Central Arizona – Phoenix LTER (DEB-9714833)
Land-Use Change and Ecological Processes in an Urban Ecosystem of the Sonoran Desert

Annual Progress Report, 1999-2000 (Project Year 3)

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I. GENERAL INFORMATION ABOUT CAP LTER

The CAP LTER project is a multifaceted study aimed at answering the question, "How does the pattern of development of the city alter ecological conditions of the city and its surrounding environment, and vice versa?" Central to answering this question is understanding how land-use change is driven by societal decisions, how these decisions alter ecological pattern and process, and how changes in ecological conditions further influence human decision-making. Of the 24 sites funded under the nationwide LTER program, Phoenix and Baltimore are the only 2 established specifically to study urban areas.

Initial projects began in spring 1998 to synthesize data, develop long-term monitoring methodology, conduct short- and long-term experiments and develop frameworks for modeling structure and patch typology. In the past year, we completed a long-term monitoring survey at 200 randomly selected points across the Phoenix metropolitan area and have moved toward establishing 10 to 12 permanent monitoring sites.

This year's report provides updates on our core effort, new and continuing projects, educational outreach programs, and project management activities. The CAP LTER All Scientists Council continues to meet monthly in a forum focusing on current research (open to all interested parties) and an Executive Committee meets as needed (usually biweekly) to establish and review policy, select postdoctoral associates, and allocate resources. We have enlarged our Executive Committee to include scientists from a broader range of disciplines in order to enhance communication among the various project participants, effectively replacing the Management Leadership Council, which has not met as frequently as originally envisioned. Our winter poster symposium continued with 30 presentations and featured Steward Pickett, BES LTER, as the keynote speaker. This year, due to the LTER All Scientist Meeting, we replaced our summer summit with a more informal gathering to present posters to be displayed at Snowbird. CAP LTER participants attended the All Scientists' Meeting en force contributing 13 posters and 8 workshops. Thirty-five total attendees included 13 social scientists, 2 earth scientists, 1 engineer, and 2 education specialists in addition to 17 life scientists.

For the first 3 project years, 97 faculty, 4 outside scientists (e.g., from USGS and MAG), 10 postdoctoral scholars, 73 graduate students, 24 undergraduates (including 9 summer REU students), 32 professional, technical, and office staff, 59 pre-college teachers, and 88 volunteers have been or currently are actively involved in CAP LTER projects. Project descriptions and previous annual progress reports can be viewed on the CAP LTER Web site (http://caplter.asu.edu/).

II. HIGHLIGHTS OF RESEARCH ACTIVITIES FOR YEAR 3

Activities in Year 3 centered on establishing a rational, spatially based monitoring program. Based on our experience in the previous 2 years, we were able to determine the important variables to be monitored, sampling frequencies, and the temporal and spatial scales (in grain and extent) of monitoring. We have continued to acquire existing data to better understand the overall structure of the study area, define patch typology and long-term monitoring schemes, and construct initial materials budgets for the whole system. In addition, we have continued to collect new data and develop models to be incorporated into the CAP hierarchical patch dynamics model (HDPM); leveraged funding (to CAP Co-PIs J. Wu and D. Green) from the EPA to develop the model has strengthened this activity. The award (to CAP Information Manager, P. McCartney and several co-PIs) of a Biological Database and Informatics grant to develop new database tools has bolstered our efforts in data management and use of existing data as components of our research projects. Finally, our conviction that effective interdisciplinary science requires new approaches to graduate training and, indeed, retraining of ourselves led us to develop an IGERT program in urban ecology, which has been funded beginning in summer 2000.

Our approach to long-term monitoring will be 2-pronged: 1) an extensive, expansive, multi-site (200 point) "snapshot" survey of ecological and social variables, conducted once every 3-5 years; and 2) higher-resolution, detailed investigations in permanent plots and permanent aquatic monitoring sites. Several initial projects are complete and have evolved into elements of the core monitoring effort (urban water chemistry, primary production, organic matter storage and soil respiration, arthropod sampling). Using our experience from these initial projects, considerable effort was devoted to the design of the 200-point survey, which was implemented in spring 2000. Another initial project describing urban growth patterns evolved into key contributions from CAP scientists to a major study of the patterns and implications of rapid urban-suburban growth in Phoenix, conducted by ASU's Morrison Institute for the Brookings Institution. Ecology Explorers, our educational outreach program, continues to attract a strong following of teachers and students who directly participate in CAP LTER data acquisition and analysis (reported in Education and Public Outreach section). The following narrative highlights key areas of research but is not intended to summarize all projects active in 2000.

Survey 200: Interdisciplinary Core Long-Term Monitoring

The goal of the Survey 200 project is to quantify basic ecological characteristics of the CAP LTER study area and monitor long-term ecological trends over time and space. The data may also be used in a cross-site comparison with a similar survey being planned for the Baltimore Ecosystem Study, including data on urban trees to parameterize the UFORE forest model being carried out by David Nowak of BES. Using a dual-density, randomized, tessellation-stratified sampling design, 206 sample sites were selected within the CAP LTER area (Figure 1). A grid of 4-km x 4-km cells was superimposed on the study site. Within the main urban core (defined by a 'beltway' comprising the major existing and proposed freeways) 1 sample site was randomly located within each grid cell; in largely undeveloped fringe areas outside this core, 1 sample site was randomly located within every third grid cell. Each GPS-located survey site consists of a 30m x 30m square plot centered on the randomized point. An initial pilot phase of sampling at 20 representative sites was undertaken in April/May 1999, during which the field protocols were tested and refined. The first full study was completed between mid-February and mid-May 2000 at 204 of the 206 designated sample sites and will be repeated every 3-5 years. The following variables were measured:

Basic plot characteristics
Documentary photos
Observable landscape practices
Vegetation cover
Soil cores (to 30 cm depth)
Microbial activity
Pollen
Decomposition in litterbags and buried wood
Arthropod diversity
Human activities

In addition, a bird species survey and a human-activity survey will be initiated at 40 of the 206 sites and carried out 4 times per year, as part of core monitoring efforts.

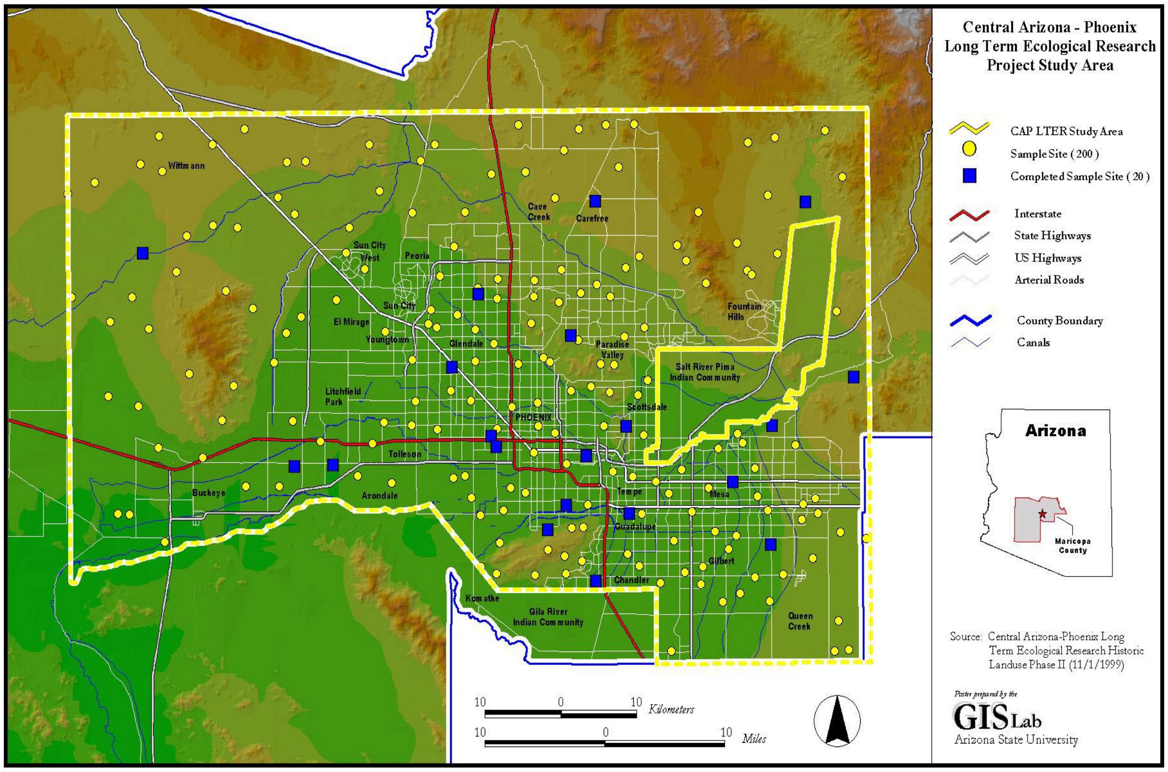

Figure 1. Map of the CAP LTER study area showing the 200 sites randomly selected for long-term monitoring of a range of ecological variables.

The resulting field data have been entered into the CAP LTER database; all the main plot features (e.g., position of main land-cover types, individual trees and shrubs, sample locations) are fully geo-referenced. Laboratory analysis of soils, pollen, microbes and litter decomposition is ongoing. The data will soon be available for query and analysis by CAP researchers; data analysis and manuscripts reporting results of the survey are beginning.

Remote Sensing and Patch Typology

The primary focus of the remote sensing team over the past year was constructing a reference dataset for accuracy assessment of Landsat Thematic Mapper (TM) data and production of land-cover classifications for the Phoenix metropolitan area. A pilot study of land-cover classification using TM data (completed early 1999) employed existing land-use data as the reference dataset. A number of assumptions about land-cover to land-use correlation were necessary to use the land-use data as a reference, which led to considerable ambiguity (and inaccuracy) in the classification results. Subsequent research activities therefore concentrated on 2 main areas: 1) constructing a land-cover reference dataset using digital orthophotos; and 2) developing and implementing an expert system for land-cover classification of TM data obtained during 1985, 1990, 1993, and 1998.

Expert systems incorporate remotely sensed information with other data sources in a classification or post-classification sorting mode using logical decision rules. Such systems have been used to classify land cover in temperate urban centers, but to our knowledge this is the first such application of the method to a semiarid-arid urban center. Initial classification of the study area was performed using visible/near-infrared band reflectance of 1998 Landsat TM data and SAVI (soil-adjusted vegetation index) values derived from the same dataset. Spatial texture was also calculated from the TM data and combined with ancillary datasets (land use, water rights, incorporated city boundaries, Native American reservation boundaries) in the expert system to perform post-classification sorting of the initial land-cover classification. Classification accuracy was assessed using a reference dataset of 981 randomly selected points for which land cover was determined using a 1999 orthophoto mosaic georeferenced to the TM data. The original TM data was also used in accuracy assessment to avoid introducing errors into the reference dataset for temporally sensitive classes (such as cultivated vegetation).

The expert system land-cover classification was used to generate 100 random validation points for each output class. A 3 x 3 moving window with a class majority rule was passed over the output classification to determine validation points. Validation pixels that fell within their own class training regions were removed from the reference dataset. Similarly, validation points that did not have pixel values equal to the class under inspection (an artifact of the pixel selection method) were discarded. This resulted in a range of 70-100 validation points for each output class. Additional land-cover data for the reference dataset was collected by field verification of the classified image. Additional research included investigation of hillslope soil development and transport processes using high-resolution thermal infrared remotely sensed data and laboratory emission spectroscopy.

All of these efforts have resulted in a much clearer picture of urban patch structure than was possible using land-use data alone. We have applied the classification to our survey 200 points to identify the patch type in which each point is located. We anticipate that this classification system will prove useful both to our modeling efforts and to future applications in remotely sensed arid land cities worldwide.

Hierarchical Patch Dynamics Model (HPDM)

HPDM is composed of linked models at different spatial scales. At the local scale, patch models relate patch characteristics (e.g., size, shape, land cover, disturbance regime) to ecological and socioeconomic variables of interest. A family of ecosystem process models is being developed for different land-cover types. These models will provide information necessary not only for understanding fine-scale interactions between urbanization and ecology, but for constructing and parameterizing coarser-scale models. At the landscape level, we will build models for distinctive landscapes: natural vegetation dominated areas, suburban areas, and highly urbanized areas. These landscape models explicitly consider spatial heterogeneity and interactions among patches of different types. At the regional (CAP) scale, we are building a hierarchically structured, patch dynamic, spatially explicit simulation model (HPDM-CAP), which incorporates the interactions between landscape pattern and ecological and socioeconomic processes at different scales. To date we have completed the following components:

- the hierarchical patch dynamics modeling platform, programmed in C, on which land-use change models and ecosystem models will be linked;
- hierarchically structured land-use simulator for Phoenix;
- series of landscape pattern analyses at different scales and comparison of the historical pattern of land-use change between Phoenix and Las Vegas areas, done in collaboration with visiting scholars;
- cellular automaton/Markovian simulation model of land-use change for the CAP area (Jenerette and Wu in press);
- urban funnel model for human-ecosystem interactions; development of the concept and procedures for estimating a spatially explicit ecological footprint (Luck et al. in review);

Our objectives and scope for next year are to develop the patch ecosystem models, revise and refine the land-use change model, and link the 2 types of models. To achieve our long-term goals, the 3 tasks will have to be carried out interactively in a development-evaluation-development circle: 1) develop and evaluate a land-use change model for the Central Arizona – Phoenix area; 2) adapt and evaluate patch-level ecosystem process models appropriate for the CAP LTER project; 3) link patch ecosystem models with the land-use change model to construct a hierarchical patch dynamics model of Central Arizona – Phoenix (HPDM-CAP); and 4) evaluate HPDM-CAP.

Geosciences and Engineering

Three main projects in Geosciences and Engineering were conducted in Years 1 and 2, supported by a 2-year Geosciences and Engineering Supplement: 1) quaternary geomorphology of the Phoenix Basin; 2) century-scale channel change in the Salt River; and 3) a pilot project on the Tempe Town Lake/Rio Salado. See Research Findings section below for brief updates on these projects. In addition, a geography graduate student is conducting a geomorphology dissertation project to determine what controls the presence of bedrock pediments in the greater Phoenix area and to develop and test a model that predicts the presence of bedrock pediments versus alluvial slopes.

Land-Use Change

Data continue to be collected and assimilated during Phase 2 of the historic land-use project. This phase of the project is examining land use in square mile sections for sites from the 200-survey project (see above). Land use is being mapped for the cadastral section of each of the 200 study sites for the years 1934, 1949, 1961, 1970, 1980, 1990, and 1995.

An urban fringe infrastructure project is in its initial phases. Permissions have been obtained from the City of Phoenix to use water and sewer infrastructure information in the form of paper plats and electronic files, and water and sewer-line attributes at the urban fringe and throughout the city have been inventoried at the smallest geographically accurate unit available (quarter section) using paper plats and electronic files. Results are not yet available.

Primary Production and Organic Matter Dynamics

Year 3 marked the transition to the long-term monitoring phase for our primary productivity research. The previous year's pilot phase highlighted the need to develop allometric relationships for plants in human-managed landscapes. A permanent long-term monitoring plot was installed to measure net primary productivity as affected by human activities and to obtain the measurements needed to establish allometric relationships. The long-term study site, located at the Desert Botanical Garden (a community partner), includes plots of different yardscape plantings receiving variable watering regimes. Long-term monitoring of urban water use also continues in residential sites established in the pilot phase. In the winter of 1999, meteorological transects assaying microclimate of residential areas were established. An analysis of the data showed that there is an urban heat island in the Phoenix area that can be partitioned into 7 concentric zones of 6-km width from the urban core to the urban fringe (see climate section in Research Findings section below). A socioeconomic study of human preferences of environment and landscape was completed in September 1999. The survey was distributed to 1800 residential homeowners in new communities at the Phoenix urban fringe; 53% responded.

Populations

Populations research is focused on 5 groups: vascular plants, mycorrhizal fungi, arthropods, birds, and insect pollinators. Thus, in 1998 we initiated pilot studies, taking advantage of existing datasets as well as the data-gathering potential of K-12 classes and the public (see Education and Public Outreach). Information generated from these pilot studies has fed into the core-monitoring program, and some studies have been redesigned to complement the core monitoring.

The vascular plant studies have 3 main goals: 1) to create a preliminary classification of desert plant communities; 2) to relate this classification to remotely sensed information; and 3) to coordinate this project with the education project so as to enlist schools in extending sampling efforts.

Since the last progress report (summer 1999), we have sampled 4 more patches, and sampled more extensively 3 of the 4 original patches. Woody species have now been surveyed in a total of 8 patches, using 100-m^2 quadrats arrayed along transects. Each transect samples a representative habitat type in a patch (e.g., south-facing slope). Summer herbs have now been sampled in a total of 6 patches; the other 2 patches had no significant summer herb growth. A lingering spring drought, resulting from La Nina, made it impossible to further sample spring herbs since 1998. Herbs have been sampled using the same protocol as for woody species, with the addition of 4 nested 1-m^2 plots within each 100-m^2 quadrat.

Soil samples collected from the 20 sites that were part of the Survey 200 pilot study were analyzed for components of arbuscular mycorrhizal diversity including species richness, composition and abundance. We found that very low spore abundance and species richness at most of the sampling sites, a result typical of arid ecosystems where most mycorrhizal species do not readily sporulate in soil. A greenhouse technique for promoting sporulation of the arbuscular mycorrhizal fungi from arid environments has been developed (Stutz and Morton 1996). Successive pot cultures revealed high species richness of arbuscular endomycorhizal fungi in arid ecosystems. Greenhouse pot cultures were set up with the soil collected from the 20 sites of the pilot survey project using this technique and will be further applied to samples from the full 200-point survey, to identify the arbuscular mycorrhizal fungi present in a wide variety of patch types.

