivity-diversity relationships (Shochat *et al.* 2004). Insect pollinators, on the other hand, key-in specifically to native desert vegetation (McIntyre & Hostetler 2001). For birds, experimental manipulation of seed supply and water showed that reduced predation, higher food abundance, and competitive exclusion of natives by urban specialists, replace water limitation (in the desert) as the primary controls on bird-foraging behavior. A theoretical study (Katti *et al*. *in prep.*) supports empirical observations of high abundance but low diversity of birds in urban areas (Shochat *et al. in review*). Species richness of AM fungi correlates positively with time since development at older urban sites (Stutz & Martin 1998) and is reduced at agricultural (or formerly farmed) sites (Cousins *et al.* 2003).

1.7. DATABASE AND INFORMATICS

With funding from NSF-BDI (McCartney *et al.* 1999), the CES Informatics Lab worked on several contributions to the field: 1) *Ecological Metadata Language*, content standards for dataset and literature descriptors encoded in XML; 2) *Xanthoria*, an XML-based query engine for executing clearinghouse searches against a network of distributed metadata catalogs or bibliographic databases; 3) *Xylopia*, a data-access system that uses EML metadata to dynamically open connections to remote data, perform a variety of basic statistical, processing, or visualization functions online; and 4) integration of biological collections databases via a central taxonomic thesaurus and query system. All these products are implemented in the Southwest Environmental Information Network (http://seinet.asu.edu; see Section 4). We are also completing a new analysis wizard for our Ecology Explorers program, based on the SEINet infrastructure. We have begun to integrate urban ecological models from government partners using a Web-services approach under a separate grant from NSF-ITR (McCartney *et al.* 2002). This project builds on the BDI effort by defining metadata standards for documenting models and coupling model inputs and outputs via a workflow processing system.

1.8. BROADER IMPACTS

CAP LTER's impacts lie in three main areas. The first is in raising the national awareness and profile of urban ecology—in the literature (>130 journal articles, book chapters, and reports), at conferences (several Ecological Society of America and American Geophysical Union special sessions since 1998), on University curricula (especially graduate education), and in the news media (most recently, on NPR's *Science Friday*). Aided by leveraged funding, CAP LTER has led the way in crafting arguments for socioecological integration (Kinzig *et al.* 2000; Kinzig 2001; Harlan *et al.* 2003; Redman *et al.* 2004) in and across LTER sites. Towards this goal, CAP LTER coordinated workshops, symposia, and cross-site proposals (1998 CC meeting in Madison; 2000 workshop in Tempe; 2000 and 2003 All Scientist Meetings).

The second impact has been our contributions to education and outreach at all levels. In its first six years, CAP LTER had over 500 participants, of which more than 100 were community volunteers. Students in our Integrative Graduate Education and Research Training (IGERT) program in urban ecology are forging new paths towards interdisciplinarity. At the K-12 level, Ecology Explorers, our education-outreach program has expanded to include 87 teachers at 64 public schools (encompassing 25 school districts), 3 charter schools, and 2 private schools. In addition, over 20 community partners are substantively involved in the CAP LTER, such as Salt River Project, Motorola, Maricopa Association of Governments, the USGS, and the Gila River and Salt River-Pima Indian communities.

The third area of impact outside the field is our role in decisionmaking in Greater Phoenix. CAP LTER has enhanced its impact with funded projects that promote community and governmental outreach. For example, Greater Phoenix 2100 uses CAP LTER data to help policymakers and others envision the future of our region (Fink *et al.* 2003). Our Information Management team leads the way in developing IT tools for handling ecological data. In spring 2003, this group released an environmental atlas for futures planning in Phoenix (www.gp2100.org/eatlas). Based upon the SEINet data-access infrastructure, the Greater Phoenix 2100 EAtlas added over 60 new GIS datasets to the data catalog. Finally, ASU has launched a new Consortium for the Study of Rapidly Urbanizing Regions (Redman is Director), largely as an outgrowth of research activities in urban environmental science and policy that the CAP LTER has spawned.

2. PROJECT DESCRIPTION

2.1. OVERVIEW

CAP LTER is a long-term ecological study of the 6400-km^2 central Arizona and metropolitan Phoenix region, encompassing 24 municipalities of metro Phoenix and surrounding agricultural lands embedded in undeveloped Sonoran Desert. In CAP1, we gained significant insights into the central question:

> *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?*

At the same time, CAP LTER has been very successful in the investments it has made in fledgling research projects and at leveraging other external research grants for those projects. Therefore, our LTER is now a hub for research projects related to the urban environment. Six years of extensive research has strengthened our conviction that we have an appropriate conceptual framework for understanding complex socio-ecosystems (Fig. 1A). For CAP2, the second part of our central question, feedbacks to the social system, will receive increased attention. We have formulated five new Integrative Project Areas (IPAs; Fig. 1B) that form the foundation of proposed research, incorporating the traditional LTER core areas while instilling interdisciplinary significance. Theoretical and empirical approaches will reflect the wide variation in disciplinary traditions of CAP LTER scientists and the complexity of the ecosystem to which they are applied. These approaches are specifically integrated with the IPAs to ensure continued reference of all research projects to our central research question.

2.2. OBJECTIVES AND SIGNIFICANCE OF THE RESEARCH

The primary objectives of the CAP LTER research program remain:

1. **To advance ecological understanding through development of ecological theory.** Ecology lacks a theory that fully includes human and societal drivers and responses. As systems defined by the presence of humans, cities are ideal for developing this theory.
2. **To understand the structure and functioning of the urban ecosystem.** Well-known aspects of ecosystem structure and function (e.g., material input and cycling, ecosystem metabolism, organic matter storage) differ dramatically between cities and wildlands.
3. **To develop ecological scenarios that can be used to guide future development of urban environments while sustaining ecological and societal values, and to engage decisionmakers in this process through deliberate knowledge exchange.** Although LTER projects are grounded in basic science, they present enormous opportunities for guiding human decisions about managing land, protecting biodiversity, and preserving or restoring critical ecosystem services. Our program interfaces with several projects that have the explicit objective of informing better decisions in the urban environment.
4. **To involve the public in the research effort through dissemination of information via the media, public outreach, and educational initiatives.** Education at all levels (K to gray) is a prime directive of the CAP LTER program.

Significance: Ecological theory has developed over the past century with relatively limited reference to the massive and pervasive alterations of natural ecosystems made by *Homo sapiens* and to the increasing integration of humans into natural systems, as drivers of and respondents to ecological processes. The past decade, however, has seen a renewed interest in human-dominated ecosystems (Vitousek *et al.* 1997*a,b*) coupled with a critical need to find solutions to environmental problems where they are most severe. The creation of two LTER sites devoted to the study of urban ecological systems has allowed us to reconceptualize and revitalize ecology by considering the integration of new elements into ecological theory. In particular, urban-ecosystem structure differs dramatically from non-urban ecosystem structure in its inclusion of the built environment, while urban function is at the extreme of the spectrum in having human decisions, actions, and reactions added to the suite of ecosystem processes that are normally studied (Grimm *et al.* 2002). Urban ecosystems, because of the clearly dominant influence of people, institutions, and the built environment, therefore offer the best laboratory for examining refinements to ecological theory that may be required to understand how humans, as integral parts of environmental systems, are influencing ecological trajectories (Collins *et al.* 2000).

2.3. SITE DESCRIPTION

Phoenix has proven an excellent choice for launching the new urban emphasis within the LTER network. The Phoenix metropolis is situated in a broad, alluvial basin where two major desert tributaries of the Colorado, the Salt and Gila Rivers, converge (Fig. 2). The basin, dotted with eroded volcanic outcrops and rimmed by mountains, once supported a vast expanse of lowland desert and riparian systems and now houses the sixth-largest city in the US. The metropolitan population has increased by 47% since 1990 to over 3.5 million people (US Census Bureau 2000). Growth and expansion of Phoenix has occurred mostly in the second half of the twentieth century, initially consuming farms. In contrast, the newest housing has been established mostly on desert land, leading to spatial variation in extant vegetation, soil properties, and structure of residential landscapes.

The region's growth has been underpinned by water-supply projects involving the construction of local reservoirs and the Central Arizona Project Canal (Kupel 2003), as well as by development of air conditioning and widespread use of motor vehicles. Reliance upon irrigation to create and sustain agricultural production and urban landscapes gave rise to an abrupt delineation between managed landscapes with their exotic plants and undeveloped desert with its native vegetation (Hope *et al.* 2003). Water use is the single-most important controlling factor for NPP in this desert city (Martin 2001). Moreover, demands for flood protection and water delivery have led to massive alterations of hydrologic systems with far-reaching consequences for species and biogeochemical dynamics (Grimm *et al.* 2004).

2.4. CONCEPTUAL FRAMEWORK

CAP LTER research continues to be directed to answering the central research question in the context of our conceptual model (Fig. 1A), which focuses our thinking upon the interaction between the ecological and human domains (Grimm *et al.* 2000, Redman *et al.* 2004). In the past six years, we have identified many of the ecological and societal consequences of urbanization, but we are only beginning to understand how those consequences feed back to the social system to generate future changes. Although we retain a focus on understanding consequences of continued urban growth and expansion, new research strategies and projects proposed for CAP2 also are designed to enhance understanding of these feedbacks.

Coupled human-ecological systems (hereafter socio-ecosystems) share certain characteristics that engender findings of general, rather than merely local, interest and relevance. Identifying and understanding these characteristics will advance not only urban ecology (Objective 2), but the entire field (Objective 1). One characteristic is that scales and periodicities of ecological and social phenomena differ, and human manipulation of the environment may not be synchronous with environmental periodicity (e.g., regulating flow for irrigation purposes alters the seasonal hydrograph). The consequences of mismatches in scale and periodicity have important implications for socio-ecosystem functioning (Objective 2) and our ability to envision future states (Objective 3). Another characteristic is the possibility that certain phenomena operate fundamentally differently under human influence than in the absence of humans. If ecological theory would benefit from modification (Objective 1), discovery of such fundamental differences will reveal how it should be changed. Third, humans not only alter state variables of ecological systems, they may also control their variability. What are the consequences of control of *variability* for ecosystem function (Objective 2)? Further, we ask, what features of socio-ecosystems make them vulnerable to disturbances of different types (e.g., ecological disturbance, but also social, economic, or political disturbances)? What features impart resilience? Although these are fundamental science questions (Objective 2), they also have relevance to policy choices and institutional structures that can protect urban socio-ecological systems from dramatic, undesirable changes at all scales (Objective 3). Finally, our research can be shared with students at all levels, as it concerns an ecosystem type in which most (>85%) Americans live. Our educational and outreach programs (see Section 5) therefore make ecology relevant to greater numbers of citizens (Objective 4).

2.5. PROPOSED RESEARCH

2.5.1. Research Design and Approach

Although our program is fundamentally ecological (*sensu* Likens 1992), we include humans among the organisms that are interacting and participating in fluxes of energy and materials. We are committed to the notion that any ecological study must monitor and interpret change from a perspective that includes humans as part of nature (Cronon 1995; Kinzig *et al*. 2000). Standard ecological theories are insufficient to address the complexity of human culture, behavior, and institutions; thus, our ecological investigations require the integration of social science research, require longer time horizons, and must be informed by flexible models and multi-scaled data. We therefore have reorganized the project under five IPAs, with crosscutting teams guiding our multiple research strategies (Section 3).

The LTER research strategies have been called the four "legs of the table" of LTER research (Carpenter 1998): long-term research (monitoring), experiments, comparative ecology, and models or theory. To these strategies we add data mining—an essential means of testing hypotheses and understanding ecological change across a large urban area such as CAP, where there have been numerous agencies collecting data in great detail (albeit not under an ecological paradigm). This wealth of background data is tremendously important and much of our early work involved mining these sources of information and putting them into a format and conceptual framework that was amenable to our own analyses. We use all five "legs of the table" in our research, although some IPAs may favor one over the others.

Finally, education, informatics, and knowledge exchange with urban policymakers, managers, and stakeholders are as fundamental to our project as the core scientific activities. We have been successful in leveraging LTER funding to accomplish outreach and data management objectives that are beyond the capability of the CAP LTER, but we retain significant communication and involvement with these activities (see descriptions in Sections 4 and 5).

2.5.2. *Integrative Project Areas*

A particular strength of the US LTER program is consistency of measurement in the five, broad core areas. However, during CAP LTER's ongoing research we have found that organization of projects and working groups under the traditional LTER core areas does not necessarily facilitate interdisciplinary integration (Redman *et al.* 2004). Therefore, we have identified five IPAs, each of which blends life, earth, and social science (Fig. 1B). Here, we describe the major objectives and/or questions of each IPA:

Land-Use and Land-Cover Change (LULCC). Land use and land cover define the context of the socio-ecosystem, and alterations in their patterns represent some of the most seminal changes to the system. We ask: How have land use and land cover changed in the past, and how are they changing today? How do land-use and cover changes alter the ecological and social environment in the city, and how do human perceptions of these changes alter future decision-making? This understanding, in turn, sets the stage for all other IPA research.

Climate-Ecosystem Interactions. Climate is an important driver of processes in most ecosystems. The spatial and temporal dynamics of human actions both deliberately (irrigation) and inadvertently (urban heat island) modify the urban climate. Studies of climate-ecosystem interactions will be conducted at multiple scales from single organism to regional. We ask: 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 (NPP) and vegetation processes?

Water Policy, Use, and Supply. Humans now appropriate 100% of the surface flow of the Salt River and are increasingly exploiting groundwater resources and surface waters from more distant basins (e.g., Colorado River). Controlled management and engineering shift the characteristic spatial and temporal variability of the hydrologic system. What are the ecological and economic consequences and potential vulnerabilities of those shifts? What institutional responses best address those vulnerabilities? Within this IPA, we examine landscape water management, water supply and delivery, riparian restoration, and resilience of the socio-ecosystem to water-related stress or catastrophe.

Fluxes of Materials and Socio-Ecosystem Response. 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. The main question driving the ecological research in this IPA is: How do urban element cycles differ qualitatively and quantitatively from those of nonhuman-dominated ecosystems? Nutrient, pollutant, and toxin element cycles drive our main sociological questions: What are the socio-spatial distributions of anthropogenic toxins and other pollutants in the CAP ecosystem, and what hazards to organisms (plants, animals, humans) result from these distributions? Do citizens and decisionmakers accurately perceive these hazards?

Human Control of Biodiversity. 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 will move beyond these approaches to ask: How do human activities, behaviors, and values change biodiversity and its components—population abundance, species distribution and richness, and community and trophic structure? In turn, how do variations in biodiversity feed back to influence these same human values, perceptions, and actions?

2.5.3. *Continuing Research*

In this section, we describe our ongoing research activities, organized according to our five research strategies and major research participants (in parentheses). In some cases, such as the Survey200 monitoring (see Section 2.5.3.2), virtually every IPA has elements associated with the continuing research described here. Others (e.g., the data-mining efforts to construct materials or water balances) are primarily associated with one or two IPAs. New research proposed for CAP2 will be described separately for each IPA in Section 2.5.4.

2.5.3.1. Data mining

Historic Land Use (Redman, Wentz). Considerable information on land use was developed during CAP1, derived from historical aerial photographs and county records. These resources provided data for basic models of urban growth (Agarwal *et al.* 2001; Lambin *et al.* 2001) and assessments of associations between land-cover and land-use categories and other characteristics of the urban environment. Initial land-use research was limited to changes in four basic categories over the past century. For the square-mile sections around each of the Survey200 sites, more detailed land-use information has been collected according to 26 categories (Fig. 3). During CAP2 these data will be enriched with long-form census data, information from the county assessor's office, agricultural statistics, and more advanced analysis of remotely sensed imagery, giving detailed pictures of neighborhood-level change over the past century. Combining census and land-use data is especially important for understanding how both human and urban environmental forces co-vary over decadal time scales. Historical integration of the social and the environmental is one research design factor that makes our ecological approach both unique and valuable. For example, knowledge of historical distribution of agricultural fields gives a basis for selecting sites in a study of agricultural impacts on soil C and N storage.

Hydrologic Budget (Arrowsmith, Baker, Westerhoff). A hydrologic budget that quantifies the flow of water from the atmosphere, through its interactions with the land surface (including vegetation and the built environment), overland and subsurface flow, and ultimate return to the atmosphere via evapotranspiration, was developed for the CAP region (Fig. 4). This budget has served as a valuable foundation for constructing materials budgets (e.g., Baker *et al.* 2001) and understanding how human action has altered the pathways and availability of this critical resource (Fig. 5). In CAP2, we will build on this balance, improving understanding of human-altered flow paths and estimation of surface-groundwater interaction, particularly the partitioning between natural and artificial recharge. Research questions will include: 1) How have the inputs and outputs of the hydrologic cycle changed over time? 2) Can thresholds be identified, beyond which water limitation will stress ecosystems or human activity in the region? 3) How have hydrologic flow paths changed over time, and how are they likely to change in the future? Existing analyses by agencies and others charged with management of the region's water delivery will be refined, converting the static representation of these data into dynamic representations of the hydrologic budget at higher temporal resolutions. This refinement will provide a rich measure of the system behavior given intrinsic and extrinsic forcing.

Major data sources include those of the Arizona Department of Water Resources (ADWR), the Salt River Project, the Central Arizona Project, and the cities of metropolitan Phoenix, who in a "Water Dialogue" (http://ces.asu.edu/csrur/WaterDialogue.htm) sponsored by the Center for Environmental Studies identified a need for a common framework and clearinghouse for data related to water. Working with these colleagues and our Information Technology partners (http://ces.asu.edu/CES/Informatics.htm; http://www.geongrid.org), we will develop a collective, historic, real-time database on water sources, water uses, water obligations, and groundwater conditions that can produce a robust and queriable hydrologic budget for the CAP region.

Nutrient Budgets (Kaye, Baker, Grimm, Hope, Westerhoff). At the scale of the entire CAP study region, we are building elemental mass balances for N, C, P, and salts. We will continue work on the C mass balance and will initiate a P mass balance study (leveraging funds in a recent NSF-BE, *Hope and Kaye 2003*). The N mass balance was the first completed (Baker *et al.* 2001) and it showed that the urban ecosystem differed both quantitatively and qualitatively from desert ecosystems (Fig. 6). The socio-ecosystem was characterized by large anthropogenic N inputs, large engineered gaseous outputs, and an accumulation of N in unknown compartments of the CAP ecosystem. In contrast, N inputs to desert ecosystems are typically <¼ of urban inputs, internal plant and microbial cycling are much greater than inputs and outputs, and N accumulation is slow or negligible (gaseous losses account for about 100% of inputs). The N mass balance raised at least two questions that we will pursue in CAP2. First, what are the consequences of these massive inputs, especially those associated with NO_x production, for ecosystem productivity and functioning in surrounding desert ecosystems? We are seeking non-LTER funding to address this question. Second, if 14 kg N $ha^{-1}y^{-1}$ are accumulating in the CAP ecosystem, where is the N stored? Although denitrification processes at wastewater treatment plants and associated effluent discharge prevent large riverine N exports, it is possible that some of the N accumulates in the vadose zone and may eventually interact with groundwater (Walvoord *et al.* 2003). A second possibility is that N deposition is stored in surface soils, alleviating biological N limitation (see new research in 2.5.4.4).

Other Data-Mining Efforts. We will add to our growing databases by updating US Census-derived data on social measures (income, ethnicity, education level) for the CAP region. We will also mine data from historic climate, streamflow (Fig. 6), and transportation databases maintained by governmental agencies (see List of Databases in Supplemental Documents).

2.5.3.2. Monitoring

Survey200 (Hope, all). The 200-point spatial survey (Fig. 2) forms a cornerstone of our long-term monitoring efforts. Carried out in full once every five years, the Survey200 provides: 1) a broad-scale characterization of major physical, biotic, biogeochemical, and human characteristics not quantifiable from aerial photos/remote sensing/census data (see Section 1, Table 1, and Web-based protocols); and 2) a framework of sites within which more detailed and more frequent measurements can be co-located (see Section 2.5.5). The sampling scheme is a probability-based, tessellation-stratified, dual-density (3:1) design, which was deliberately not stratified for land use/cover or other characteristics. Instead we chose to maintain maximum post-stratification flexibility and make the data amenable to spatial autocorrelation analysis, kriging and other spatial-estimation techniques. In CAP2, we will develop novel statistical approaches *(Oleson)* to calculate broad-scale characteristics of the entire site (e.g., accurate estimates of soil C and N pools for the CAP ecosystem). During the next complete survey in spring 2005 and again in 2010, the integrated field inventory will be repeated, to provide a spatially extensive comparative dataset of change over time. Data from the Survey200 provide important insights into broad-scale spatial variation of key ecosystem variables (see Section 1), as well as providing essential context for other work. For example, we will use these data to further develop a vegetation index-biovolume calibration curve appropriate for the region and residential yards. This will improve comparability of remotely sensed vegetation indices with field-collected vegetation cover and volume data.

Intensive Sites. To allow more frequent and detailed measurements, subsets of the Survey200 sites have been selected for more detailed study. Choosing a smaller number of sites enabled us to characterize seasonal and interannual variations; these sites have been co-located to maximize overlap between studies. At these site, we measure (see also Table 1, Sec. 2.5.5):

- Standing biomass (focusing on trees; *Martin*) at 32 of the Survey200 sites (plus 18 additional locations) is monitored via biannual measurements of tree volume, along with determination of N content of leaf tissue (summer only). This is allowing us to address the question: How does tree growth change over the long term as a function of position variables (e.g., distance from urban center or roads), socioeconomic variables (e.g., income level and landscaping practice), and historic variables (e.g., former land use)?
- Ground arthropods (*Faeth*) are collected on a bimonthly basis at 22 sites using standard pitfall-trapping protocols available on our Web site and also used by K-12 participants (see Section 5). We will use the data to answer the question: How do diversity-abundance patterns vary seasonally and interannually among different land-use types?
- Bird survey sites (*Warren*) include 40 of the Survey200 sites plus 10 riparian locations. All sites are surveyed quarterly by a team of birders using point-count methods (see Web site). Here too we will focus on seasonal and interannual variation and diversity-abundance patterns among different habitat types.
- Phoenix Area Social Survey (PASS; *Harlan*): key demographic and socioeconomic variables are acquired for the US census block groups surrounding each of the 91 urban sites from the Survey200 (e.g., population density, median household income, ethnicity, median housing age). In six of these block groups, an additional detailed survey instrument (PASS) has been developed and used to address the question: How do behaviors, attitudes and perceptions of residents influence ecological conditions in neighborhoods? Results from this pilot study (Larsen *et al.* 2004; Harlan *et al.* 2003) have already demonstrated the importance of building social monitoring into as many of the CAP2 IPAs as possible. *Therefore, additional funding is being sought in a supplemental proposal to extend this work to the neighborhoods surrounding all 91 of the urban sites in the extensive monitoring network.*

Intensive/Experimental Sites. A small number of intensive study sites have been established in locations with long-term, site ownership (ASU and Desert Botanical Garden, DBG; Fig. 2). Public access to these sites is limited, allowing for manipulative experiments and security for monitoring equipment. Currently, four main sites, the ASU President's House yard (PH; mesic residential yard), DBG (disturbed desert remnant, with power and water supply), the grounds of ASU's Community Services Building (CSB; relatively undisturbed desert remnant, including a natural desert wash), and the ASU East "North Desert Village" (NDV; residential neighborhoods) are monitored intensively. Climate monitors are installed at intensive sites to provide detailed long-term meteorological monitoring. A scaled-down version of the CAP1 atmospheric deposition program will be continued at these and two additional sites, chosen based on spatial and temporal variations in wet and coarse particulate dry deposition documented in CAP1. Throughfall and runoff chemistry from roof and pavement surfaces will be measured periodically. Replacing our existing dry bucket collectors with filter packs will improve the measurement of dry deposition (a major component of annual atmospheric nutrient inputs to the ecosystem). Leveraged funds are being sought to supplement this limited deposition monitoring *(Grimm, Allen, Kaye pending proposal to NSF-CBC).*

Remote Sensing and Patch Typology (Stefanov, Christensen). LULCC characterization and monitoring will continue, using data acquired by the Landsat ETM+ and ASTER, as well as new data acquired by the Landsat Data Continuity Mission scheduled to begin in 2006. We plan to improve existing expert-system land cover classification algorithms (Stefanov *et al.* 2001) and explore new classification approaches such as object-oriented classification (Burnett & Blaschke 2003). The NDV experimental site (see 2.5.3.3) will greatly facilitate calibration of remotely sensed data and field verification of change-detection algorithms. In addition, we plan to acquire very high resolution (15-20 cm/pixel) visible to near-infrared High-Resolution Stereo Camera data to investigate vegetation patterns at the household scale and as input for scaling analyses.

Human-Climate Interactions (Brazel, Harlan, Stefanov). The Neighborhood Ecosystems Project (NSF-BE, *Harlan et al. 2002*) is built upon earlier CAP1 work on feedbacks to urban climate (Baker *et al.* 2002; Fig. 7) and has measured variability in human-vegetation-climate interactions across the region and in six neighborhoods co-located at Survey200 sites. Initial analyses of both neighborhood-scale (Prashad *et al.* 2003) and regional-scale (Jones *et al.* 2003) remotely sensed vegetation and surface temperature patterns indicate that the city is hotter in poorer, nonwhite neighborhoods than in wealthier areas. Research in progress is investigating: "What are the mechanisms (e.g., vegetation density, topography, and built environment) that mediate the human-microclimate relationship in urbanized areas?" Future research in this area will continue to combine satellite, airborne, and field sensor data with surveys of Phoenix area residents (PASS). This work will elucidate the political, cultural, and economic controls (both current and "legacy") on neighborhood climate as well as the resulting costs and feedbacks to the neighborhood socio-ecosystem, in terms of energy, water, and ecological function.

Aquatic Monitoring (Hope, Grimm). Analysis of long-term temporal patterns in stream water chemistry above and below metro Phoenix addresses three questions: 1) What is the influence of dams on water chemistry entering the urban ecosystem? 2) How do seasonal patterns and discharge-related variation in water chemistry change over time? Do these changes serve as an indicating that urbanization may have altered biogeochemical cycling? and 3) What "signals" in water chemistry can be detected that indicate a response to policy change, such as the introduction of a new water source, enactment of water quality legislation, or improvements in water treatment? Using USGS' National Water Quality Assessment Program (NAWQA) protocols, modified to focus on major nutrients, cations, and anions, we sample surface water at the three main inflows and two "integrator" outflow sites for metro Phoenix, selected using data from a two-year pilot study at seven locations (Fig. 2). To date, we have compared seasonal and inter-annual patterns in biologically conservative and reactive ions and compounds, using our own sampling in combination with 40-y datasets from previous USGS monitoring (Edmonds 2004). In CAP2, we will capture samples during rare, high-flow events and determine the effect of continuing urban growth on spatial variations in surface water chemistry. Monitoring will be suspended during NAWQA's Arizona sampling interval.

Small Watershed Studies (Grimm). This research investigates the dynamics of material storage, transformation, and transport in small urban watersheds, incorporating the effects of episodic events (rainstorms and flash floods) that link aquatic and terrestrial components of urban watersheds. The CAP mass balance for N suggests that 14 kg ha^{-1} y^{-1} of N is retained somewhere in the ecosystem (excess of inputs over outputs; Baker *et al.* 2001). The question of where in the landscape N (and other elements, especially C) is retained is best answered by considering both aquatic and terrestrial components of the landscape (Grimm *et al.* 2003). Small urban catchment research during CAP1 indicated that impervious urban surfaces can form important temporary storage sites for nutrients such as N and C (Hope *et al.* 2004), but that transport of these nutrients during storm runoff to recipient surface soils in retention basins where microbial process rates are high (Zhu *et al.* 2004) may result in smaller-than-expected nutrient fluxes from these basins overall (Hope *et al.* 2004). In CAP2, small watershed studies will continue using acquired datasets of material export (USGS, cities), along with measurements of process rates in soils and sediments at sites co-located with other projects, to test the following hypotheses:

- spatial variability of material export is higher and temporal variability lower than in non-human-dominated watersheds (Grimm *et al.* 2004);
- recipient systems (those terrestrial or aquatic ecosystems that receive materials from the landscape during episodic flooding) are "hot spots" (*sensu* McClain *et al.* 2003) of nutrient retention and transformation in the urban landscape.