The primary goal of the ongoing arthropod project is to establish long-term monitoring of populations and communities of arthropods (insects and arachnids) within the context of the patch-mosaic model. We are documenting the abundance and distribution of ground arthropods in 6 different forms of urban land - use types (with 4 replicate sites each of: residential xeriscape, residential mesiscape, industrial/commercial property, agricultural field, urban desert-remnant parks, and desert parks on the urban fringe). We are pitfall trapping arthropods at each of our 24 study sites for 3 days once each month. The objective of this study is to characterize arthropod assemblages as functions of land use and land cover so as to be able to predict (and preserve) patterns of arthropod diversity with future urban development.

To better understand the impact of urbanization on an insect/plant interaction, we investigated causes of variation in population density between urban and natural desert sites in 3 species of bruchid beetles: *Mimosestes amicus, M. ulkei* and *Stator limbatus* (Coleoptera: Bruchidae) on the Blue Palo Verde, *Cercidium floridum* (Leguminoseae). Results to date are found in the Research Findings section below. An important part of our research is engaging students and teachers in collecting data through the Ecology Explorers program.

To assess the effects of urban horticulture on insect pollinator community structure, we compared the richness and abundance of pollinator (Hymenoptera: Apoidea, i.e., bees) communities in 2 seasons (September 1998 and April 1999) among 4 urban land-use types (xeriscaped residential yards, mesiscaped residential yards, urban desert-remnant parks, and natural desert parks on the urban fringe). The results of this study are in the Research Findings section below.

The goals of the bird project are to study changes in species diversity and population abundance and distribution over time and space as a result of urbanization. Between April 1998 and May 2000, birds were counted along 30 line transects in 4 key habitats: older residential neighborhoods (8 sites), younger residential neighborhoods (8 sites), desert remnants (6 sites) and golf course (6 sites). Each site contained a 1-km-long transect and was sampled 3 times per month. Birds were counted 40m to each side within a 30-minute time period. In addition to these core transects monitored by LTER staff, some transects were set up and monitored intermittently by volunteer birders from the community.

In August 2000 we changed the sampling method from line transects to point counts. In this method birds will be surveyed for 15 minutes at each point, 3 times in a season, 4 seasons per year. Locations were also changed from original sites to 40 points randomly selected from the 200-Point Survey sites, augmented by 10 additional riparian habitat sites chosen for their ecological importance and accessibility. Our reasons for changing methods are that point counts are more frequently used in bird population studies than are transects, in which counting birds is especially difficult within a suburban landscape. The habitat also varies considerably over short distances in ways that affect the probability of detecting birds. Such heterogeneity causes problems in estimating the abundance of birds by the transect method, because one cannot accurately estimate the area being sampled. In the former protocol, most but not all the transects were linear, and all the residential neighborhood transects were in heterogeneous habitats. By using the point count method, all sites will be surveyed with an equal effort. The point-count protocol is also simpler to follow, making it easier for volunteers to participate in the project by setting up point counts in their neighborhoods. Students from K-12 schools participating in the Ecology Explorers program have also been using point counts to conduct censuses in their schoolyards. The new point count protocol will make it easier to compare and integrate data from these different sources. Counting birds will allow us to directly relate bird densities to other environmental variables being monitored.

A project focusing on physiological responses of birds to urbanization was initiated in July 2000. We survey birds by using traps and mist nets and bird traps, a method that while subjective (because not all bird species can be trapped), is useful to determine qualitative differences between habitats. Our goal is to compare the physiological condition of native and non-native birds in different habitats to understand the impact of habitat modification on birds at the individual level. So far we have trapped birds in residential and desert habitats. We mark captured birds with numbered metal bands from the US Fish & Wildlife Service (Permit #22640-A, under the supervision of Dr. Pierre Deviche) before releasing them. If continued over the long-term, this banding program will allow the monitoring of local populations. We are also measuring morphology, body mass, fat reserves, status of molt, as well as the age, sex and reproductive status of each bird (Pyle 1997). Blood samples are collected, which will be assayed for levels of reproductive and stress hormones. These data should help us develop a more comprehensive understanding of the mechanisms underlying the distribution and abundance of native and non-native bird species in different habitats.

Transport and Retention of Materials

This research area includes both aquatic and terrestrial elements of the urban landscape and has included projects at a range of scales, though much of our initial focus was on whole ecosystem characterization. Data have been analyzed and synthesized for some initial projects; several projects are completed (chemical and biological monitoring of urban lakes, a comprehensive nitrogen mass balance, and heavy metal analysis of lichens); a carbon balance project has begun. Long-term monitoring of surface water inputs and outputs of nutrients and major ions continues, as does dry and wet atmospheric deposition monitoring. We are interested in the transfer of materials from atmosphere to land to aquatic ecosystems and to groundwaters and, to that end, we have initiated sampling of storm events in collaboration with municipal and county agencies who are sampling floods and studies of aquatic nutrient cycling in a new urban watersheds project. Research findings are reported in the section below.

A long-term water-monitoring project (WMP) was established in February 1998 to measure the chemistry of surface waters upstream, downstream, and within the Phoenix metropolitan area. The WMP's primary objective is to facilitate construction of nutrient budgets for surface waters and to look for changes in retention or export over time. WMP sites were established at, or as close as practical to, 7 of the USGS's NAQWA program's river sites in the CAP study area, at which water chemistry was monitored by USGS from 1994-97. Water samples were taken monthly at 7 WMP sites during the first 14 months of the project. Monitoring of surface water chemistry continued over the past 12 months at 5 of these 7 sites: the 3 main perennial surface water inflows to the study area (Salt River, Verde River, Central Arizona Project Canal) and 2 sites on the outflow channel (91^{st} Ave Waste Water Treatment Plant outfall & Gila River at Gillespie Dam). Two sites located along the flowpath from the 91^{st} Ave to

Gillespie Dam sites were deleted from the regular monitoring program, after reviewing water chemistry data for the initial sampling period. Since July 1999, sampling has continued on a monthly basis at the main 'integrator' output site from the CAP ecosystem (Gila River at Gillespie Dam) and bi-monthly at the 91^{st} Ave Waste Water Treatment plant outlet site where seasonal variation in chemistry is low. Upstream site sampling has been redesigned to occur 6 times per year at 3 sites. The objective of sampling at these sites is to capture high and low discharge periods in order to construct accurate flow-concentrations relationships to help with more accurate riverine flux calculations, rather than at regular intervals. An addition to the program has been the implementation of laboratory determinations of total dissolved solids and total volatile solids to the analytical protocol.

The main goals of the atmospheric deposition research at CAP LTER are to: 1) develop a monitoring network to quantify the spatial variations in rates of atmospheric deposition for major nutrients and ions across the study area; 2) determine the role of atmospheric deposition in urban biogeochemical cycling; and 3) understand how inputs of nutrients and other materials via atmospheric deposition affects the function of other ecosystem processes such as primary productivity of native desert and introduced urban plant species. Existing monitoring of atmospheric deposition in the region consists of a Clean Air Status and Trends network (CASTNet) site operated by NOAA (measuring dry deposition of nitrogen species and sulfate) at an undeveloped desert site 10 miles east of the city, along with 3 National Atmospheric Deposition Program sites (for wet deposition of major nutrients and ions) in other parts of Arizona. All these sites are in undeveloped areas, deliberately located away from any direct urban influence. Therefore, monitoring of deposition of major nutrients and ions was initiated by installing a network of wet-dry bucket collectors (Aerochem Metrics, Inc Model 301) at 8 sites, from the urban center to agricultural areas and undisturbed desert beyond the urban fringe, between July and October 1999. Collectors are co-located with Arizona Department of Environmental Quality (ADEQ) and Maricopa County Air Quality monitoring network sites, where concentrations of ozone, fine particulates (PM_{10} and $PM_{2.5}$) are monitored routinely (at sites 1-6), with additional monitoring of CO and NO_x concentrations at a smaller subset of the sites.

Data from the wet-dry bucket network will be used to determine the degree of broad scale temporal and spatial variability in both wet and dry deposition across the study area. Although bucket collectors are considered adequate for collecting large particulate matter, they do not account for processes such as deposition by nitric acid, nor do they simulate real surface properties well. The magnitude of these effects can be evaluated by comparing dry bucket data with results obtained from the CASTNet site, where filter packs and inferential modeling are used to determine dry deposition of NO_3, NH_4, HNO_3 and SO_4 species. The CASTNet data, along with the wet/dry bucket data will be supplemented by more comprehensive and accurate measurement of dry deposition during future years at a smaller number of sites.

The urban watersheds project is intended to address the question: Where in the landscape is N (and other elements, especially C) retained? This question is best answered using a hierarchical, patch dynamics approach that incorporates both aquatic and terrestrial components of the landscape. Given the size and complexity of the study area, our initial focus on 1 or 2 smaller watersheds is warranted. In this research, we hope to integrate atmospheric deposition, stormwater runoff, retention basin processes, and aquatic biogeochemistry studies. To date, we have initiated or completed pilot projects on: 1) soil N cycling processes in retention basins; 2) nutrient limitation in a highly modified urban stream-pond system; 3) spatial variation in nutrient concentrations in urban waterways; and 4) sporadic sampling of floods (see "Disturbance" for further information on storm and flood sampling).

There are numerous small urban lakes artificially created to serve recreational, aesthetic, and flood-control purposes in Phoenix. Monitoring of the lakes has been infrequent and uncoordinated. Although individual lakeowner associations have conducted some level of lake monitoring over the years, little effort has been made to bring these datasets together or to systematically investigate the lakes chemically or biologically. The objective of the study was: 1) to determine how the chemistry, primary productivity, and algal populations in the urban lakes are related to lake age, water source and other urban lake features; and 2) to determine if the urban lakes represent sinks for nutrients and contaminants.

To achieve the objectives of this study, 6 urban lakes were selected to maximize variations in age (urbanization) and water source: Dawn Lake (Sun City), Dobson Ranch Lakes (Mesa), Fountain Hills Lake (Fountain Hills), Lakewood (Ahwatukee), Ocotillo Lake (Chandler), and Val Vista Lake (Mesa). Monthly water sampling was initiated in fall 1998 and completed in spring 2000. Monthly samples were examined for depth of visibility, pH, conductance, Dissolved Oxygen (DO), Dissolved Total Nitrogen (TDN), Dissolved Total Phosphorous (DTP), Dissolved Organic Carbon (DOC), Particulate C (PC), particulate N (PN), and Chlorophyll a. Bimonthly samples were examined for algal density and composition. The pollutants analyzed include Cu, Pb, Zn, Benzene, Toluene, Ethyl benzene, Xylene (BTEX), and Total Petroleum Hydrocarbons (TPHC).

A heavy metal analysis of lichens was conducted in 1998 and 1999 to determine whether trends in elemental deposition patterns in Maricopa County are evident both spatially and to a limited degree temporally (mid-1970s compared to 1998) based on an analysis of lichen *Xanthoparmelia* populations. The atmospheric trace metal depositions patterns in Maricopa County were assessed using a spatial grid of 28 field sites. Samples of *Xanthoparmelia* were collected in 1998, and ASU herbarium material (1972-76) was added for a limited number of stations to explore temporal trends. The material was cleaned, wet digested, and comprehensive elemental portfolios were compiled (Sr, Cr, Ni, Co, Cu, Zn, Ag, Cd, Sn, Sb, Ce, Pr, Nd, Eu, Gd, Tb, Sc, Dy, Ho, Er, Tm, Yb, Lu, Au, and Pb) via inductively coupled plasma mass spectrometry (ICP-MS). Results are summarized in the Findings section below.

Disturbance

Flash flooding characterizes Southwestern desert ecosystems, and urban areas are not immune to this disturbance. A graduate dissertation on the history of flooding in this desert metropolis, supported by CAP LTER, will provide a historical context for research on the effects of this disturbance. A project using remote sensing to identify fire-flood interaction and hazards (funded by NASA) also provides context. We are primarily interested in how and to what extent materials are transported from urban patches to waterways during the intense, localized storms that characterize the region. During the past year, we have devoted effort to making contacts with the entities responsible for stormwater sampling, so that we are not duplicating effort. With data on stormwater chemistry across the city, we will be able to test our hypotheses about spatial variability in nutrient exports.

Human-Environment Feedbacks

Studies in this domain are increasing. In Year 1 we completed an economic value of open space (see 1998 progress report); in Years 2 and 3 we began studies in environmental risk assessment, social area analysis, urban labor markets, a Phoenix area social survey, and political institutions and water policy.

The environmental risk study aims to map the geographic and social distributions of environmental hazards, to learn how such hazards are understood by those who live with them, and to understand when and how people exposed to such hazards will organize and take action. More specifically, the research asks: 1) what is the spatial distribution of environmental hazards in the Phoenix MSA and how has it changed over time?; 2) what is the social distribution of environmental hazards, with particular attention to social class, ethnicity and age, and how has it changed over time?; 3) to what degree do people understand the hazards in their environment, and how do their views compare with expert judgments?; and 4) under what circumstances and in what ways do people take action about environmental hazards? What are the social characteristics of people who choose to act, and how do they do so? What sorts of scientific and technical evidence are used and to what effect?

Our main methods have been to use GIS to map point-source air releases of substances reported in the EPA's Toxic Release Inventory (TRI, available since 1986). EPA data report only the amount of air releases of various substances (in pounds), taking no account of their relative toxicity. The Environmental

Defense Fund has developed a weighting system that indicates the "toxic equivalency potential" of many listed substances, giving some measure of the relative toxicity of releases. We have merged these release data, at the census-tract level, with social variables available from the 1995 Special Census. For historical data, we are using the census and local industrial directories. Research findings are presented below.

The social area analysis will examine the relationship between socioeconomic status and vegetation patterns in the urban landscape at the neighborhood level. Sociologists in the 1950s developed a methodology for social area indicators to examine the spatial heterogeneity of socioeconomic and demographic characteristics. Scientists from BES recently applied it to Baltimore to assess links with vegetation patterns. Our study will provide both an analysis of the socioeconomic/vegetation relationship in Phoenix and a launching point for a cross-site project with BES. We have created indexes of socioeconomic status, ethnicity, and household type for the Phoenix MSA; calculated a composite social area index; mapped each of the 4 indexes by Census block-group (neighborhood); discussed a plan of action to coordinate vegetation data with socioeconomic data; and discussed a cross-site comparison of Phoenix and Baltimore using this methodology with BES scientists. The main research question to be addressed is: Do vegetation patterns differ with respect to socioeconomic status at the neighborhood level and, if so, how? Additionally, is this relationship the same when large-scale contexts differ; do the different socioeconomic and demographic structures of Phoenix and Baltimore result in different relationships of socioeconomic status to vegetation patterns?

The main objective of the Phoenix area social survey is to examine the reciprocal relationships, or the interplay, between the social and natural environments in an urban ecosystem. To understand this complex process, we will conduct a longitudinal social survey of residents in the Phoenix-Mesa MSA. The survey will measure the social ties of individuals to their communities, values and sentiments regarding communities, behaviors that affect the natural environment, and satisfaction with the area's quality of life. The community that people experience most intimately is the neighborhood. Our central research questions ask how neighborhood social ties, values, and behaviors are connected with one another in ways that reflect willingness to act socially and politically with respect to the environment, and how changing environmental conditions, in turn, affect quality of life.

A study on gender and racial/ethnic inequality examines the effects of relocation and restructuring on women's and minorities' employment levels, occupational segregation, wages, and the socioeconomic condition of urban neighborhoods. Economic restructuring is characterized as the shift in employment from manufacturing to services and the spatial migration of jobs out of central cities. The history of the US has been one of increasing standard of living, and economic restructuring benefits the country as a whole. However, social scientists argue that not all segments of society benefit equally from this economic transformation. There is little research that explicitly investigates the effects of the new economy on gender and racial/ethnic inequalities. This project will measure the effects of changes in the location and types of employment opportunities on gender and racial/ethnic inequality in urban labor markets. Many argue that the geographic movement of jobs from central cities to the suburbs has increased inequality because new locations are inaccessible to city residents. Similarly, as the national industrial and occupational profile is reshuffled in favor of the service sector, it is thought that the economic standing of minorities and women may change with respect to one or more indicators of employment equity.

The dynamic political institutions and water policy project studies the relationship between institutional evolution and ecological policy outcomes. Phoenix and other Central Arizona cities have changed institutionally, and these changes have affected policy outcomes and thus the environmental fabric we have today. The specific focus of this study is on water policy in Central Arizona – Phoenix. Why do we have the water policy situation that we do? What changed institutionally across time that produced water policy changes? A major aim of CAP LTER is to provide unbiased information to policymakers. However, political and institutional circumstances affect the fate of sound recommendations based on scientific data, no matter how meritorious. Hence, it is in our (CAP LTER) interest to understand the institutional setup in which policy decisions are made. Building on a study done in the context of Northern Nevada water policy in 1991-92, we studied the formation and breakup of a long-entrenched policy subsystem, which resulted in dramatic policy change on water issues in northern Nevada. Drawing on the qualitative methodology employed in the Nevada water policy study, in-depth interviews with various actors involved in Central Arizona water policy are being conducted. These actors include government policymakers, bureaucrats who run the water system, environmental and business interest groups, Native Americans, and agricultural interests. The interviews will provide context in which to place a quantitative test, which will be based on water usage rates to various users. Finally, we seek to measure the institutional scope of water policy decision-making and how it changes with population growth (i.e., greater proportion of water to urban, as opposed to agricultural, water uses).