2.5.3.3. Experiments

DBG Landscape Water-Use Experiment (Martin, team). The DBG experiment to study the interacting effects of pruning and irrigation established during CAP1 (see Section 1) will be slightly modified in CAP2 to examine the relationship between NPP and surface mulches.

The overall aim is to obtain a better understanding of the utility of such practices in improving water conservation. The experimental design includes replicate plots containing common perennial plants used in residential landscaping watered at recommended or high rates; the modification will add two types/levels of surface mulch. Quarterly measurements will be made of plant growth (at a minimum), but additional studies of soil biogeochemistry, water-use efficiency, trace-gas fluxes, and other variables are likely to be added to the response-variable set by graduate-student and postdoctoral researchers.

NDV Experimental Suburb (Hope, Martin, team). Variation in landscaping style and maintenance practices associated with different styles may influence a wide range of ecological and social phenomena, including biogeochemical processing, water consumption, avian and insect communities, and quality of life for residents. Experimental tests of these linkages, however, are largely lacking in urban ecology. Using the NDV residential development recently acquired by ASU at its East Campus, we will undertake an unprecedented neighborhood-scale experiment. Four residential landscape design/water delivery types established in blocks of six households each (mini-neighborhoods) will recreate the four prevailing residential yardscape types found across the CAP study area during the last five years of research (Martin *et al* 2003; Fig. 8). These are: mesic/flood irrigation—a mixture of exotic high water-use vegetation and turf grass; oasis—a mixture of drip-watered, high and low water-use plants, and sprinkler-irrigated turf grass; xeric—individually watered, low water-use exotic and native plants; and native—native Sonoran Desert plants and no supplemental water. Six additional households will be monitored as no-plant, no-water controls. Although NDV is not representative of the entire breadth of socioeconomic groups in the CAP region, it *is* a residential village for students with families. Thus, many of the socioeconomic issues applicable to single-family residences, which comprise the largest component of housing across metro Phoenix, will be addressed.

A central research question for the NDV experiment is: **How does residential landscape design affect socio-ecosystem function at household and neighborhood scales (**Fig. 8)? The experiment will also allow us to examine how biophysical information feeds back into human decision-making and behavior, at the household scale. We will address the following detailed research questions: 1) How do different landscape-treatments influence recreational behavior in yards and common areas*?* 2) Does structural complexity correlate with quantity of residents' ecological "folk" knowledge*?* 3) Are people less likely to move into or out of a landscape that conforms to their broader social values*?* and 4) Do people living in desert landscapes use less water inside and outside their homes? The experiment will also allow us to tackle the question: **How are biodiversity and ecosystem function related in urban ecosystems where there has not been a long co-evolutionary history?** For example, we will be able to determine how NPP compares between natural and human-created plant communities.

Research activities began in fall 2003 with pre-treatment baseline surveys of soil profiles (characterizations by the Natural Resource Conservation Service), soil physicochemistry and fluxes, mycorrhizal species identification, estimations of above- and belowground vegetation biomass, ground arthropod and bird abundance and diversity surveys, and human-occupant surveys. Along with the residential landscapes themselves, we will install micrometeorological stations within each of the six mini-neighborhoods (blocked planting/water-regime treatments), in addition to the standard meteorological installation. We will monitor several parameters (see Sections 2.5.4.2, 2.5.4.4, and 2.5.4.5 for proposed measurements), which will allow us to answer the above questions, as well as discern the effects of residential landscape design on a suite of neighborhood physical, chemical, biotic, and social variables.

Trophic Structure and Dynamics Experiment (Faeth, Cook). A central and long-pondered question in ecology is: What controls trophic relationships and structure in communities? Theory and empirical studies show that both top-down (e.g., predators) and bottom-up (resource availability and quality) forces influence community structure and trophic dynamics to varying degrees (Power 1992; Chase *et al.* 2000), depending on herbivore and predator or parasite species composition, intraguild predation, spatiotemporal variation in environmental resources and plant competition (Duffy 2003). In most such studies, human activities are ignored, especially outside the realm of agriculture. This omission is unfortunate, as one of the most intensive and expanding of human activities, urbanization, alters top-down and bottom-up forces in dramatic ways, but rarely has been incorporated into studies of trophic dynamics and food webs. We established an experiment to test the effects of vertebrate (birds) and ground-dwelling vertebrate and invertebrate predators, combined with manipulated resources (water). The focal plant species, *Encelia farinosa* (brittlebush), is a native Sonoran Desert plant that is widely used in xeriscapes. A replicated, full-factorial experiment (Fig. 9) established at three sites (a mesic yard [PHY], a desert remnant [DBG], and an outlying natural desert area) includes four treatments: 1) netting (to exclude vertebrate predators); 2) ring barriers (to exclude ground-dwelling invertebrate predators); 3) supplemental water; and 4) controls (no caging, ring barriers, or supplemental water). We determined (bimonthly) plant productivity, leaf damage, abundances and diversity of herbivores, predators and parasitoids. Preliminary results indicate that diversity (Fig. 9) and abundances of arthropod herbivores, predators and parasites differ dramatically among the sites and with season. Furthermore, top-down effects, especially from avian predators, are more pronounced in mesic urban habitats, whereas bottom-up forces (e.g., plant resources) dominate outlying natural deserts. We are seeking non-LTER funds to conduct similar experiments at the scale of entire yards and mini-neighborhoods at the NDV experimental suburb (*Faeth and Sabo, proposal pending*). Here, the yard type is manipulated and controlled, and we can examine the consequences for trophic structure and diversity on a common plant species, brittlebush.

2.5.3.4. Models

Ecosystem-Process Models and Scaling-Up (Wu). Much of the modeling effort during CAP1 focused on developing models of land-use change and urban growth (Jenerette & Wu 2001; Wu & David 2002; Berling-Wolff and Wu 2004), as well as quantifying the spatiotemporal patterns of the urban landscape (Luck & Wu 2002; Wu *et al.* 2002) (see Section 1). CAP1 employed a

Hierarchical Patch Dynamics Modeling (HPDM) approach to build a modeling framework for guiding our efforts in gathering land-use and land-cover data, studying the processes that lead to change in individual patches, and analyzing the interaction among patches. The HPD modeling approach will remain a central tool in CAP2, but it will be supplemented by more focused models. In CAP2, we will: 1) conduct comprehensive scenario-based analysis using the urban growth models (UGM-PHX, UrbanSim) to explore the socioeconomic processes and factors that affect land-use change patterns; 2) modify, parameterize, and validate PALS-PHX for different types of plant communities, including agricultural fields; 3) employ simulation experiments using PALS-PHX to study ecosystem responses to elevated carbon dioxide (CO_2), increasing temperature, and atmospheric nitrogen (N) deposition induced by rapid urbanization; 4) couple UGM-PHX and PALS-PHX to explore the effects of land-use change on ecosystem processes; and 5) scale-up biomass, NPP, and other ecosystem properties from the local ecosystem to the region using an integrated approach that combines remote sensing, GIS, and ecosystem modeling (Fig. 10).

Methods and approaches: The advantages of using PALS for CAP2 study are: 1) it includes all the major ecosystem processes in the Sonoran Desert needed to address our research questions; 2) it has been tested on other sites; and 3) model parameterization and testing are greatly facilitated because of the similarity in dominant plant species between the Jornada and CAP sites. Data for parameterizing PALS-PHX will come from our existing databases, including remote sensing, Survey200, intensive plots, and literature (see Shen *et* al. *in review*), whereas CAP2 datasets, such the new NDV experiment and the Survey200 in 2005 will be used to validate the model directly against field observations. The PALS-PHX is designed for simulating biophysical processes of local ecosystems (ranging from 10^2 to 10^6 m^2). With the aid of remote sensing and GIS, PALS-PHX will be used to scale up ecosystem processes from the local ecosystem to the entire study area, using several approaches (e.g., spatially explicit summation, Monte Carlo simulation). At the regional scale, three parallel methods will be employed to test model-predicted NPP: 1) comparing model predictions to future field-survey data (e.g., Hope *et al.* 2003; Shen *et al. in review*); 2) comparing model predictions to aboveground NPP estimated from remotely sensed data (based on methods in Burke *et al.* 1991 and Running *et al.* 2000); and 3) conducting sensitivity and uncertainty analyses (Wu *et al.* 2004b).

Dynamic Mass-Balance Models (Kaye, Hope, Baker, Westerhoff). To date, mass balances have been snapshots in time for a specific element. This approach places values on the flux rates and pool sizes (e.g., Fig. 6, plus fluxes of many other subcompartments) without enabling dynamic modeling of changes in elemental fluxes over time. CAP2 will begin with the N model to make these mass balance models dynamic in time so that scenarios of development or changes in land use can be used to generate hypotheses about changing elemental fluxes. Scenarios regarding population growth, land-use change, and groundwater pollution and reallocation will provide a strong scientific link to the land-use, water-quality, and education groups.

2.5.3.5. Comparative studies

In addition to the widespread use of comparative ecosystem studies within the CAP study area (e.g., comparison among different land-use types), CAP LTER has actively sought interactions with our sister urban LTER, the Baltimore Ecosystem Study (BES) and other LTER sites. We intend to develop these relationships further, continue cross-site comparative research started during CAP1, and initiate new research. Land-cover transformations of agrarian landscapes ("Ag Trans" Project, NSF-BE; *Redman et al. 2002*) are compared for five LTER sites (CAP, HFR, SGS, CWT, KBS) with remotely sensed and ancillary geospatial data, focusing in particular on recent land-cover, land-use, and vegetation-index data (*Stefanov, Netzband, Banzhaf, Moeller*). Research on urban animal populations and communities, especially associated with urban parks, has been conducted in parallel and in communication with BES (*Warren*) and will be further developed in a planned workshop on community ecology of urban ecosystems (February 2004, *Warren* organizer). Our Survey200 was developed in consultation with BES to parallel their urban forest monitoring; arthropod pitfall trapping was designed in consultation with Sevilleta and Jornada scientists; and ongoing ecosystem modeling uses a modification of the Jornada-based PALS model (Reynolds *et al*. 1993, 1997, 2000). CAP LTER climatologists (*Brazel, Ellis*) are active participants in LTER network climate activities, and the CAP regional C mass balance is being compared to the Minneapolis/St. Paul C mass balance in a separate NSF-Biocomplexity project (*Baker, Hope, Kaye*). Finally, CAP LTER scientists initiated a series of workshops aimed at instilling more social science into the LTER network (NSF-BE Incubation, *Redman and Grove 2001).*

2.5.4. Proposed New Research

This section highlights many of the new projects proposed for CAP2 during the proposal development process, which began with a summer retreat in 2002. Although it is unlikely that all the proposed research will ultimately be incorporated into our long-term monitoring and experiments (a Scientific Leadership Council [see Section 3] will make decisions on research directions), we prefer here to expose the richness of topics generated by CAP LTER's 50+ scientists. The proposed new research is organized under the five IPAs introduced in Section 2.4.

2.5.4.1. Land-use and land-cover change

At its core, the urbanization process is LULCC. This change, in turn, alters the hydrological system, air-movement patterns, the spread of built environments, trophic interactions within biotic communities, NPP, biogeochemical process rates, land-surface characteristics, and the resulting ecological footprint of the city. Questions such as "When does excessive urban growth significantly impair water supply, air quality, or agricultural viability?" are of paramount importance to the citizens of central Arizona. At what point in the urbanization process do cities contribute to catastrophic vulnerability, such as infrastructure inadequacy, transportation gridlock, air-pollution extremes, geological hazards, health risks, and widespread elimination of native species? CAP2 will investigate the impacts of LULCC through these questions.

Using the ever-increasing database derived from remote sensing, census, community partners, and our own ecosystem monitoring (Section 2.5.3.2), we will embark on a new generation of urban growth and operation models. During CAP1, the landscape ecology-oriented team (*Wu*) developed a variety of urban-growth models that employed our historic data and a variety of organizing principles (see Sections 1 and 2.5.3.4.). In CAP2, this team will expand its activities to more dynamic models that include causes, mechanisms, and socioeconomic consequences. In collaboration with modelers using approaches from several disciplines, we will identify and employ the best features of each approach. A team of urban planners, for example, is adapting the UrbanSim modeling approach to Phoenix (Waddel 2000; Guhathakurta 2002, 2003). A geography team will develop another urban simulation model in the context of a cognitive-based, geospatial analysis of the environment (*Wentz*), while a team of engineers and others (*Crittenden*) will employ an agent-based approach focused on an urban metabolism model (Milhelcic *et al.* 2003).

We expect each of these modeling approaches to yield its own set of insights. Our focus remains on the drivers of urban change, social and ecological indicators of those changes, and the ability to understand complex interactions that comprise the urban ecosystem. The uniqueness of our approach is found in our concern with spatially explicit patterns, social and ecological legacies, models at multiple scales, as well as the recognition that a diversity of approaches will yield value to the inquiry. Whereas much of this work will result in identifying alternative developmental trajectories and relationships in the past and present (Zoldak *in review*), it will also provide the input for futures scenarios that we will undertake with our community partners. We recognize that, just as past land use and development have a long-lasting imprint on the environment, human populations have long-term momentum and social legacies. Human population composition with regards to race, wealth, age, and other characteristics often evolve over decadal scales, and we plan to incorporate these forces into our models.

2.5.4.2. Climate-ecosystem interactions

Studies of climate-ecosystem interactions will focus on three cross-scale integrations: 1) global-to-regional; 2) regional-to-mesoscale; and 3) local-to-neighborhood microscale. We will investigate how patterns and processes of urbanization alter the climate of Phoenix and its surroundings and how these alterations feed back to socio-ecosystem interactions (Fig. 7).

Global-to-Regional Scale Research (*Brazel, M. Kaye*). We ask: 1) How does short-term climate variability relate to longer-term forcing processes*?* 2) Are recent (i.e., last few decades) climate changes in the region unprecedented over the last 500-1000 years*?* and 3) What is the spatial coherence of decadal and long-term processes over the LTER network in the Southwest? A comprehensive assessment of current climate variability at global-to-regional scales requires an understanding of the underlying, long-term climatic trends and patterns. We will reconstruct long-term climate for the CAP region by improving and adding to current tree-ring based reconstructions, as well as acquiring new long-term proxy records for the region. We expect to reconstruct climate for the past 500 years (minimum) to the past millennium.

Regional-to-Mesoscale Research (*Zehnder, Stefanov, Brazel, Grossman-Clarke*). Larger-scale research asks: 1) How does climate variability at larger scales force climatic patterns within the CAP region? 2) What landscape variables best explain the urban heat island? and 3) How is regional climatic variability, in turn, affected by changing local variability due to surface fluxes (e.g., how do city structures and vegetation affect surface topography and albedo, surface thermal capacity, emissivity, roughness, and available surface moisture)? We propose using the Fifth-Generation Mesoscale Model with high-resolution land cover and normalized difference vegetation index (NDVI) data and extant networks of weather and climate stations across urban, peri-urban, and rural areas to reproduce the structure of the Phoenix mesoscale climate systems.

Local-to-Neighborhood Scale Research (*Martin, Brazel*). Microscale research questions are: 1) What specific role does vegetation cover have on microclimate, and what feedbacks cause municipalities to reduce water and energy use*?* 2) To what extent are ecosystem/local climate interactions and feedbacks shaped by human response to local climate or other parameters, such as water conservation, desert preservation, human preference for green space, architecture and density of impervious urban surfaces*?* 3) What costs, benefits, and efficiencies of human inputs (nutrients, water, elevated urban atmospheric CO_2, urban heating) and outputs (CO_2 respired, evapotranspiration, vegetation removal) affect urban vegetation productivity*?* and 4) How will human perceptions of environmental quality in Phoenix change quantitative patterns of future urban vegetation NPP? The availability of high spatial- and spectral-resolution remotely sensed data (Fig. 11), and the increasing density of climatic monitoring sensor networks at high temporal frequencies, allows construction and implementation of urban climate models incorporating detailed urban topography, land cover, and geophysical parameters. However, mechanistic linkages among remotely sensed data, urban microclimate, and ecosystem processes like NPP are still lacking. For example, despite ambient CO_2 enrichment, increased urban heat storage and elevated temperatures have reduced productivity of urban vegetation by as much as 87% (Fig. 7; Stabler 2003).

Our proposed new research on NPP-climate relationships in human-modified landscapes will refine our understanding of these linkages. Studies based at the NDV will include seasonal and annual measurements of CO2 flux of individual leaves (photosynthesis), and C accumulation of whole canopies and communities (NPP), linked with the network of yard-scale monitors to measure variables such as soil temperature and moisture. Simultaneous measurement of NPP and local soil conditions using remotely sensed data will confirm patterns established with ground-based measurement. Measurements of vegetation growth and leaf-area index (LAI) will allow establishment of relationships between NPP, LAI and NDVI (normalized difference vegetation index) for scaling of NPP from individual plant to yard to neighborhood to landscape. Linking NDV monitors to a regional network (AZMET) will aid in assessing the impacts of seasonal and temporal variations in Southwest climate on the local climate variability and NPP patterns at the NDV site. We propose to instigate an AZMET-networked base weather station at ASU East, linked by telemetry to ASU for timely archiving and dissemination of data, to CAP LTER researchers (e.g., Material Flux group-Section 2.5.4.4) and the wider research community.

All permanent stations (Fig. 2) will at a minimum uphold the national LTER weather-station standards of a first-order station and will collect surface energetic values such as net radiation, reflected solar radiation, incoming solar radiation (total and photosynthetically active radiation), soil temperature, and soil moisture. The automated base station will be used: 1) to assess the rapidly changing climate conditions of the rural landscape at ASU East as development takes place along the urban fringe to the west of ASU East (tracking impending urbanization effects); and 2) as a “control” site for comparison with in-neighborhood landscape microclimate sampling.

2.5.4.3. Water policy, use, and delivery

Whereas previous water-research efforts at CAP LTER have focused upon water and landscape management (Sections 1 and 2.5.3.3) and a preliminary water budget for the metro area (Fig. 4; Section 2.5.3.1), we recognize a need for a more complex hydrologic cycle, with natural variability altered by the need to supply water for human activities and protect from floods. Controlled management activities shift the characteristic spatial and temporal variability of the system, leading to ecological consequences, human perceptions of change, and further institutional responses. This pattern can lead to vulnerabilities and unanticipated ecological consequences, inability to recognize key processes, and reduced capacity to withstand perturbations. We highlight three new conceptual areas: 1) water supply and delivery; 2) riparian restoration; and 3) resilience and institutions.

Water Supply and Delivery (Arrowsmith, Westerhoff). We will achieve a better understanding of the hydrologic cycle and the partitioning of water into both supply and use categories, with both historic and forward-looking perspectives, relying primarily on a data-mining approach (Fig. 5; Section 2.5.3.1). In proposed new projects, we would: 1) develop future scenarios of water supply and use, drawing upon demographic and land-use projections formulated by government agencies (e.g., Maricopa Association of Governments) and CAP2 researchers; 2) conduct a social survey across the CAP region to gather information about the public’s perception of water quality, current water regulations, planning for water sustainability, and willingness to pay for water use; and 3) continue mapping groundwater quality throughout the basin by expanding past work on N (Xu *et al. in prep.*) to include arsenic, synthetic organics, and other toxic pollutants. The proposed activities will help develop policies for the CAP region that integrate scientific knowledge and public preferences. We expect to conduct Items 1 and 2 with leveraged funding.

Riparian Restoration (Stromberg, Feller, Grimm, Sabo). Widespread degradation of riparian-zone vegetation is an important ecological consequence of anthropogenic alterations to water supply and delivery in the western US. The Salt-Gila River (SGR) riparian ecosystem has been severely degraded. Restoration requires an understanding of the processes shaping the biotic community, people's perception of the services that rivers provide, and the factors that assist or obstruct restoration. We plan three projects, to: 1) assess the present and historic condition of riparian ecosystems in the SGR, including the determinants (e.g., water flow, land use) of species composition and biogeochemical function, by conducting correlative studies across spatial site gradients and by analyzing historical documents; 2) elucidate societal restoration goals through interviews, surveys, and focus groups; and 3) examine the physical, legal, and societal factors that will aid or obstruct these goals. The latter examination will draw upon mined data on water sources, assess the legal mechanisms for devoting water from these sources to instream flows, offer a literature review comparing the success of different restoration strategies, and evaluate on-going restoration projects on the SGR.

Resilience and Institutions (Anderies, Kinzig, Redman). A resilience conceptual framework suggests that it is the interaction of “fast,” “medium,” and “slow” variables that create robustness or introduce vulnerabilities into socio-ecosystems (Folke *et al.* 2002). In the SGR basin, “fast” variables are associated with flood events, “medium” variables with water supply (including drought), and “slower” variables with groundwater levels and recharge. Each of these risk portfolios not only carry different temporal signatures, but introduce different spatial arrangements of risk (Fig. 12). Managers and decisionmakers need to mediate and tradeoff these different risk portfolios—for instance, the resources and strategies for protecting against flood versus drought. Both limited resources and the potential for conflicting strategies mean that policymakers must navigate potentially difficult policy decisions over the coming years. Complications introduced by climate change—both exogenously (e.g., global change) and endogenously (e.g., urban heat island) forced—will exacerbate these difficulties.

We propose to examine the trade-offs in these risk portfolios, the “mental models” (perceptions and assessments of the system) used by decisionmakers, and the institutional arrangements that could be used to reduce vulnerabilities, in three ways: 1) determining how risk is perceived by various water managers through in-depth interviews, more extensive written surveys, and statements made during public meetings; 2) elucidating the spatial and temporal signatures of risk associated with flood, drought, and groundwater subsidence; and 3) examining alternative institutional arrangements (e.g., division of flood and groundwater management; greater regional coordination) that may reduce future vulnerabilities. Item 1 will be partly supported by CAP2 funds and partly through leveraged funding (McDonnell Foundation, *Kinzig and Redman 2001*; NSF-BE, *Redman et al. 2002*). Item 2 will be accomplished through collaboration with climatological, hydrological, and environmental risk groups within the CAP region, as well as various community partners who assess these risks as a matter of course. Item 3 will be accomplished through the use of simple dynamical models linking information on spatial and temporal patterns of resource variability and different market and property-right regimes (e.g., tradable permits versus command-and-control restrictions versus variable pricing).

2.5.4.4. Material flux and socio-ecosystem response

Linkages at the interfaces of the major compartments of the ecosystem constrain material transport through landscapes. Our conceptual model identifies four reactive ecosystem compartments (atmosphere, land, surface water and groundwater), any of which may be a source, sink (recipient system) or transporting/transforming system for a particular material flux. Toxins and pollutants may concentrate in recipient systems to generate biogeochemical "riskscapes" for urban inhabitants. The spatial distribution of naturally occurring, anthropogenically enhanced nutrient fluxes (e.g., combustion-derived NO_x) and those of novel materials (e.g., atmospheric deposition of organic C from pesticides) may represent fundamental shifts in biogeochemical cycling. The source and sink locations for these toxins and nutrients often occur in hotspots of altered stoichiometry where complex chemical interactions may enhance or retard element transport. Our research on the spatial distribution of recipient systems, altered stoichiometry, and the consequences for humans and ecosystems focuses on the following three areas:

Nutrient Cycling (Kaye, Grimm, Allen, Hope, Nash, Shock, Westerhoff, Sommerfeld). Urban atmospheres are fundamentally different from non-urban areas due to (among other things) elevated ozone, CO_2, N, and organic C concentrations. Our research on nutrient cycling will focus on achieving a mechanistic understanding of how properties of the urban atmosphere cause fundamental shifts in the biogeochemistry of recipient systems. We intend to develop our understanding of how the spatial distribution of atmospheric pollutants (e.g., Grossman-Clarke *et al. in revision*) affects spatial patterns in biogeochemistry. Our main questions will be:

1) What are the major fluxes from the atmosphere to land in urban ecosystems, and how do these differ from non-urban surroundings? This research has three components: a) quantifying atmospheric deposition; b) discovering chemical species (e.g., organic C and metals) that are important components of urban atmospheres but are rare in non-urban atmospheres; and c) determining the temporal as well as the spatial distribution of deposition to understand the effects of the urban atmosphere on within-city and downwind biogeochemistry.

2) Are urban and downwind ecosystems resilient to chronic high N deposition and to the unique chemistry of the urban atmosphere (high N and organic C)? To what extent do spatial and temporal patterns in atmospheric deposition entrain spatial and temporal biogeochemical patterns in urban and downwind ecosystems? To answer these questions, we will modify existing monitoring and initiate a factorial N and P experiment along a depositional gradient.

Monitoring: We will refine our wet and dry deposition program, which uses bucket, throughfall, and bulk-deposition collectors, by focusing our efforts on a subset of the CAP1 sites, replacing dry buckets with filter packs. We will run simple eddy-correlation measurements of momentum, H_2O, and CO_2 flux at the intensive/experimental sites. When combined with filter bank data, local estimates of deposition velocity from eddy correlation will yield reasonable estimates of speciated nutrient deposition (*Allen Hope, Grimm, Kaye*). (Using the system-wide mass balances from CAP1 to provide a regional context, we are seeking non-LTER funding to undertake periodic eddy correlation mass spectrometry measurements of dry deposition of organic C, N, P, and metals [*Grimm, Allen, Kaye, proposal pending*]). Use of portable met station will allow realistic dry deposition calculations based on the eddy correlation campaigns. To determine the effects of N deposition on soil processes, we will initiate a soil to atmosphere trace-gas (NO_x and N_2O) monitoring program at selected intensive sites. Previous research shows that N deposition is lowest west of the city, intermediate at the urban core, and highest downwind (east) of the city (Fig. 6B). Our monitoring program will focus on remnant deserts along this N deposition gradient during important seasonal transitions (e.g., monsoons, winter rains).

Experiments: We will initiate two long-term experiments in CAP2. To test the hypothesis that elevated N deposition alleviates N limitation in remnant deserts, we will initiate a factorial N and P fertilization experiment along the deposition gradient described above for trace-gas monitoring. We will monitor plant (growth and foliar chemistry) and microbial (N cycling, soil respiration) responses to the fertilizer additions (*Kaye, Grimm*). A second experiment will monitor soil N storage and cycling in urban lawns at the NDV experimental suburb (*Martin, Hope, Kaye*). By monitoring soil N accumulation and cycling over decades, we will quantify the size of the residential soil N sink relative to N-deposition rates and the N-accumulation rate identified in the CAP N mass balance (Fig. 6A).

Contaminants and Toxics (C&T) (Kaye, Grimm, Shock, Westerhoff, Crittenden, Nash, Allen). Urban biogeochemistry is unique in terms of the abundance of novel biogeochemical pathways such as rapid metal cycling or fluxes of synthetic organic compounds. These uniquely urban fluxes provide an opportunity to develop new biogeochemical theory, but they are also relevant to the social system when the element or compound of interest is a toxic contaminant. Research questions are: 1) At the scale of the CAP region, how does the mass balance of various elements imported/exported by humans (via trains, plane, trucks) in urban areas differ from that of non-urban ecosystems? 2) At the watershed or neighborhood scale, what are the spatial and temporal distributions of contaminants in surface water and soils?

Data mining: Compiling business-activity and shipping records, landfill/garbage-hauling records, recycling records, and synoptic sampling of representative shipments will be the main approach used to answer question 1. Regional mass balances of human import and exports will be statistically compared against the biogeochemical sources and sinks (water, air) expected for non-urban ecosystems. Historical data will be plotted against time and population, which changed as agricultural exports (e.g., cotton, citrus) were replaced by industrial products (e.g., microchips). Data collected while answering this question will also provide information on major sources of toxics (metals) entering and leaving the CAP region.

Monitoring: At a decadal scale (1974, 1998, 2008), we will document integrated metal deposition patterns across the study area as reflected by lichen accumulation (Nash *et al*. 2003; Zschau *et al.* 2003). We will also add selected contaminant measurements (e.g., metals and organic contaminants) to our water (water monitoring, small watersheds) and soil (Survey200) monitoring programs. A pilot phase will be used to identify contaminants upon which to focus.

Environmental Risk (Bolin, Peccia, Harlan, Dillner, Allen, Anderson, Hackett, Shock). An important challenge in studies of material flux in urban ecosystems is to document and characterize risks to humans and ecosystems that aggregate distributions and concentrations of toxics and other contaminants produce across varying temporal and spatial scales. This knowledge provides bases for assessing hazard burdens, risk distributions, ecosystem effects and environmental equity questions. Our research question is: What are the scalar patterns and risks of environmental contaminants in relation to human populations and ecosystem processes?

Data mining and monitoring: Characterizing the Phoenix "riskscape" involves both data mining for mobile, area, and point-source pollutants as well as new environmental monitoring of contaminants. We have developed methods to evaluate contaminant distributions in terms of averages, peak concentrations, "pollution hot spots," and transport patterns, and will use all of these methods in our analyses (Bolin *et al.* 2002; Fig. 13). Data mining will provide detailed map overlays of human risks/impacts, including health indicators (asthma, valley fever) in relation to ambient environmental pollutants. New monitoring (described above) will identify pollution types, transport patterns and concentrations in different dispersal media. Environmental equity assessments draw on both types of studies to investigate the changing exposure profiles of different locations and socio-demographic groups in the metro area.

Place-based comparisons of hazard burdens will be developed to "ground truth" risk-map overlays at the neighborhood scale, using ecosystem indicators and ambient pollution measures in relation to socio-demographic variables. Relevant data from the Survey200 and neighborhood-scale social surveys integrated with PASS (described in 2.5.3.2) will be combined to analyze differential risks and human perceptions.

2.5.4.5. Human control of biodiversity

Human activities in urban areas have dramatically altered the population abundances and distribution of native species through habitat alteration and loss, modification of climate, alteration of nutrient and water availability, and introduction of nonnative species. Human-mediated changes in population abundances and species distribution translate into radically altered species richness, composition, and trophic structure and dynamics in urban settings. Changes in biodiversity, mediated by cumulative human behaviors and actions, in turn, feed back upon these same human perceptions, behaviors and interactions. In CAP1, the emphasis was on documenting altered species richness and composition. CAP2 will show an increased emphasis on trophic structure and dynamics, while still monitoring decadal changes in richness and composition. We will study a variety of human controls of biodiversity at different scales and through a combination of experiments and long-term monitoring: broad-scale regional effects of urbanization, metropolis-level controls on species invasions, neighborhood-scale socioeconomic variation, within-neighborhood landscaping styles, and individual human perceptions of biodiversity. The long-term nature of the project allows us to address additional temporal dimensions for all of these aspects of human-biodiversity interactions.

Patterns of biodiversity (Faeth, Stutz, Cook, Warren, Hope). A major goal of CAP LTER is to determine the effect of human activities on local and regional biodiversity. Data collected (as part of the Survey200 and at sites with more continuous monitoring) on arthropods, birds, mycorrhizal fungi and plants are providing an increasingly detailed spatial and temporal picture of biodiversity in the CAP region (Fig. 14). Based upon data analyses, we have modified sampling protocols, sites and frequency for greatest efficiency, without compromising a comprehensive picture of the spatiotemporal variation in biodiversity patterns. Long-term monitoring of the targeted biodiversity groups, as well as the more comprehensive Survey200, which captures a broader spatial and temporal view of biodiversity, will continue in CAP2. New research will add invasive species to the mix.

Invasive Species: Human and Natural Conduits of Invasive Species in Urban Areas (Faeth, Kinzig, Warren). Accidentally and/or intentionally introduced nonnative species account for an increasing fraction of biodiversity in urban areas. Introduced species may have negative effects, often unforeseen, on native flora and fauna. A few introduced plant species have become invasive to surrounding Sonoran Desert habitats, whereas some native species flourish and some even become "weedy" or "invasive" in urban areas. Monitoring animal populations at the NDV experimental suburb allows us to measure effects of nonnative plant species on vertebrate and invertebrate communities.

Neighborhood Social Variation and Biodiversity (Warren, Harlan, Kinzig, Martin). Typical indices of urbanization, such as population density, often fail to fully explain patterns of biodiversity in urban areas (Whitney & Adams 1980). Human behaviors, values, and resource consumption levels also influence vegetation composition and habitat and food availability for animal populations in residential areas (Warren *et al. in review*). We have identified a set of 19 relatively homogeneous neighborhoods varying in socioeconomic status, each surrounding a subset of the Survey200 sites. This design allows us to explicitly test the degree to which human socioeconomic and lifestyle factors predict variation in ecological patterns such as bird distribution and abundance. During CAP1, we conducted a pilot study of neighborhood social variation and biodiversity, focusing small, neighborhood parks located in relatively homogeneous neighborhoods in the city of Phoenix. We found a strong correlation between neighborhood socioeconomic status and avian diversity in and around parks, independent of variation in the parks themselves (Martin *et al* 2004; Warren *et al. in review*; Fig. 14). Thus, we have shifted our focus to neighborhood-level patterns of plant and bird community structure and are moving our sites to correspond with ongoing research on both biophysical features (Survey200) and social features (PASS survey) of neighborhoods. New research in CAP2 will address two major questions: 1) What forces mediate the correlation between neighborhood socioeconomic status and the structure of animal and plant communities*?* and 2) How does community structure change as the social structure of neighborhoods change through time?

Monitoring: We will monitor abundance and diversity of birds, cats, arthropods, and plants. Methods are standard (http://caplter.asu.edu), except for the cats (a major avian predator), which are effectively counted along transects (based on a pilot REU project). To maintain continuity from CAP1 to CAP2, during the first two years of CAP2 we will continue to monitor birds at the 16 sites from the pilot study as well as at the 19 new sites co-located with PASS and Survey200 sites. Point-count censuses for birds will be conducted at four points per neighborhood in four seasons: breeding, winter, and fall and spring migration. We will seek external support to conduct additional experimental studies of the top-down vs. bottom-up controls on avian reproductive success in these neighborhoods. Finally, we will evaluate long-term data on bird and plant communities (Survey200 and intensive sites) to detect changes in biotic community structure associated with changing social conditions (PASS) in these neighborhoods.

Human Perception and Valuation of Diversity (Casagrande, Yabiku). The cumulative effects of individual human behaviors significantly affect macro-scale patterns in urban biological diversity. In turn, biological diversity influences human perceptions, preferences, and well-being (Fig 8). For example, previous empirical studies have revealed that people prefer more “natural” environments (Balling & Falk 1982), that environmental values (ecocentric, anthropocentric, and apathetic orientations) influence landscape preferences (Kaltenborn & Bjerke 2002), and that personal characteristics such as age, gender, education, income, and residential history affect landscape preferences and sensitivity to different environments (Balling & Falk 1982). However, understandings of the causal links in this relationship are inadequate. As part of the NDV experiment, we will monitor human reactions to the experimental manipulation of their residential landscapes using five variables: 1) ecological knowledge, which tends to correlate with favorable perceptions of biodiversity (Kellert 1984); 2) behavior, including recreation and landscape manipulation by residents; 3) preferences for natural desert versus artificial landscapes; 4) social interaction, which tends to influence knowledge and perceptions; and 5) personal status attributes, including age, marital status, presence of children, gender, education, income, and geographic mobility history. We are currently collecting pre-manipulation, baseline data for these five variables. We monitor changes in knowledge, perceptions and neighborhood social networks via semiannual face-to-face surveys/interviews.

2.5.5. *Integration of IPAs*

The redesign of CAP LTER’s research structure (IPAs) has strengthened our ability to work together toward synthesis of diverse ongoing projects (e.g., Warren *et al. in review*), and much of the new research proposed crosscuts the five IPAs. We therefore believe these areas much better encompass the logical next steps for our research, while adequately incorporating the LTER core areas (Fig. 1B). For example, the riparian-restoration project proposed for the Water IPA will have elements that include studies of populations and materials movement (core areas), but also include investigation of feedbacks to the social system. Research on resilience and institutions work is related to the disturbance core area, but in the social context of institutional response.

The IPAs can be well integrated because much of the research is place-based, at a range of scales. Co-location of sites will continue to prove essential to integrating CAP LTER's disparate research areas. The Survey200 sites and intensive sites have provided an integrating framework to help CAP LTER researchers co-locate their monitoring and experimental work (Table 1). Only a few studies (e.g., water monitoring program, atmospheric deposition program, riparian bird-survey sites) are located independently of this network, due to their requirements to be positioned on a specific landscape feature (river channel, riparian corridor) or co-located with other monitoring equipment (e.g., Arizona Department of Environmental Quality air-quality monitoring network equipment).

Modeling will be closely linked with data mining, field survey, and experimental studies, and used to synthesize research outcomes from across the IPAs to address the overall research question, *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?* This synthesis will proceed in two parallel research streams: the actual coupling of several of the individual models from specific IPAs into a larger-scale model and the development of simple models focused on specific questions of interest across the IPAs.

Model coupling (first research stream) is a natural extension of the work done in CAP1. Simulation modeling has been the primary tool for integrating interactive components of complex ecological and socioeconomic systems in the past several decades (Wu & Marceau 2002; Guhathakurta 2003). We will have two broad types of simulation models: LULCC models and biophysical models. LULCC models include both existing urban-growth models and agent-based models to be developed in CAP2. These models are useful for envisioning socio-ecological consequences of urbanization and are thus a key component of the LULCC IPA. The biophysical models include ecosystem process models, biodiversity models, local/regional climate models, and air quality models, which are closely integrated with the Material Flux, Biodiversity, and Climate-Ecosystem IPAs. As all the IPAs are intrinsically linked with one another, coupling will allow questions regarding human-urban environment interactions to be addressed.

The second research stream will focus on synthesizing the knowledge generated by previous and ongoing research within the IPAs. This synthesis will be driven by the need to develop models to address questions that emerge from and link the IPAs. One example is the interaction of water use and policy and LULCC. LULCC affects the demand for water, as well as surface and groundwater hydrology. Water use and policy will influence water use and thus feed back to LULCC. As a complement to a large-scale model that couples a LULCC model with a human-decision model, a simple model that captures the essential features of key drivers from LULCC research coupled with key drivers from water-use and water-policy research will be developed to address a specific question: how does LULCC associated with urban growth affect the ability of a urban system to cope with increased variation in rainfall? What are the implications for risk management? We envision several such modeling activities emerging as CAP2 proceeds.

Table 1. List of CAP Monitoring Sites, Showing Variables Measured and Frequency of Sampling. Letters indicate variables measured: A = arthropods; B = bird abundance and diversity; D = wet/dry atmospheric deposition; K = prokaryote diversity; M = modeling; N = soil nutrients; O = pollen; P = plants; S = social survey of neighborhoods; T = tree growth; V = various human management indices; W = full suite of chemical analyses.

Sites	Number of sites	Variables measured	Frequency of sampling
Perennial surface water flow sites	4	W	6 times/yr
Atmospheric deposition sites:			
wet/dry deposition collectors	8	D	Per event
air quality monitoring modeling	6	M	Per event
Survey200 extensive sites (incl. N, P, O, K, V)	200	N, P,O,K,V,M	Once/5 yrs
Bird survey sites	52	B,V	4 times/yr
Arthropod pitfall trapping sites	22	A	6 times/yr
Tree growth sites	37	T	Annually
Social survey sites	8	S	Annually
Co-located sites (subsets of the above):			
Survey200 and birds	40	N,P,O,K,B,V	
Survey200 and trees	21	T,N,P,O,K,V	
Survey200, birds and arthropods	17	N,P,O,K,B,A,V	
Survey200, trees, birds, and arthropods	7	T,N,P,O,K,B,A,V	
Survey200 and social	6	N,P,O,K,V,S,	
Survey200, social, birds, and arthropods	1	T,N,P,O,K,B,A,V,S	
Experimental plots:			
President's House	1	T,M	
Desert Botanical Garden	2	T,M	
Community Services Building	1	T,M	
Usery Mountain Park (trophic exp.)	1		

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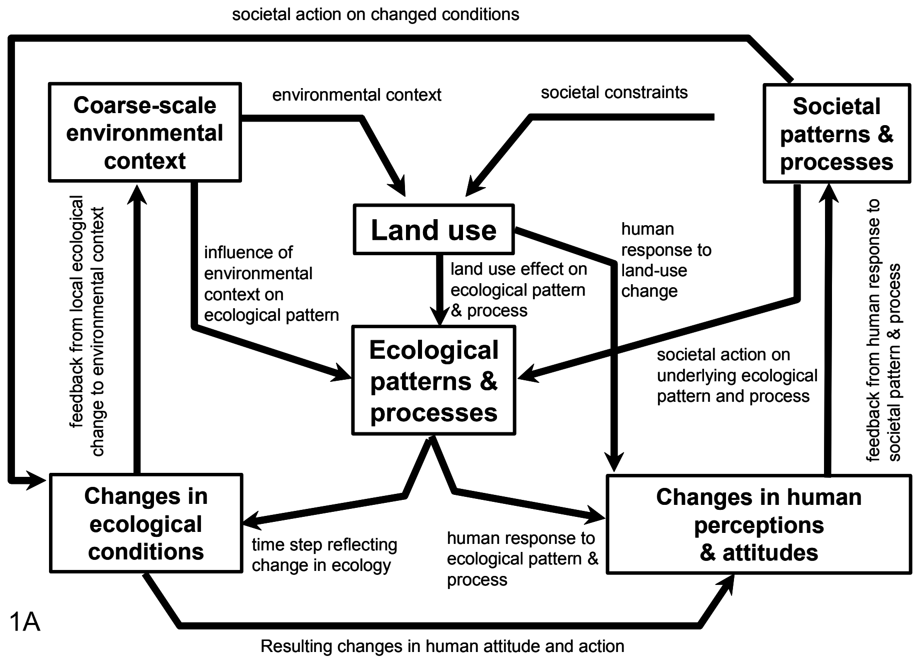


Figure 1A

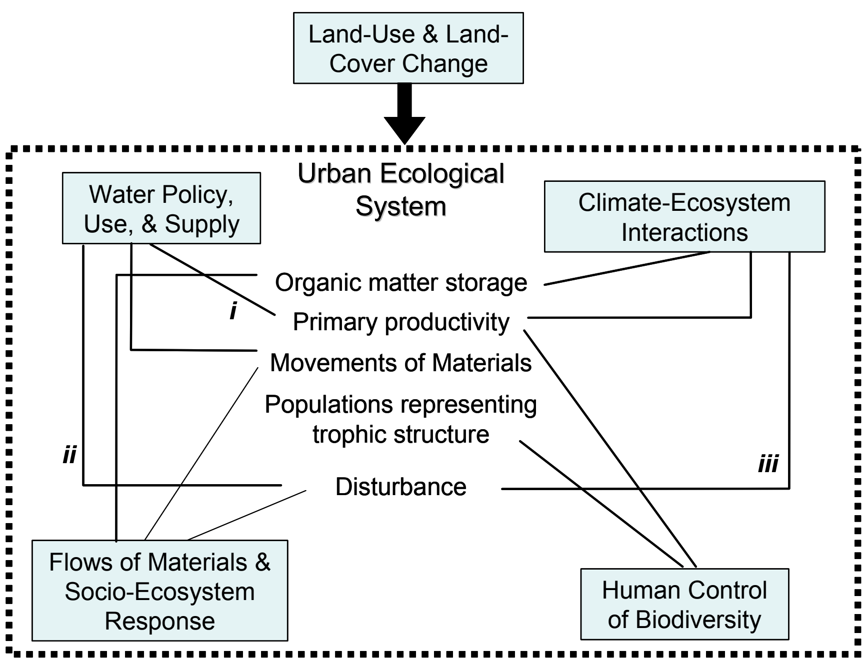


Figure 1B

Figure 1. A) Conceptual scheme for integrating socio-ecological systems in urban environments. Variables are in boxes; interactions and feedbacks are labeled arrows. At the core is land-use change, which is constrained by both biophysical and societal factors and which drives ecological change. Feedbacks result from changes in either human perception and action or ecological conditions. **B)** Relationship of the CAP2 Integrative Project Areas (IPAs) to the LTER core areas, with the most important linkages shown. Examples of projects that link the IPAs to the core areas include: i) DBG and NDV landscaping experiments, which focus partly upon the control of primary productivity by landscape watering regimes; ii) the response of human water-management institutions to drought; iii) the interaction of long-term climate trends and resilience of social institutions. All these projects incorporate both social and ecological responses to larger-scale environmental drivers.

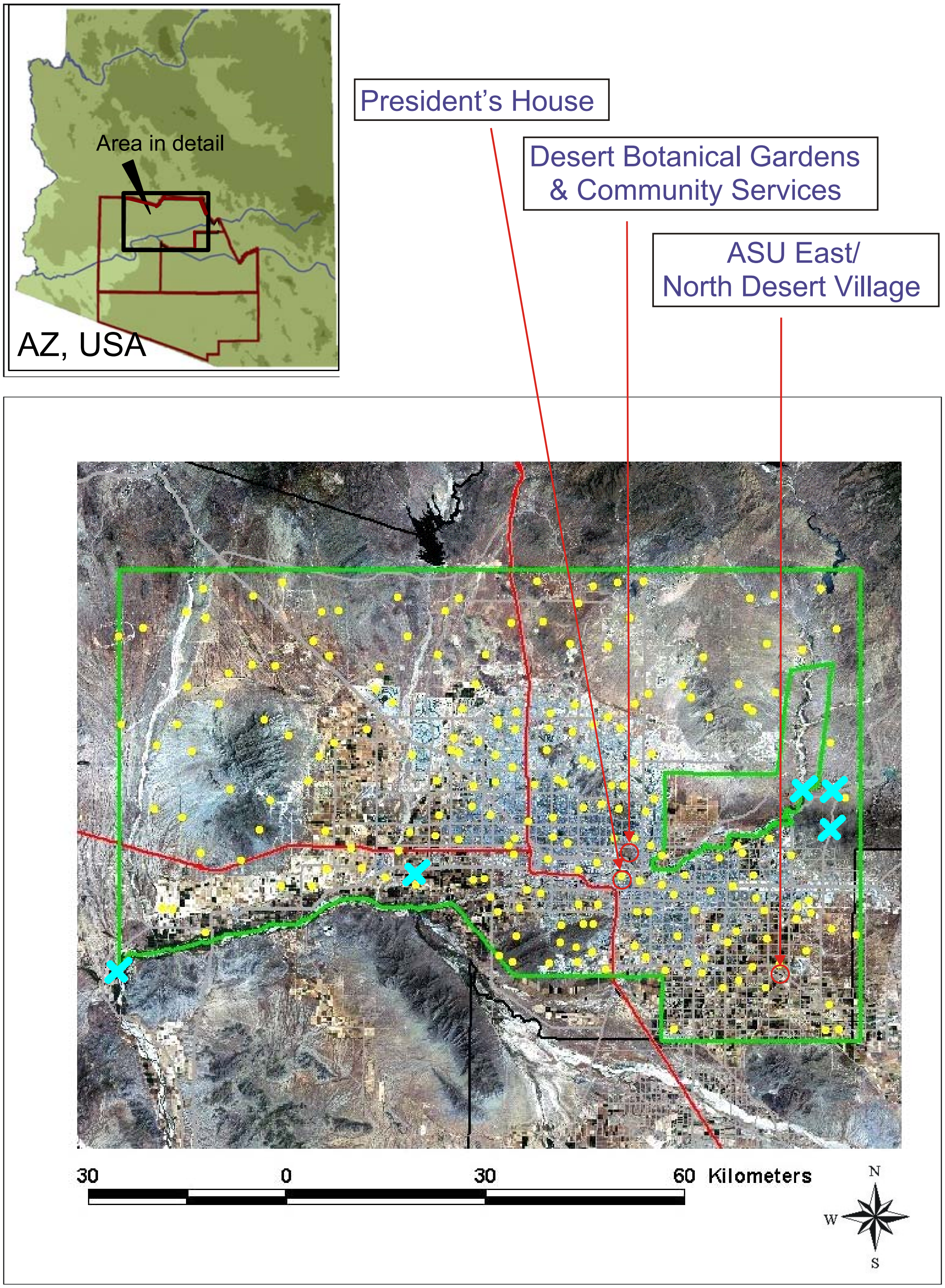


Figure 2. Location map showing the extent of the CAP study region in Arizona, the Survey200 sampling scheme (closed yellow circles), the intensive/experimental sites (open red circles), and the water monitoring sites (blue X's). The red lines in the Arizona map indicate Maricopa, Pinal, and Pima counties.

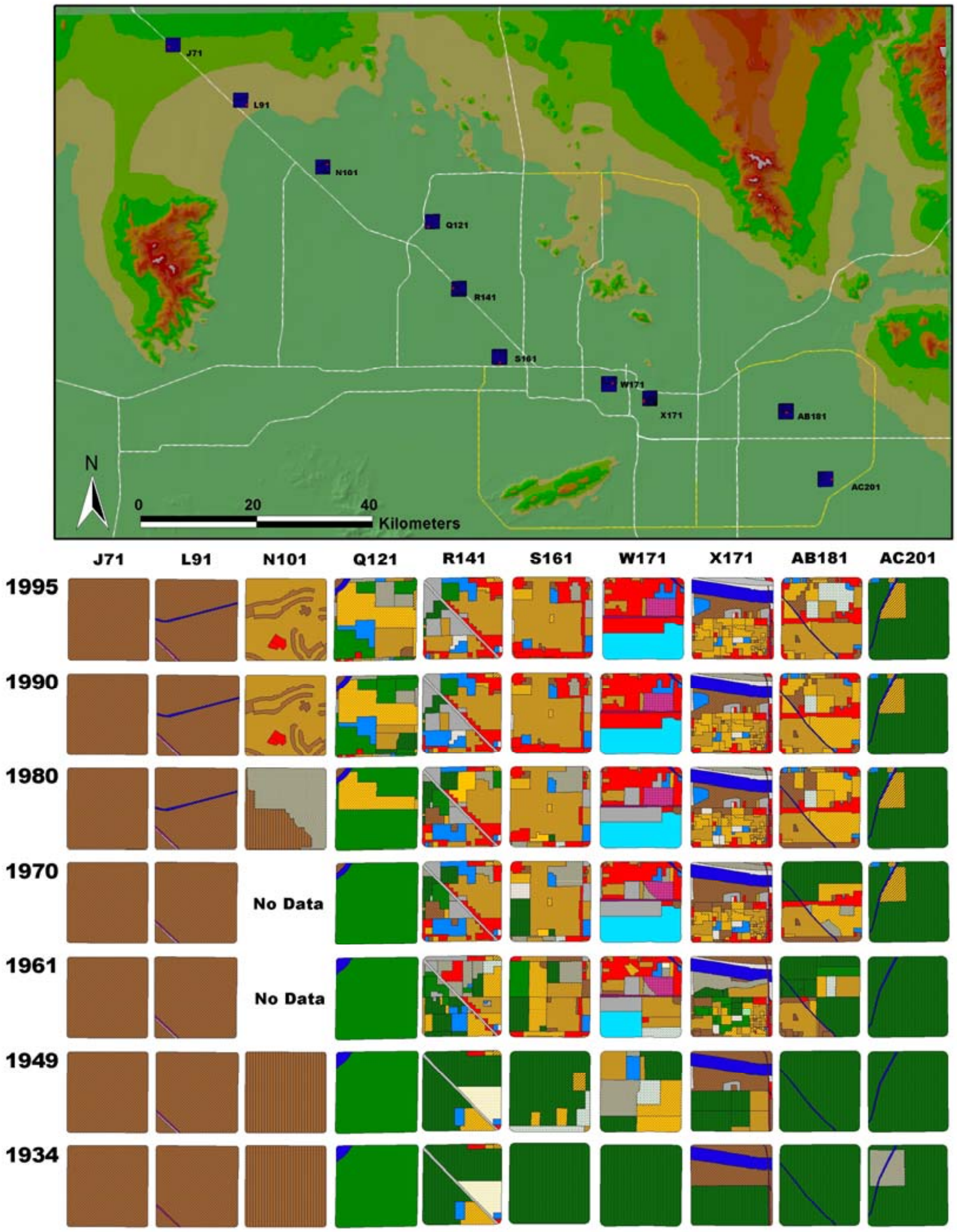


Figure 3. As part of documenting and quantifying land-use and land-cover change, land use for each 1-square-mile section around each Survey200 site has been interpreted from aerial photography on a decadal basis from 1930 to 1995. Transect of 1-mile squares across the study region shows how land use has changed in core versus fringe areas. Color codes for some of the main land use types are: brown - desert, green - agricultural, yellow - urban/built-up, red - commercial (malls, office buildings), pale blue - airport, mid blue - institutional (schools, churches), dark blue - streams/rivers/canals, gray - industrial, white - transportation.

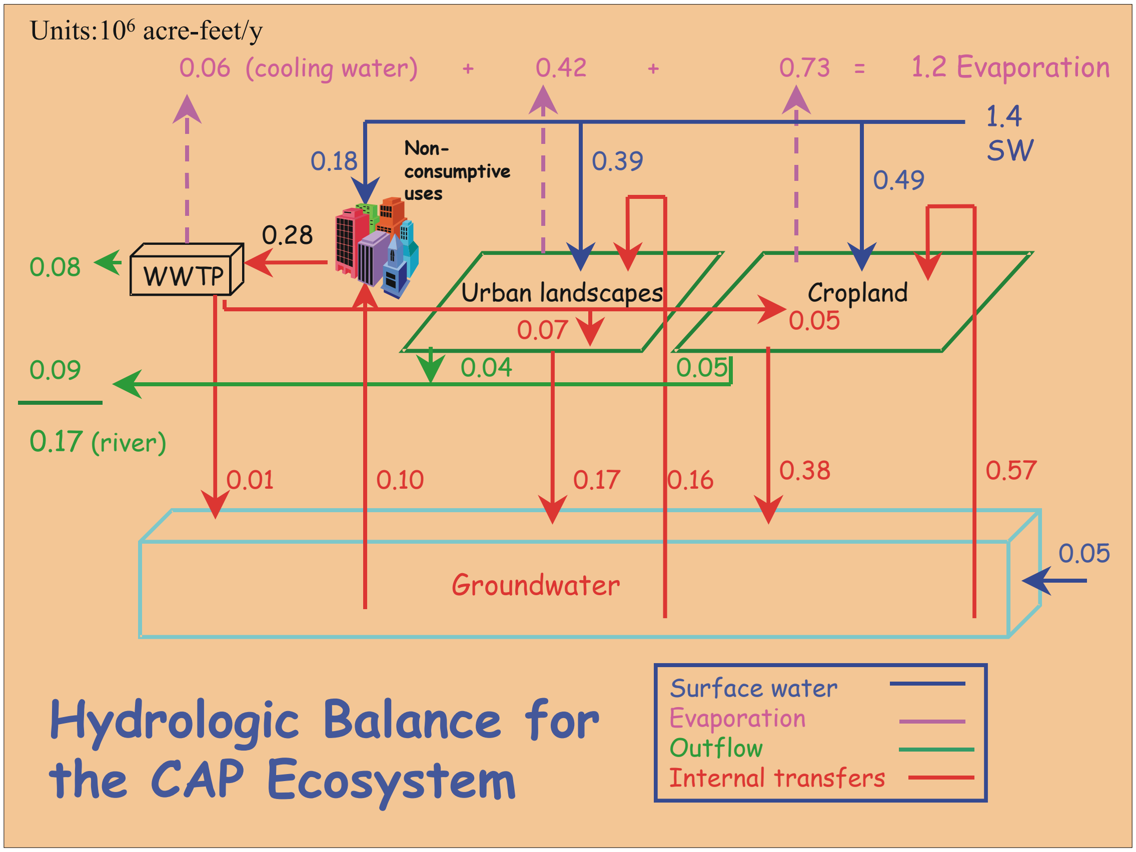


Figure 4. Hydrologic balance for the CAP ecosystem showing major inputs (blue arrows), surface-water outputs (green arrows), internal fluxes (red arrows) and evaporative fluxes (pink arrows). Note that only a small percentage of water inputs leave the city.