Information Management

The Center for Environmental Studies, which houses CAP LTER, acquired approximately 1400 square feet of additional space in January 2000 to incorporate the CES Informatics Lab. The lab now has 12 lab workstations ranging from Pentium 200 to Pentium III 800. A new staff position of GIS technician was created and filled that will allow better integration of data management with the modeling team. Enhancements have begun that permit online query, re-projection, and download of GIS data, which was the centerpiece of a presentation at a workshop on Internet Mapping at the ASM 2000. Core catalog databases used for general project management and access to LTER datasets were maintained and improved. Support and management of databases for monitoring projects continued, and databases and entry applications were designed for several new LTER monitoring projects including the bird point survey, the bird physiology study, and the atmospheric deposition project. Online data entry pages were enhanced for the Ecology Explorers Web site, and new features allowing student downloads of data were added. An extensive database was designed for the Survey 200 project with integrated input from GPS and micro-meteorological data collectors. We continued our efforts to assist researchers in acquiring existing data relevant to CAP research. Data from LandisCorp, USGS, Maricopa County Tax Assessor, and various remote-sensing sources were acquired and converted to formats and/or projections compatible for use in LTER research. Posters from the January 2000 CAP LTER poster symposium were produced digitally using Adobe PDF as an intermediary print and archive format and are being added to our Web site.

Enhancements were made to integrate spatial search, visualization, and processing into the existing CAP Online Data Catalog. An application demonstrated in the DM-5 Workshop at the ASM meeting uses Internet map tools to present users with options to clip and/or reproject data before downloading. In connection with these changes, CAP has moved toward greater use of enterprise tools such as Spatial Database Engine and 3-tiered Web applications in its data management and delivery.

With LTER supplemental funding, we began developing a Z39.50 search access to biological collections databases at ASU. This search access will provide a common search interface to these different data sources, as well as integrated them into a larger search network developed by the University of Kansas Natural History Museum.

Our proposal to the NSF Biological Databases and Informatics program was fully funded in January 2000. The BDI project seeks to expand ASU's infrastructure for managing biological data by developing tools for acquiring, processing, and reporting metadata and then using them to build delivery solutions that interconnect the search, acquisition, and application process associated with using archived data. Three additional staff members were added to support this grant. Activities for the first year involved working with LTER metadata team and the NCEAS KDI project on metadata standards, establishment of a comprehensive taxonomic information database for ASU based on the ITIS model, and initial design specifications for the first of our application tools—an interactive wizard for creating metadata.

Data Lab activities are detailed in the Information Manager's report at http://caplter.asu.edu/data/siteflash/CAPsitebyte00.htm.

III. RESEARCH FINDINGS

Major early efforts in development of a conceptual basis for urban ecosystem research saw fruition during year 3. In collaboration with BES scientists (Grimm et al. 2000) and as a result of a NCEAS workshop (Collins et al. 2000), we have set out a framework for the study of urban ecosystems, including key questions and the thorny issue of dealing with humans, in all their complexity, as parts of ecosystems (rather than as external disturbances). This fundamental work has continued through the cross-site efforts of social and natural scientists to forge a new kind of research agenda for LTER sites (Redman 1999; ASM workshops in social-natural science integration; 1999 Tempe workshop on social-natural science integration; cross-site proposals; Biocomplexity incubation grant and many others).

Our efforts over the last 3 years continue to yield findings that have significantly developed our long-term core monitoring strategy and ultimately will contribute to the Hierarchical Patch Dynamic Model (HPDM). We report on project findings below, generally following the categories described in the Research Activities section above.

Survey 200: Interdisciplinary Core Long-Term Monitoring

Preliminary findings from the pilot survey of 20 sites carried out in early summer 1999 indicated a number of interesting trends. For example, the percentage of non-native plant species in residential yards appears to be higher in the Phoenix metropolitan area than in temperate European cities. Shrub biomass per unit area in the desert exceeds that in residential yards, while tree biomass is higher in residential yards compared to desert sites. Soil extractable NO_3-N varied by a factor of 500 in surface soils from the pilot plots, with highest concentration (up to 528.3 mg N kg^{-1}) in sites close to the urban center (particularly at unvegetated sites close to busy roads), low to moderate concentrations (5 – 50 mg N kg^{-1}) in residential and agricultural sites and lowest concentrations (<10 mg N kg^{-1}) in outlying desert sites.

Remote Sensing and Patch Typology

Overall classification accuracy obtained using the expert system was 85%. Individual class user's accuracy ranged from 73-99%, with the exception of the Disturbed (Commercial/Industrial) class (49%). The poor performance of this class is due to confusion with other classes stemming from the similarity of subpixel components at the scale of a TM pixel. In general, however, the classification results obtained for the Phoenix study area are comparable to previously published works. The expert system model was also used to generate land-cover classifications for TM data of the Phoenix metropolitan area acquired in 1985, 1990, and 1993. A major strength of the expert system approach is its flexibility with regard to data sources. The methodology developed for TM data will be used to classify Multispectral Scanner (MSS) data acquired in 1975 and 1980, as well as monitor future land-cover changes in the study area using Enhanced Thematic Mapper (ETM) and Advanced Spaceborne Emission and Reflectance Radiometer (ASTER) data. Collaborative research focusing on historical vegetation change in the metropolitan region is ongoing.

The collected image spectra were used to create bedrock and soil unit maps for 3 study areas. Relative depth of image spectral emission features was used as a proxy for dominant grain size within each pixel, and the ratio of parent to secondary minerals was used to assess degree of surficial soil development. Results of these analyses suggest that the degree of soil development across the 3 areas is similar, with surficial hillslope material dominantly composed of coarse (sand- to gravel-sized) particles. Localized regions of more highly developed soil material (detected using the proxies described above) may represent hillslope sediment storage reservoirs and suggest the study areas are transport-limited in the current climatic regime.

Hierarchical Patch Dynamics Model (HPDM)

Our research on pattern and scale analysis has generated much insight into the following questions in the context of CAP LTER: How does changing extent affect the results of different landscape metrics? How does changing grain size affect the results of different landscape metrics? How does changing the direction (or orientation) of analysis affect the results of different landscape metrics? How do the responses of landscape metrics to scale changes resemble or differ from each other across scales and across landscapes, and are these changes predictable? What does the scale-dependency of various landscape metrics entail and imply for landscape analysis? Detailed results are included in already published, or yet-to-be published papers by study participants.

Our newly developed hierarchical land-use change simulator seems to produce more reliable land-use projections than the one we developed earlier, which was a single-scale CA model. The new model also allows political and administrative boundaries to be incorporated as constraints in the model.

Geosciences and Engineering

The quaternary geomorphology study continued to develop methods of processing cosmogenic radionuclide data for numeric age determinations. The method has required significant literature review and programming, but we are confident in the results and the potential impact of this analysis method. The century-scale channel change project was completed last year (1999 progress report). Town Lake measurements continue, and the mean water-table elevations below Tempe Town Lake have stayed close to pre-lake levels, but water table surface curvature has increased significantly, possibly indicating unanticipated groundwater flow directions.

Primary Production and Organic Matter Dynamics

Our data on urban landscaping practices and water use has practical applications for urban ecosystem management, as well as providing data for the long-term monitoring effort. Answers to several questions are being sought in this research: Is human land use a good predictor of annual net primary productivity of urban landscapes? How are variations in urban landscape microclimates related to urban land use, urban plant community structure, and landscape patch dynamics? At what spatial scales do landscape maintenance practices such as pruning affect within-patch vegetation density? Are the intensities and densities of spatial patterns of urban plant communities related to human preference? What is the spatial pattern of urban plant communities in relation to urban land-use typology? Do mechanistic linkages exist between socioeconomic factors, human landscape preferences, and the structure and composition of urban plant communities? What are the comparative relationships and linkages between above-ground and below-ground productivity in urban systems?

Populations

Analyses of vascular plants were performed by estimating species-area curves for spring and summer herbs and the woody species. We expected the logistic model would provide the best fit; however, power and exponential curves were more appropriate in most cases. These results indicate that the scale of environmental heterogeneity in these habitats is very small. This finding contrasts sharply with results from other biomes. Future analyses will include spatially explicit data on woody species within subsets of each study area. Maps of woody individuals will be used to generate species-area curves under a variety of sampling situations. Other analyses will include non-metric scaling ordination, nestedness analysis, and indicator species analysis.

In the coming year, more patches will be surveyed, and more spring and summer herbaceous data will be collected (rains permitting). A GIS database will be developed. We will explore how disturbance dynamics affect a patch's plant communities. Using aerial photography, we will examine how disturbance has affected each patch over time. Assuming sufficient resolution, disturbance events should show up as reductions in plant cover for a particular year.

Although taxonomic richness of arthropods was comparable among land-use types, community composition differed, with certain taxa being uniquely associated with each form of land use (Figure 2). Three taxa (springtails, ants, and mites) were extremely widespread and abundant, accounting for over 92% of individuals captured. When these 3 taxa were excluded from analysis differences were revealed in arthropod community composition with urban land use. Trophic dynamics also varied with land use: predators, herbivores, and detritivores were most abundant in agricultural sites, while omnivores were equally abundant in all forms of land use (Figure 3). These community-level differences resulted from

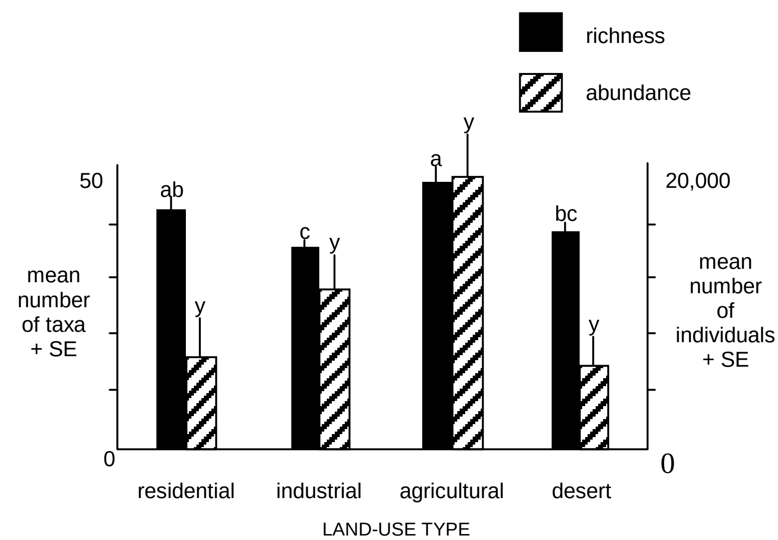

Figure 2. Mean (+SE) taxonomic richness (left Y-axis) and number of individuals (right Y-axis) by land-use type. Letters denote significant differences (Tukey's test, $\alpha = 0.05$).

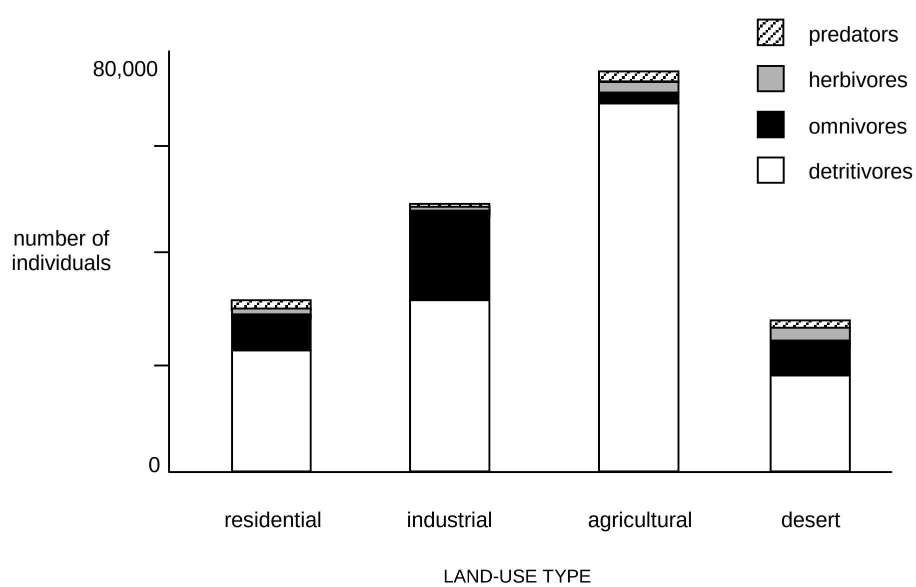

Figure 3. Stacked bar diagram of trophic structure by land-use type.

taxon-specific responses to habitat structure, which varied with land use. Because arthropod community structure is affected by habitat structure and land use, and because arthropods play key roles in nutrient cycling, organic matter decomposition, pollination, and soil aeration, the spatial heterogeneity of arthropod communities in urban ecosystems therefore may affect ecosystem functioning.

Population densities of the 3 beetles studied in the impact of urbanization on insect/plant interaction project varied between urban and desert sites (Figure 4). *Stator limbatus*, which is highly polyphagous, had significantly higher densities in urban sites ($F_{1,94} = 8.44$, $p < 0.005$). *Mimosestes ulkei*, which feeds on seeds of only one native and one introduced species, had much higher densities in undisturbed desert sites ($F_{1,94} = 23.00$, $p < 0.001$). *Mimosestes amicus*, which feeds on seeds of 5 native species, had higher egg densities in the urban sites. However, rearing studies indicated that adult emergence rates of *M. amicus* did not differ between urban and desert sites ($F_{1,94} = 0.46$, p = n.s). We hypothesized that differences in population densities could be explained by differences in preference for, and performance on, urban and desert pods. In a laboratory choice experiment, *Mimosestes amicus* had a preference for urban pods of *Cercidium floridum* (Oneway ANOVA $F_{1,70} = 10.29$, $p < 0.002$, Figure 5). In the field choice experiments there was a complex pattern of oviposition preference in *M. amicus*. There was a preference for urban pods, but preference was also influenced by the site where the experiment was carried out, the number of seeds per pod, and the length of the pods. Survival was strongly influenced by an interaction between source (urban or desert) and the location where the experiments were carried out. These data imply that the differences in the population densities of the bruchid beetles between desert and urban sites is due to both behavioral choices by the beetles and variation in host plant quality.

This year's (2000) survey indicated that water availability to the Palo Verde affects *Mimosestes amicus* oviposition preference and offspring performance. Egg numbers and survival rates to emergence were measured in 5 desert sites, and 5 sites in urban areas. Trees in the urban sites and wild sites differed significantly in their pod characteristics and beetle attack. Analysis showed that the most significant factor was water availability. Two of the desert sites were located near irrigation canals, and trees evidently obtained water from these sources. Trees in urban and desert areas that had access to water produced pods with significantly more seeds (Oneway ANOVA $F_{1,9} = 15.55$, $p < 0.004$, Figure 6) and significantly greater mass (Oneway ANOVA $F_{1,9} = 6.96$, $p < 0.03$). Beetles on pods from trees that had been watered had significantly lower survival rates than those from unwatered desert sites (Oneway ANOVA $F_{1,9} = 8.27$, $p < 0.021$, Figure 7). The mean *M. amicus* survival rate in these larger pods from watered sites was 22.22% compared to the mean survival rate of 44.3% in the desert sites without water. The source of this unanticipated decrease in survival rate on watered trees is currently being investigated. These results indicate that watering induces changes to the trees that may be altering the relationship between oviposition preference and offspring performance. We would predict that females should prefer to oviposit where offspring survival would be highest. Counter to this prediction we have found that *M. amicus* females prefer larger urban pods, where larval survival is lower than on the smaller, wild pods. It may be that urban seedpods have been altered so that they represent a novel resource for which the beetles have not evolved an optimal response.

The attack and survival rate of *Mimosestes* beetles is important because there is a complex community that depends on these beetles. The most common seed predator, *Stator limbatus* can only enter the pod through exit holes left by *Mimosestes* (Mitchell 1977), so that all of the seeds in a multi-seeded pod become available with a single *Mimosestes* emergence. In addition, in extensive rearing studies we conducted this year, we have recorded 8 species of parasitoid wasps, 12 other insect species, and 11 species of spiders. The parasitoids attack the beetles, and the rest of the community presumably gains access to the pods through the beetle emergence holes. *Mimosestes* beetles may act as a keystone species and their presence may determine the structure of the whole community. Watering trees in urban environments may have effects that "cascade upwards" through several trophic levels, altering the entire community that depends on Palo Verde seed pods.

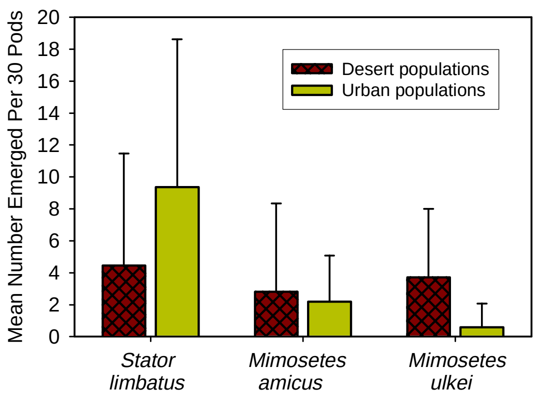

Figure 4. The mean number of 3 species of adult bruchid beetles that emerged from pods collected from 5 sites in the desert and 5 urban sites in the Phoenix metropolitan area.

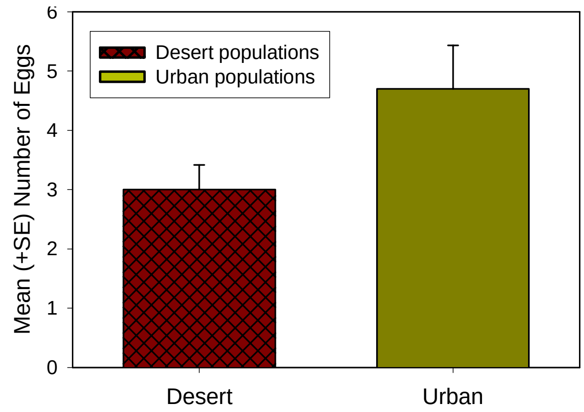

Figure 5. The mean number of eggs oviposited by *Mimosestes amicus* on pods collected from urban and desert sites in a choice experiment. Two pods from each sites were placed in an experimental area with a mated female, and the number of eggs were recorded after 48 hours.