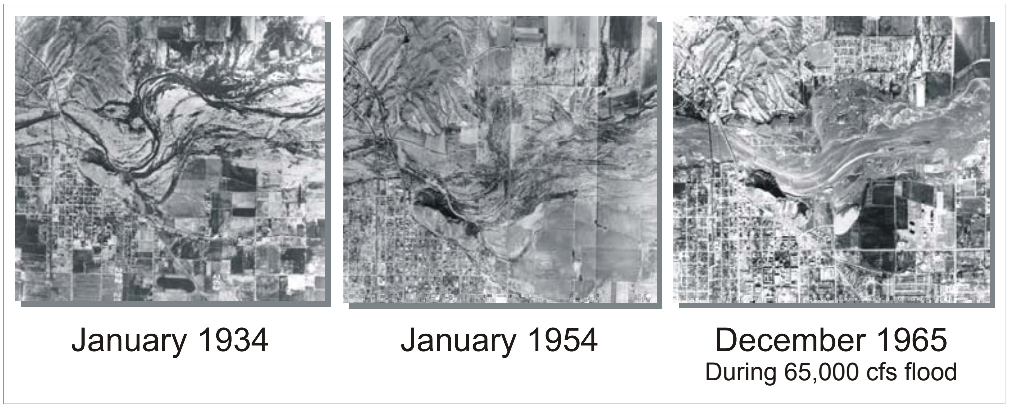


Figure 5A

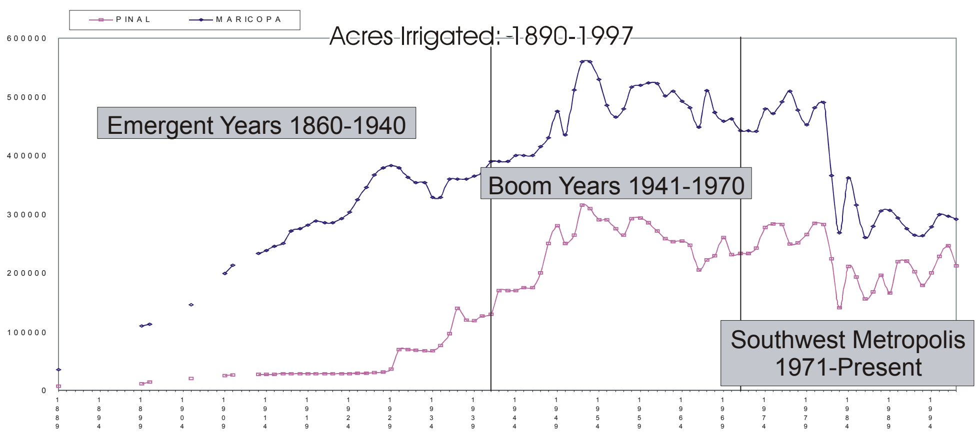


Figure 5B

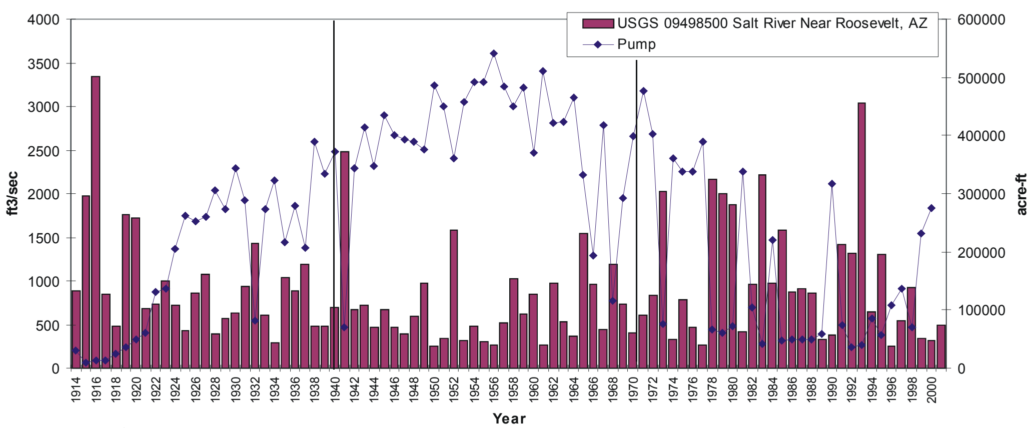


Figure 5C

Figure 5. A) Aerial photos showing changes in the channel of the Salt River from 1934 to 1965. Prior to 1938, the river's discharge was relatively uncontrolled and the river migrated in an extensive channel (left). 1954 photo (center) shows encroachment on the now-dry channel by both agricultural fields and housing, which are susceptible to the rare floods that still occur (right). **B)** Changes in farm acreage irrigated during agricultural expansion (emergent, boom years) and during the recent urban expansion (1971-present). **C)** Long-term data records such as these for streamflow and groundwater pumping are mined for budgets and historical analysis, and stored in the CAP LTER database.

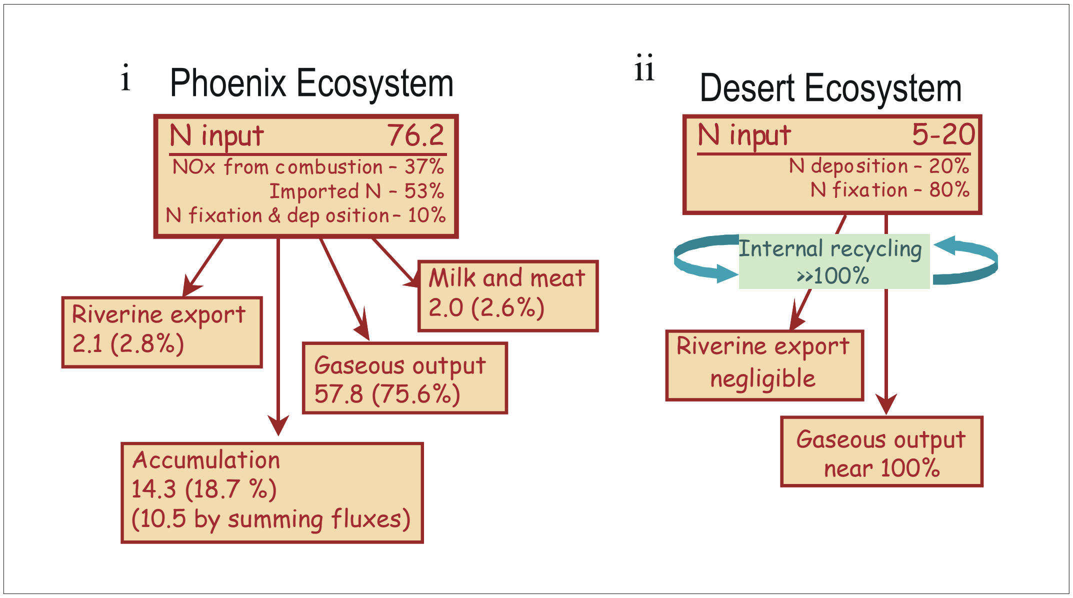


Figure 6A

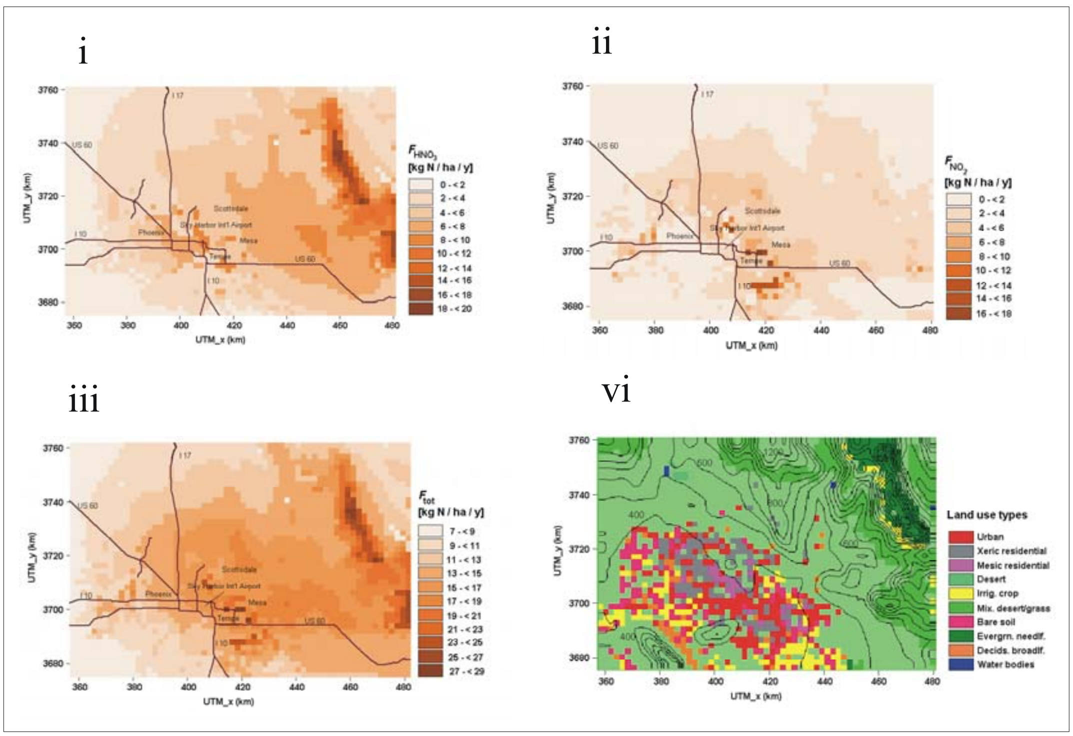


Figure 6B

Figure 6. A) Comparison of nitrogen budgets for i) the CAP socio-ecosystem and ii) a desert ecosystem. All units in kg/ha. Note that inputs to the urban ecosystem exceed those to surrounding desert by a factor of 7-10 and are dominated by deliberate and inadvertent inputs of N mediate by humans, such as atmospheric deposition (Baker *et al.* 2001). **B)** Estimated annual dry nitrogen (N) deposition as: i) nitric acid (HNO_3), ii) nitrogen dioxide (NO_2), iii) total N across the CAP region, determined using Models-3 Community Multiscale Air Quality model simulations, and iv) land use determined from CAP research (Fenn *et al.* 2003).

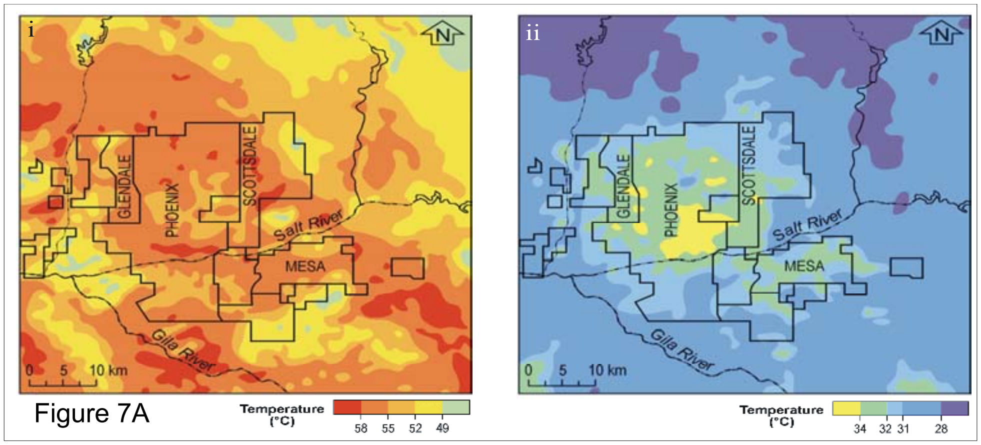


Figure 7A

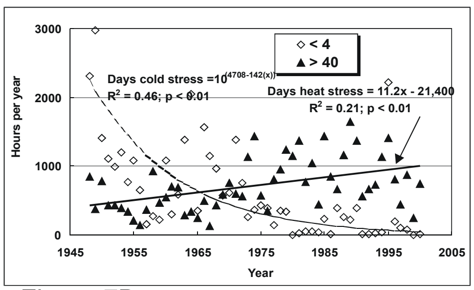


Figure 7B

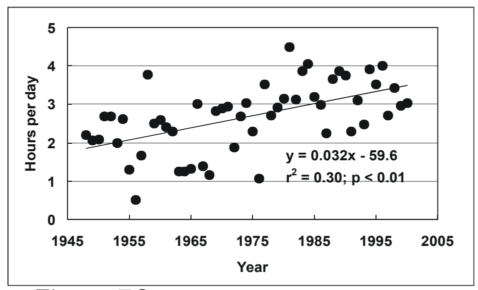


Figure 7C

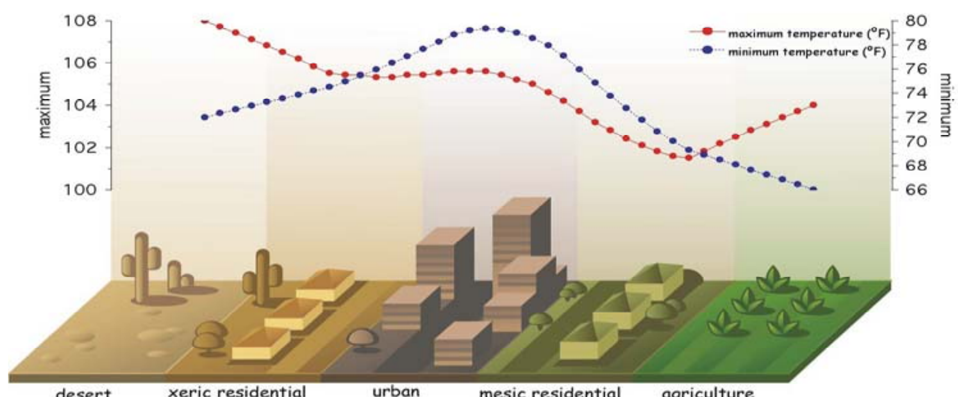


Figure 7D

Figure 7. A) An AVHRR satellite image of composite patterns for several days in summer for the Phoenix area, showing surface temperatures for day (2 PM) and night (2 AM) from Baker *et al.* 2002. Spatial and temporal expansion of urban heating in the Phoenix metro area has increased daily minimum temperatures—it now takes less time to reach uncomfortable temperatures during the day and longer to cool off. **B)** Physiological effects on vegetation of the increased degree-hours >40°C in summer and decreased number below 4°C in winter include exacerbation of indirect heat stress and increased chilling stress, resulting in plant injuries. However, the long-term decline in the annual number of wintertime degree-hours below 4°C also enables greater productivity of evergreen species during the winter and survival of imported subtropical and tropical species year round (Baker *et al.* 2002). **C)** Most noticeable for human inhabitants is an increase in the average number of hours with effective temperature over 38°C, known as "misery hours per day" per day, which have nearly doubled during the hottest months since 1948 as a result of urbanization (Baker *et al.* 2002). **D)** Changes in minimum and maximum daily temperatures with land use.

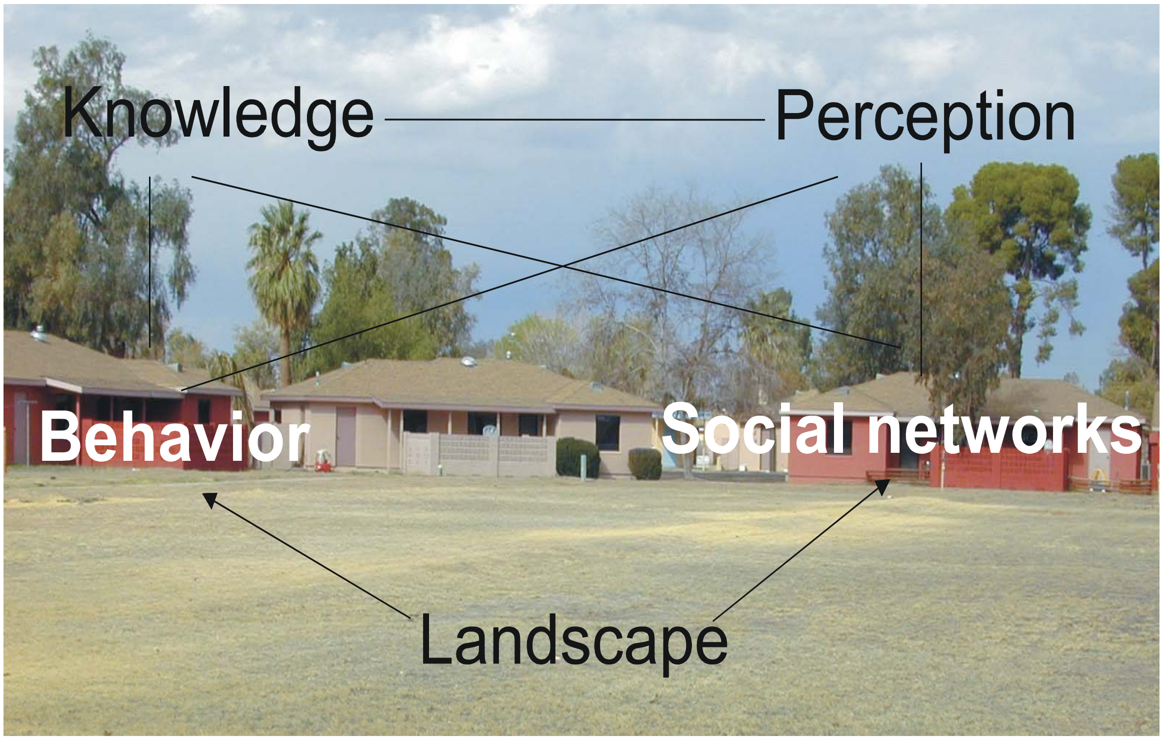


Figure 8A

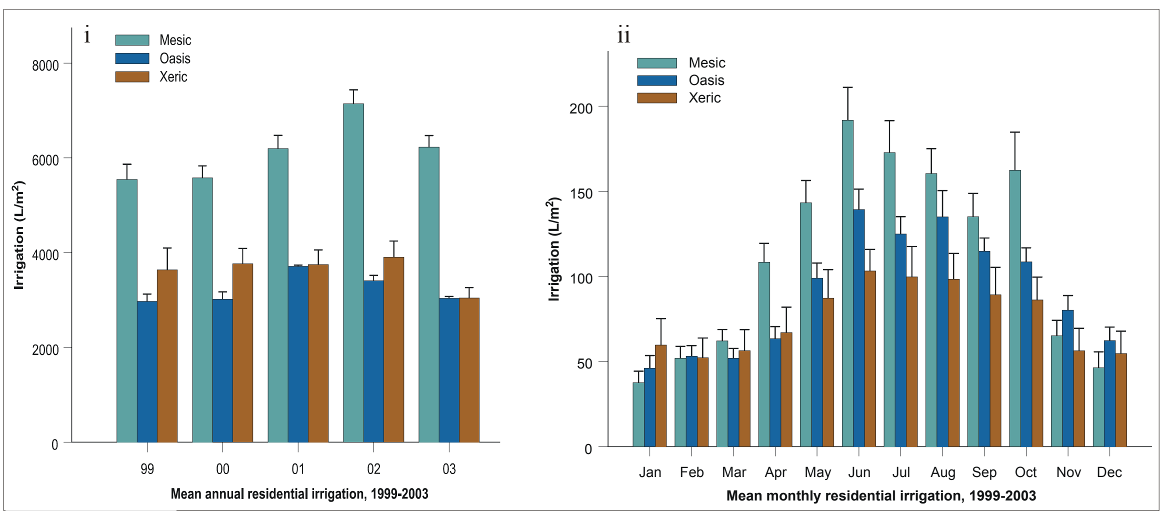


Figure 8B

Figure 8. A) The conceptual scheme framing our research questions for the NDV (pictured) landscaping experiment which will allow us to examine how biophysical information feeds back into human decisionmaking and behavior, at the scale of the household, within a replicated, four treatment (mesic, xeric, oasis, native desert) design. **B)** Mean monthly-irrigation volume per landscape surface area applied to privately owned residential yards in Phoenix (n=6 per landscape type) between 1998 and 2003 were much smaller than expected, despite the three disparate landscape types (mesic, oasis, and xeric).

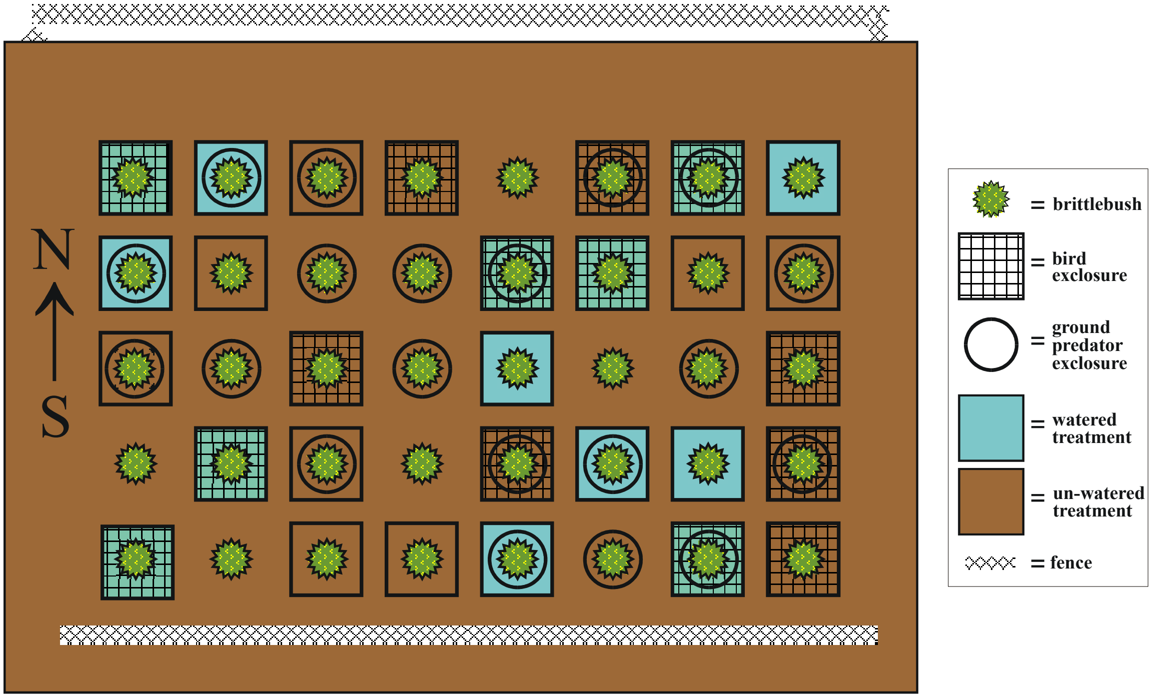
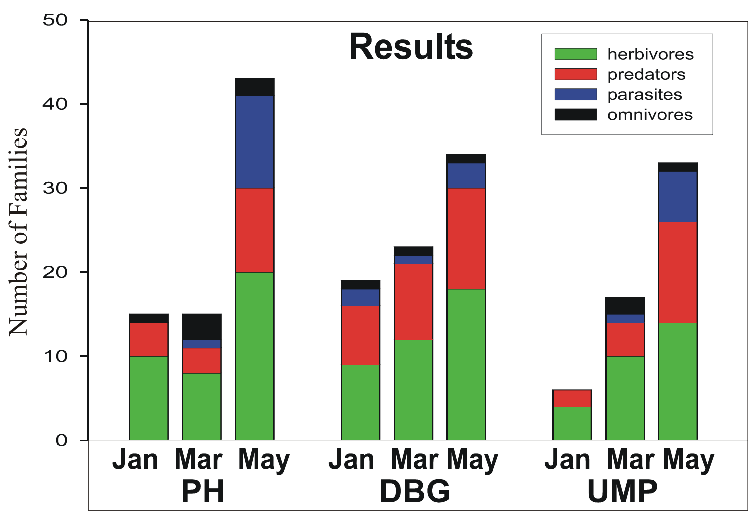


Figure 9A



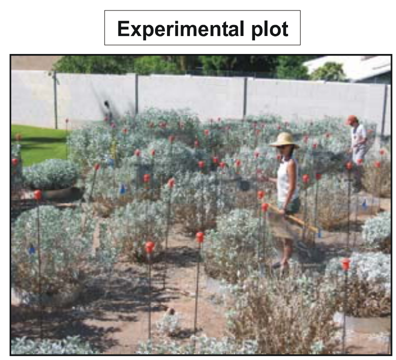


Figure 9C

Figure 9B

Figure 9. A) Schematic of the experimental design for the long-term trophic structure and dynamics experiment at the Desert Botanical Garden (DBG) site. **B)** Graph shows the number of arthropod families by site (President's House, Desert Botanical Garden, and Usery Mountain Park) and by month with proportions of predators, herbivores, parasites, and omnivores indicated; the number of families varies by site for each month ($P<0.001$ in each case). **C)** Maintenance taking place in one of the experimental brittlebush plants.

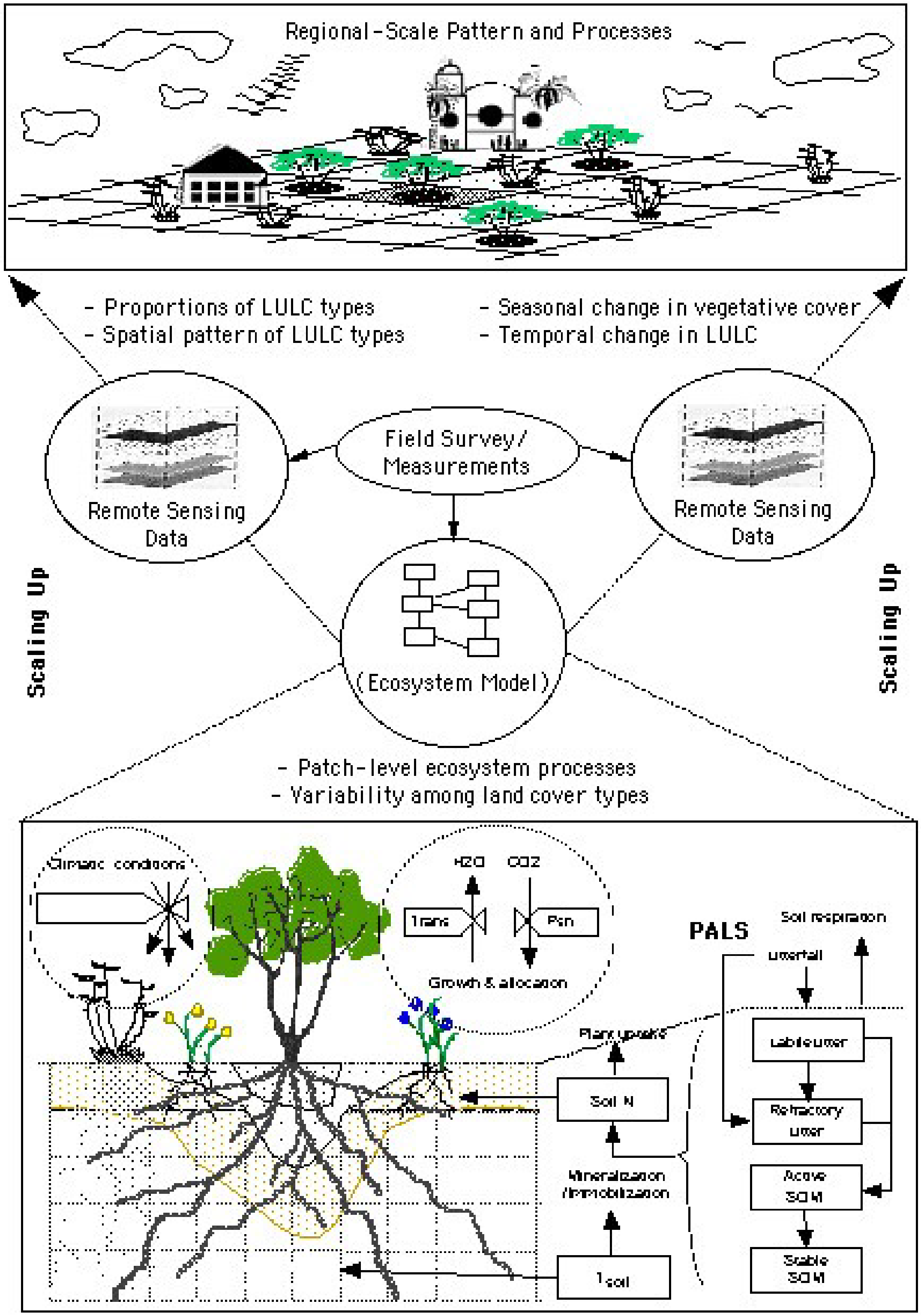


Figure 10. A schematic representation of the strategy to scale-up ecosystem properties from local to regional levels using an integrated modeling approach (Wu & David 2002).

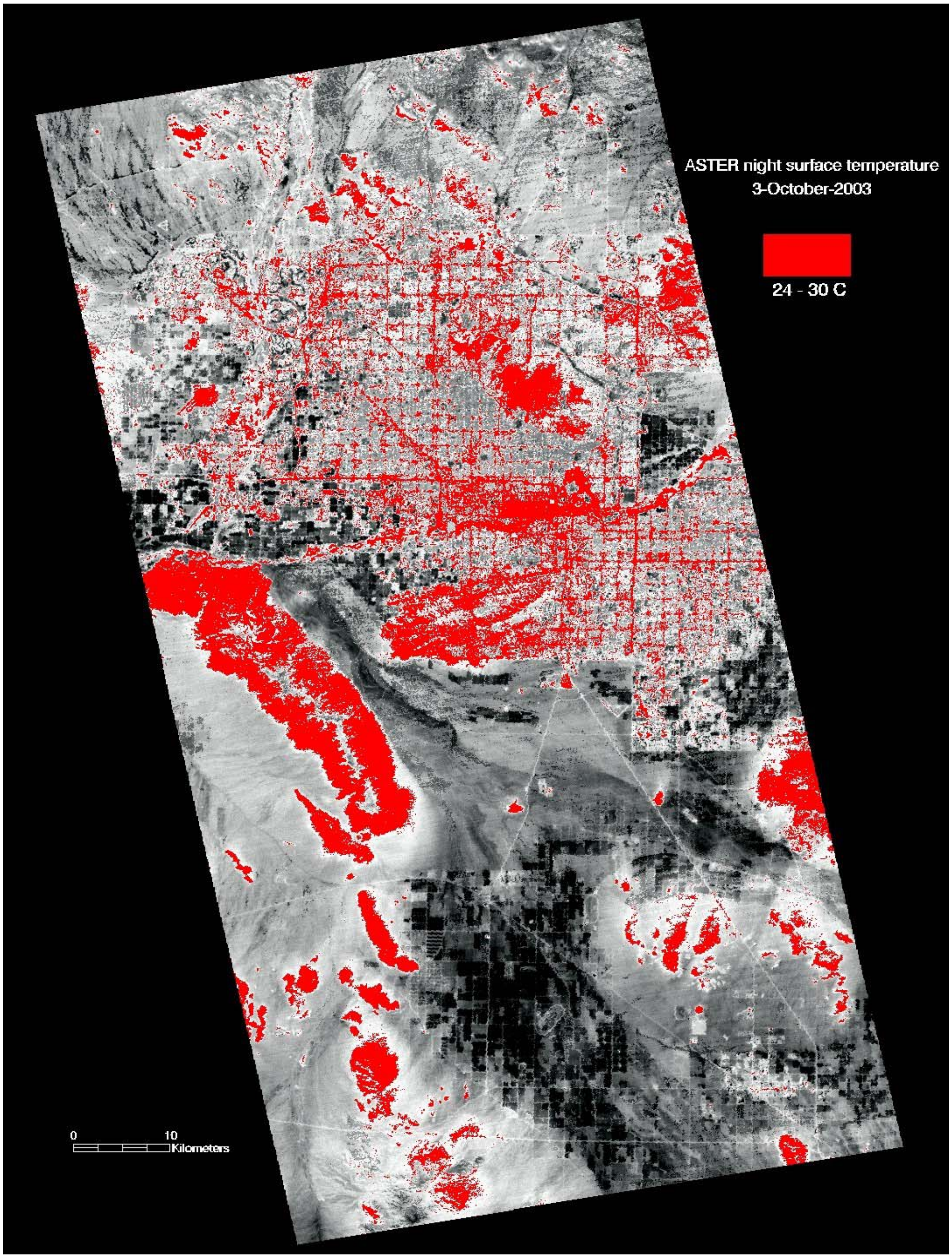


Figure 11. Constructed from Level 2 ASTER data, this image depicts surface temperatures for the majority of metro Phoenix on October 3, 2003. The hottest temperatures (24-30°C), highlighted in red, clearly delineate high thermal emission surfaces e.g., the major roadways, Sky Harbor Airport, other paved surfaces, and the talus-covered midslopes of the surrounding mountain ranges (NASA/ERSDAC and the Geological Remote Sensing Laboratory, ASU). In CAP2, such datasets from ASTER and other sensors will be used to understand the contribution of different surface types to urban heat islands, regional and "neighborhood-scale" climatic patterns and to investigate potential heat island mitigation strategies.

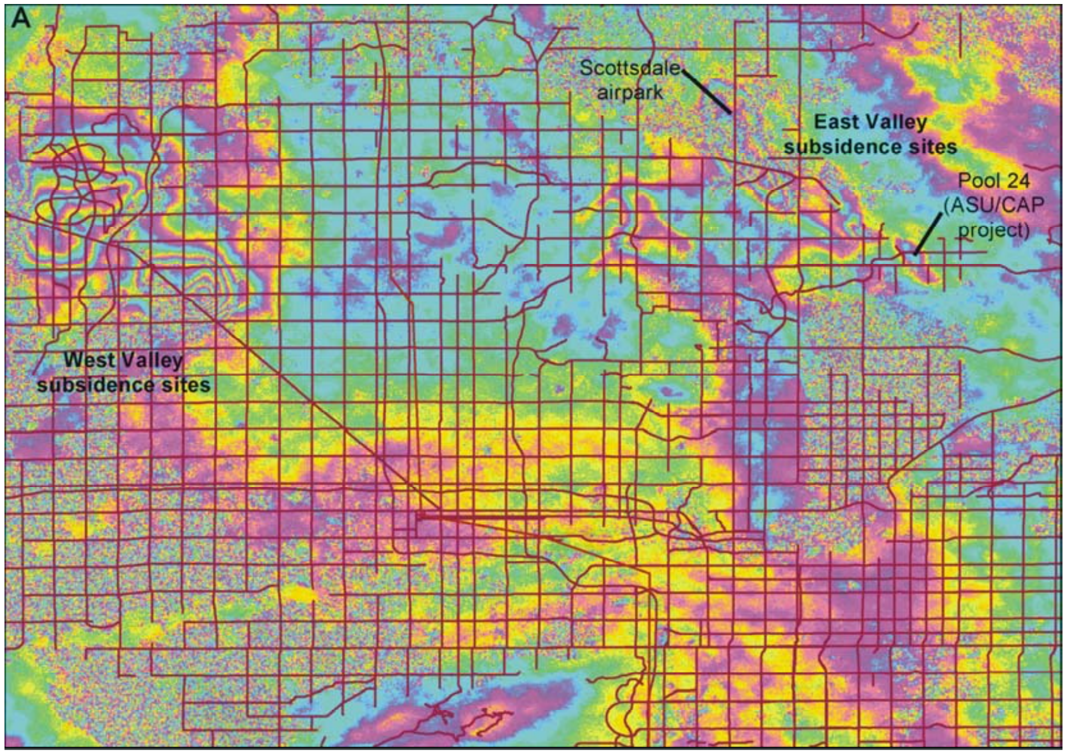


Figure 12A

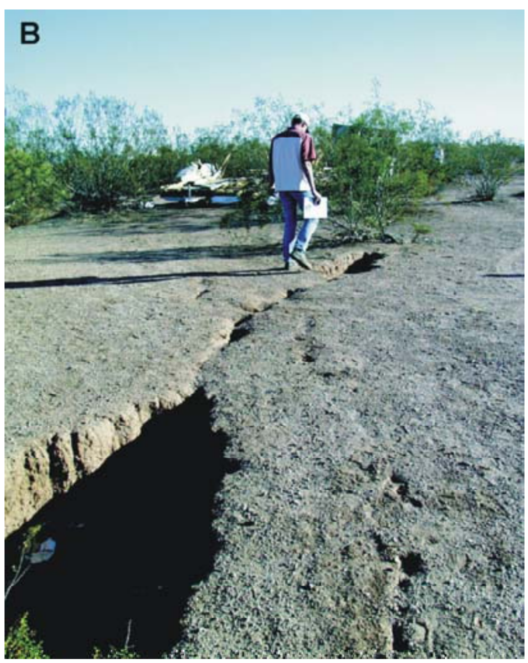


Figure 12B

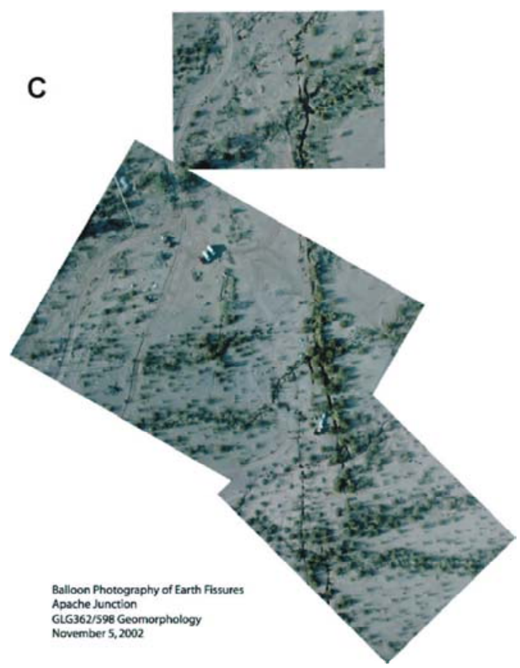


Figure 12C

Figure 12. A) Ground-motion map for metro Phoenix showing subsidence bowls in northeast and southeast Valley. Each set of yellow-to-blue fringe colors represents 2.8 cm. 1330 day INSAR data from M. Tatlow (ADWR) and S. Buckley (UT Austin). Phoenix streets from GIS Lab, ASU (Map by R. Arrowsmith from P. Ivanich data system January 30, 2003). **B)** Earth fissures formed on the edge of a subsidence zone in Apache Junction. **C)** Balloon aerial photography of earth fissure zone.

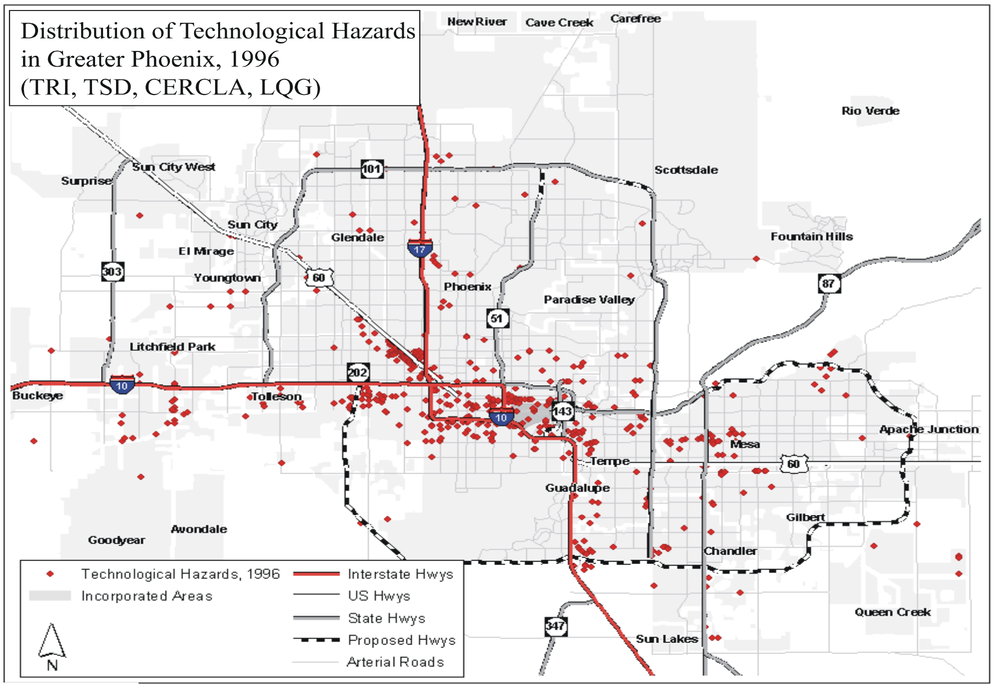


Figure 13A

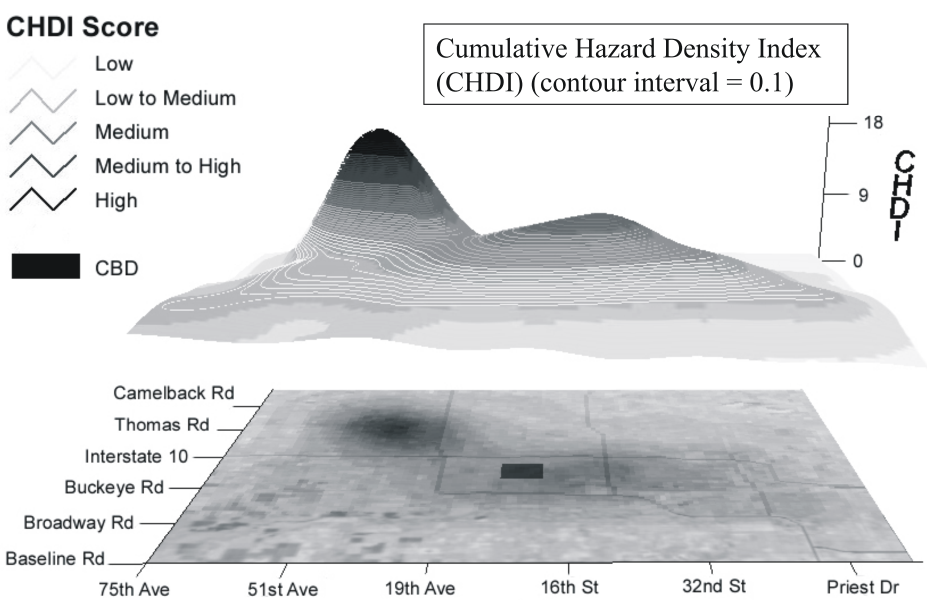


Figure 13B

Figure 13. A) This map shows the locations of four major types of technological hazards: Toxic Release Inventory (TRI) sites - large industrial polluters; Treatment Storage and Disposal Facilities (TSDF) - toxic waste processors/shippers; Large Quantity Generators (LQG) - industrial sites that use or store federally regulated hazardous chemicals; and Comprehensive Emergency Response and Community Liability Act (CERCLA) sites –with significant toxic contamination, including Superfund sites. **B)** Cumulative Hazard Density Index–a spatially standardized measure of the cumulative distribution of four types of technological hazards (see 7A) aggregated at the level of census tracts. The index provides a relative score for the hazardousness of each census tracts, the darker areas having the highest hazard burdens.

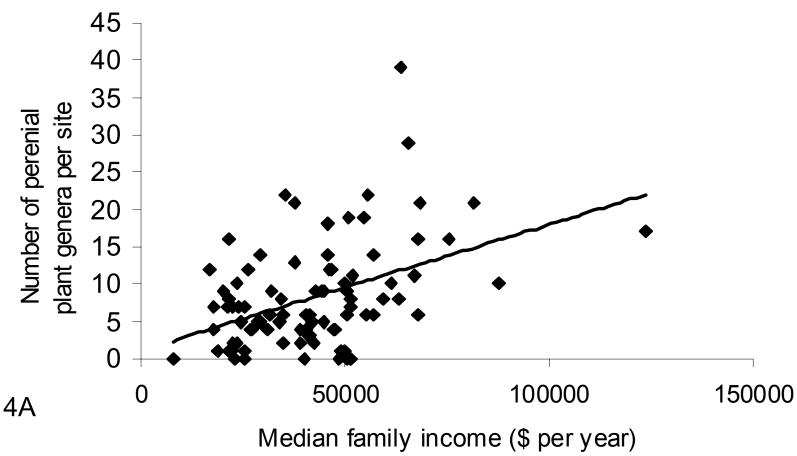


Figure 14A

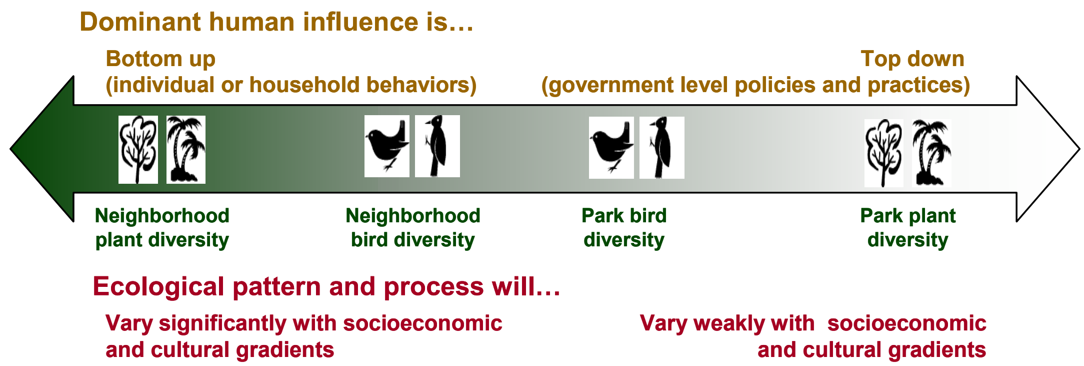


Figure 14B

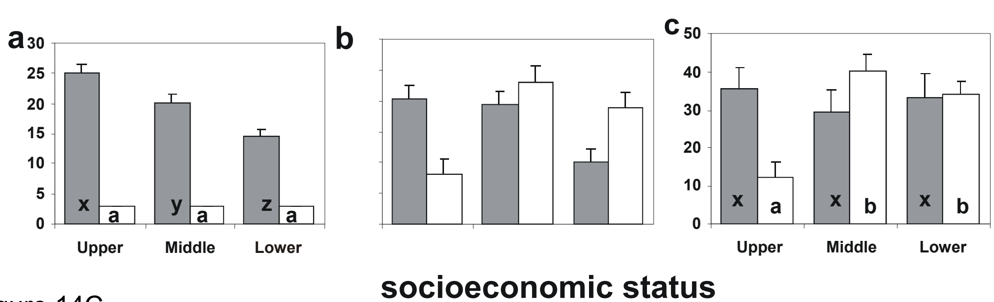


Figure 14C

Figure 14. A) Socioeconomic factors appear to be one of the important determinants of urban plant diversity, as seen in the variation in the number of perennial plant genera with median family income (in $ per year) from the US Census of Population and Housing for the block group surrounding each Survey200 site in the urban area (Hope *et al.* 2003). **B)** However, we predict that not all patterns of urban biodiversity will be equally affected by socioeconomic or cultural status of human residents, but rather will differ in the degree of "bottom-up" and "top-down" human influences. "Bottom-up" influences are likely to reflect the integrated outcomes of small-scale (individual or household) choices or actions, whereas "top-down" influences will reflect city-level management strategies and decisions (Kinzig *et al. in review*). **C)** Effects of socioeconomic status (SES) on bird-species richness (a) and abundance (b-c) in 16 urban parks for native (gray bars) and exotic (white bars) species. Letters indicate significant differences between groups (two-tailed t-test, $p<0.05$). Abundances are calculated as the number of individuals of each species averaged across observers and summed across species for the non-breeding season (b - December 2000) and the breeding season (c -March 2001) from Warren *et al. in prep*.

3. PROJECT MANAGEMENT

The objective of our project management plan is to allow CAP LTER scientists to generate significant research results that are disseminated through appropriate media and archived in a continually expanding database. The management system must work to enhance scientific creativity, quality data generation, interdisciplinary cooperation, and timely dissemination of information, while insuring the efficient use of limited financial resources, meaningful involvement of K-12 students, and cooperation with community partners. Although the ultimate success of any scientific project relies on the energies and talents of its scientists, an endeavor of this scale and complexity also requires clear lines of responsibility and an adequate infrastructure. We have made few changes to a management plan that has served us well and was applauded by the midterm site review team.

3.1. ADMINISTRATIVE HOME AND INFRASTRUCTURE

The Center for Environmental Studies (CES) provides the administrative infrastructure and houses most CAP LTER non-faculty personnel. Arizona State University, through the Office of the Vice President for Research and Economic Affairs, supports the activities of CES and thus the CAP LTER. CES is housed in a large facility with an open floor plan, offices, Informatics Laboratory, and variously sized meeting rooms (see Facilities). Center staff members contribute substantially to the coordination and outreach efforts of the project (Cindy Zisner, Webmaster; Linda Williams, financial and personnel tracking; Wayne Porter, network systems administration; Shirley Stapleton, meeting scheduling and coordination; and project managers listed below).

3.2. ORGANIZATION AND LEADERSHIP

Project Co-Directors (PDs) Grimm and Redman share responsibility for overall direction of project activities and are ultimately responsible for final decisions on projects included and personnel supported by CAP LTER (Fig. 15). Both also participate in the project as researchers and IPA co-leaders. Over the past six years Grimm and Redman have partitioned responsibility in ways that fit their talents, interests, and positions, but most decisions are made in consultation with one another and three advisory groups. A Science Advisory Council (SAC), new for CAP2, will be formed of excellent scientists who are not necessarily involved with CAP LTER and who represent the breadth of disciplines in our project (life science, earth science, social science, and engineering). This advisory group will make recommendations based on a report of activities delivered once per year in conjunction with our annual symposium (Section 3.3). The second group is the Scientific Leadership Council (SLC), which includes project scientists who lead the IPAs and Practical Working Groups (PWGs; Table 2). The SLC also will meet once per year to make recommendations on the research agenda and budget allocations for the upcoming summer and academic year, based on the symposium and annual reports submitted by the IPAs. A subgroup of the SLC will review graduate-student research proposals (see below). The third group, the Project Management Team (PMT, see individual roles below), will meet quarterly, advising Grimm and Redman on most decisions.

Management of the science itself is vested in the core scientists. Our research subject matter is organized into IPAs as discussed above (Section 2.5.2), while PWGs represent the different strategies of research and can provide coordination among the intellectual areas (e.g., the NDV experiment as a place-based research effort will bring together Climate-Ecosystem, Material Flux, and Biodiversity IPAs and will include research in the primary production, populations, materials movements, and organic matter storage LTER core areas). The team leaders of the IPAs and PWGs are expected to communicate with the different projects and the senior personnel (additional core scientists) that comprise each group.

Each project manager is a co-leader of one or more PWGs but also has unique responsibilities for managing parts of the project. Administrative Project Manager Shears coordinates administrative operations (hiring, annual reports, budget, supervision of administrative staff) and all outreach and educational components (community partners, K-12, REU, other CES projects related to urban ecology). Field Project Manager and Co-PI Hope supervises project-wide long-term monitoring, coordinates field operations (monitoring sites, permissions, project coordination, organization of field teams, long term sign-out of equipment), and supervises field and laboratory technicians (with assistance of postdoctoral researchers). Informatics Laboratory Manager and Co-PI McCartney supervises some informatics technical staff, leads informatics development efforts, and works closely with the LTER network in information-technology research. Data Manager Gries works with researchers to design and populate databases, provides training on data management to researchers, supervises data technicians, and has a scientific role in Survey200. Education Manager and Co-PI Elser directs the Ecology Explorers education program and supervises education staff members. Communications Manager Kuby develops and maintains ties with community partners and communicates project results to a range of audiences, including ASU faculty members, governmental agencies, the LTER network of scientists, and the general public.

Postdoctoral researchers are mentored by Grimm and Redman, along with other CES-affiliated faculty members. Search committees for postdocs are formed with at least one additional CAP LTER scientist's participation. Postdocs are associated with specific projects and are encouraged to find a faculty mentor outside CES. They usually have responsibility for a component of LTER long-term research or data analysis and are free to develop their own projects. They also work in a supervisory role for technical staff and student assistants, in collaboration with Hope or McCartney. Graduate students participate as researchers but are generally NOT used to staff long-term projects. However, they may be hired by IPAs as research assistants during the academic year to work with specific projects. In CAP2, we will initiate a competitive program to support independent graduate research related to CAP, which will provide summer salary or research expenses. A subgroup of the SLC will evaluate proposals submitted each spring. Laboratory Coordinator Kochert supervises laboratory operations and undergraduate assistants. In addition, all users of the analytical laboratory must be "certified" by Kochert. Field, laboratory, and data technicians work under supervision of Hope, McCartney, Gries, postdocs, or Kochert. Undergraduate field, laboratory, and data assistants are employed to work on individual projects.

3.3. COMMUNICATION

The highlight of a year in CAP LTER is our annual symposium, held in winter each year. The program features a keynote speaker (Table 3) and poster presentations by all supported projects. (Posters can be seen at http://caplter.asu.edu/symposia.htm). Meetings of the SLC and SAC follow this symposium. A midsummer workshop or retreat is held at an off-campus site each year to address theoretical issues (social science-natural science integration, contributions to ecological theory, and development of CAP2 were prior themes). Monthly All Scientist Meetings attract between 40 and 100 participants and feature scientific presentations by visitors (Table 3) or discussions of project results. CAP LTER news is presented on our Web site and in the quarterly CES newsletter.

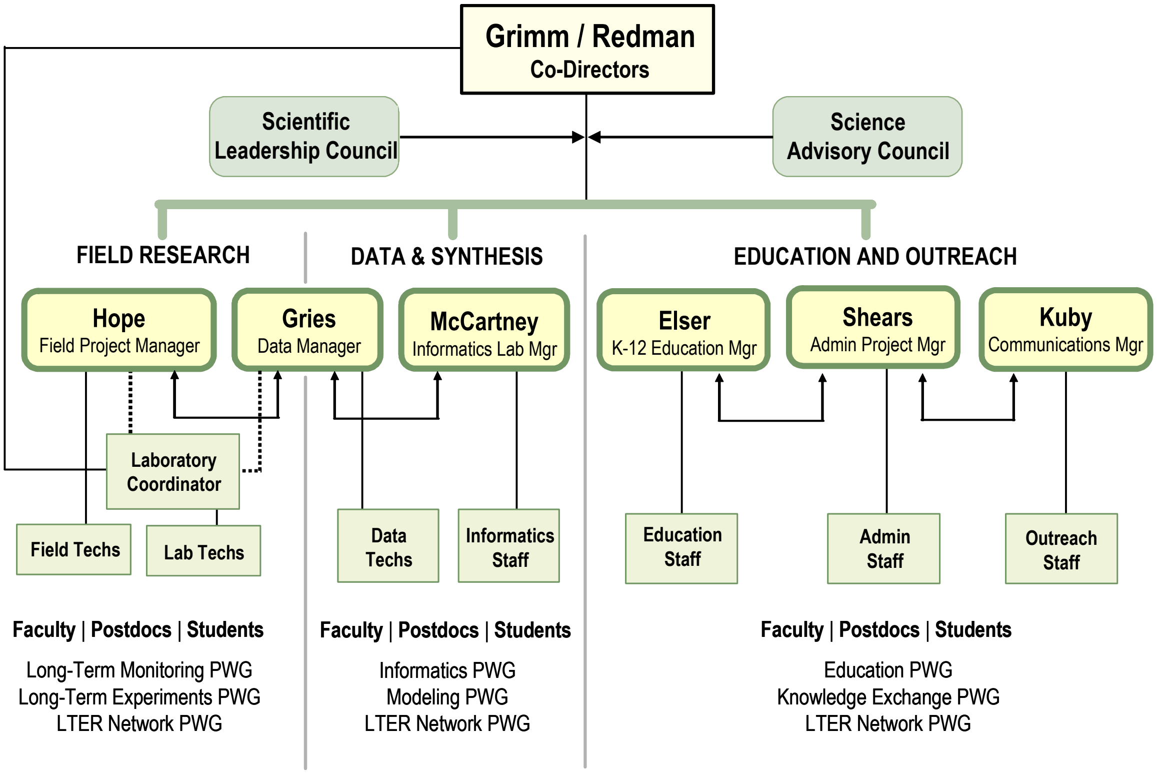


Figure 15. Organizational chart for CAP2, showing interconnections among Project Directors, two Advisory Councils, Project Management Team, and the project's three main components: research (Section 2), data and synthesis (Section 4), and education and outreach (Section 5). Chart is not intended to be hierarchical, but to show how managers interact with each other and with the three components. Faculty participants (Senior Personnel and other faculty researchers), postdocs, and students conduct activities in each of the three areas, which have several associated practical working groups.