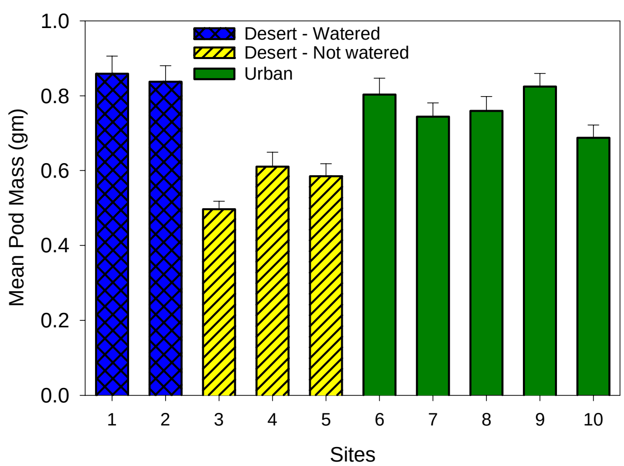

Figure 6. The mean mass of pods collected from Blue Palo Verde, *Cercidium floridum* from 10 sites in the Phoenix metropolitan area.

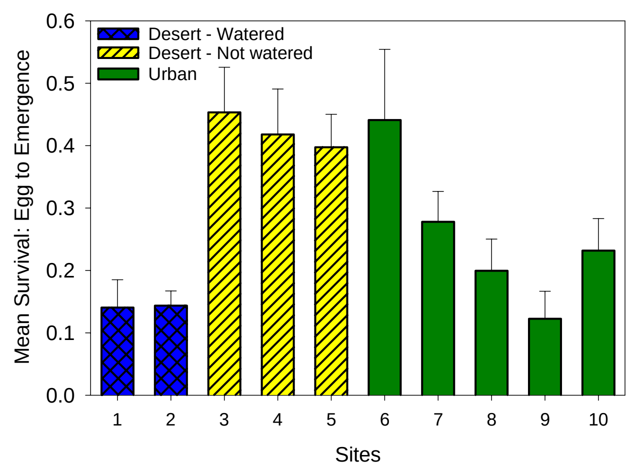

Figure 7. The mean proportion of eggs that produced adult *Mimosestes amicus*, from pods collected at 10 sites in the Phoenix metropolitan area.

In the pollinator study, both richness and abundance of bees were lower in residential areas than in desert areas, and desert areas on the fringe of the city possessed the highest diversity of all sites. Residential yards that used xeric landscaping were richer in bees than mesic (turf grass) yards. Although bee community structure was apparently unaffected by the number of local habitat features (native and exotic trees, shrubs, cacti, and herbaceous plants in addition to human-built structures), the types of habitat features do appear to influence the number and types of bees present in an area.

About 180 species of birds have been recorded on the transects, and we are analyzing seasonal trends and habitat associations from the 2-year dataset. The avifauna includes a number of non-native bird species (e.g., the Eurasian House Sparrow, the Great-Tailed Grackle) that specialize in urban habitats, or have become human commensals. At the same time, many native desert species (e.g., Cactus Wren, Abert's Towhee) also appear to be doing well in urban habitats. Other native species (e.g., Phainopepla, Black-Throated Sparrow), however, do not occur even in newer residential neighborhoods.

So far we have trapped birds in residential and desert habitats. Preliminary results suggest that species composition is fairly different between these 2 habitats. The data also suggest that while bird density is higher in the residential habitat, species diversity is higher in the desert. These findings are similar to the results of other studies on bird communities in suburban landscape (Emlen 1974; Beissinger and Osborne 1982), and also to the results from the CAP LTER arthropod species diversity project summarized by McIntyre et al. (in press).

Transport and Retention of Materials

Results from the detailed nitrogen mass balance for the Central Arizona – Phoenix ecosystem show that N input to the ecosystem was 94.1×10^6 kg yr^{-1}. Of this, humans deliberately import or mediate the fixation (alfalfa) of 49.0×10^6 kg N yr^{-1}; combustion processes inadvertently added another 33.8×10^6 kg yr^{-1}; fixation by desert plants, atmospheric deposition, and surface water input combined accounted for 12% of total N input. Total N output was 76.9×10^6 kg N yr^{-1}, mostly as NO_x from combustion processes and N_2, N_20 and NO from denitrification. Riverine export was only 2.6×10^6 kg N yr^{-1}, < 3% of N input. Computed accumulation of N was 17.2×10^6 kg yr^{-1} (total input minus total output) or alternatively, 13.0 $\times 10^6$ kg yr^{-1} (summing individual accumulation fluxes). Key uncertainties include dry deposition of atmospheric N, soil processes, and denitrification rates. The N cycle of the CAP ecosystem is characterized by a dramatic (25-fold) elevation in N inputs compared to the surrounding desert, along with a significant increase in N accumulation. In contrast, N exports from the CAP ecosystem are elevated only 7-fold, because water management practices intended to conserve water also tend to promote N accumulation and volatilization, while reducing riverine N export.

An important hypothesis arising from the N mass balance is that N is accumulating in the subsurface. One reason that N may be accumulating, despite upward pumping of nitrate-contaminated groundwater, is that N is applied to crops in excess of N requirements. A large fraction of "excess" N, regardless of source, leaches to aquifers and contributes to N accumulation. Much of this N comes from the groundwater being used to irrigate crops. Excess N applied during irrigation is therefore leached back to aquifers, perpetuating N accumulation. In theory, if farmers were aware of the N supplied in irrigation water, they would compensate for N applied during irrigation by reducing fertilizer inputs. Our calculations show that this management effort alone would reverse the rate of accumulation from positive to negative.

We postulate that N recycling from groundwater is localized. Hence, a project has been initiated to examine the spatial patterns of N inputs from irrigation. The Salt River Project has provided data on groundwater nitrate levels, daily flows in canals and laterals, and water deliveries and irrigated acreage at 240 "gates" within their system. These data are being synthesized with the objective of making a map of irrigation N loading to cropland and urban areas. If areas of high nitrate loading can be identified, remote monitors could be installed in canals and laterals to measure nitrate in real time. These data and irrigation volume would give farmers real-time information on how much nitrate (lb N/inch water) they are adding in irrigation water and allow them to safely reduce commercial fertilizer inputs. This would improve the quality of some crops (e.g., cotton), reduce fertilizer costs, and reduce nitrate accumulation in the groundwater.

A separate groundwater nitrogen mass balance project contributed to the overall nitrogren mass balance with the following specific findings:

- Historical nitrate concentration records from more than 50 desert-area wells show that the groundwater nitrate concentrations, in absence of man's impact, would be expected to be approximately 3 mg-N/l in the Salt River Project service area.
- About 52% of Salt River project product wells serving the Phoenix area have nitrate concentrations in excess of the 10 mg-N/l Maximum Contamination Level.
- Statistical analysis shows that groundwater nitrate concentrations under agricultural land-use areas are significantly higher than expected background levels. In contrast, there is no significant difference between groundwater nitrate concentrations beneath agricultural and urban land-use areas.
- Within agricultural land-use areas, the groundwater nitrate concentrations beneath dairies are greater than those beneath other agricultural land-use areas.
- A mass balance suggests that the downward fluxes of nitrate from fertilized agriculture, dairy wastes, septic tanks, and wastewater irrigation slightly exceed the removal rate of nitrate from the aquifers by groundwater pumping.
- Historical data show a current trend of increasing nitrate concentrations as urbanization of agricultural and desert lands continues.
- A strong correlation between the depth to groundwater and groundwater nitrate concentrations has been observed.

Results of the long-term water monitoring project show that concentrations of nutrients, salts, dissolved organic carbon and suspended solids are consistently and markedly higher (by a factor of 1.5 to over 800, depending on constituent) at the sites downstream of the urban area compared to the upstream sites (Table 1). The only exception to this trend is seen in the proportion that dissolved organic nitrogen (DON) comprises of the total N pool, which decreases on passage through the urban system. At the input sites upstream of the urban area DON constitutes 70-90% of the total N pool, but less than 25% of that pool downstream of the city. Concentrations of nutrient and dissolved organic carbon are almost all similar between the 2 years, with the exception of higher concentrations of potassium at the Gila River during the second sampling period, higher concentrations of sodium at the Salt River during the second period, and lower concentrations of DOC at the Verde River the second sampling period. These differences are probably related to flow-related differences (i.e. lack of high-flow events) in the second year as compared to the first. Table 1 presents WMP data for the latest 11-month sampling period (July 1999-May 2000) at 2 main input sites and the output integrator site downstream of the CAP urban ecosystem. The table includes average concentrations and associated standard errors (in parentheses) of several important chemical constituents.

Annual wet and dry deposition of NO_3-N, NH_4-N and DOC (in kg ha^{-1} yr^{-1}) for the 4 sites at which atmospheric deposition monitoring has been ongoing for 12 months since late June 1999 are shown in Table 2. Preliminary data show that NO_3-N and NH_4-N deposition are typically of a similar order of magnitude (when wet and dry deposition are combined) and that together account for inputs of between 0.56 and 6.29 kg inorganic N ha^{-1} yr^{-1}. Moreover such inputs are around 3 times higher in the urban core than in outlying desert, although this pattern can obviously be significantly affected by the occurrence of 1 or 2 localized heavy rainfall events, as evidenced by the high annual wet NH_4-N deposition estimate for site 7. Atmospheric deposition of DOC is significantly higher than for inorganic N, ranging from 5.56 to 11.64 kg ha^{-1} yr^{-1}; inputs of both wet and dry fall increase steadily from outlying desert to urban core sites.

Table 1. WMP data for the latest 11-month sampling period (July 1999-May 2000) at 2 main input sites and the output integrator site downstream of the CAP urban ecosystem.

CHEMICAL CONSTITUENT	INPUT SITES		OUTPUT SITE
	Salt River	Verde River	Gila River, Gillespie Dam
Nitrate-N (mg/L)	0.006 (0.002)	0.037 (0.029)	7.870 (0.316)
	n= 5	n= 4	n= 11
Ammonium-N (mg/L)	0.012 (0.001)	0.011 (0.004)	0.370 (0.068)
	n= 3	n= 4	n= 11
Phosphate-P (mg/L)	0.019 (0.003)	0.010 (0.004)	1.031 (0.149)
	n= 4	n= 4	n= 11
Dissolved Organic Carbon (mg/L)	2.8 (0.2)	2.0 (0.1)	4.9 (0.1)
	n= 5	n= 4	n= 10
Potassium (mg/L)	5.48 (0.2)	2.89 (0.2)	13.2 (0.4)
	n= 5	n= 3	n= 10
Sodium (mg/L)	194.3 (1.8)	35.0 (1.12)	624.6 (27.1)
	n= 5	n= 3	n= 9
Conductivity (uS)	1205 (34)	517 (23)	3726 (285)
	n= 5	n= 4	n= 8
Total Dissolved Solids (mg/L)	590 (7.5)	252 (7.6)	1671 (96)
	n= 5	n= 4	n= 5

Table 2. Annual wet and dry deposition (in kg ha^{-1} yr^{-1}) for NO_3-N, NH_4-N and DOC for 4 sites along a gradient from the urban core to outlying desert, over a 12-month period starting in late June 1999.

	NO_3-N		NH_4-N		DOC	
SITES	Wet	Dry	Wet	Dry	Wet	Dry
3 urban core	0.42	1.03	1.67	0.34	4.63	7.01
6 mid urban	0.81	1.19	1.54	0.53	4.32	4.37
7 desert fringe (to E)	1.31	0.60	6.07	0.22	3.76	3.34
8 outlying desert (to NE)	0.48	0.41	0.46	0.10	3.72	1.84

Table 3. Wet and dry deposition rates of NO_3-N (in mg m^{-2} d^{-1}) for all 8 monitoring sites between mid Oct 1999 and late June 2000.

SITE (see location map)	Wet NO_3-N (mg m^{-2} d^{-1})	Dry NO_3-N (mg m^{-2} d^{-1})	Dry NO_3-N deposition as % of total
1 Palo Verde	0.079	0.164	67
2 Duncan Family Farms	0.014	0.236	94
3 Phoenix Supersite	0.281	0.251	47
4 Sunny Slopes	0.171	0.202	54
5 Chandler W T Plant	0.106	0.245	70
6 Brooks Road	0.008	0.273	97
7 Lost Dutchman	0.090	0.158	64
8 Sycamore Creek	0.016	0.112	88

Monthly wet and dry deposition rates for NO_3-N for the complete suite of 8 sites operational since mid October 1999 are shown in Table 3. These data confirm the pattern of higher NO_3-N deposition rates at the urban sites compared to the outlying desert and agricultural locations. Dry NO_3-N deposition is obviously an important component of atmospheric inputs in this arid-urban system, comprising 47-97% of wet-dry NO_3-N inputs combined. More precise measurement of fine particulate NO_3-N, NH_4-N, and HNO_3 deposition planned for future studies can be expected to significantly increase overall rates of N-deposition to the system.

The mostly poorly constrained terms of the mass balance that could account for the apparent retention of N in the CAP LTER ecosystem (discussed above) are denitrification, accumulation in the vadose zone and soils, and fate of combustion-derived NOx. These processes can be considered at the scale of the whole ecosystem or region, as discussed above, but may vary considerable among and within individual urban watersheds, given the high degree of spatial heterogeneity in urban landscapes. Our urban watersheds project aims to explore potential localized sinks in the urban landscape as well as consequences of increased loading to aquatic ecosystems. Initial measurements in neighborhood retention basins show a high potential for denitrification in these soils. Very preliminary findings from our nutrient limitation experiments in an urban stream are that phosphorus is limiting to algal production, in marked contrast to the situation for most regional streams (Grimm and Fisher 1986). These experimental results confirm predictions from sampling of waters that indicate a high N:P ratio in urban streams.

Urban lake chemistry, especially specific conductance and nutrients, and biology (algal biomass and species composition) differs appreciably among the lakes and appears to relate primarily to water source. Priority pollutants were typically not detectable in lake waters.

The lakes with effluent source waters exhibited greater annual primary production than lakes fed by surface or canal waters and ground water or well lakes. This elevated primary production, as indicated by Chl a, was manifested in many other water parameters characteristic of effluent lakes but not well and canal lakes. For example: high/but less annually variable pH, high/more annually variable DO, high/more annually variable PN, high/more annually variable PC, high/more annually variable TP, high/more annually variable SRP, higher DOC, and low/less annually variable water clarity. The primary production of effluent lakes was not limited by phosphorus concentration, in contrast to well and canal lakes, which were limited by phosphorus concentration.

The well and canal lakes were not distinguishable by their Chl a, pH, DO, PN, PC, TP, SRP, DOC, and water clarity values but were characteristically different than the effluent lakes. The designations well, canal, and effluent were not adequate to characterize the water quality of all lakes. The effluent lakes, for example, differed considerably in TN and DOC. The effluent lakes of this study were hyperutrophic; however, while canal and well lakes were mesotrophic or eutrophic. Regardless of water source type, the lakes had similar numbers of phytoplankton genera (ca. 30). No genera were found in only lakes of a particular water type, and few were limited to a particular lake. Divisional phytoplankton succession appeared to be unique in each of the lakes. Exceptions to this were the presence of diatom blooms during the winter in effluent lakes and cyanobacterial pulses in all lakes during the summer.

The heavy metal lichen analysis indicated distinct spatial and temporal patterns. Highly urbanized regions in Phoenix and copper mining and smelting regions had greater concentrations of zinc, copper, lead, and cadmium. Other elemental concentrations in Maricopa County were generally comparable to those reported for relatively unpolluted areas. Lead levels have fallen over the last 30 years by 71%, but Zn concentrations for some regions have increased by as much as 246%. The elemental fallout pattern was mapped for Zn, Cd, Co, Cr, Ni, Pb, Sb, and Cu, and the subsequent spatial analysis identified agriculture, mining, industrial activities, rock substrate and traffic as the major elemental sources in Maricopa County. These conclusions were supported by both cluster analysis and principal component analysis. In both analyses 3 major factors were identified that, depending on regional aerosol fractionation, explained most of the variation in elemental signature: 1) geologically derived material; 2) a highly homogenous Co, Cr, Ni, and Sc component; and 3) anthropogenic emissions. Regional impacts from long-range transport dynamics were perhaps possible but highly debatable. The study has also shown that the traditional gradient approach is an unsatisfactory conceptual framework to explain the complex atmospheric fallout patterns in Maricopa County.

Human-Environment Feedbacks

The environmental risk study has shown that in the Phoenix area, the presence of a TRI facility and the volume of emissions are strongly associated with measures of socioeconomic status and ethnicity at both the census tract and block levels. When the volume of emissions is weighted by a measure of their toxicity, however, the relationship becomes negligible. New forms of industry, such as computer chip manufacturers, which are often located in middle-class neighborhoods, are bringing toxic emissions to new areas and new populations, altering traditional patterns of environmental equity. Across the full areas of sites that might emit airborne hazards, including CERCLIS (or "Superfund") sites, Large-Quantity Generators, Toxic Release Inventory (TRI) facilities, and Transfer, Storage and Disposal Facilities (TSDFs), there are substantial and significant relationships between the siting of such a facility within a census tract and the socioeconomic characteristics of that tract. As predicted, tracts that contain such facilities have with lower median household income and higher fractions of minority population. For counties of the Southwest border states, which include California, Arizona, New Mexico, and Texas, the volume of industrially generated toxic emissions is correlated with the ethnicity, earnings, and age distribution. Counties with such facilities tend to have lower incomes, higher proportions of ethnic minorities, higher fractions of young children (< 6) and higher fractions of seniors (65 and over).

The labor market dynamics analysis indicates that the largest occupational category in the Phoenix metropolitan area is office and clerical workers followed by professionals. Office and clerical jobs comprise the largest category of employment for women across all races, with women disproportionately employed in the service sector. Men’s employment is more heterogeneous with respect to industry, with manufacturing and services the dominant sectors. Men’s occupations are much more heterogeneous by race. For white men, professional occupations make up the largest job category, followed by officials and managers; for Hispanic men, the largest category is semi-skilled operatives and unskilled laborers; for Asian men, they are professional and semi-skilled operatives, Black men semi-skilled operatives and service; and for Native American men, semi-skilled operatives followed by skilled craftsmen. There are 224 high technology firms in the Phoenix metro area; of these, 116 are manufacturing. The map (available upon request) of large-firm density shows that companies cluster in the East Valley.

Results from the first part of the social area analysis show that in many Phoenix neighborhoods, the percentage of non-white residents and the percentage of foreign-born residents do not follow a similar pattern (i.e., many non-white, few foreign-born or vice versa). As a result, the ethnicity index must be altered for the Phoenix study. The ethnicity index may not be comparable between Phoenix and Baltimore. Neighborhoods with a high percentage of non-whites are concentrated in South Phoenix, the Native American Reservations, and along Grand Avenue (also the location of many of Phoenix’s toxic waste release sites). Neighborhoods of low socioeconomic status are spread throughout the Valley, but a high correlation exists between non-white and poor neighborhoods. The household index, a proxy measure for owner-occupied families headed by a married couple, is the most spatially heterogeneous of the 3 indicators. There is a correlation between non-white and poorer neighborhoods that score low on the household index, indicating a compounding of social distress in particular areas of Phoenix.

Work on urban climate thus far this year has resulted in a number of findings: 1) Time trends of urban effects in Baltimore and Phoenix are controlled by population growth rates in a non-linear manner with time (Brazel et al 2000); 2) Analysis of weather station data must be accompanied by land-cover and land-use analysis to unravel the local effects, after careful station history inspection to eliminate extremely local effects due to instruments, heights, changes in immediate surface, observation times for max/min temperatures, etc. (Brazel and Heisler 2000); 3) The urban fringe environment of the metropolitan area defines a boundary of well-defined discontinuity in microclimate (Brazel et al. 1999); 4) Remote sensing, using images from 1985-present, shows the dramatic land-cover alterations in the southeast Valley over time and follows closely the housing wave phenomenon (. Heating, as indicated by looking at the thermal band, is substantial (exceeding in May from 1985 to present some 10^{o}C) along the developing and migrating urban fringe. A weather station “overrun” by the housing wave, development, and land-cover change during just the last 10 years experienced a May monthly mean temperature shift of some 2^{o}C (more than predicted for CO_2 climate change in 50 years!; Brazel et al. 1999); 5) What is classified as “rural” determines the magnitude of what we measure as a heat island phenomenon in

Phoenix, and this makes a difference in comparing Phoenix with other places (i.e., is rural desert or farmland?). The magnitude of the heat island (using the minimum temperatures between cities and rural areas) is different by $2^{o}C$ in May depending on whether it is desert (cooler at night) or agricultural landscape (not as cool at night). The concept of thermal admittance (or hysteresis – lag) tends to explain this rural response difference relative to urban places at night. During the day, there is an oasis effect evident in the city (city actually cooler than rural desert); 6) Transects along the urban fringe from Tempe to Queen Creek illustrate the abrupt climate boundary from development to agriculture and desert lands in temperature and humidity. These differences are maximized when the wind regime shifts from east to west in the late morning and after sundown in the mid-evening hours; 7) Solar radiation receipt in and out of the metro area responds to the pollution dome over the city and attains values of 15% less solar receipt in the city (Tomalty and Brazel 2000); and 8) UV-B radiation transects correlate with the total incoming solar radiation variations with an r^2 value of 0.7.

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IV. RESEARCH TRAINING AND DEVELOPMENT

The CAP LTER project enhances the research and teaching skills of its participants, including undergraduate students, graduate students, postdoctoral students, faculty members, K-12 teachers and students, and high-school student interns.

The project has supported 9 NSF-funded REU students who gained research training via summer projects integral to CAP LTER. REU students have worked with faculty members, postdoctoral associates, and senior graduate students. Other undergraduate students have benefited by participating in data collection for the ground arthropod study, collections and curation activities, and courses that relate to the CAP LTER. About 14 graduate students serve as research associates each year and are trained in field-investigation techniques, data analysis, scientific writing, oral presentation, interdisciplinary interaction, GIS, and remote sensing. Students also receive exposure to the interactions of government agencies and the effects of large public works projects on public attitudes. Faculty members in geography, geological sciences, biology, and civil and environmental engineering have delivered additional training through graduate courses designed around CAP LTER activities. In many instances graduate students are full colleagues in the research activities, taking part in the framing, analysis, interpretation, presentation, and writing of results.

Since the inception of the CAP LTER project, 11 postdoctoral associates have taken leadership roles in research and outreach activities. The project currently supports 7 postdocs, 4 of them full-time. They interact with each other, participate in planning meetings with the co-project directors and project managers, work with faculty member participants and team leaders, collaborate with graduate students, and organize and coordinate the winter poster symposium and summer summit gatherings. They are integral to the research and field experience of CAP LTER and receive training in interdisciplinary collaboration, graduate student supervision, data analysis, and presentation techniques.

Monthly All Scientists Council meetings provide opportunities for cross-disciplinary fertilization and information exchange through science- and results-based presentations. Attendance ranges from 40-80 people per meeting and includes faculty members, postdoctoral associates, graduate students, and community partners. Monthly Remote Sensing Working Group meetings are held to foster collaboration between CAP LTER scientists doing research involving remote sensing via discussion of ongoing and planned work, proposal generation, and workshops. Attendance ranges from 3-10 people per meeting and includes faculty members, staff, postdoctoral associates, and graduate students. Lastly, graduate students meet monthly at research-focused gatherings designed to facilitate interdisciplinary cross-fertilization.

The Schoolyard LTER supplement has created special opportunities for K-12 teachers to work alongside LTER researchers in summer internships on several monitoring projects. In turn, the teachers have engaged their students in ongoing research and enhanced their ability to communicate science (See Education and Outreach section). Each year, high-school students are mentored as part of the Southwest Center for Education and the Natural Environment's K-12 project, with day-to-day supervision provided by a graduate research associate. These high-school students participated in lab and field research activities and presented their findings to their classmates in poster format.

V. EDUCATIONAL AND OUTREACH ACTIVITIES

Environmental education and outreach activities are woven throughout the CAP LTER, as we engage an active cadre of community partners in our research and education efforts. In addition, we encourage ASU faculty members to draw upon CAP LTER resources and incorporate urban ecological issues and data into their classrooms. We reach out to the K-12 community through Ecology Explorers, a program that aims to:

- develop and implement 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;
- improve science literacy by exposing students and teachers to real research conducted by University-level scientists;
- enhance teachers' capabilities to design lessons and activities that use scientific inquiry and encourage interest in science;
- provide access to and promote the use of CAP LTER-generated materials and information;
- and encourage collaboration between CAP LTER researchers and the K-12 community

From the initial collaboration sparked with 12 schools in 1998, Ecology Explorers has expanded to include 31 schools and 42 teachers in 14 school districts. We have developed popular summer workshops and internships have engaged numerous teachers in our schoolyard sampling protocols.

In 1998, we offered a 3-day workshop for teachers interested in birds, plants, and bruchid beetles (plant/insect interaction) and a 1-month internship with the ground arthropod research team. The protocols developed during these summer programs with teachers became the basis for the Ecology Explorer Web site that was developed during the 1998-1999 academic year. A database has been constructed for teachers and students to enter collected data on the Web (http://caplter.asu.edu/explorers). In 1999, we built upon the previous summer's experiences and offered 5 internships (bruchid beetle/Palo Verde study, ground arthropod survey, plant diversity survey, bird survey, and biogeochemistry study) with an initial 2-day workshop. The internships, which lasted from 1 week to 1 month, depending on the project, allowed teachers to participate in a research project and learn to collect and analyze data. The 2-day workshop given before the internships offered a brief overview of CAP LTER, a hands-on inquiry based lesson, and an introduction to data analysis and the Ecology Explorers Web site. The education liaisons worked with each of the teachers to help integrate the science project into their classroom. Follow-up with the teachers included bi-annual dinner meetings, as well as individual visits to classrooms by CAP LTER personnel. Additions to the Ecology Explorer Web site made during the 1999-2000 academic year included refinement of the data-entry feature and creation of a data retrieval feature and the addition of a "Kid's Newsletter." We also encouraged students to participate in the annual CAP LTER poster session and other ASU events.

This summer's program included 17 teachers (7 from schools new to our program and 4 from school districts new to our program) and 15 CAP LTER participants. We retained the workshop/internship model from the 1999 summer programs with a few additions. These additions included a new internship on water relations in plants and a revised internship on biogeochemistry in the schoolyard. We continued to offer internships on the bruchid beetle/Palo Verde study, ground arthropod survey, plant diversity survey and the bird survey. This year we also included 5 "mentor teachers" in the summer program to share their experiences with the Ecology Explorers program. The new teachers met with our education liaisons and the mentor teachers to develop lesson plans and curriculum. We anticipate further changes to the Web site during the 2000-2001 academic based on discussions with current and new Ecology Explorer teachers.

Through teacher evaluations and discussions, teachers have reported they had a better understanding of ecological research; students' enthusiasm for the project exceeded expectations; students felt projects were important because of the ASU connection and were willing to put in extra effort to carry out the projects; more parents were involved than anticipated; and workshops/internships were valuable and enhanced their ability to teach science. Teachers have also reported that students' math abilities improved as a result of participating in Ecology Explorers and that participating in poster presentations enhanced communication skills. Although the program has always been aligned with the Arizona State Science Standards, this past year we have been working to align with other Arizona State Standards such as math, English, and social studies.

Our education liaisons also work closely with the Southwest Center for Education and the Natural Environment (SCENE) to implement other environmental education programs. Specifically, we conducted one workshop on using science inquiry in the outdoor classroom and one on mapping the schoolyard. Many teachers in SCENE's Native Habitat Project use sampling protocols to monitor changes in schoolyard ecology as native habitats are developed at schools. We also conducted 2 science inquiry workshops for teachers on the Gila River Indian Reservation. Contacts have been made with many members of the environmental education community, and joint programs are being developed. For example, a group of high school students sampled plant diversity at Usery Mountain Park. We also worked extensively with the Phoenix Zoo to develop a focused field trip relating to the bird survey.

Outreach activities and services to the K-12 community and beyond have become an integral part of many CAP LTER projects. The bird survey project in particular has generated many presentations to school and community groups. The bird survey project, the ground arthropod project and the bruchid beetle project were featured in recent articles in *Chain Reaction*, a magazine produced by ASU for the K-12 community.

At the university level, elements of the work from the remote sensing and patch typology team have been incorporated into Department of Geological Sciences classes. Class exercises and field trips in remote sensing, advanced remote sensing, and applied remote sensing have used the both the TM dataset and the Maricopa County land-cover classification. Current work was presented to the Arizona Geographic Alliance (faculty members from the Geography Department who reach out to K-12 teachers), and a workshop was presented in the summers of 1999 and 2000. A graduate seminar on "Risk Perception" was taught that involved all members of the environmental risk group—faculty and students—and attracted outside participants. The study of hazard perceptions became a hands-on research experience for those taking the seminar. Another seminar based on the urban climate project was held in Geography for LTER researcher graduate students (11 took the class) in fall 1999.

CAP LTER public outreach activities were not limited to educational audiences. As an example, Environmental risk team members have developed contacts with state and county agencies and with citizens interested in environmental issues; findings will be communicated to these audiences. In addition, homeowner associations have embraced the urban lakes project and are collaborating by providing information about lake operation and management. The data is also useful to the newly developed Arizona Department of Environmental Quality Urban Lake Task Force. This body will review urban lake issues and determine whether state water quality standards should be applied to urban lakes.

CAP LTER participants presented research findings to additional public and professional presentations (see Section VII).

VI. CONTRIBUTIONS

Contributions within Disciplines

Several overarching projects are contributing baseline data upon which to build future work and projections. The Hierarchical Patch Dynamics Modeling (HPDM) project serves as a synthesizing device and is crucial for integrating data obtained from individual projects. HPDM is laying important groundwork for understanding how the spatial pattern of land use has changed in the past and how it will change in future. It is equally important for understanding the effects of land-use change on ecological processes. The historic land-use synthesis provides an overall understanding of historical land use and change for the study area. The remote sensing and patch typology activities have drawn on land-use data for Maricopa County (past, present, and future) to provide a higher spatial resolution database for more accurate ecological modeling and monitoring of the urban ecosystem. The database will be used to increase the accuracy of future governmental land-use decisions and databases.

A wide range of individual studies in the realm of biology, botany, and zoology are contributing to our understanding of the processes and impacts of urbanization in an ecological framework, often working in uncharted territory. For example, there has been surprisingly little ecological research conducted on arthropods in urban environments, so fundamental information about how various facets of urbanization affect the diversity and distribution of ground arthropods may have important ramifications on ecosystem-level trophic dynamics, nutrient cycling, and other functions from the diverse roles that arthropods play in ecosystems. Our sampling has revealed a diverse arthropod fauna characteristic of each land-use type, which may be useful in indicating latent effects of urban development.

These preliminary results of the arbuscular mycorrhizal (AM) fungi study indicate that, shortly after urban development (25 years), species richness of AM fungi is similar to that found in the adjacent Sonoran Desert. Because so little is know about AM fungi in urban ecosystems, our preliminary results are a unique contribution to the knowledge of this important group of organisms. The results of a habitat fragmentation study contain several wide-ranging implications that touch on many avenues of research. This project provides one of the first large-scale studies of urbanization and habitat fragmentation on plant community structure, especially in a desert biome. It will test various theories of landscape ecology concerning the effects of landscape fragmentation. Habitat fragmentation in an urban matrix incorporates many complex variables that more traditional studies have not analyzed. The urban matrix itself is a varied and dynamic landscape not easily modeled. Despite this complexity, this project shows that even fast-changing urban matrices produce habitat fragments with similar properties to those of slowly changing land bridge islands over much longer time scales.

The urban lakes project is providing information to ecologists and urban planners about how water sources influence the quality of urban lakes, the extent to which urban lakes become sinks for contaminants from urban runoff, and knowledge of changes to be anticipated as the lakes age.

The detailed nitrogen mass balance is apparently a first for an agro-urban ecosystem and is therefore a landmark effort. In particular, the influence of high nitrogen inputs and modified hydrology have been integrated into a conceptual model of nitrogen cycling in human-dominated ecosystems. A groundwater nitrogen mass balance is an important part of the whole-system nitrogen mass balance. This information can also be used to help guide more responsible use of commercial fertilizers by accounting for the use of high nitrate content groundwater for irrigation. The determination of spatial-temporal trends and controlling factors of groundwater nitrate is the key of future modeling work.

The labor market dynamics project provides 2 major intellectual contributions. First, there is little research that investigates how and why economic changes in the location and character of jobs are affecting gender, social class, and racial/ethnic equity. In addition, past research does not take into account that economic changes are not uniform in different parts of the country. Most social science research in the 1980s and early 1990s focused on economic decline in the East without considering the growing economies of the South and West. Second, we plan to compare economic restructuring and the spatial relocation of jobs over a 15-year period in the Phoenix and Baltimore Metropolitan Statistical Areas (MSAs). As a thriving Sunbelt city, Phoenix has experienced rapid growth in population and jobs, including manufacturing jobs. Baltimore fits the more typical pattern in the Northeast of population loss and deindustrialization. Manufacturing employment declined through the 1970s and 1980s. By studying these 2 areas, we can compare 2 sets of economic conditions that both characterize the national experience in recent years. We can also compare the effect of economic change in African American communities (Baltimore's largest minority) with Hispanic communities (Phoenix's largest minority).

Contributions to Other Disciplines

The remote sensing and patch typology project has already lead to applications beyond the discipline and the CAP LTER: 1) the analysis tools developed provide a test case for future remote sensing of arid regions and urban metropolitan areas (in association with the NASA ASTER program); 2) the use of band ratio techniques to investigate man-made surficial materials as well as natural surfaces is a new and potentially important contribution to the remote sensing classification of cities; and 3) the availability of data products on the WWW will allow for immediate data access by participating scientists with possible extension to general public access for selected data products. The Geologic Remote Sensing Laboratory (GRSL) at ASU has produced research and data products that will be of use to the ecological, biological, geological, and social science disciplines. Land-cover classifications for the Phoenix metropolitan region are immediately useful for patch dynamics modeling and provide a baseline database for social science research. Vegetation indices for the Phoenix metropolitan area provide information useful to understanding biomass flux, water use, carbon and nitrogen budgets, and geomorphic processes operating within urban park and undeveloped regions. Understanding of hillslope soil processes and pediment geomorphology operating within the semiarid to arid regions of the CAP LTER site has been increased. The lab is also responsible for acquiring data from over 100 of the world's fastest growing urban centers and producing near real-time land-cover classifications 2 times/year.

The plant community survey will provide one of the first large-scale studies of urbanization and habitat fragmentation on plant community structure, especially in a desert biome. This project will test theories of landscape ecology concerning the effects of landscape fragmentation. Results from the graduate student habitat fragmentation study will be relevant to botanists studying the effects of fragmenting landscapes on plant species abundance and diversity. Fragmentation effects on various trophic levels of vertebrates have variable top-down influences on plant species within a fragment. The data shows that negative effects on plant communities may be predicted by the rapid population growth of herbivores, which are in turn affected by particular land uses adjacent to desert remnants and island biogeographic variables that determine predator abundance. The pilot phase of the urban landscaping practices study answered preliminary questions about urban plant ecology and allowed us to revise these questions to include long-term monitoring considerations. Little research has been done in the area of urban horticultural ecology; this work is unique in both horticulture and ecology and might offer a useful bridge between the disciplines. It also offers many opportunities for collaborative research between social and natural scientists because horticulture is a science closely linked to human influence.