Table 2. List of Personnel in the Scientific Leadership Council, Comprising IPA and PWG Leaders

Integrative Project Areas	Team Leaders
Land-Use and Land-Cover Change	Briggs, Redman, Wentz
Climate and Ecosystem Dynamics	Brazel, Martin
Water Policy, Supply, and Use	Arrowsmith, Kinzig
Fluxes of Materials and Socio-Ecosystem Response	Allen, Bolin, Grimm, Kaye, Peccia
Human Control of Biodiversity	Faeth, Stutz
Practical Working Groups	**Team Leaders**
Long-Term Monitoring	Gries, Hope
Long-Term Experiments	Faeth, Hope, Martin
Modeling	Anderies, McCartney, Wu
Informatics (includes data mining)	Gries, McCartney
Ecosystem comparison	Brazel, Kinzig
Education	Elser, Saltz
Knowledge Transfer	Arrowsmith, Kuby, Shears

Table 3. Selected List of Visitors to CAP1

Symposium Keynote Speakers	All Scientist Meeting Speakers and Other Visitors
John Magnuson, Steward Pickett, Deborah Jensen, Michael Rosenzweig, Carole Crumley, Jim Reichman	Greg Asner, Roger Bales, Mary Clutter, Bob Costanza, Robert Fisher, Grady Gammage Jr., Terry Goddard, Stanley Gregory, Peter Groffman, Richard Harriss, Peter Kareiva, Margaret Leinen, James MacMahon, Mark McDonnell, Emilio Moran, Bill Schlesinger, Sander van der Leeuw

4. INFORMATION MANAGEMENT

Information Management (IM) is an integral part of CAP LTER, originally designed with two goals: to provide data support for research activities and to ensure the long-term availability and usability of CAP LTER data products. Although these remain prime goals, the IM team has developed a third goal—contributing research toward advancing ecological informatics.

4.1. RESEARCH SUPPORT

Our data management procedures are designed according to the five-part organization of continuing research (Section 2.5.3): monitoring, data mining, modeling, experiments, and comparative studies. Common to all is an initiation process in which PIs of any new research activity meet with IM staff to discuss data needs and likely data products that will result from the activity. Our management database is initialized with information such as personnel and their roles, short abstract, long description, and research design. In addition, entries are made for each data product anticipated from that project, including title, description, nature (primary, secondary, or acquired), anticipated release status (public or restricted), and date. The PI and project directors decide when and under what terms a dataset is to be released; all access prior to release is at the discretion of the PI. Current status for most of this tracking information is available through the Web site and via periodic reports. Projects are requested to turn in a detailed protocol for each dataset and samples of field or lab entry forms, if relevant. A GIS cover indicating the study area and/or sampling locations is created for each project, either by digitizing from imagery, geo-coding from street addresses, or determining locations with GPS devices.

Monitoring: After a project is initialized, the PI meets with the IM staff to discuss data-management needs. Data-modeling tools are used to produce a generalized schema of the database with reference to the PI's protocol and the entry forms. The databases are built on Microsoft SQL Server. The data-modeling schemas and an EML document of the database are stored and updated as the data schema is modified. Interfaces for data entry are developed with Access, which features rapid development time, rich options for quality control, and event code to perform any necessary transformations. Technicians enter data for core-monitoring databases to ensure rapid turnaround and consistent data quality. Data sheets are archived in the lab. PIs are encouraged to proof entry and, when requested, the IM staff has included report formats in the application to print proofing sheets that approximate the original data-entry forms. Quality control of CAP LTER databases relies heavily on the use of rigid relational schemas and extensive check constraints to evaluate data as they are entered. Appropriate scripts have been developed for rapid upload and quality control of data generated by automatic data loggers. During the first grant cycle, few standard procedures were developed for doing post-processing quality checks on data after entry, leaving such screening up to the researchers. A goal for the CAP2 will be to better incorporate such screening tests into the data-entry applications. We are also planning an automated system for reporting the status of a dataset to the researchers, e.g., a "data-audit statement" that includes simple descriptive statistics to alert to outliers or other problems.

Data mining: Many CAP LTER projects involve synthesizing and analyzing existing data (e.g., Section 2.5.3.1). Metadata-creation tools are used to extract the structure of these imported datasets to capture their low-level syntax. When available, metadata provided by the source is added to the EML documentation.

Experiments: One-time experiments follow a less-rigid protocol for data management with some of the initial management done either by the researchers or by specialized labs (e.g., social-science interview data or remote-sensing data). Data not managed by the CES Lab are checked in for archiving at the end of the research and typically undergo reformatting to make them compatible with the Lab's storage formats. A metadata file is created according the information provided by the researcher. This is a satisfying model for ecological datasets. In CAP2, we will concentrate on improving metadata for social-science experiments, which are mostly questionnaires, producing a database of questions plus metadata for researchers' use.

Modeling: IM staff recently began a policy for archiving modeling outputs as datasets, which will become standard practice during CAP2. The Lab is working under separate funding to develop metadata standards for model documentation that can be used to extend the existing EML. Once completed, this standard will be used to document and archive models developed and/or used by CAP LTER.

Comparative studies: Synthetic research at the network level requires information systems that can integrate with other archives. CAP LTER contributes data to the LTER Network Information System databases such as ClimDB, SiteDB, and Bibliography. IM staff also provide data-management support for cross-site projects such as the LINX (NSF-IRCEB, Grimm subcontract, *Mulholland et al. 2002*) and Ag Trans (NSF-BE, *Redman et al. 2002*) projects.

4.2. ARCHIVE AND DISSEMINATION

Primary data consisting of original observations and value-added **secondary**, derivative data are archived in the CES Lab with complete metadata documentation (see list of databases in Supplemental Documents). **Acquired** data gathered during data-synthesis projects are archived as a service to other CAP LTER researchers, but receive lower priority for extensive metadata documentation. A limited set of data formats is used for archiving data according to type. Restricting the number of supported formats encourages more standardized access tools and simplifies the process of forward migration to new versions or formats (see Table 4). CAP LTER strives to make data available within two years of their collection. A data-access policy based on the draft policy developed in 1999 by the LTER Information Management Committee is posted on the Web. The guidelines for acceptable use are inserted as part of the EML for every dataset and constitute the use license for any data released by CAP LTER. All access to the online data is logged by user, date, and dataset ID. The core-management system consists of a series of integrated databases: projects, personnel, bibliography, datasets, digital documents, images, protocols, and calendar. Most information provided on the Web site is drawn dynamically from this database. Following the release of EML 2.0 in 2002, the database design was modified to conform to this new standard. A complete metadata editing application was written to allow IM staff to edit and manage the metadata catalog. Under separate funds, tools were developed to expedite metadata generation by either reverse-engineering information from the actual data source or translating metadata produced by proprietary applications into EML. The EML files are edited with XML editors and loaded into the relational database. In 2002, Internet forms were created on the CES

Intranet Web site, where researchers may enter and edit certain descriptive and personnel information about their projects and datasets directly into the database.

In 2003, CAP LTER switched from its previous online data catalog to a new system, the Southwest Environmental Information Network (http://seinet.asu.edu). SEINet was created under separate funding by CES to provide an integrated gateway to multiple environmental data resources at ASU and in the central Arizona region, thus leveraging the value of CAP LTER data. In addition to serving as the Web portal to CAP LTER metadata, datasets, literature, and protocols, SEINet also provides access to nine biological-collections databases, a taxonomic thesaurus, identification keys, and other Arizona data archives. The system currently provides download and simple visualization and analytic functions, while logging all access for accountability. SEINet uses an abstracted data-access layer based on Web services (McCartney 2003), which encourages development of diverse Web applications that use a common data framework, such as a recently released electronic atlas (http://www.gp2100.org/eatlas) on the environmental future of Phoenix.

In addition to SEINet, CAP LTER relies on a series of Web sites for information management which all draw from a common data framework (Figure 16). Our Web site is dynamically linked with the management database to provide up-to-date information on project events, products, project activities, and personnel. It uses data-access protocols developed for SEINet to deliver CAP LTER content to the Web in displays that are simpler to use but still linked to SEINet. The data section of the Web site provides access to protocols, information on the activities of the IM staff and links to SEINet and other supporting Web sites including CES Informatics Lab site, and other participating lab Web sites.

A separate database is managed for the Ecology Explorers schoolyard ecology project. A Web data center provides data-entry forms for four separate protocols and a query wizard for enabling students to download data. With leveraged funding, a new analysis wizard has been created to enable students to formulate and test hypotheses visually and statistically online. Goals for the upcoming session are to use these new tools to better integrate the Ecology Explorers Web site with data from the main science activities of CAP LTER.

4.3. ECOLOGICAL INFORMATICS

In 1998, the CES Informatics Lab actively began to pursue development of an advanced information infrastructure for the broad ecological community (Brunt *et al.* 2002). Since then, the IM staff has been engaged in sponsored research with the LTER Network Office, National Center for Ecological Analysis and Synthesis, and San Diego Super Computer Center. This collaboration has included the development and continued maintenance of EML (McCartney & Jones 2002), development of EML-based tools for querying and accessing data (Schoeninger *et al.* 2002), and participation in the Science Environment for Ecological Knowledge (Michener 2003). Future goals for ecological-informatics research focus on continuing to build SEINet as a platform for interagency data sharing, model integration, and dissemination of CAP LTER research products to diverse audiences including K-12, informal education, and decisionmaking. In addition, we will strive to make the use of EML more efficient and to integrate EML into site-management applications.

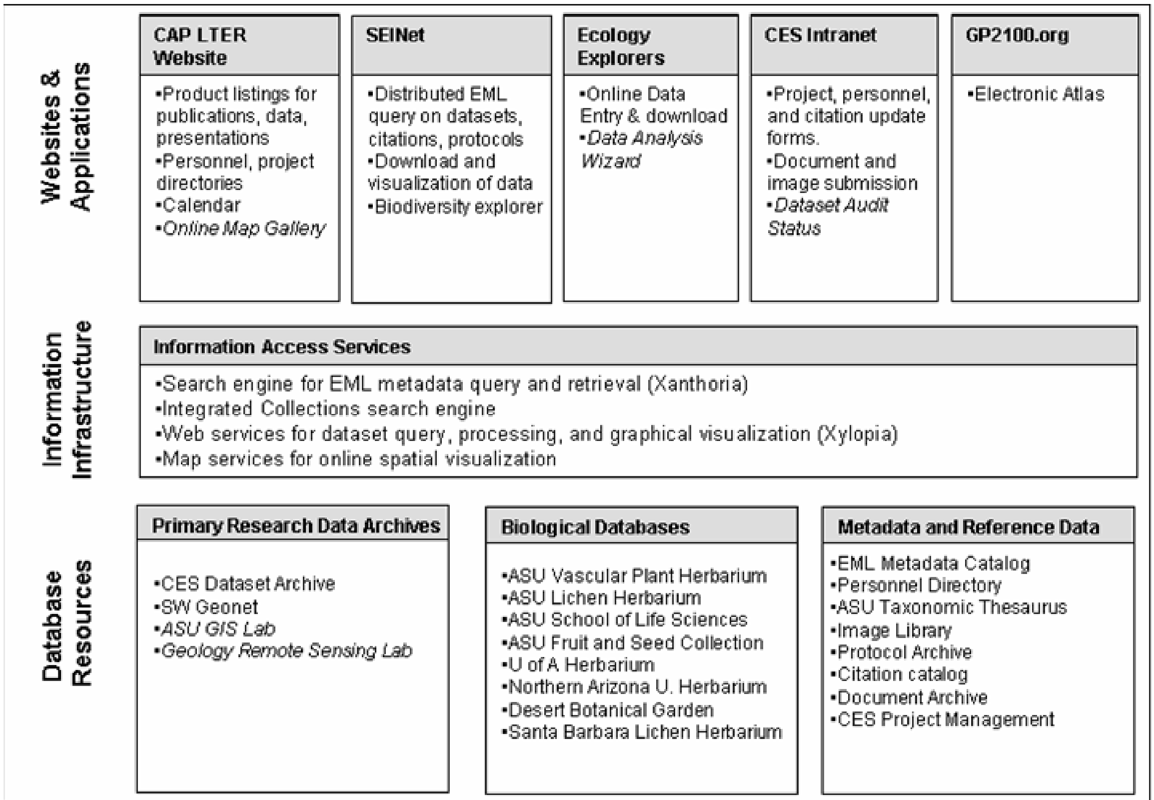


Figure 16. Integrated information resources supporting CAP LTER. Italicized items will be implemented during the first two years of CAP2.

Table 4. Storage Format Types for CES Dataset Archive

EML Entity Type	Format(s)
Tabular data	MS SQL Server 7.0
Spatial Vector	ArcView shapefile ESRI Spatial database engine 8.3
Spatial Raster	ERDAS Imagine files ArcInfo GRID ESRI Spatial Database Engine 8.3

5. EDUCATION AND OUTREACH

Education and outreach activities are woven throughout CAP LTER. Our project enhances the research and teaching skills of undergraduate, graduate, and postdoctoral students, faculty members, and teachers and students. In addition, we are committed to sharing what we learn with community organizations, governmental agencies, industry, and the general public.

K-12 Education: Our Ecology Explorers program engages teachers and students in a schoolyard-ecology program where students collect data similar to CAP LTER data, enter results into our database, share data with other schools, and develop hypotheses and experiments to explain their findings. We offer summer internships and school-year workshops for teachers. The internship programs are in high demand; we receive five applications for every slot. Each year, 10-15 scientists including faculty members, research technicians, postdocs, graduate students, and advanced undergraduates participate in the internships, workshops, and classroom visits.

Ecology Explorers offers a useful and engaging Web site (http://caplter.asu.edu/explorers; Fig. 1). Collaborations with the Informatics Lab and Life Science Visualization Lab have created new and fun ways for students and teachers to access and use CAP LTER data on our Web site. This collaboration has been so successful that our Web site was awarded a Digital Dozen Award from the Eisenhower National Clearinghouse for Mathematics and Science Education in 2002.

An advisory committee of informal education institutions, school districts, and ASU outreach programs meets yearly to advise our education team. We also contracted a professional evaluator to assess factors affecting implementation of the Ecology Explorers program. She concluded that teachers did alter their teaching, using more technology and long-term research projects.

CAP2: Based on this assessment and the need to link CAP LTER to the community, we will continue to: offer internships linked with academic-year support; target underserved populations; develop protocols linked to CAP LTER research areas; build relationships with school districts, with the intent of district adoption of Ecology Explorers; develop more Web-based applications for teaching urban ecology; strengthen our partnership with University and CES projects, including ASU's Service Learning program, GK-12 Research Fellowships, and IGERT fellowships in Urban Ecology; work with informal education organizations; formally evaluate outcomes for teachers, students and researchers; forge cross-site LTER work. Another goal is to create an Urban Ecology Guide and a publication that would be an overview of CAP LTER for teachers and the general public.

University Students: We aim to immerse undergraduate, graduate, and postdoctoral students in interdisciplinary collaboration, create research communities that foster professional skills, and encourage students to become involved in the community. Both the NSF and ASU support approximately 20 graduate students a semester, drawn from a wide range of graduate programs including: anthropology, biology, curriculum and instruction, engineering, economics, geography, geological sciences, planning and landscape architecture, plant biology, and sociology. In addition, faculty members, postdocs, and graduate students have mentored 24 NSF-funded REU students who gained research training via summer projects.

CAP2: We will accomplish our educational goals through three integrated programs that: 1) incorporate undergraduate and graduate students into research labs and field projects; 2) create a Community of Research Scholars, in partnership with Barrett Honors College, which brings undergraduates into an interdisciplinary seminar that builds professional skills for communicating research; and 3) provide opportunities to participate in the Community of Research Interns, in which students intern with a CAP LTER community partner. Participating students will prepare poster and oral presentations by the end of the seminar. All posters will be presented at the CAP LTER Annual Symposium; selected posters will be presented at the annual meeting of the American Association for the Advancement of Science and at the national LTER meeting. Selected oral presentations will be given before faculty members, fellow students, and the community partner. We will continue to strive to attract underrepresented students to these programs.

Applications to Policy and Management: From CAP LTER's inception, we have focused upon meaningful community outreach by establishing a series of community partnerships. Some of these partners have been very active, such as the Maricopa Association of Governments, the Salt River Project, and those relating to K-12 education. More can and should be done to build bridges between academic research and public policy, and ASU has taken this charge very seriously, sponsoring Greater Phoenix 2100 (GP2100) and, in April 2003, establishing the Consortium for the Study of Rapidly Urbanizing Regions (CSRUR; http://ces.asu.edu/csrur). CSRUR, housed at CES and directed by Redman, engages academic, business and governmental groups in dialogues about pressing environmental issues affecting our rapidly growing desert metropolis. CSRUR issues timely "Research Vignettes" (http://ces.asu.edu/csrur/vignettes.htm) based on CAP LTER research and aimed at decisionmakers both at the household and government level; recent issues have focused upon landscape water use and the impact of urbanization on local climate. GP2100 has outlined four steps towards integrating science and policy: 1) a comprehensive, interactive environmental database; 2) an electronic-environmental "EAtlas;" 3) a series of models that would complement a "SIM-Phoenix" approach to scenario-building; and 4) an immersion "Decision Theater" that would provide 3-D portrayals of scenarios for policymakers. To date, the EAtlas and a version in book form, the *Greater Phoenix Regional Atlas,* have been produced, and the Decision Theater concept is gaining momentum and has been incorporated into several grant proposals. When implemented, CAP LTER models and data will figure prominently in Decision Theater scenarios. Lastly, a Sustainable Technologies Program is working to minimize the impacts of rapid urbanization, through existing and emerging technologies and sound policy recommendations.

CAP2: Because it is a source of fundamental, long-term data, CAP LTER is critical to the success of ASU initiatives in science-policy outreach related to urban environments. The CES plays a central, liaison role in ensuring effective knowledge exchange from academic researchers (i.e., CAP LTER) to decisionmakers and end users of the science. Cooperation is also assured by Redman, McCartney, and Elser's involvement in these initiatives.

Public Activities and Media Interactions. Since 1997, CAP LTER participants have made over 200 presentations, as well as innumerable talks to community groups. In addition, we have reached out to over 100 community organizations and schools representing over 3,000 children. We publish a newsletter three times a year that is distributed to researchers, students, K-12 teachers, and community partners. Faculty and student researchers (including K-12 students) present findings and updates at the yearly poster symposium, which is attended by community partners and media representatives. Monthly All Scientists Meetings feature crossdisciplinary interaction and information exchange through science- and results-based presentations and also are regularly attended by educators, students, and community partners.

The CAP LTER and individual projects have been the focus of articles in major scientific journals such as *BioScience, Science News, Science,* and *American Scientist*, many newspaper articles, feature radio interviews, and in *Chain Reaction*, an ASU magazine for the K-12 community. A recent addition to our Web site, a virtual tour of CAP LTER (http://caplter.asu.edu/capltertour), is a forum for communicating CAP research results to the broader community. In *CAP2*, we expect these public activities and interactions to continue to grow in scope and impact.

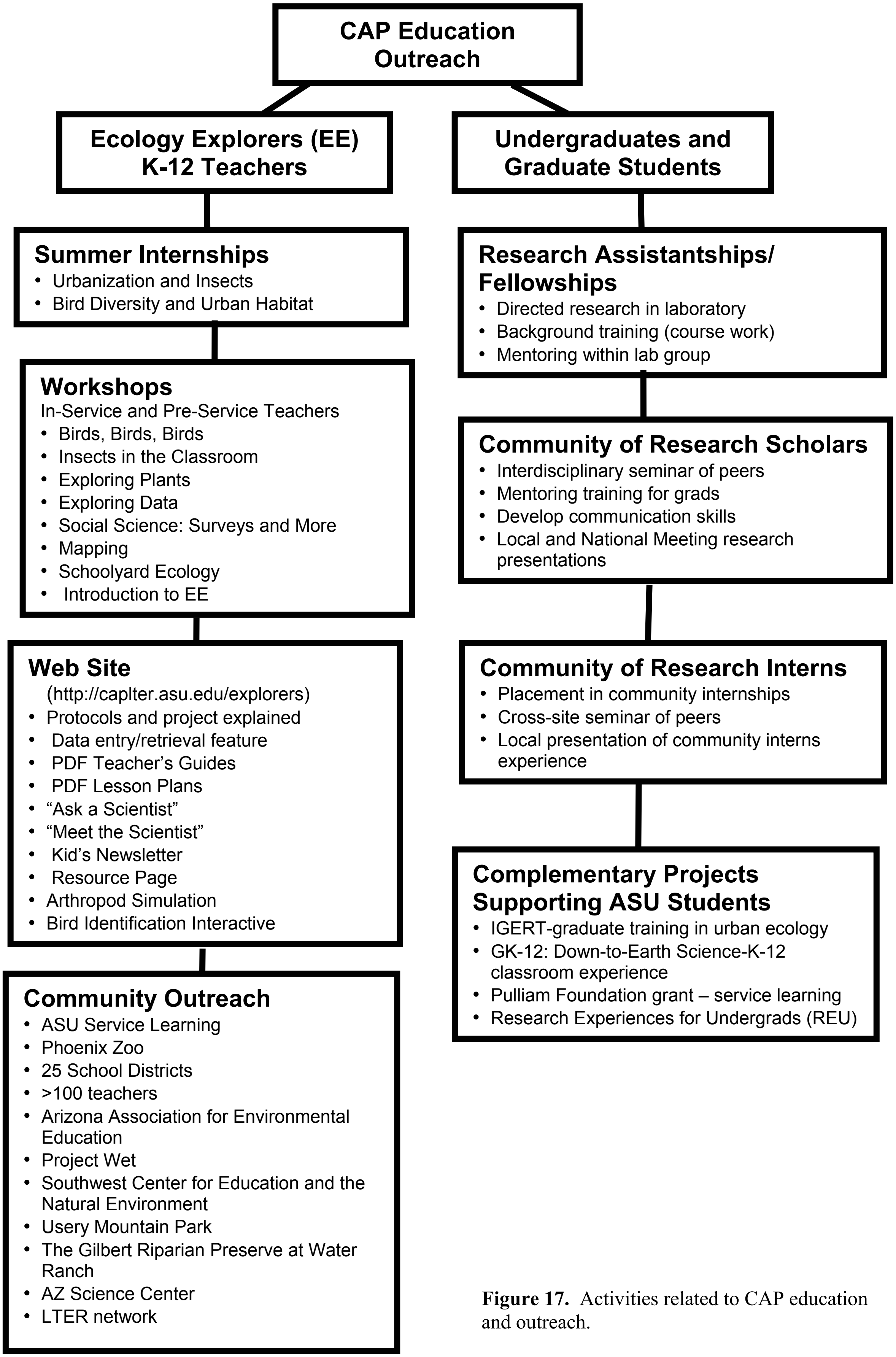


Figure 17. Activities related to CAP education and outreach.

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FACILITIES, EQUIPMENT, AND OTHER RESOURCES

PROJECT MANAGEMENT AND ADMINISTRATION FACILITIES

The **Center for Environmental Studies** (CES), an interdisciplinary research center directed by Redman, is the administrative home of CAP LTER and provides key logistical support for the project. CES has a long history of involving academics, government, industry, and the community in mutually beneficial projects. In our first 6 years, over 100 faculty members, 75 graduate students, 25 undergraduate students, 60 K-12 teachers and close to 100 community partners have worked together to assess the effect of urban development on the ecosystem of the Sonoran Desert and the reciprocal effects of ecological conditions and urban development. CES offers the administrative staff to plan and coordinate CAP2 activities, including hosting visiting scientists. CES also has a large conference room with videoconferencing and computer presentation capabilities (interactive whiteboard), for use for Scientific Leadership Council meetings. An adjacent, large meeting room can be reserved for workshops and conferences and is the location of monthly All Scientist Meetings. Grimm, Redman, McCartney, Hope, and Elser have office space at CES, and office spaces are available for off-campus PIs and senior personnel as needed. The CES Informatics Lab, Ecology Explorers, and Field Technicians are also based at CES.

The Center also houses the new Consortium for the Study of Rapidly Urbanizing Regions (CSRUR). Building on the work of separate ASU projects such as GP 2100, CAP LTER, and urban remote sensing with NASA's ASTER instrument, the CSRUR will bring a new focus on rapid urban development issues and apply a wide range of resources and expertise. It will be involved in developing global partnerships and will sponsor conferences and other events to engage the community locally, nationally and internationally.

DATA MANAGEMENT

Computing activities at CAP LTER are carried out over a distributed network of resources. At the core is the **CES Informatics Lab,** managed by McCartney and housed in the CES offices in Tempe Center. The lab has 7 NT and 2 Linux servers with a total storage capacity of two terabytes. Services include a production and development database server (SQL Server 7), Esri Spatial Database Engine GIS server, and an ArcIMS internet map service. A dozen lab workstations range in suitability from data entry to GIS. Connectivity within the lab is switched 100Mbs on the vBNS network. Software resources Java development tools, XML productivity tools, relational database modeling software, ArcView/ArcGIS, Erdas Imagine, MapObjects, Matlab, SPSS, and office productivity software. In addition to the CAP data manager, the lab has a full-time systems administrator and a full-time GIS technician. Two other full-time academic associates working in databases development and programming are supported on either LTER or related grant funds. The **Information Technology GIS lab** and the **Geological Remote Sensing Lab** (GRSL) are partnering facilities. Because of pre-existing working relationships with many LTER community partners, the GIS lab is a primary channel for data-sharing between these sources, and GRSL processes all remote sensing data used by CAP LTER. This lab provides archiving of raw remote-sensed data acquired for LTER research. Security and data protection are addressed in multiple ways. The CES Informatics Lab maintains its own Windows NT security domain. As projects are defined, workspace is created and a security group for that project is set up. Security for the SQL Server databases is managed separately since a great many users of this database do not log into the CES Informatics Lab. Users may access both the lab file servers and the secured web applications with their ASURITE id assigned by ASU. Users without ASURITE accounts can subscribe to a user directory managed by CES. It is hoped that these disparate access control lists will one day be unified under a single certificate-based system, but that is not possible at present. All critical servers use RAID 5 storage arrays and have redundant power systems. All server directories and staff workstations are backed up to tape following a 3-month rotation with monthly full back ups and daily incremental backups. A duplicate set of backups are made to an online server for redundancy and faster restores. Tapes are stored off site. Routine virus protection software is installed on all lab machines and all critical machines are patched on a regular basis.

ARIZONA STATE UNIVERSITY SHARED FACILITIES

Project faculty and students draw upon additional resources throughout ASU: The multi-user **Goldwater Environmental Laboratory (GEL)** is equipped with a Perkin-Elmer 2400 CHN Elemental Analyzer, LACHAT QC-8000 flow injection autoanalyzer, Bran-Luebbe TrAAcs 800 autoanalyzer, Dionex 4000i ion chromatograph, Shimadzu TOC-5000 organic-inorganic carbon analyzer, Varian Spectra AA 400 flame atomic absorption spectrometer, Varian Zeeman graphite furnace atomic absorption spectrometer, and a Varian Saturn 4D GC/MS with purge and trap. GEL also houses the **Stable Isotope Laboratory**, which features a Europa 20-20 Tracermass isotope ratio mass spectrometer that is semi-automated and equipped with solid, liquid, and gas measurement modules. The Europa is useful for tracer-addition studies involving stable isotopes, but is not as sensitive as the instruments to be housed in the Keck Lab (below). The CAP LTER has a field-portable chemiluminescence detector and gas-flux chambers for trace-gas research. An infrared gas analyzer for soil respiration measurements and a Li-Cor system for leaf photosynthesis are also available.