Several unique aspects of developing a mass balance for an urban system have been enlightening to ecologists, e.g., the importance of vertical exchange between the aquifer and ground surface, the concept of "patchiness" with respect to input loadings, and the importance of combustion processes and ecological impacts of near-source deposition. The concept of using whole-ecosystem mass balances is novel to engineers, although the concept of mass balances at smaller scales is ubiquitous. Findings from this work were presented to the Association of Environmental Engineering Professors "Research Frontiers" conference. In follow-up workshops to develop a research strategy document, the role of environmental engineers in studying and managing urban ecosystems was a major theme of discussion. We have now formed an "ecological feedbacks" discussion group comprising ecologists, sociologists, planners, anthropologists, and other disciplines. Results from several early projects—nutrient synthesis, urban climate, plant productivity, and others—are being discussed in the context of ecological feedbacks: how do human alterations of the environment affect our lives, using quantifiable measures?

The urban lakes study will provide data for the field of phycology about the distribution of algal populations and species composition over time and in relation to certain variables (water type, nutrients, treatments, etc.).

The urban fringe is a place of ecological disturbance where open desert and agricultural land is being converted to human uses. The urban fabric formed by water and sewer infrastructure creates a new ecological framework of urban landscape. LTER scientists from a variety of disciplines should be able to use historic land-use data to supplement data they are collecting at the sites currently. The historic data can also be used as an input to predictive land-use models.

This social area analysis is an interdisciplinary project that links social processes with ecosystem outcomes. Specifically, it will provide evidence about the relationship between socioeconomic heterogeneity and heterogeneity of urban landscapes. The social area indicators data may provide a launching point for other interdisciplinary work relating sociodemographic and ecosystem processes. The environmental risk project contributes to the rapidly growing field of environmental equity. More generally, the project is situated at the intersection of social and natural science, ethics and policy, representing a new, integrative style of research. Its main contribution to date is demonstrating that analyses that rely solely on the presence of large-quantity generators or on the volume of toxic releases can be quite misleading. Instead, it is essential to take account of the toxicity of releases. Secondarily, because it is situated in Phoenix, the project offers a valuable contrasting case to other studies of environmental equity, which tend to be sited in the Northeast or South. Finally, by studying the shift of industry from center to periphery (and from traditional industries, such as foundries, to new industries, such as computer component manufacture), the project adds a forward-looking dimension to the environmental equity literature. Our most striking result, the comparison of weighted and unweighted releases, suggests that apparently clean new industry may harbor significant environmental hazards.

Contributions to Human Resources Development

The CAP LTER project provides a powerful framework for training graduate students, nourishing cross-disciplinary projects, and contributing to the new and growing field of urban ecology. Our project is committed to engaging pre-college students and teachers, community organizations, governmental agencies, industry, and the general public in disseminating and sharing our findings. Both NSF and ASU support over 20 graduate students a semester, each immersed in the research at hand and working together as a cohort for the project at large. Graduate students are currently drawn from a wide range of university programs and departments, including: anthropology, biology, curriculum and instruction, engineering, economics, geography, geological sciences, plant biology, and sociology. Our successful grant proposal to the NSF's IGERT program has added 8 IGERT Fellows and 13 IGERT Associates (many of the latter are CAP LTER RAs) to this active group of graduate students. The IGERT program is integrated with CAP LTER activities; for example, IGERT students have formed a reading group in urban ecology, participate in the monthly ASC meetings, and are designing research projects (both independent and collaborative) that contribute to our understanding of a complex urban ecosystem.

The Ecology Explorers program (details are provided below and in the Educational and Outreach section) serves the K-12 community and has a growing cadre of teachers who have completed workshops and internships associated with CAP LTER research projects. They, in turn, draw upon CAP LTER resources to actively involve students in collecting and analyzing data drawn from an urban setting.

Contributions to Resources for Research and Education

CAP LTER's university setting enhances the ability to conduct, communicate, and synthesize our research activities. Faculty members have expanded their courses to include a consideration of urban ecology and, in some cases, have designed new courses to accommodate CAP LTER research interests. For example, the Biology Department offered a seminar in urban ecology in the first and current year of the project, and last year the river channel change project contributed to the multidisciplinary education of 30 graduate students in botany, zoology, biology, agriculture, planning, geology, and geography by combining the study with a graduate course taught through the Geography Department.

In addition, graduate assistants gain exposure to interdisciplinary research, the importance of long-term datasets, metadata, and data archiving, as well as experience in database design and management, and lab processing and analysis. The Goldwater Lab for Environmental Science has been expanded to accommodate CAP LTER's analytical needs and provide graduate student training on instruments housed in this facility. Data collected as part of the remote sensing lab's research programs is archived at the GRSL and is available to CAP LTER researchers and graduate students. This archive includes data collected within the study area as well as many other sites through the western U.S. As such, it represents a rich source of data for future faculty and graduate student research. Data products produced by the GRSL are available for use as class and presentation materials and have been used both for K-12 and college-level classes and presentations. The datasets that result from the historic land-use project can be used for further research as well as in GIS, geography, planning, or other instruction.

Ecology Explorers enhances the teaching and learning of science, inquiry-based learning, and critical thinking skills in the K-12 realm. Three schoolyard supplements and additional corporate and foundation monies support activities that promote scientific inquiry through schoolyard ecology. These activities engage students and teachers in "real" university-level science projects; enhance the use of technology in the classrooms via the Web site and databases; offer stimulating research experiences that enhance teaching; and provide an interface between the scientific community and schools to facilitate science standards reform. To date there has been student/teacher participation in plant survey, ground arthropod survey, bird survey, plant/insect interaction, and water sampling efforts.

Contributions beyond Science and Engineering

By taking the long-term view of complex issues that defy simple explanation, not simply the circumstances we find ourselves into today, CAP LTER is striving to understand the social, economic, and biological forces that drive these processes. We are working with our community partners to define the issues and processes that shape our city. Project results are percolating that may offer contributions beyond science and engineering. CAP LTER activities and research potentially provide information for planning urban growth, especially in sensitive ecosystems. Our work also has the potential to reach many nontraditional audiences through our "backyard ecology" outreach efforts.

The plant community survey will provide information needed for planning urban growth, especially in sensitive ecosystems. Results from the pollinator study suggest that urban development can be designed to promote the conservation of pollinator bees. Specifically, preservation of desert and greater use of xeric landscaping rather than mesiscaping may help preserve this ecologically and economically vital group of organisms.

The modeling project is important for understanding how the spatial pattern of land use has changed in the past and how it will change in future. On the other hand, it is equally important for understanding the effects of land-use change on ecological processes. The modeling project is also crucial for integrating and synthesizing pieces of information obtained from individual projects.

The urban fringe morphology study will provide a current evaluation of the breadth of water and sewer infrastructure facilities and their relationship to land development, both at the urban fringe and throughout the city. Historic land-use data contributes to studies in planning, population studies, and cultural geography. The labor market dynamics project will expand our knowledge about the degree of progress toward the nation's equal employment opportunity goals. We have already attracted the attention of the U.S. Equal Employment Opportunity Commission (EEOC), which has agreed to let us use confidential data on the characteristics of workers employed by individual firms. This project will require the use of several datasets, and once we have assembled the pieces, we can pursue external funding to carry out our analyses. This project will also provide a base level of information for all CAP LTER scientists who seek on understanding of economic reasons that people settle within, and migrate to, particular locations in the Central-Arizona Phoenix region.

VII. PRODUCTS

Publications in Refereed Journals

In Press

Bolin, B., E. Matranga, E. J. Hackett, E. K. Sadalla, K. D. Pijawka, D. Brewer, and D. Sicotte. In press. Environmental equity in a Sunbelt city: The spatial distribution of toxic hazards in Phoenix, Arizona. *Environmental Hazards.*

Fagan, W. F., E. Meir, S. Carroll, and J. Wu. In press. The ecology of urban landscapes: Modeling housing starts as a density-dependent colonization process. *Landscape Ecology.*

Graf, W. L. In press, 2001. The fluvial imperative: Connecting science and policy for America's rivers. Annals of the Association of American Geographers.

Hope, D., S, Palmer, M. F. Billett, and J. J. C. Dawson. In press. Carbon dioxide and methane evasion from a temperate peatland stream. *Limnology and Oceanography*.

Jenerette, G. D., and J. Wu. In press. Analysis and simulation of land use change in the central Arizona – Phoenix region. *Landscape Ecology*.

McIntyre, N. E., K. Knowles-Yánez, and D. Hope. In press. Urban ecology as an interdisciplinary field: Differences in the use of "urban" between the social and natural sciences. *Urban Ecosystems.*

Palmer, S. M., D. Hope, M. F. Billett, and C. Bryant. In press. Sources of organic and inorganic carbon in a headwater stream: Evidence from carbon isotope studies. *Biogeochemistry*.

In Review

Dawson, J. J. C., M. F. Billett, and D. Hope. In review. Diurnal variations in the carbon chemistry of two acidic upland streams in NE Scotland. *Freshwater Biology*.

Luck, M., and J. Wu. Characterizing the landscape pattern of urbanization: An example from the Central Arizona – Phoenix urban LTER.

McIntyre, N. E., J. Rango, W. F. Fagan, and S. H. Faeth. In review. Ground arthropod community structure in a heterogeneous urban environment. *Landscape and Urban Planning*.

Submitted

Baker, L. A., Y. Xu, L. Lauver, D. Hope, and J. Edmonds. Nitrogen balance for the Central Arizona-Phoenix ecosystem. Submitted to *Ecosystems*.

Martin, C. A., and L. B. Stabler. Plant gas exchange and water status in urban desert landscapes. *Journal of Arid Environments*.

2000

Brazel, A. J., N. Selover, R. Vose, and G. Heisler. 2000. The tale of two climates: Baltimore and Phoenix urban LTER sites. *Climate Research* 15(2):123-135.

Christensen, P. R., J. Bandfield, V. E. Hamilton, D. Howard, M. Lane, J. Piatek, S. W. Ruff, and W. L. Stefanov. 2000. A thermal emission spectral library of rock-forming minerals. *Journal of Geophysical Research* 105:9,735-9,739.

Collins, J. P., A. P. Kinzig, N. B. Grimm, W. F. Fagan, D. Hope, J. Wu, and E. T. Borer. 2000. A new urban ecology. *American Scientist* 88:416-425.

Drewes, J. E., M. Sprinzl, A. Soellner, M. D. Williams, P. Fox, and P. Westerhoff. 2000. Tracking residual dissolved organic carbon using XAD-fractionation and ^{13}C-NMR spectroscopy in indirect potable reuse systems. *Vom Wasser* 93:95-107.

Gober, P. 2000. In search of synthesis. *Annals of the Association of American Geographers* 90(1):1-11.

Graf, W. L. 2000. Locational probability for a dammed, urbanizing stream, Salt River, Arizona. *Environmental Management* 25:321-335.

Grimm, N. B., J. M. Grove, C. L. Redman, and S. T. A. Pickett. 2000. Integrated approaches to long-term studies of urban ecological systems. *BioScience* 70:571-584.

Jenerette, G. D., and J. Wu. 2000. On the definitions of scale. *Bulletin of the Ecological Society of America* 81(1):104-105.

Lauver, L., and L. Baker. 2000. Wastewater reuse: Implications for nitrogen export and retention in the Phoenix ecosystem. *Water Research* 34:2734-2760.

McIntyre, N. E. 2000. Ecology of urban arthropods: A review and a call to action. *Annals of the Entomological Society of America* 93(4):825-835.

Stabler, L. B., and C. A. Martin. 2000. Effect of irrigation frequency on growth and water use efficiency of two Southwest landscape plants. *Journal of Environmental Horticulture* 16:66-70.

Wenninger, E. J., and W. F. Fagan. 2000. Effect of river flow manipulation on wolf spider assemblages at three desert riparian sites. *Journal of Arachnology* 28:115-122.

Westerhoff, P., and D. Anning. 2000. Concentrations and characteristics of organic carbon in surface water in Arizona: Influence of urbanization. *Journal of Hydrology* 236:202-222.

Wu, J. and Y. Qi. 2000. Dealing with scale in landscape analysis: An overview. *Geographic Information Sciences* 6(1):1-5.

Zipperer, W. C., J. Wu, R. V. Pouyat, and S. T. A. Pickett. 2000. The application of ecological principles to urban and urbanizing landscapes. *Ecological Applications* 10(3):685-688.

1999

Aitkenhead, J., D. Hope, and M. F. Billett. 1999. The relationship between dissolved organic carbon in streamwater and soil organic carbon pools at different spatial scales. *Hydrological Processes* 13(8):1289-1302.

Baker, M. A., and D. J. Pinkava. 1999. A new Arizona hybrid cholla, *Opuntia ×campii* (Cactaceae). *Cactus and Succulents Journal* (Los Angeles) 71(6):320-322.

Drewes, J. E., M. Sprinzl, A. Wendrock, M. D. Williams, P. Fox, and P. Westerhoff. 1999. Tracking residual DOC using XAD-fractionation and C^{13}-NMR spectroscopy in indirect potable reuse. *Vom Wasser* 93:95-107.

McDowell, L. B., and C. A. Martin. 1999. Landscape design and history affect urban plant gas exchange parameters. *HortScience* 34:549.

McIntyre, N. E. 1999. Influences of urban land use on the frequency of scorpion stings in the Phoenix, Arizona, metropolitan area. *Landscape and Urban Planning* 45:47-55.

Peterson, K. A., L. B. McDowell, and C. A. Martin. 1999. Plant life form frequency, diversity, and irrigation application in urban residential landscapes. *HortScience* 34:491.

Redman, C. L. 1999. Human dimensions of ecosystem studies. *Ecosystems* 2:296-298.

Stefanov, W. L., and P. R. Christensen. 1999. Comparative analysis of soil development on semiarid hillslopes using linear deconvolution of thermal infrared multispectral scanner (TIMS) data. *American Geophysical Union EOS Transactions* 80(46):442.

Wu, J. 1999. Hierarchy and scaling: Extrapolating information along a scaling ladder. *Canadian Journal of Remote Sensing* 25(4):367-380.

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2000

Wu, J. 2000. Desertification. In *Plant sciences for students*, R. Robinson, ed. Macmillan Reference, New York, NY.

Wu, J. 2000. *Landscape ecology: Pattern, process, scale and hierarchy*. Higher Education Press, Beijing.

In Press

Grimm, N. B., L. J. Baker, and D. Hope. In press. An ecosystem approach to understanding cities: Familiar foundations and uncharted frontiers. In *Understanding urban ecosystems: A new frontier for science and education*, A. R. Berkowitz, K. S. Hollweg, and C. H. Nilon, eds. Springer-Verlag, New York, NY.

Kinzig, A. P., and J. M. Grove. In press. The urban environment. In *The encyclopedia of biodiversity*, S. Levin, ed. Academic Press, Inc.

1999

Brazel, A. J., A. Anderson, and N. Selover. 1999. Microclimate and housing waves along the urban fringe, In *Proceedings Biometeorology and Urban Climatology at the Turn of the Millennium*, Int. Congress of Biometeorology & Int. Conference on Urban Climatology, 8-12 Nov. Sydney, AU (Preprint Paper on CD ROM).

Ramsey, M. S., W. L. Stefanov, and P. R. Christensen. 1999. Monitoring world-wide urban land cover changes using ASTER: Preliminary results from the Phoenix, AZ, LTER site. Pp. 237-244 in *Proceedings of the 13th Applied Geol. Remote Sensing Conference*, Vancouver, British Columbia, Canada. Vol. 2.

Publications – Other

Submitted

Robinson, S. E., and Arrowsmith, J R. Quaternary mapping of a desert piedmont using NS001 and TIMS remote sensing datasets. Open File Report 2000-xx, Arizona Geological Survey, Tucson, Arizona, 10 pp. and 4 plates.

Grant Awards and Proposals Submitted

Awarded in 2000

"16th Annual Symposium of the International Association of Landscape Ecology," ($1,500). U.S. Chapter Arizona Commission on the Arts. L. Musacchio, PI.

"A Hierarchical Patch Dynamics Approach to Regional Modeling and Scaling," U.S. EPA, 1/1/2000-1/1/2003. J. Wu and D. Green, PIs.

"Ecology Explorers Summer Teacher Internship," ($25,000). Arizona Community Foundation.

"Faculty Grant-In Aid Award," 2000-2001, graduate student support. S. Harlan, PI.

"Identification of Urban Particulate Source Regions Using Remote Sensing: Classification of Landsat ETM Data for the Nogales, AZ Area," ($31,554). Southwest Center for Environmental Research and Policy, 2000-2001. P. Christensen, PI; W. Stefanov, M. Ramsey Co-PIs.

"Integrative Graduate Education and Research Training in Urban Ecology," ($2,698,494), National Science Foundation, IGERT, 2000-2005. S. Fisher, PI/PD, C. Redman Co-PI/PD; W. Graf, N. Grimm, E. Hackett, Co-PIs.

"Landscape Change at the Urban Fringe: Interactions Between Geology, Ecology, and Culture in Phoenix," ($3,000). Mini-Plus Grants for Interdisciplinary Team Research, Herberger Center for Design Excellence, Arizona State University. L. Musacchio, J. R. Arrowsmith, and S. Robinson, Co-PIs.

"UMEB: Diverse Approaches to Environmental Research." ($215,983). National Science Foundation, 1999-2003. D. Pearson, PI/PD; J. Collins, S. Faeth, N. Grimm, R. Rutowski, Co-PIs.

Two CAP LTER Supplements: "LTER Schoolyard Supplement," ($15,000); "CAP LTER REU Supplement" ($15,000). National Science Foundation. C. Redman and N. Grimm, Co-PIs.

Submitted

"Down to Earth Science: Graduate Teaching Fellows in K-12 Education." ($1,397,825) National Science Foundation, 2000-2003. B. Ramakrishn, PI/PD; C. Redman, F. Staley, P. Christensen, S. DiGangi , Co-PIs. Other LTER participants: T. Craig, N. Grimm, M. Elser, M. Nelson, and S. Williams.

Professional Presentations at Regional, National, and International Conferences

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, K. S., B. Benson, J. Brunt, N. Gardiner, D. L. Henshaw, E. Melendez, J. Porter, P. McCartney, and D. Steigerwald. 2000. LTER information management: Paradigm shift or paradigm stretch? Poster presented at 2-4 August 2000, *Long-Term Ecological Research: Unifying Principles and Global Applications,* LTER All Scientists Meeting, Snowbird, UT. *Ecological Society of America 85th Annual Meeting Abstracts* p. 400.

Baker, L. 2000. Ecosystem-level nutrient dynamics: Cross-comparisons. Workshop presented at 2-4 August 2000, *Long-Term Ecological Research: Unifying Principles and Global Applications*, LTER All Scientists Meeting, Snowbird, UT.

Blair, J. M., M. J. Taylor, and A. Brazel. 2000. Urban climate change: Defining the magnitude of islands and oases. Poster presented at 19 January 2000, *CAP LTER Second Annual Poster Symposium*, Center for Environmental Studies, Arizona State University, Tempe.

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

Bolin, R., E. Hackett, D. Pijawka, E. Sadalla, D. Brewer, E. Matranga, and D. Sicotte. 2000. Environmental equity in a Sunbelt city. Poster presented at 19 January 2000, *CAP LTER Second Annual Poster Symposium*, Center for Environmental Studies, Arizona State University, Tempe.

Bolin, R., E. Matranga, E. Hackett, E. Sadalla, D. Pijawka, D. Brewer, and D. Sicotte. 2000. Environmental equity in a Sunbelt city. Poster presented at 2-4 August 2000, *Long-Term Ecological Research: Unifying Principles and Global Applications,* LTER All Scientists Meeting, Snowbird, UT. *Ecological Society of America 85th Annual Meeting Abstracts* p. 370.

Bolin, R., E. Matranga, A. Nelson, E. Hackett, D. Pijawka, D. Brewer, and D. Sicotte. 2000. The ecology of risk in a Sunbelt city: A multi-hazard spatial analysis. Poster presented at 2-4 August 2000, *Long-Term Ecological Research: Unifying Principles and Global Applications*, LTER All Scientists Meeting, Snowbird, UT. *Ecological Society of America 85th Annual Meeting Abstracts* p. 375.

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.

Clark, K. B., G. D. Jenerette, and J. J. Rango. 2000. Heterogeneous urban landscape structural effects on desert remnant bird species assemblages in Phoenix, Arizona. Poster presented at 19 January 2000, *CAP LTER Second Annual Poster Symposium*, Center for Environmental Studies, Arizona State University, Tempe.

Compton, M., J. Hunter, and M. Sommerfeld. 2000. Urban lakes – relationships between source water, lake age, water chemistry, and biota. Poster presented at 19 January 2000, *CAP LTER Second Annual Poster Symposium*, Center for Environmental Studies, Arizona State University, Tempe.

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.

Cousins, J. R., and J. C. Stutz. 2000. Arbuscular mycorrhizal fungal species composition, richness, and abundance in the Phoenix metropolitan area. Poster presented at 19 January 2000, *CAP LTER Second Annual Poster Symposium*, Center for Environmental Studies, Arizona State University, Tempe.

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.

Edmonds, J. 2000. Strategies for the integration of social and biological sciences. Workshop presented at 2-4 August 2000, *Long-Term Ecological Research: Unifying Principles and Global Applications*, LTER All Scientists Meeting, Snowbird, UT.

Edmonds, J., D. Hope, and N. Grimm. 2000. Spatial and temporal trends in surface waters moving through the Phoenix metropolitan area. Poster presented at 19 January 2000, *CAP LTER Second Annual Poster Symposium*, Center for Environmental Studies, Arizona State University, Tempe.

Elser, M. M., S. Bestelmeyer, and R. Boone. 2000. Models for linking schoolyard ecology with LTER sites: What has worked and what hasn't. Workshop presented at 2-4 August 2000, *Long-Term Ecological Research: Unifying Principles and Global Applications*, LTER All Scientists Meeting, Snowbird, UT.

Elser, M. M., and S. Williams. 2000. K-12 student contributions to the CAP LTER project. Poster presented at 19 January 2000, *CAP LTER Second Annual Poster Symposium*, Center for Environmental Studies, Arizona State University, Tempe.

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., R. Arrowsmith, and J. Tyburczy. 2000. Changes of groundwater elevation associated with Tempe Town Lake. Poster presented at February 2000, *Graduates in Earth and Life Sciences Symposium*, Arizona State University, Tempe, AZ.

Fergason, K. C., J R. Arrowsmith, and J. A. Tyburczy. 2000. Changes of groundwater elevation associated with Tempe Town Lake. Poster presented at 19 January 2000, *CAP LTER Second Annual Poster Symposium*, Center for Environmental Studies, Arizona State University, Tempe.

Fergason, K. C., Arrowsmith, J R., and Tyburczy, J. A. 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:In press.

Foster, D., N. Brokaw, B. McDowell, C. Redman, J. Thompson, and R. Waide. 2000. Importance of past and current human and natural disturbance in ecosystems. Workshop presented at 2-4 August 2000, *Long-Term Ecological Research: Unifying Principles and Global Applications*, LTER All Scientists Meeting, Snowbird, UT.

Gries, C., W. Zhu, D. Hope, and S. Carroll. 2000. CAP LTER 'survey 200' update: First experiences and preliminary results. Poster presented at 19 January 2000, *CAP LTER Second Annual Poster Symposium*, Center for Environmental Studies, Arizona State University, Tempe.

Grimm, N., L. Band, and D. Childers. 2000. Human modifications of hydrologic cycles: Effects on nutrient dynamics at local and regional scales. Workshop presented at 2-4 August 2000, *Long-Term Ecological Research: Unifying Principles and Global Applications*, LTER All Scientists Meeting, Snowbird, UT.

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.

Grimm, N. B., and C. L. Redman. 2000. Central Arizona - Phoenix LTER: Initial studies in a southwestern urban ecosystem. Poster presented at 2-4 August 2000, *Long-Term Ecological Research: Unifying Principles and Global Applications*, LTER All Scientists Meeting, Snowbird, UT.

Harlan, S., A. Nelson, E. Hackett, R. Bolin, A. Kirby, and D. Pijawka. 2000. Phoenix area social survey. Poster presented at 2-4 August 2000, *Long-Term Ecological Research: Unifying Principles and Global Applications*, LTER All Scientists Meeting, Snowbird, UT. *Ecological Society of America 85th Annual Meeting Abstracts,* p. 375.

Honker, A. M. 2000. Choices and consequences: An overview of Salt River flooding, 1891-present. Poster presented at 19 January 2000, *CAP LTER Second Annual Poster Symposium,* Center for Environmental Studies, Arizona State University, Tempe.

Hope, D., J. Anderson, N. B. Grimm, and S. Boone. 2000. Atmospheric deposition across the CAP ecosystem: Some preliminary findings. Poster presented at 19 January 2000, *CAP LTER Second Annual Poster Symposium*, Center for Environmental Studies, Arizona State University, Tempe.

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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.

Luck, M., G. D. Jenerette, and N. B. Grimm. 2000. The spatial scale of human – ecological interactions: An analysis of effective urban size. Poster presented at 19 January 2000, *CAP LTER Second Annual Poster Symposium*, Center for Environmental Studies, Arizona State University, Tempe.

Luck, M. A., G. D. Jenerette, J. Wu, and N. B. Grimm. 2000. Determining the size of urban landscapes: The urban funnel model and estimation of ecological footprint. Presented at 15-19 April 2000, *Annual Meeting of International Association for Landscape Ecology,* Fort Lauderdale, FL.

Martin, C. A., J. C. Blank, K. A. Peterson, and L. B. Stabler. 2000. Urban land use affects landscape microclimate and CO_2 concentration. Poster presented at 19 January 2000, *CAP LTER Second Annual Poster Symposium*, Center for Environmental Studies, Arizona State University, Tempe.

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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.

Martin, C. A., L. B. Stabler, and A. J. Brazel. 2000. Summer and winter patterns of air temperature and humidity under calm conditions in relation to urban land use. Presented at 14-18 August 2000, *Third Symposium on the Urban Environment,* American Meteorological Society, University of California, Davis.

Matranga, E., R. Bolin, D. Brewer, E. Hackett, D. Pijawka, and E. Sadalla. 2000. Technological hazards in the Southwest: Environmental equity and the demographics of risk. Poster presented at 19 January 2000, *CAP LTER Second Annual Poster Symposium*, Center for Environmental Studies, Arizona State University, Tempe.

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McCartney, P. H. 2000. Building a network of environmental data resources for central Arizona. Poster presented at 19 January 2000, *CAP LTER Second Annual Poster Symposium*, Center for Environmental Studies, Arizona State University, Tempe.

McCartney, P., I. Robertson, and G. Cowgill. 2000. Using metadata to address problems of data preservation and delivery: Examples from the Teotihuacan Data Archiving Project. Paper presented at 6 April 2000, *65th Annual Society of American Archaeology*, Philadelphia, PA.

McIntyre, N. E., J. Rango, W. Fagan, and S. Faeth. 2000. Ground arthropod community structure in a heterogeneous urban environment. Poster presented at 19 January 2000, *CAP LTER Second Annual Poster Symposium*, Center for Environmental Studies, Arizona State University, Tempe.

McIntyre, N. E., and M. E. Hostetler. 2000. Effects of urban land use on Hymenopteran pollinator community structure in a desert metropolis. Poster presented at 19 January 2000, *CAP LTER Second Annual Poster Symposium*, Center for Environmental Studies, Arizona State University, Tempe.

Melack, J., T. Dunne, and N. Grimm. 2000. Development of coupled hydrological-biogeochemical models of materials transport at the landscape scale. Workshop presented at 2-4 August 2000, *Long-Term Ecological Research: Unifying Principles and Global Applications*, LTER All Scientists Meeting, Snowbird, UT.

Mueller, E. C., and T. A. Day. 2000. Effects of urban ground cover on microclimate and landscape plant performance. Poster presented at 19 January 2000, *CAP LTER Second Annual Poster Symposium*, Center for Environmental Studies, Arizona State University, Tempe.

Nelson, A., and S. Harlan. 2000. Labor market dynamics in a postindustrial city: A spatial and sectoral analysis of employment changes in the Phoenix MSA. Poster presented at 19 January 2000, *CAP LTER Second Annual Poster Symposium*, Center for Environmental Studies, Arizona State University, Tempe.

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Community Outreach Presentations and other Miscellaneous Activities

<u>2000</u>

Bolin, R. 2000. Environmental equity in a Sunbelt city. April, presented in the Colloquium Series, Sociology Department, Arizona State University, Tempe, AZ.

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Nash III, T. H. 2000. Effects of copper smelter on desert vegetation: A retrospective after 26 years. Seminar presented January 2000, Department of Biogeochemistry, Max Planck Institute for Chemistry, Mainz, Germany.

<u>1999</u>

Gober, P. 1999. LTER and the potential for integrating social and natural science research. Paper presented 24 September 1999 to the Department of Geography, University of Toledo, Toledo, OH.

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Community Outreach Publications, News Articles about CAP LTER, and Other Non-Standard Publications

<u>2000</u>

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<u>1999</u>

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Internal Publications, Reports, and Presentations

<u>2000</u>

McCartney, P. 2000. Report of the Long-Term Ecological Research Metadata Committee Meeting, February 2000, NET Office, Albuquerque.

Stefanov, W. L. 2000. 1985, 1990, 1993, 1998 Land Cover Maps of the Phoenix, Arizona Metropolitan Area, Geological Remote Sensing Laboratory, Department of Geological Sciences, Arizona State University, Tempe, AZ, 4 Plates, scale 1:115,200.

<u>1999</u>

Knowles-Yánez, K, C. Moritz, J. Fry, C. L. Redman, M. Bucchin, and P. H. McCartney. 1999. Historic land use: Phase I report on generalized land use. Central Arizona–Phoenix Long-Term Ecological Research Contribution No. 1. Center for Environmental Studies, Arizona State University, Tempe, AZ.

McCartney, P. 1999. ASU proposal to BDI. Contribution for 1999 Report of the LTER Information Management Annual Meeting. http://www.lternet.edu/cgi-bin/list.cgi?./Reports/Data-management-committee/1999-DM-committee-report

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Theses and Dissertations, in Progress and Completed

In progress

Anderson, S. Spatial and Temporal Change Detection through Integration of Geographic Information Science and Thermal Imagery: A Case Study Investigating Climate Change along the Urban Fringe (M.S., Geography, A. Brazel).

Applegarth, M. Pediment controls in the Sonoran Desert. (Ph.D., Geography, R. Dorn).

Clark, K. Vertebrate species composition of desert islands in Phoenix (M.S., Biology, R. D. Ohmart).

Damrel, D. A horticultural flora of the ASU Arboretum (M.S., Plant Biology, D. J. Pinkava).

Edmonds, J. Understanding linkages between dissolved organic carbon quality and microbial and ecosystem processes in Sonoran Desert riparian-stream ecosystems (Ph.D., Biology, N. B. Grimm).

Fergason, K. Microgravity monitoring of Tempe Town Lake hydrogeology (M.S., Geology, J R. Arrowsmith and J. Tyburczy).

Holloway, S. Proterozoic and Quaternary geology of Union Hills, Arizona (M.S., Geology, J. R. Arrowsmith).

Honker, A. A river sometimes runs through it: a history of Salt River flooding and Phoenix (Ph.D., History, P. Iverson and S. Pyne)

Oleksyszyn, M. Native-exotic vegetation interactions in abandoned agricultural fields (M.S., Plant Biology, J. C. Stromberg).

Peterson, K. A. Assessing impacts of socioeconomic factors and residential community ordinances on new urban landscape vegetation patterns (M.S., Plant Biology, C. A. Martin).

Roberge, M. Desert urban hydrology: Human encroachment onto hillslope and channel systems (Ph.D., Geography, R. Dorn).

Robinson, S. E. Understanding Quaternary landscape development in the Phoenix area using remote sensing and cosmogenic dating (Ph.D., Geology, J R. Arrowsmith and P. R. Christensen).

Stabler, L. B. The urban forest and microclimate: Interactive and feedback effects on CO_2 and water cycling (M.S., Plant Biology, C. A. Martin).

Stefanov, W. L. Soil development, hillslope geomorphology, and land cover in the Phoenix, Arizona region: Investigations using visible to mid-infrared remote sensing and laboratory spectroscopy (Ph.D., Geology, P. R. Christensen).

Stiles, A. Influence of urbanization on vascular plant species diversity within desert remnant patches (Ph.D., Plant Biology, S. Scheiner).

Vining, E. Plant-microclimate interactions (M.S., Plant Biology, T. Day).

Xu, Y. A spatial model of N cycling within the Phoenix metropolitan ecosystem (Ph.D., Civil and Environmental Engineering, P. Johnson and L. Baker).

Completed

Mark A. Compton. 2000. A Comparative Study of Desert Urban Lakes Receiving Well, Canal, and Effluent Source Waters (M.S., Plant Biology, M. Sommerfeld, August 2000).

McPherson, N. 1999. Fate of 50 years of fertilizer N application sin the Phoenix ecosystem (M.S., Civil and Environmental Engineering, L. Baker).

Stefanov, W. L. 2000. Investigation of hillslope processes and land cover change using remote sensing and laboratory spectroscopy (Ph.D., Geology, Christensen).

Zschau, T. 1999. Effects of a copper smelter on desert vegetation: A retrospective after 26 years (M.S., Plant Biology, T. H. Nash).