The **GIS Laboratory** features hardware, software, and staff to help for support the analysis, query, and display of spatial data across campus. The lab houses 12 workstations running on both UNIX and PC platforms and features a wide range of mapping software. The GIS lab shares space and resources with the **Visualization Lab**, which aids in the innovative presentation of data, including Silicon Graphic workstations and an application library of visualization and public-domain products. **The Partnership for Research in Spatial Modeling (PRISM)** is an interdisciplinary lab serving research and teaching needs in computer-based 3D design; visualization and modeling; and rapid prototyping. ASU's **Information Technology** administers the general-purpose computing system at ASU. It provides a well-supported campus-wide network of microcomputers and with an extensive statistical library, and including standard software like SAS, SYSTAT, SPSS, and BMDP. **The Center for Solid State Science (CSSS)** is one of the most complete university laboratories in the US for: 1) materials synthesis, processing and characterization; 2) micro-structural and chemical analysis; 3) and computing, consultation, and analysis with sophisticated graphical software for physical modeling and visualization. The **ASU Library** has more than 2.6 million volumes and is the 27th largest research library in the USA and Canada. The Noble Science and Engineering Library has about 360,000 books, about 11,500 serials and periodicals, and 135,000 maps. The ASU Library is a depository for US Government publications. The general catalog is accessible by computer via the internet.

LABORATORIES AND EXISTING MAJOR EQUIPMENT

CAP LTER has access to a variety of laboratories throughout the University**.** The **CES** has a small wet lab equipped with hood, a large-capacity drying oven, and storage space for field equipment. Although most of our samples analyses are done in the Goldwater Lab or in faculty laboratories, this lab is used by technicians for staging field campaigns and pre-sorting samples upon return from the field. The **School of Life Sciences** (SoLS) has laboratories is equipped with state-of-the art computers. SoLS supports four full-time staff members responsible for maintaining computers. Other specialized equipment includes Trimble Pathfinder Pro XR/Pro XRS Mapping GPS with real time satellite correction for sub-meter accuracy, LICOR LAI2000 Plant Canopy Analyzer, AccuPAR PAR-80 Linear Par Ceptometer and standard field equipment to conduct plant ecology work. The School of Life Sciences has a suite of greenhouses and growth chambers that are reserved for research projects. The **Vascular Plant Herbarium** is the second largest in the arid Southwest, having over 240,000 mounted specimens. It has a full-time curator and a collections manager who can aid in plant species identification. The **Mammals Museum** maintains a small teaching and research collection of mammals (approximately 6,000 specimens) and employs a full time curator (whose responsibilities include all zoological collections maintained by SoLS). **The Life Sciences Visualization Lab** facilitates the production of visual materials used in manuscripts, grants, poster presentations, and slides for professional meetings.

The **Geological Remote Sensing Laboratory** (GRSL) headed by Phil Christensen is part of the Department of Geological Sciences at Arizona State University. The primary responsibility of the lab is to engage in terrestrial (primarily geologic) research using, and develop software for the analysis of, remote sensing. Current research projects utilize both airborne and satellite data that span the EM spectrum from the visible/near infrared (VNIR) to the microwave (radar). However, the primary focus is on the thermal infrared (TIR) because of the ease of identifying the primary earth-forming minerals in this wavelength region. The majority of geologic studies currently underway at the GRSL focus on geomorphology and surficial processes. In addition, collaborative projects are currently underway with researchers in the School of Life Sciences and Geography. Much of this work stems mainly from the Central Arizona – Phoenix Long-Term Ecological Research (CAP LTER) project funded by the National Science Foundation. The focus here is spatial and temporal analysis of urban and vegetation land cover in the central Phoenix area. The GRSL is also involved in global-scale studies of urban geology and growth using data from the Advanced Spaceborne Thermal Emission and Reflectance Radiometer (ASTER) instrument on board the Terra satellite.

The **ASU Office of Climatology** (OoC) in the Department of Geography has three primary missions: 1) conduct climatological research of interest to the State of Arizona, the nation, and the global community, 2) provide educational experiences for undergraduate and graduate students, and 3) provide climatological services to the public at large. The core group at the OoC is comprised of five Ph.D.'s including Brazel and Zehnder, one full-time administrative secretary, an assistant state climatologist, and a varying number of graduate and undergraduate student employees. The OoC houses archives of historical weather records for the state of Arizona as part of a Memorandum of Agreement with the National Climatic Data Center, Western Region of the National Weather Service, and the Arizona Board of Regents of Arizona. The office houses the position of the State Climatologist, a governor-appointed state position. The office also houses special network weather and climate data for the central Arizona region in concert with private industry and NOAA. The archived databases are available to link with the CAP databases. Atmospheric research at ASU is also ongoing in many departments focusing on global climate change, regional meso-scale numerical modeling, urban climate and air quality modeling, and planetary atmospheres and remote sensing. The Department of Geography also maintains a computer laboratory for numerical model simulations and data archive. Hardware consist of a 4 processor DEC/Compaq ES-40 server, a DEC/Compaq DS-10 workstation, two 4 Processor Sun 420R workstations and 3 PCs. There is also a 560 GB RAID and a DLT tape library. The ES-40 is devoted to running mesoscale meteorological models such as MM5 and the Environmental

Protection Agency CMAQ model. ASU has access to real-time meteorological data (observations and NCEP model) through Unidata. The real-time meteorological data are used for initialization of the MM5 model runs.

The **Survey Research Laboratory** (SRL), directed by Shapard Wolf, was established in 1974 by the Department of Sociology. The SRL has two major purposes: training graduate students in survey research methods and supporting the research programs of the faculty. The SRL staff consists of the director, a full-time field director, a full-time administrative assistant, a graduate methodologist, and various project specific staff. The SRL uses a Computer-Assisted Telephone Interviewing (CATI) System for all telephone surveys. Interviewers read the questions from a computer screen and key the respondents' answers directly into the computer. This system also controls sample administration and interviewer management. It is now possible to administer quite complex surveys without extensive interviewer training because complex skip patterns are handled by the program, and only allowed values for each question are accepted. The SRL offers consultation on issues of sampling design, questionnaire construction, data entry and analysis. The Phoenix Area Social Survey is administered by the SRL. The SRL has recently (1/2004) moved into new facilities with greatly expanded space and capabilities. There are now 34 CATI stations, two focus group rooms with observation, a large training area and other research spaces for a total of 6,664 square feet. The SRL carries out social policy/social problem studies for a wide range of local, state, and federal clients; by mail, telephone, in-person, and over the web.

The **Keck Laboratory for Environmental Biogeochemistry**, directed by Shock, is a new facility under construction with a grant from the W.M. Keck Foundation (Grimm is Co-PI) that will house four mass spectrometers. Two of these mass spectrometers will be most useful to CAP LTER researchers. One is a Thermo-Finnegan Delta-10 "work-horse" mass spectrometer that will be connected to solid and liquid preparation units and used for determination of isotopic ratios of N and C. A total carbon analyzer will be another useful sample input unit for this instrument. The second is a higher-resolution instrument that will be connected to a "gas bench," enabling determination of isotopes in aerosol, water, and gaseous samples. This mass spectrometer also will be configured with a gas chromatograph for determining compound-specific isotopic ratios of C and N. Two other mass spectrometers for heavier elements may be used for pilot projects, such as determination of metals in soil. The lab is slated for completion in fall 2004.

Many CAP LTER faculty have labs where CAP LTER research is conducted. Grimm and Kaye have adjacent labs equipped for most standard soil and chemical analyses whose complementary resources are available for CAP LTER use. **Grimm's newly remodeled ecosystems/biogeochemistry laboratory** (>900 ft^2) is equipped with a hood with acid bath, Nanopure® water system, a shaker table, two drying ovens, a muffle furnace, two analytical balances, a large refrigerator, a freezer, and offices for data analysis, map analysis, and graphics preparation. An additional, small prep room for soil/sediment sieving is located on the roof and connected via dumbwaiter to the laboratory. Grimm's lab also houses a Schimadzu gas chromatograph (GC) with electron-capture and flame-ionization (with methanizer) detector for N_2O and CO_2 analyses. The GC is used primarily for N_2O analysis at the higher concentrations associated with the acetylene block technique for denitrification measurement. Grimm owns or has access to field equipment including chambers, soil cores, field vehicle, and soil moisture and temperature probes. **Kaye's new terrestrial biogeochemistry laboratory** (>900 ft^2) is equipped with a LACHAT QC8000 autoanalyzer with inline persulfate digestion for analysis of inorganic and organic N and P in soil solutions and extracts, a Varian 3800 GC with ECD and FID detectors, and a hood and large cold room. These labs contain several personal computers equipped with laser and color printers, and Ethernet connection to ASU, CES, and LTER servers. Software available includes word processing, statistical (Systat), spreadsheet, graphics, modeling (Stella, Matlab), GIS (ArcView), and communications. Finally, a small meeting room for LTER use adjoins the office of the CAP LTER administrative assistant and the Grimm and Kaye labs. **Wu's Landscape and Systems Ecology Laboratory** is equipped with advanced computing facilities and software systems. The lab offers excellent opportunities for ecological research involving spatial analysis, simulation modeling, and geographic information systems. It contains 2 Sun Sparc Stations, 6 Power Macintosh computers, and 3 PC computers, Printing, Digitizing, Scanning and Storage Systems: Digitizer Set (Tablet-AccuGrid, Stand-Numonics), Scanner (ScanMaker III), 2 Laser Printers, 2 Color Printers, Several Jaz and Zip drives and tape drives. Major Software Packages for Simulation Modeling and Spatial Analyses: Compilers: C, C^{++}, and Fortran on UNIX and Power Macintosh platforms, Spatial statistics packages: S Plus, S Plus Spatial Stats, GSLIB, GIS packages: Arc/Info, S Plus GISLink, ArcView, IDRISI, GRASS, STELLA (on both Power Macintosh and PC platforms). **Anderies'** laboratory has computing equipment including two networked PC's that are dual boot with Windows XP and RedHat Linux 10 to run a range of sophisticated modeling and numerical analysis software, a high-speed HP 4000 series networked printer, and a meeting/discussion area. **Martin** and **Stutz** have 800 ft^2 research laboratories on the ASU East campus. These are wet labs with soil traps for processing samples containing soil. They incorporate exhaust fume hoods and have gas, air, and vacuum lines installed. Martin's ecophysiology laboratory contains portable infrared gas analysers for water and CO_2 gas exchange, dew point pressure osometer and pressure bomb for water relations, high top loading balance, digitizing video system and root elutration systems for measurements of above- and below-ground net primary productivity. It also has a large refrigerator, exhaust fume hood, temperature controlled recirculating water bath, and spectrophotometer. Four PC computers, digitizing and scanning equipment, Ethernet connections to ASU, CES and LTER servers, and one laptop PC for analysis of data in the field are available for ASU East researchers. Greenhouse facilities at ASU East are in the planning stages and are expected to be available for controlled environment research.

LETTERS OF SUPPORT

1. Gerald J. Gottfried, Research Forester, Rocky Mountain Research Station, US Forest Service
2. Dennis Smith, Executive Director, Maricopa Association of Governments
3. Michael S. Ellegood, P.E., Chief Engineer and General Manager, Maricopa County Flood Control District
4. Ray Quay, Assistant Director, Water Services Department, City of Phoenix
5. Patricia Mariella, PhD., Director, Department of Environmental Quality, Gila River Indian Community
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7. O. J. Reichman, Director, National Center for Ecological Analysis and Synthesis, University of California, Santa Barbara
8. Mark Jacobs, PhD., Dean, The Barrett Honors College, Arizona State University
9. Nancy R. Crocker, PhD., Assistant Director for Science and Math Outreach, Division of Undergraduate Academic Services, Arizona State University
10. Monica Pastor, Assistant Agent, 4-H Youth, Agricultural Literacy Program, University of Arizona Agricultural Extension
11. Lynn M. Davey, PhD., Principal, William T. Machan School, Phoenix, AZ
12. Birgit Musheno, Science Department Chair, Desert Vista High School, Phoenix, AZ
13. Madhusudan Katti, Postdoctoral Research Associate, School of Life Sciences, Arizona State University

CAP LTER PRODUCTS
1997-PRESENT

JOURNAL ARTICLES

In Press

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OTHER – PRESENTATIONS AND POSTERS

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Baker, L., and S. Wolf. 2003. Sources of salt to municipal wastewater. Presented at 18-22 March 2003 *29th Annual Conference of the Water Quality Association*, Las Vegas, NV.

Hill, C., and C. Saltz. 2003. Linking scientists, teachers and children in scientific research. Presented at March 2003, *Microcomputers in Education Conference*, Arizona State University, Tempe.

Kirby, A., S. L. Harlan, R. Bolin, E. Hackett, L. Larsen, T. Rex, and S. Wolf. 2003. Building walls, building community? A preliminary examination of common-interest neighborhoods in Phoenix. Presented at the June 2003 second annual *Hawaiian International Conference in Social Sciences*.

Larsen, L., and S. L. Harlan. 2003. The wealth of neighborhoods: Exploring the concept of neighborhood capital. Presented at the 12 July2003 *Third Joint Congress of the ACSP and AESOP,* Leuven, Belgium.

Lewis, D. B., and N. B. Grimm. 2003. Mechanisms of nutrient export in storm water runoff from catchments. Presented at 06-11 April 2003 *European Geophysical Society - American Geophysical Union - European Union of Geosciences,* Joint Assembly, Nice, France.

Lewis, D. B., L. B. Stabler, and C. A. Martin. 2003. Ecological stoichiometry of horticulture: Consequences of pruning and water for plant nutrient use efficiency. Presented at the 03-08 August 2003 *Ecological Society of America Annual Meeting*, Savannah, GA.

McIntyre, N. E. 2003. Arthropods in urban ecosystems: Community patterns as functions of anthropogenic land use. Invited talk, *The Sixth World Congress of the International Association of Landscape Ecology*, Darwin, Australia.

Musacchio, L. 2003. The comparative ecology of cities and towns: opportunities and limitations. Invited guest speaker at July 2003 *IALE World Congress Symposium*, Darwin, Australia.

Nash III, T. H., C. Gries, T. Zschau, S. Getty, Y. Ameron, and A. Zambrano. 2003. Historical patterns of metal atmospheric deposition to the epilithic lichen *Xanthoparmelia* in Maricopa County, Arizona, U.S.A. Poster presented at May 2003 *XIIth International Conference on Heavy Metals in the Environment*, Grenoble, France.

Netzband, M., and W.L. Stefanov. 2003. Remote sensing and landscape metrics for global ecological monitoring. Presented at 8 March 2003 *AAG Annual Meeting*, New Orleans, LA.

Stefanov, W. L. 2003. Geological remote sensing in the LTER network: Terra cognita? *Third Long Term Ecological Research Network Mini-Symposium*. National Science Foundation, Washington, DC.

Stefanov, W. L., and M. Netzband. 2003. Characterization and monitoring of urban/peri-urban landscapes using ASTER. *24th ASTER Science Team Meeting*, Tokyo, Japan.

Stiles, A., and S. Scheiner. 2003. Effects of habitat fragmentation on remnant Sonoran Desert plant communities in the CAP LTER, Phoenix, Arizona. Presented at the August 2003 *Ecological Society of America* meeting, Savannah, GA.

Stutz, J. C., S. A. Whitcomb, and J. R Cousins. 2003. Local arbuscular mycorrhizal fungal diversity is strongly coupled to regional diversity in an urban ecosystem . Presented August 2003 at the *Fourth International Conference on Mycorrhizae (ICOM4)*, Montreal, Canada.

Warren, P. S. C. Nilon, A. Kinzig, M. Cox, J. M. Grove, and C. Martin. 2003. Human socioeconomic factors and avian diversity: A cross-site comparison. Presented by C. Nilon at the August 2003 *Ecological Society of America* meeting, Savannah, GA.

Whitcomb, S. A., and J. C. Stutz. 2003. Small-scale spatial patterns of arbuscular mycorrhizal fungal species in an experimental xeric landscaped site. Presented August 2003 at the *Fourth International Conference on Mycorrhizae (ICOM4)*, Montreal, Canada.

Wu, J. 2003. Key research topics in landscape ecology. Beijing Normal University, Beijing, January 3, 2003.

2002

Applegarth, M., and W. Stefanov. 2002. Use of Thermal Infrared Multispectral Scanner (TIMS) imagery to interpret particle size on desert hillslopes. *American Association of Geographers Annual Meeting Abstracts*.

Arrowsmith, J R., G. R. Keller, L. Prashad, M. Diaz, W. L. Stefanov, C. Eisinger, M. Fouch, S. Reynolds, S. M. Richard, and P. A. Pearthree. 2002. A geospatial data systems for the transition between the Colorado Plateau and Basin and Range Provinces: An essential tool for basic and applied research in earth science and urban ecology. *Geological Society of America* Abstracts with Programs, Abstract 97-8.

Baker, L., and W. Stefanov. 2002. Information engineering: A new paradigm for environmental management in the 21st century. Presented (invited) at 17-19 April 2002, *Minnesota Water Conference*, St. Cloud, MN.

Dillner, A. M., J. Boreson, and T. Paez-Rubio. 2002. Indoor and outdoor speciated PM2.5 aerosol in a low income neighborhood. Platform presentation at the 2002 *Annual Conference of the American Association of Aerosol Research*, Charlotte, NC.

Elser, M., and C. Saltz. 2002. Linking scientists, teachers and children in scientific research. Presented at March 2002, *Microcomputers in Education Conference*, Arizona State University, Tempe.

Elser, M. 2002. LTER education programs. Presented at 4-9 August 2002, *87th Annual Meeting of the Ecological Society of America*, Tucson, AZ.

Gade, K. J., W. Bigler, T. Collins, E. Ng, J. Parker, and L. Stabler. 2002. From horse-drawn streetcars to light rail: Exploring social and ecological roles at Eastlake Park. Presented at 4-9 August 2002, *87th Annual Meeting of the Ecological Society of America*, Tucson, AZ.

Grimm, N. B., J. D. Schade, J. R. Welter, D. B. Lewis, and E. Marti. 2002. Nitrogen retention in arid-land stream and riparian zones. Presented at June 2002, *Special Session, Physical Forcing and Pelagic-Benthic Interactions in Aquatic Systems*, Annual meeting, American Society of Limnology and Oceanography, Victoria, BC.

Grossman-Clarke, S., D. Hope, S. M. Lee, H. J. S. Fernando, P. G. Hyde, W. L. Stefanov, and N. B. Grimm. 2002. Modeling temporal and spatial characteristics of nitrogen dry deposition in

the Phoenix metropolitan area. *EOS Transactions American Geophysical Union*, 83(47), Fall Meet. Suppl., Abstract B22B-0755.
Hope, D., S. Grossman-Clarke, S. M. Lee, H. J. S. Fernando, P. G. Hyde, W. L. Stefanov, and N. B. Grimm. 2002. The importance of dry deposition to the nitrogen mass balance of an arid urban ecosystem. *EOS Transactions American Geophysical Union,* 83(47), Fall Meet. Suppl., Abstract B22B-0756.
Hostetler, M. E. ,and K. Knowles-Yanez. 2002. Land Use, scale, and bird distributions in the Phoenix metropolitan area. Presented at July 14-16, *Society for Conservation Biology*. Canterbury, UK.
Katti, M. and E. Shochat. 2002. Population and physiological responses of Sonoran desert birds to urbanization in central Arizona, USA. *Proceedings of the 23rd International Ornithological Congress, Beijing, China*, page 177.
Kinzig, A. P., P. Warren, J. M. Grove, C. Martin, D. Hope, and C. Redman. 2002. Biodiversity in modern urban habitats. Presented at 16 February 2002, *American Association for the Advancement of Science Annual Meeting*, Boston, MA.
Koerner, B. A., and J. M. Klopatek. 2002. Seasonal responses of soils to water and nitrogen along an urban to rural gradient. Presented at 4-9 August 2002, *87th Annual Meeting of the Ecological Society of America*, Tucson, AZ.
Krasney, M., and M. Elser. 2002. Developing students' research and data manipulation skills. Presented at March 2002, *National Science Teachers Association Conference*, San Diego, CA.
Lewis, D. B. 2002. Stoichiometry and load of nutrients and metals discharged from urban catchments by storms. Presented at 21-24 May 2002, *CEREVE: University of Paris XII-Val de Marne, World Wide Workshop for Junior Environmental Scientists Annual Meeting,* Domaine de Chérioux, Vitry sur Seine, France.
Lewis, D. B., and N. B. Grimm. 2002. Nutrient and metal loads exported from hydrologic catchments by storm runoff. Presented at 4-9 August 2002, *87th Annual Meeting of the Ecological Society of America*, Tucson, AZ.
Martin, C. A., L. B. Stabler, S. B. Celestian, and J. C. Stutz. 2002. Urban plant ecology: A horticultural perspective. Initial results from a Long Term Ecological Research (LTER) site. Poster presented at 23-25 May 2002, *Proceedings of the 12th METRIA Conference,* Asheville, NC. Online publication at http://fletcher.ces.state.nc.us/programs/nursery/metria/metria12/martinetal/index.html
Musacchio, L., and J. Wu. 2002. Cities of resilience: Integrating ecology into urban planning, design, policy, and management. Workshop, presented at 4-9 August 2002, *87th Annual Meeting of the Ecological Society of America*, Tucson, AZ.
Musacchio, L., and J. Wu. 2002. Cities of resilience: Four themes of the symposium. Presented at 4-9 August 2002, *87th Annual Meeting of the Ecological Society of America*, Tucson, AZ.
Perry, D. L., J. R. Anderson, and P. R. Buseck. 2002. Analysis of atmospheric particles deposited onto mesquite leaves in the Central Arizona – Phoenix LTER area. Presented at 20-24 May 2002, *Fourth Symposium on the Urban Environment,* American Meteorological Society, Norfolk, VA.
Redman, C. L., and N. B. Grimm. 2002. The urban ecology of central Arizona-Phoenix. Presented at August 2002, Presented at 4-9 August 2002, *87th Annual Meeting of the Ecological Society of America*, Tucson, AZ.

Saltz, C. 2002. Scientist-teacher partnerships in environmental education. Presented on 8 August 2002 at *North American Association for Environmental Education Annual Conference*, Boston, MA.

Schaafsma, H., and J. M. Briggs. 2002. Agricultural perturbations and the herbaceous legacy of the prehistoric Hohokam people in Arizona. Poster presented at the 4-9 August 2002, *87th Annual Meeting of the Ecological Society of America,* Tucson, AZ.

Shochat, E., and M. Katti. 2002. Differences in bird foraging behavior between Sonoran Desert and urban habitats in central Arizona. Presented at August 2002 *XXIII International Ornithological Congress*, Beijing, China, page 157.

Stabler, L. B., and C. A. Martin. 2002. Irrigation and pruning affect growth and water use efficiency of two common landscape shrubs. Poster presented at 15 February 2002, *Graduates in Earth and Life Sciences Poster Symposium*, Arizona State University, Tempe.

Stefanov, W. L. 2002. The ASTER Urban Environmental Monitoring Project: Progress and Current Results. Presented at the 14-18 January 2002, *21th ASTER Science Team Meeting,* Pasadena, CA.

Stefanov, W. L. 2002. The ASTER Urban Environmental Monitoring Project: Progress Update. Presented at 21-23 May 2002, *22nd ASTER Science Team Meeting*, Tokyo, Japan.

Stefanov, W. L. 2002. Ecological remote sensing at the CAP LTER site. Presented at 5-7 August 2002, *Arizona Geographic Information Council Annual Meeting*, Mesa, AZ.

Stefanov, W. L. 2002. Assessment of landscape fragmentation associated with urban centers using ASTER data. *American Geophysical Union EOS Transactions* 83(47) abstract B61C-0739.

Stiles, A., and S. Scheiner. 2002. Using remote sensing to generate a map of desert plant community distribution for the CAP-LTER, Phoenix, Arizona. Poster presented at 4-9 August 2002, *87th Annual Meeting of the Ecological Society of America*, Tucson, AZ.

Warren, P. S., A. P. Kinzig, and C. A. Martin. 2002. Ecological characteristics of urban parks show different human imprints. Presented at 4-9 August 2002, *87th Annual Meeting of the Ecological Society of America*, Tucson, AZ.

Whitcomb, S., C. A. Martin, and J. C. Stutz. 2002. Spatial patterns of soil respiration, temperature, and moisture in an experimental urban landscaped site. Poster presented at 4-9 August 2002, *87th Annual Meeting of the Ecological Society of America*, Tucson, AZ.

Whitcomb, S., and J. C. Stutz. 2002. Small-scale spatial patterns of arbuscular mycorrhizal fungal diversity in an experimental urban landscaped site. *Inoculum* 53(3):59.

Wu, J. Scaling across heterogeneous landscapes: Theory and methods. Invited symposium presentation at *The VIII International Congress on Ecology*, Seoul, Korea, August 11-18, 2002.

Wu, J. 2002. Toward a landscape ecology of cities: Beyond buildings, trees and forests. Plenary speech, *International Symposium on Urban Forestry and Eco-Cities,* Shanghai, Sept. 16-22, 2002.

Wu, J. 2002. Landscape ecology as a scientific basis and methodology for understanding and combating desertification and dust/sand storms. Presented at the *Sino-US Workshop on Dust Storms and Their Effects on Human Health*, Raleigh, North Carolina, November 25-26, 2002.

Wu, J. 2002. Landscape ecological principles for nature conservation and ecological restoration. Plenary speech at *International Symposium on Ecosystem Succession Theory and Ecological Restoration,* Guangzhou, December 27-29, 2002.

Wu, J., and R. Hobbs. 2002. Top 10 list for landscape ecology: An idiosyncratic synthesis. Presented at 23-27 April 2002 *The Seventeenth Annual Symposium of the International Association of Landscape Ecology (US-IALE)*, Lincoln, NE.

Wu, W., and J. Wu. 2002. Spatial pattern of an urban stream landscape: flowpath and impervious surface cover in Cave Creek, Arizona. Poster presented at the 23-27 April 2002 *Seventeenth Annual Symposium of the International Association for Landscape Ecology - United States Regional Association (US-IALE)*, Lincoln, NE. p.69. (Abstract and Poster)

2001

Baker, L. 2001. An ecosystem-level approach for engineering the biogeochemical cycles of cities and farms. Keynote Talk, presented at 6-7 October 2001, *Midwest Water Chemistry Conference.*

Baker, L.A., D. Hope, Y. Xu, and J. Edmonds. 2001. Multicomparment ecosystem nitrogen balances as a tool to understand and manage biogeochemical cycles in human ecosystems. Presented at 14-18 October 2001, *The Science World*, Proceedings of the Second International Nitrogen Conference (N2001), Potomac, MD.

Baker, L.A., Y. Xu, and N. McPherson. 2001. Salinity -- an emerging issue for the Phoenix Metropolitan Area. Presented at 4-5 May 2001, *Arizona Water Pollution Control Assoc. Conference*, Mesa, AZ.

Berling-Wolff, S., and J. Wu. 2001. Simulating urban growth in the Phoenix metropolitan region: Relating pattern to process. Presented at 25-29 April 2001, *16th Symposium of the U.S. Chapter of the International Association of Landscape Ecology*, Arizona State University, Tempe.

Bigler, W. 2001. Historic channel changes in the Salt River, Arizona, 1890-1931. Poster presented at 11-12 May 2001 *15th Annual Meeting of the Arizona Riparian Council*, Tucson.

Bolin, R., A. Nelson, S. Smith, E. Hackett, D. Pijawka, E. Sadalla, M. O'Donnell, S. Grineski, T. Collins, and D. Sicotte. 2001. Environmental equity in Phoenix, Arizona: The spatial distributions of hazardous facilities and vulnerable populations. Presented at 29-31 October 2001, *Annual Federal State Toxicology and Risk Analysis Committee Meetings*, Phoenix, AZ.

Cousins, J. R., S. A. Whitcomb, and J. C. Stutz. 2001. Arbuscular mycorrhizal fungal species composition, richness and abundance in the Phoenix metropolitan area. *Phytopathology* 91:S107.

David, J., and J. Wu. 2001. Toward developing a hierarchical patch dynamics modeling platform. Presented at 25-29 April 2001, *16th Symposium of the U.S. Chapter of the International Association of Landscape Ecology*, Arizona State University, Tempe.

Grimm, N. B. 2001. Nitrogen retention in arid-land stream and riparian zones. Guest speaker at September 2001, *First Annual Conference, Global Nitrogen Enrichment Program*. University of Wales, Bangor, Wales.

Grimm, N. B., and C. L. Redman. 2001. Ecological pattern and process and human-ecosystem interaction in central Arizona. Plenary presented at 25-29 April 2001, *16th Symposium of the*

U.S. Chapter of the International Association of Landscape Ecology, Arizona State University, Tempe.
Hobbs, R., and J. Wu. 2001. Perspectives for landscape ecological research. Presented at *IALE European Conference 2001*, Stockholm Sweden (30 June-2 July 2001) and Tartu, Estonia (3-6 July 2001).
Hope, D. C. Gries, W. Zhu, S. Carroll, A. Nelson, L. Stabler, C. L. Redman, N. B. Grimm, and A. Kinzig. 2001. Landscape pattern and process of an urban ecosystem: An integrated field inventory approach. Presented at 6-10 August 2001, *Ecological Society of America 86th Annual Meeting*, Madison, WI.
Jenerette, G. D., M. A. Luck, J. Wu, N. B. Grimm, D. Hope, and W. Zhu. 2001. From points to regions: Estimating soil organic matter spatial patterns in central Arizona. Presented at 25-29 April 2001, *16th Symposium of the U.S. Chapter of the International Association of Landscape Ecology*, Arizona State University, Tempe.
Jenerette, G. D., J. Wu, and N. B. Grimm. 2001. Spatial nitrogen dynamics and self organization. Presented at 25-29 April 2001, *16th Symposium of the U.S. Chapter of the International Association of Landscape Ecology*, Arizona State University, Tempe.
Katti, M., and E. Shochat. 2001. Phoenix or Tucson – does landscape determine where Abert's Towhees choose to live? Presented at 25-29 April 2001, *16th Symposium of the U.S. Chapter of the International Association of Landscape Ecology*, Arizona State University, Tempe.
Katti, M., and E. Shochat. 2001. Bird species diversity in the greater Phoenix area, Arizona. Presented at 6-10 August 2001, *Ecological Society of America 86th Annual Meeting*, Madison, WI..
Keller, G. R., R. Arrowsmith, M. Fouch, A. Gates, N. Hicks, V. Kreinovich, K. Mickus, S. Reynolds, S. Richard, and W. Stefanov. 2001. The southern Colorado Plateau and adjacent Basin and Range Province: A testbed for geoinformatics and data integration. *Geological Society of America Abstracts with Programs, Annual Meeting, Abstract 72-65.*
Kinzig, A. P. 2001. Invited panel speaker at 24-27 March 2001, *Human Dimensions of Biodiversity.* American Institute of Biological Sciences Annual Meeting, Washington, DC.
Kinzig, A. P. 2001. Concluding speaker for 1-3 May 2001, *Cary Conference IX Understanding Ecosystems: The Role of Quantitative Models in Observation, Synthesis, and Prediction*. Institute of Ecosystem Studies, Millbrook, NY.
Kinzig, A. P. 2001. *National and international trends in research integrating nature and society.* Presented at 19-23 May 2001, *Workshop on Emergence, Transformation, and Decay in Socionatural Systems*. Abisko Scientific Research Station, The Royal Swedish Academy of Sciences, Abisko, Sweden.
Li, H., and J. Wu. 2001. Landscape analysis with pattern indices: Problems and solutions. Presented at 25-29 April 2001, *16th Symposium of the U.S. Chapter of the International Association of Landscape Ecology*, Arizona State University, Tempe.
McIntyre, N. E., and M. Hostetler. 2001. Effects of urban land use on pollinator communities in a desert metropolis. Presented at 25-29 April 2001, *16th Symposium of the U.S. Chapter of the International Association of Landscape Ecology*, Arizona State University, Tempe.
Musacchio, L. University/town interface and collaboration session. Invited guest speaker at July 2001 *Western Planners/Four Corners Planners/New Mexico APA Conference,* Santa Fe, New Mexico.

Musacchio, L. R., K. Crewe, F. Steiner, and J. Schmidt. 2001. The future of agriculture landscape preservation in the Phoenix metropolitan region. Workshop at the April 25-29 *Sixteenth Annual Symposium of the U.S. Regional Chapter of the International Association of Landscape Ecology*, Arizona State University, Tempe.

Musacchio, L. R., J. Ewan, and R. Yabes. 2001. The equity of riparian conservation and restoration projects in the Phoenix metropolitan area: Is a regional planning framework needed? Workshop at the April 25-29 *Sixteenth Annual Symposium of the U.S. Regional Chapter of the International Association of Landscape Ecology*, Arizona State University, Tempe.

Roach, W. J., and N. B. Grimm. 2001. Biogeochemistry in a extensively modified urban desert stream: Preliminary results from Indian Bend Wash. Presented at 11-12 May 2001 *15th Annual Meeting of the Arizona Riparian Council*, Tucson.

Saltz, C., and M. Elser. 2001. Scientists as partners. Presented at September 2001, *Arizona Association for Environmental Education Conference*, Phoenix, AZ.

Schoeninger, R., C. Gries, and T. H. Nash. 2001. Herbarium databases: Creation, maintenance, and access via the internet. Poster presented at 12-16 August 2001, *Botany 2001: Plants and People*, Albuquerque, NM.

Shochat, E., and M. Katti. 2001. Differences in House Finch foraging behavior between Sonoran Desert and urban habitat in central Arizona. Presented at July 2001, *Animal Behavior Society Annual Meeting*, Corvallis, OR.

Shochat, E., and M. Katti. 2001. Phoenix or Tucson: Does landscape structure influence where Abert's Towhees choose to live? Presented at 6-10 August 2001, *Ecological Society of America 86th Annual Meeting*, Madison, WI.

Sprott, P. L, K. S. Baker, M. E. Krasny, M. M. Elser and R. E. Bohanan. 2001. Long term ecological research network K-12 education partnership: Students and teachers experiencing LTER. Presented at 6-10 August 2001, *Ecological Society of America 86th Annual Meeting*, Madison, WI.

Stefanov. W. L. 2001. Desert geology. Presented at March 2001, *Design with the Desert Conference*, Arizona State University, Tempe.

Stefanov, W. L. 2001. Potential applications of remote sensing to assessments of road surface condition. Presented at April 2001, *50th Annual Roads and Streets Conference*, Arizona Consulting Engineers Association, Tucson.

Stefanov, W. L. 2001. Global urban center classification. Presented at 21-24 May 2001, *ASTER Science Team Meeting*, Tokyo, Japan.

Stefanov, W. L., and M. T. Applegarth. 2001. Geomorphic analysis of semiarid landforms using mid-infrared spectroscopy and remote sensing. *American Geophysical Union EOS Transactions* 82(47):Abstract H42D-0393.

Stefanov, W. L., and P. R. Christensen. 2001. Classification of global urban centers using ASTER data: Preliminary results from the Urban Environmental Monitoring Program. *American Geophysical Union EOS Transactions* 82(20):10-11.

Stefanov, W. L., M. S. Ramsey, and P. R. Christensen. 2001. Mapping of fugitive dust generation, transport, and deposition in the Nogales, Arizona, region using Enhanced Thematic Mapper Plus (ETM+) data. *American Geophysical Union EOS Transactions* 82(20):77-78.

Stiles, A., C. Gries, and S. Scheiner. 2001. Analysis of Sonoran Desert vegetation in the CAP LTER study area, Phoenix, AZ. Poster presented at 6-10 August 2001, *Ecological Society of America 86th Annual Meeting*, Madison, WI.

Tueller, P. T., M. Limb, and J. Wu. Landscape pattern and ecosystem attributes on a western Nevada rangeland ecosystem. Presented at 25-29 April 2001, *16th Symposium of the U.S. Chapter of the International Association of Landscape Ecology*, Arizona State University, Tempe.

Westerhoff, P., D. Bruce, M. L. Nguyen, M. Sommerfeld, T. Dempster, Q. Hu, L. Lowry, and L. Baker. 2001. Production sources of algal metabolites (MIB and geosmin) in Arizona reservoirs, rivers, and canals. Presented at June 2001, *AWWA Conference*, Washington, DC.

Whitcomb, S. A., and J. C. Stutz. 2001. Effects of pruning on root length density, root biomass, and arbuscular mycorrhizal colonization in two landscape shrubs. *Proceeding 3rd International Conference on Mycorrhizas*, Abstract 1-157.

Wu, J. 2001. Effects of changing grain size and extent in landscape characterization and pattern analysis: Generalities and idiosyncracies. Presented at 25-29 April 2001, *16th Symposium of the U.S. Chapter of the International Association of Landscape Ecology*, Arizona State University, Tempe.

Wu, J. 2001. Top 10 list for landscape ecology in the 21st century: Introduction. Presented at 25-29 April 2001, *16th Symposium of the U.S. Chapter of the International Association of Landscape Ecology*, Arizona State University, Tempe.

Wu, J. 2001. Top 10 lists for landscape ecology from M. Anthrop, R. J. Hobbs, S. A. Levin, A. S. Lieberman, R. V. O'Neill, and M. G. Turner. Presented at 25-29 April 2001, *16th Symposium of the U.S. Chapter of the International Association of Landscape Ecology*, Arizona State University, Tempe.

Wu, J. 2001. Scales and processes of flow regime, hydrologic connectivity, and riverine landscape patterns on braided river floodplains. Presented at 25-29 April 2001, *16th Symposium of the U.S. Chapter of the International Association of Landscape Ecology*, Arizona State University, Tempe.

2000

Anderson, S., and A. J. Brazel. 2000. A look at spatial and temporal climate change on the urban fringe. Presented at 14-18 August 2000 *Third Symposium on the Urban Environment*, American Meteorological Society, University of California, Davis.

Baker, L., D. Hope, N. Grimm, C. Martin, J. Briggs, and J. Klopatek. 2000. Carbon cycling in the central Arizona - Phoenix ecosystem: Advances in ecosystem carbon inventory, measurement, and monitoring. Presented October 2000 to USDA Forest Service, Raleigh, NC.

Bolin, R. 2000. Environmental equity in a Sunbelt city. Presented at May 2000, *Urban Affairs Association*, Los Angeles, CA.

Brawley-Chesworth, A., and P. Westerhoff. 2000. Fate of MIB and Geosmin in surface water treatment plants. Presented at May 2000, *AWPCA Annual Conference*, Mesa, AZ.

Brazel, A. J., and G. M. Heisler. 2000. Some considerations in using climate data from existing weather stations or installing stations for research in Baltimore and Phoenix urban LTER sites. Presented at 14-18 August 2000 *Third Symposium on the Urban Environment*, American Meteorological Society, University of California, Davis.

Bruce, D., P. Westerhoff, M. Sommerfeld, L. Baker, M-L. Nguyen, H. Qiang, T. Dempster, and D. Lowry. 2000. Occurrence and potential causes of Geosmin and MIB in Arizona drinking waters. Presented at May 2000, *AWPCA Annual Conference*, Mesa, AZ.

Chambers, F. B., and A. J. Brazel. 2000. Heating and cooling in Colorado mining towns. Presented at 14-18 August 2000 *Third Symposium on the Urban Environment*, American Meteorological Society, University of California, Davis.

Compton, M., J. Hunter and M. Sommerfeld. 2000. Urban lakes - relationships between source water, lake age, water quality and biota. Presented at 14-15 April 2000 *44th Annual Meeting of the Arizona-Nevada Academy of Science*, University of Arizona, Tucson, AZ. *Journal of the Arizona-Nevada Academy of Science* (Proceedings Supplement) 35:46.

Davis, J., and J. Wu. 2000. A hierarchical patch dynamics modeling platform for modeling complex systems. Presented at 31 July-3 August 2000, *International Conference on Modeling Complex Systems*, Montreal, Canada.

Elser, M., C. Saltz, and D. Boomgaard. 2000. Linking scientists, teachers, and children in long-term scientific research. Presented at December 2000 *National Science Teachers Association Regional Meeting*, Phoenix, AZ.

Elser, M. M., and S. L. Williams. 2000. Urban ecology and urban schools: A model for encouraging long-term research with school children and teachers. Poster presented at 6-10 August 2000, *Ecological Society of America 85th Annual Meeting,* Snowbird, UT. *Ecological Society of America 85th Annual Meeting Abstracts* p. 271.

Esparza, M, and P. Westerhoff. 2000. Characterization of soluble microbial products during full-scale wastewater treatment. Presented at May 2000, *AWPCA Annual Conference*, Mesa, AZ.

Fergason, K. C., J R. Arrowsmith, and J. A. Tyburczy. 2000. Changes of groundwater elevation associated with Tempe Town Lake. Presented at September 2000, *Arizona Hydrological Society Meeting.*

Fink, J. H., C. L. Redman, and N. B. Grimm. 2000. Expanding a long-term ecological research project into a national urban environmental laboratory. Presentation at special session on "Earth Sciences in the Cities." (Abstract). *EOS, Transactions of the American Geophysical Union* 81:S11.

Grimm, N. B. 2000. Urban ecosystems as a frontier for the millennium: New challenges for aquatic ecologists. Presidential address, Presented at May 2000, *North American Benthological Society Annual Meeting.* Keystone, CO.

Grimm, N. B. 2000. Urban ecology and the challenge of integrating social and ecological sciences. April 2000, Plenary speaker, joint symposium of the *British Ecological Society* and the *Ecological Society of America*, *Ecology: Achievement and Challenge,* Orlando, FL.

Grimm, N. B., M. A. Luck, and G. D. Jenerette. 2000. Multiple-scale analyses of ecosystem function and human-ecological interaction in an urban setting, the central Arizona - Phoenix ecosystem. Presented at 6-10 August 2000, *Ecological Society of America 85th Annual Meeting,* Snowbird, UT. *Ecological Society of America 85th Annual Meeting Abstracts,* p. 17.

Harlan, S. L., and A. Nelson. Labor market trends in Phoenix: Preliminary findings. Presented December 2000, Equal Opportunity Commission, Regional Office, Phoenix, AZ.

Hope, D., J. Anderson, N. B. Grimm, and S. Boone. 2000. Atmospheric deposition in the Phoenix metropolitan area and its role in urban nutrient cycling. Poster presented at 6-10 August 2000, *Ecological Society of America 85th Annual Meeting,* Snowbird, UT.
Hope, D., J. Anderson, N. B. Grimm, and S. Boone. 2000. Atmospheric deposition across the Central Arizona - Phoenix LTER site. Presented at 14-18 August 2000 *Third Symposium on the Urban Environment*, American Meteorological Society, University of California, Davis.
Honker, A. 2000. Early reclamation and flood control on a local scale: The case of the Salt River in Phoenix. Presented at October 2000, *Western History Association Conference*, San Antonio, TX.
Hunter, J., M. Compton, D. Crowl, and M. Sommerfeld. 2000. Diatoms of Town Lake. Presented at 14-15 April 2000 *44th Annual Meeting of the Arizona-Nevada Academy of Science*, University of Arizona, Tucson, AZ. *Journal of the Arizona Nevada Academy of Science* (Proceedings Supplement) 35:11.
Jenerette, G., J. Wu, and N. B. Grimm. 2000. Nitrogen limitation and ecosystem self-organization: The effects of spatial heterogeneity. Paper presented at 6-10 August 2000, *Ecological Society of America 85th Annual Meeting,* Snowbird, UT. *Ecological Society of America 85th Annual Meeting Abstracts,* p. 127.
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Martin, C. A., and L. B. Stabler. 2000. Plant gas exchange in urban and suburban landscapes. Poster presented at 6-10 August 2000, *Ecological Society of America 85th Annual Meeting,* Snowbird, UT. *Ecological Society of America 85th Annual Meeting Abstracts* p. 308.
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Wu, J., D. Jenerette, and M. Luck. 1999. A hierarchical patch dynamics approach to urban landscape ecology. Presented at the 8-12 August 1999, *Annual Meeting of the Ecological Society of America*, Spokane, WA. *Ecological Society of America Abstracts*, p. 215.
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List of CAP LTER Datasets
Documentation of Web site usage

Administrative and catalog databases

Personnel directory
Project directory
Calendar
Online Map Gallery
Dataset Metadata Catalog
Personnel Directory
ASU Taxonomic Thesaurus
Image Library
Protocol Archive
Citation catalog
Document Archive
CES Project Management (status and cross referencing for projects, datasets, citations, personnel, images)

Taxonomic databases

ASU Vascular Plant Herbarium
ASU Lichen Herbarium
ASU School of Life Sciences
ASU Fruit and Seed Collection
University of Arizona Herbarium
Northern Arizona University Herbarium
Desert Botanical Garden Herbarium
Santa Barbara Botanical Garden Lichen Herbarium

Continuous monitoring databases, in progress

(all datasets have an associated GIS layer with site locations and are online at: http://seinet.asu.edu)

Atmospheric Deposition, Chemical analysis of wet and dry deposition at 12 stations (online)
Weather station data, Weather stations at three permanent sites; air and soil temperature, RH, dew point (online)
Aquatic core monitoring, chemical analysis of surface water at 19 sites in the metropolitan area (online)
Arthropod pitfall trap sampling, on a subset of survey 200 sites (online)
Bird population monitoring, on a subset of survey 200 sites (online)
Plant primary productivity, on a subset of survey 200 sites
Mycorrhiza population, on a subset of survey 200 sites (online)
Human activity, on a subset of survey 200 sites (online)
Survey 200, one time completed, at 204 sites (online):
  - Land use classification
  - Soil chemistry, texture
  - Pollen concentration, species diversity, distribution

Plant cover and size (Volume measurements of all tree, shrub, perennial herbs, cacti & succulents); Plant species diversity, richness, distribution (locations of each plant georeferenced)
Arthropod sweepnet sample – species diversity, richness
Site photographs
Detailed site maps of land cover materials and types
Mycorrhiza species diversity, richness, distribution
Landscape practices
Signs of human activity
Height of permanent built structures on plot
Climate data (30 minutes of RH, temperature, wind)

ONE TIME DATASETS, COMPLETED

(all datasets have an associated GIS layer with site locations and are online at: http://seinet.asu.edu)

Historic climate summary data (50 years) (online)
Transects of meteorological data, Temperature (hi, low, average) RH, pressure, heat index from east to west and west to east across the metropolitan area (online)
Transects of CO2 concentration and temperature, Transects through different land uses from the city center to rural (online)
Weather station data, Continuous monitoring of temperature, RH and dew point at six stations along an urban to rural gradient (online)
Continuous monitoring of air temperatures at ASU parking lot 44, above and below asphalt
Lichen resurvey, Metal concentration in lichens at 27 sites throughout Maricopa County in 1978 and 1998 (online)
Atmospheric particle composition, Chemical composition of particles deposited to leaf surfaces and filters at 20 sites
Elemental concentrations in urban lakes
Chemical concentrations in urban storm runoff from impervious cover (online)
Distribution of scorpion stings in the metro area (online)
Vertebrate species survey of desert remnants (online)
Bird transect survey (online)
Effects of urbanization on reproduction in birds
Avian diversity in parks and surrounding neighborhoods (quarterly for 2 years)
Effects of urban horticulture on insect pollinator community structure (online)
Bruchid beetle distribution
Photosynthesis, water content, and water potential of selected plant species in different residential landscape types (online)
Water use in different residential landscape types (online)
Effects of irrigation and pruning on plant growth and water use efficiency
Above and below ground estimates of urban plant biomass under different irrigation regimes
Measurements of bole volume of trees at commercial parking lot
Photosynthesis and transpiration measurements of trees at commercial parking lot
Leaf chlorophyll measurement of trees at commercial parking lot
Vegetation survey of desert plants. Counts of woody plants; presence/absence of annuals (online)

Perennial plant diversity in parks and surrounding neighborhoods
Vegetation classification, based on survey 200 plant cover data
Phoenix flora database (online)
Mycorrhizal colonization under different watering and pruning regimes
Park use surveys.
Urban fringe development (online)
Labor market summary data
Urban fire ecology (report) (literature citation, pdf online)
Phoenix social survey phase 1 (monitoring of environmental variables and the reaction of human inhabitants to them) (online) (literature citation, pdf online)
Environmental risk assessment, locations of multi hazards, locations of toxicity facilities in relation to population census
A river used to run through it: water use and flooding in Phoenix (report)
Database of photos documenting channel change of Salt and Gila rivers

ONE TIME DATASETS, IN PROGRESS

Arthropod diversity at three sites
Perennial vegetation structure at three sites
Nutrient transport and retention in urban watersheds
Natural ecosystem responses to urbanization effects along an urban - rural gradient (C dynamics and the above- and belowground responses to changes in water and N availability)
Phoenix social survey phase 2 (expansion into more neighborhoods and more environmental variables)
Change of fluvial landscape in urban watershed
Geophysical, geological, and geomorphic constraints on ground subsidence in piedmonts of the greater Phoenix area
Historic landuse change in Phoenix, Phase 2 (change in landuse in the square mile around survey 200 point since 1935)

DATABASES, ACQUIRED

Census data for 1980 - 2000, Geolytics Neighborhood Change Database (NCDB) (licensed cd)
Arizona Department of Water Resources Well Data (online)

GIS DATA, PRODUCED

(online at: http://seinet.asu.edu)

Pre-historic canal system in the Phoenix metropolitan area (online)
Historic land-use change in Phoenix, Phase 1 (change in 4 land-use categories since 1912) (online)
Locations of feedlots (online)
Citrus orchards (online)
Nitrogen deposits in the groundwater
Crop Locations (online)
Dairy farm locations (online)
GIS based maps of the geomorphology of the White Tank Mountains area west of Phoenix

Lichen resurvey produced modeled distribution maps for 12 of the metals investigated and distribution maps of emissions of five pollutants in Maricopa County (online)
Greater Phoenix 2100 e-Atlas (http://www.gp2100.org/eatlas.htm):
Population density, 2000, Greater Phoenix, Population Density per square mile – 2000 (online)
Housing Affordability, Layer showing the discrepancies between median income and average home sales, based on data from the Arizona State University Business Research Center (online)
General Age of Adults (21 to 74 Years), 2000, General Age Distribution of the population for Greater Phoenix based on the 2000 Census. (online)
Change in percent of Hispanic population from 1980 –2000 (online)
Distribution of Ragweed Pollen sampled in Greater Phoenix (online)
Distribution of prices of single family homes, new and resale throughout the region in 2001,based on data from the Arizona State University Business Research Center (online)
Percent of work force with some college education, based on data from the United States Census Bureau (online)
Change in groundwater level, 1985-2000, based on data from the Arizona Department of Water Resources (online)
Planned and Existing Master Planned Developments, based on data from the Maricopa Association of Governments (online)
High-Tech employment, based on data from the Arizona State University Business Research Center (online)
NDVI Images of 1975, 1980, 1985, 1990, 1993, 1998 and 2000, Normalized difference vegetation index (NDVI) produced from the 2000 Enhanced Landsat Thematic Mapper(ETM) image (online)
SAVI Images of 1975, 1980, 1985, 1990, 1993, 1998 and 2000,Soil Adjusted Vegetation Index (SAVI) map produced from the 2000 Enhanced Landsat Thematic Mapper (ETM) image (online)
Particulate Matter (2.5) pollution contours, based on data from the Arizona Department of Environmental Quality (online)
DOT map of planned and existing regional freeway system, based on data from the Arizona Department of Transportation (online)
Percent of population by zip code, admitted to hospitals and diagnosed with Asthma, based on data from the Arizona Health Service, Arizona Department of Environmental Quality (online)
Commute time to work, based on data from the Maricopa Association of Governments (online)
Estimated concentrations of ozone in the Greater Phoenix, based on modeling by ASU Environmental Fluid Dynamics Program (online)
PM10 concentration in Greater Phoenix area, based on data from the Arizona Department of Environmental Quality (online)
Population change, Population change 1980 - 2000, Map Shows the census tracts that have experienced a doubling of population between 1980 and 1990 and between 1990 and 2000 (online)
Change in population density, 1990 to 2000, Areas in the urban portions of Greater Phoenix that increased or decreased in population density between 1990 and 2000 (online)

Areas of significant agricultural and residential groundwater use, 1996-2000, shows areas in the valley depending mostly on well water, based on data from the Arizona Department of Water Resources (online)

Change in well water use, shows the change in volume of well water pumped 1985 - 2000, based on data from the Arizona Department of Water Resources (online)

Nitrogen concentration in well water, based on data from the Arizona Department of Water Resources and CAP LTER (online)

Quaternary Geomorphology, digital geological map for the CAP LTER study area and examine what geological changes have taken place in the landscape, with particular attention focused on alluvial and fluvial processes over the Quaternary period (online)

GIS DATA, ACQUIRED

Arizona soils map, Soil Survey Geographic (SSURGO) database for Maricopa County, Arizona, Central Part

Maricopa County Tax Assessor's aerial photos 1997

Landiscor aerial photos 1995, 2002

Thermal Infrared Multi-Spectral Scanner (TIMS) Data

NS001 Data, High resolution airborne remotely sensed data

MASTER Data, High resolution airborne remotely sensed data

ASTER Data, High resolution imager data from the Terra Satellite

Landsat Multispectral Scanner Data

Landsat Enhanced Thematic Mapper Plus

Digital raster graphic files for 7.5 minute USGS quadrangles covering Arizona

City of Phoenix GIS data (sewer lines, water feature, public transport, etc.)

Maricopa Association of Governments (MAG) GIS data (building permits, building completion, landuse classification, etc.)

Maricopa Flood Control District (MFCD) GIS data (hazard zones, lakes, rivers, watersheds, etc.)

Arizona Land Resource Information System (ALRIS) GIS data for Arizona (cities, roads, county lines, geology, vegetation, lakes, rivers, landownership etc.)

Arizona Department of Transportation, freeway system

Greater Phoenix 2100 e-Atlas (http://www.gp2100.org/eatlas.htm)

USGS DRG image catalog, The Digital Raster Graphic (DRG) is a raster image of a scanned USGS topographic map.

30 Minute Digital Elevation Model, Digital Elevation Model (DEM) is the terminology adopted by the USGS to describe terrain elevation data sets in a digital raster form.

AZ 7.5-Minute Digital Elevation Model, USGS 7.5 Minute Digital Elevation Model for Arizona

AZ250DEM, 1:250000 scale Digital Elevation Model of Arizona

az250kclphsd, data set is a hill shade, of the 1:250000 scale Digital Elevation Model of Arizona.

American Indian Reservation boundaries for the state of Arizona, Arizona Land Resources Information System

Park and Ride Centers, Valley metro transit system

Future Lite Rail Line, Valley metro transit system

Valley Metro Transit Centers, Valley metro transit system

Valley metro Bus routes April 2002, Valley metro transit system

TIMS image of Greater Phoenix, TIMS image of Greater Phoenix Area showing change in surface temperature

DOCUMENTATION OF WEB SITE USAGE (AS OF 1/1/04)

Table shows all individual users that have registered with CAP LTER for database usage.

Institution	# of users
Arizona Department of Water Resources	6
Arizona Geographical Alliance	1
Arizona State University	257
Arizona State University, West	5
Arizona State University, East	6
Arizona State University, East, Environmental Resources	5
Arizona State University, Center for Environmental Studies	19
Arizona State University, College of Liberal Arts and Sciences	1
Arizona State University, Plant Biology Dept	13
Baker Environmental Consulting, Inc.	1
Cal Poly Pomona	2
DecisionQuest	1
Desert Botanical Gardens	1
Hunter College	1
Hunter College, Geography Dept	13
Kalamazoo College	1
Louisiana State University	1
Maison de l'Archeologie	1
Maricopa Association of Governments	1
Maricopa Community Colleges	1
Mesa Community College	2
NACSE	9
National Science Foundation	1
Northern Arizona University	1
RJ Reynolds highschool	1
Shippensburg University	3
South African National Parks	1
State University of New York - Syracuse	1
Texas Tech University	1
The Nature Conservancy	1
U.S. Geological Survey	1
UFZ- Centre for Environmental Research	1
University of Arizona	18
University of Bergen	1
University of Michigan	1
University of Minnesota	2
University of Minnesota-Duluth	1
University of Pittsburgh	1
University of Wisconsin-Madison	1
US Army Corps of Engineers	3