Collections

Urban arthropod collection (under development, M. Tseng)

Web Sites

http://caplter.asu.edu (1998: McCartney, Lindauer, Oliver, Shears, Kupiec); main CAP LTER site

http://caplter.asu.edu/explorers (1998: Lindauer, Casey, Elser, Folsom, Fears, Sommers); K-12 outreach
http://caplter.asu.edu/ceslab (1999: McCartney, Rosales); documentation and use of CES Informatics Lab
http://elwood.la.asu.edu/grsl/maps/data_serv.html and http://elwood.la.asu.edu/grsl/lter/ (1998: Ramsey, Stefanov, Christensen); access to remote sensing data
http://ls.la.asu.edu/herbarium/herb13.htm (1999: Damrel, Pinkava, Landrum); The Phoenix Flora
http://www.public.asu.edu/~fergason/rio/ (2000: Fergason) Tempe Town Lake groundwater research page
http://lsweb.la.asu.edu/cmartin/martinlab.html (2000: Martin); urban horticultural ecology site

Datasets

LTER Produced Datasets	**Description**	**Status**
Aquatic Core Monitoring Dataset	Relational database, GIS layer showing project sample area, aquatic water quality study	In Prep
Arthropods Dataset	Relational database, GIS layer showing project sample area, arthropod population study	In Prep
Bird Transect Survey Dataset	Relational database, GIS layer showing project sample area, bird transect survey	Online
Channel Change Dataset	ArcView coverages of channel change	In Prep
Dairy farm locations	GIS layer of dairy farm locations	Submitted
Fungi Dataset	Relational database, GIS layer showing project sample area for fungi study	In Prep
Historic Climate Dataset	Historic climate data for Phoenix valley	In Prep
Nutrients and Data Synthesis Dataset	Relational database, GIS layer showing project sample area: NUTRIENTS	In Prep
Desert remnant plant survey	Relational database, GIS layer showing project sample area for desert plant survey	In Prep
Quaternary Geomorphology Dataset	GIS layers showing project study area, geomorphology maps	In Prep
Residential Patch Types Dataset	Data tables on residential patches, GIS layer showing project sample area	In Prep
Urban Fire Ecology Dataset	GIS layer showing project sample area for urban fire study	In Prep
Urban Fringe Morphology Dataset	GIS layer showing project sample area for urban fringe study	In Prep
Urban Lakes study	GIS layer showing project sample area for urban lakes study	In Prep
Lichens Resurvey Dataset	Relational database, GIS layer showing project sample area	In Prep
Vertebrates Dataset	Relational database, GIS layer showing project sample area	In Prep
Phoenix flora database	Vascular plant checklist and distribution database	Submitted
Land Cover Classification	Relational database, Image showing land cover classifications for CAP LTER study area	Submitted
Survey 200 Monitoring dataset	Relational database and GIS layers on monitoring data for 200 sample points	In Prep
Labor Market dataset	Relational database of calculated values derived from 1980 and 1990 census data	In Prep
NDVI vegetation density index	Image data of NDVI for CAP LTER Study area: 1975-1980, 1985-1998, 1999	Submitted
Soil-Adjusted Vegetation Index (SAVI)	Image data of SAVI for CAP LTER Study area: 1975-1980, 1985-1998, 1999	Submitted
Bird Point Census count dataset	Relational database of point census bird count	In Prep
Bird Physiology Study dataset	Relational database of physiology and blood chemistry of birds	In Prep
Historic Landuse Phase 2	Detailed landuse change for Survey 200 sample locations	In Prep

Aquired Datasets**		
Census data 1980	Proprietary database on CD Rom	Restricted
Census data 1990	Proprietary database on CD Rom	Restricted
Landsat Thematic Mapper (TM)	Remote sensing imagery for Maricopa County portion CAP LTER study area, 1985-1998	Restricted
Landsat Multispectral Scanner (MSS),	Remote sensing imagery for Maricopa County portion CAP LTER study, 1973-1980	Restricted
Landsat Enhanced Thematic Mapper (ETM);	Remote sensing imagery for Phoenix metropolitan area, September 1999	Restricted
Advanced Very High Resolution Radiometer (AVHRR)	Remote sensing imagery for, 1990, 1992, and 1993 on CDs	Restricted
Digital Orthophoto Quadrangles (DOQs)	Remote sensing imagery at 1 meter/pixel for the Phoenix metropolitan region	Restricted
MODIS-ASTER (MASTER) Simulator	Remote sensing imagery; hyperspectral, high resolution data for the eastern Phoenix metropolitan region, July 1999	Restricted
Landiscor Aerial Orthophotography	High resolution, orthorectified color aerial photo mosaic, Phoenix metropolitan region	Restricted
Marciopa Tax Accessors imagery	High resolution, rectified aerial photography for CAP LTER Study area	Restricted
City of Phoenix tax parcel boundary layer		Restricted
GDTC Street	Updated street lines for Arizona	Restricted

**Restricted datasets are available to CAP LTER researchers

VIII. PARTICIPANTS

Individuals

Principal Investigators/Project Directors

Nancy B Grimm, Biology	1997-present	Charles L Redman, Center Env Studies	1997-present

CoPrincipal Investigator(s)

Stuart G Fisher, Biology	1997-present	Stanley H Faeth, Biology	1997-present
Jianguo Wu, Life Sciences ASU W	1997-present	William F Fagan, Biology	1997-present
Alfredo G de los Santos, Maricopa		Patricia Gober, Geography	1997-present
Comm Colleges	1997-present	Jeffrey M Klopatek, Plant Biology	1997-present
Steve S Carroll, Biology	1997-present	Thomas H Nash III, Plant Biology	1997-present
Lawrence A Baker, Civil/Env Eng	1997-present	Michael B Ormiston, Economics	1997-2000
Elizabeth K Burns, Geography	1997-present	K David Pijawka, Plng/Lndscpe Des	1997-present
Phillip R Christensen, Geology	1997-present	Milton R Sommerfeld, CLAS/Plant Bio	1997-present
Thomas A Day, Plant Biology	1997-present	Frederick A Staley, Curr/Instruction	1997-present

CoPIs, Geoscience/Engineering Supplement, 1997-1999

Ramon Arrowsmith, Geology	1997-present	Sandra L Houston, Civil/Env Eng	1997-present
William L Graf, Geography	1997-present	Frederick R Steiner, Plng/Lnds Arch	1997-present

Senior Personnel: Managers

Diane Hope, Field Project Mgr, CES/Bio	1997-present	Brenda L Shears, Admin Proj Mgr, CES	1997-present
Peter H McCartney, Info Mgr, CES	1997-present		

Senior Personnel: Core Scientists

James R Anderson, Mech/Aero Eng	1997-present	Michael Kuby, Geography	1997-1999
Robert C Balling, Geography	1997-present	Leslie R Landrum, Plant Biology	1998-present
C. Michael Barton, Anthropology	1997-present	Theresa A Markow, Plant Biology	1997-1998
Neil S Berman, Chem/Mat Eng	1997-present	Chris A. Martin, Plant Biology	1997-present
Robert Bolin, Sociology	1999-present	James W. Mayer, Ctr for Solid State Sci	1998-1999
Ward W Brady, Resour Mgmt, ASU E	1997-1999	Rob Melnick, Morrisson Institute	1997-present
Anthony J Brazel, Geography	1997-present	Laura R Musacchio, Plng/Lnds Arch	1999-present
John M. Briggs, Plant Biology	1999-present	Michael Musheno, Center for Urban Inq	1997-1999
Timothy P Craig, Life Sciences, ASU W	1997-present	Margaret C Nelson, Anthropology	1998-present
Lisa C. DeLorenzo, Public Affairs	1999-2000	Robert D Ohmart, Biology	1997-present
Pierre Deviche, Biology	2000-present	David L Pearson, Biology	1997-present
Ronald I Dorn, Geography	1997-present	Donald J Pinkava, Plant Biology	1997-present
Michael E Douglas, Biology	1998-present	Stephen J Pyne, Biology	1998-present
James F. Eder, Anthropology	1997-1999	B.L. Ramakrishna, Plant Biology/CSSS	1999-present
James J Elser, Biology	1997-present	Michael Ramsey, Geology	1997-present
Joseph M. Ewan, Plng/Lnds Arch	1999-present	Glen E Rice, Anthropology	1997-present
Patricia L Fall, Geography	1997-present	Edward K Sadalla, Psychology	1998-present
H J S Fernando, Mech/Aero Eng	1997-present	Samuel M Scheiner, Life Sci, ASU W	1997-present
Peter Fox, Civil & Environmental Engr	1997-1999	Arleyn W Simon , Anthropology	1997-present
Jana Fry, GIS Lab	1997-present	Andrew T. Smith, Biology	1998-1999
Douglas M Green, Resour Mgmt, ASU E	1997-present	Katherine A Spielmann, Anthropology	1997-present
Corinna Gries, Plant Biology	1997-present	Juliet C Stromberg, Plant Biology	1997-present
Edward J Hackett, Sociology	1998-present	Edward Stump, Geological Sciences	1997-1998
Sharon Harlan, Sociology	1999-present	Jean C Stutz, Plant Biology	1998-present
Timothy D Hogan, Economics	1997-present	Stanley R Szarek, Plant Biology	1998-present
Paul C Johnson, Civil/Env Eng	1997-present	James A Tyburczy, Geology	1998-present
Mary R Kihl , CAED/Herberger Ctr	1997-present	Sander van der Leeuw, Sorbonne, Paris	1999-present
Bradley Kincaid, Mesa Comm College	1997-1998	Rita Walton, Maricopa Assn of Govts	1997-present

Ann P. Kinzig, Biology	1999-present	Elizabeth A Wentz, Geography	1997-present
Carol C Klopatek, Microbiology	1997-1999	Paul C Westerhoff, Civil/Env Eng	1997-present
Glen S. Krutz, Political Science	1999-present	Susan Wyckoff, Physics & Astr/ACEPT	1997-present

Postdoctoral Research Associates

Mark Hostetler, CES/Biology	1997-1999	Amy L Nelson, CES	1999-present
Madhusudan V Katti, CES/Biology	2000-present	Eyal Shochat, CES/Biology	2000-present
Kimberley Knowles-Yanez, CES	1997-1999	Russell Watkins, CES	1999-2000
Nancy E McIntyre, CES/Biology	1997-2000	Weixing X Zhu, CES/Biology	1999-2000

Other Postdocs

Markus Naegeli, Biology/runoff study	1998-1999

Other Collaborators

Dave Anning, USGS	1998-present	Charles Kazilek, Life Sciences Vis Lab	1999-present
Barbara Backes, Life Sciences Vis Lab	1999-present	John Keane, Salt River Project	1997-present
Laural Casler, Life Sciences Vis Lab	2000-present	Robert Minckley, Auburn University	1999-2000
Ken Fossum, USGS	1998-present	Fred Rainey, Louisiana State University	
Steve Getty, University of New Mexico	1998-1999*Research*		

Technical Personnel

Michael Baker, P/T Aide/Birder, CES	1998-present	Michael Myers, Research Spec, CES	1998-2000
Damon Bradbury, Tech, CES	1998-1999	Theodore Oliver, Comp Dbse Spec, CES	1997-1999
Amalya Budet de Jesus, P/T Tech, CES	2000-2000	Sandra Palais, Seidman Res Inst, ASU	1997-present
Adam Burdick, Biology	1998-1999	Wayne Porter, Com Datbse Spec, CES	2000-present
Michael Clary, Tech, CES	2000-present	Seth Paine, P/T Research Tech, CES	2000-present
Shero Holland, Tech, CES	1998-2000	Beverly Rambo, P/T Aide; Birder, CES	1998-present
Thomas Hulen, P/T Aide/Birder, CES	1998-1999	Tom Rex, Seidman Res Inst, ASU	1997-present
Meryl Klein, P/T Tech/Birder, CES	1998-1998	Stephen Rosales, Com Datbse Spec, CES	1999-2000
Cathy D Kochert, Research Spec, Bio	1999-present	Melissa Rossow, Plant Biology/ Herbrm	1999-1999
Kelly Lazewski, Tech, CES	Spring 2000	C. Scott Smith, IT GIS Lab	1998-present
Jomarie Lemmer, P/T Birder, CES	1999-2000	Maggie Tseng, Research Spec, Bio/CES	1997-present
Matthew Luck, GIS Research Spec, CES	2000-present	Jaqueline Walters, Research Spec, CES	1997-2000
Alejandria Mejia, Plant Biology/Herbrm	1998-2000		

Public Outreach Personnel

Monica Elser, Education Liaison, CES	1998-present	Peggy Lindauer, Education Liaison, CES	1997-1998
Lauren Kuby, Community Liaison, CES	1998-present	Charlene Saltz, Env Educ. Coor, CES	2000-present
Kathryn Kyle. Exec Admin, SCENE	1997-present	Susan Williams, Education Liaison, CES	1999-2000

Office Personnel

Shirley A. Stapleton, CES	1997-present	Cindy D Zisner, CES	1997-present
Linda K.Williams, CES	1997-present	Kathleen A. Stinchfield, CES/Biology	1997-present

Graduate Research Associates

Sharolyn Anderson, Geography	1999-present	Michelle M Oleksyszyn, Plant Biology	1998-1999
Stephen Ammerman, History	1998-1999	Alanna E Ossa, Anthropology	1998-1999
Todd D Becker, Economics	1998	Gemma Paulo, Economics	Spring 1998
Karen E Blevins, Geography	1998-1999	Kathleen A Peterson, Plant Biology	1999-2000
Debbie A Brewer, Geography	1999-2000	Jessamy Rango, Biology	1998-present
Kevin B Clark, Biology	1998-1999	Eva C Reid, Geography -GIS Lab	1999-2000
Mark A Compton, Plant Biology	1998-2000	Martin Roberge, Geography	1998-1999
Jamaica Cousins, Plant Biology	1999-present	Sarah Robinson, Geological Sciences	1998-present
Dixie Z Damrel, Plant Biology	1998-1999	Michael Rogers, Curr/Instruction	1998-1999

Lisa Dent, Biology	Summer 1998
Dean Dobberfuhl, Geology	1998-1999
Jennifer W Edmonds, Biology	1998-present
Kenneth Fergason, Geology	1999-2000
Wei Gao, Geography	Spring 1998
Root Gorelick, Economics/Biology	1999-2000
Dennis C Gosser, Anthropology	1998-1999
Dennis Hale, Curr/Instruction	1997-1998
Stephen D Holloway, Geology	1997-1998
Andrew M Honker	1999-present
Justin S Hoppman, Plng /Lndscp Arch	1998-2000
Jeffrey James, Geography	Spring 1998
G Darrel Jenerette, ASU W Life Sci	1998-present
Michael LaBianca, Sociology	Summer 2000
Hongyu Liu, Life Sciences, ASUW	Fall 1997
Matthew A Luck, Biology	1998-2000
Eric S Matranga, Geography	1999-2000
Wendy A Marussich, Plant Biology	1999-present
Nicole McPherson, Civil/Env Eng	1998-1999
Cherie Moritz, Plant Biology/GIS	Fall 1998
Erin Vining Mueller, Plant Biology	1998-1999
Bruce Ryan, Plant Biology	Summer 1999
Samuel Schmieding, History	1998-1999
Gina Serignese Woodall, Political Science	1999-present
Diane M Sicotte, Sociology	1998-present
Curtis Sommer, Anthropology	1999-2000
Kim Sonderegger, Anthropology	1998
L. Brooke McDowell Stabler, Plant Bio	1998-present
William L. Stefanov, Geology	1998-2000
Arthur Stiles, Plant Biology	1998-present
Glenn Stuart, Anthropology	1999-present
Anne Sumner, Curr/Instruction	1999-2000
Steven J Swanson, Anthropology	1998-1999
Wendy Thomas, Geography	Spring 1998
Niccole Villa, Geography	1998-1999
Gretchen Walters, Plant Biology	1998-1999
E Christian Wells, Anthropology	1998-1999
Steven Wood, Geological Sciences	1998-1998
Ying Xu, Civil/Env Eng	1998-present
Angel Zambrano, Plant Biology	1998-1999
Torlaf Zschau, Plant Biology	1998-1999

Other Graduate Students

Michael Applegarth, Geography	1999-present
Jeremy Buegge, Plant Biology	1999-2000
Sheila Conway, GIS Lab	1999
Aisha Coppola, Biology	2000-present
John David, ASU W Life Sciences	1999-2000
Jenny Drnevich, Bio/Eco Explorers	1998-1999
J Richard Fredrickson, Bio/Eco Exp	1998-1999
John Frisch, Biology; Ecology Exp	1998-1999
Kaberi Kar Gupta, Anthropology	2000-present
Randi Mendoza, Bio/Eco Explorers	1998-1999
Elena Ortiz-Zuazaga, Bio/Eco Exp	1998-1999
John Roach, Biology	1998-present
Nancy Selover, Geography	1999-2000
John Schade, Biology	1998 - present
Maurice Tatlow, Geography	1999-present
Russ Vose, Geography	1999-2000
Jill Welter, Biology	1998-present

Research Experience for Undergrads (REU)

Joanne C Blank, REU	Summer 1999
Shawn A Boone, REU	Summer 1999
Andy H Chan, REU	Summer 1998
Noah D Dillard, REU	Summer 2000
Christopher Farley, REU	Summer 1998
Matthew de la Pena Mattozzi, REU	Summer 2000
Christopher Putnam, REU	Fall 2000
Erik J Wenninger, REU	Summer 1998
Selena L Wightman, REU	Summer 1999

Other Undergrads

Juan Beltran, Bird data entry	Summer 2000
Robert Brant, Biology	1999-2000
Matt Bucchin, GIS Lab	Fall 1998
George Cadiente, Geological Sciences	Summer 1999
Natalie Case, Hughs BREU; urban lakes	Spring 1999
Linda Drummond, Plant Biology	1998-1999
Esther Ellsworth, Bio/Sty, Eco Explorers	1999-present
Kevin Fantozzi, Life Sci, ASU W	1998-1999
Travis Fears, IT/Ecology Exp Web site	1998-1999
Ayoola Folarin	1998-1999
Jennifer Folsom, IT/Eco Exp Web site	1998-1999
Marc Hinze, Biology	1998-1999
Moe Moe Htun, Bird data entry	1998-1999
Katie LeBlanc, Anthro, CES office supp	1997-1999
Brian Lutz, Bio/Society, Ecology Exp	1999-present
Lisa C McKelvy, Biology; arthropods	1998-present
Cathryn Meegan, pollen tech; Anthro	Summer 2000
Robert Mitchell, Biology	Spring 1998
Tracy Osborn, Civil/Env Eng	1998-1998
Chris Patterson, GIS Lab	2000-present
Christopher Putnam	2000-present
Barbara Schmidt, Plant Bio	Summer 2000
Chris Sommers, IT/Eco Exp Web site	1998-1999
Diana Stuart, Res Aide; Birder, CES	1999-present
Maria Tcherepova, Plant Biology	Summer 2000
Lisa Thompson, CES, office	1998-present

Jennifer Hunter, Hughs, urban lakes 1999
Lisa Lauver, Civil/Env Eng 1998-1999
Christian Lawrence, Biology; arthropods 1999-1999
Brian Tong, Birder data entry 1999-2000
Sean Walker, Biology; arthropods 1998-1999
Jennifer Zachary, Biology 1999-2000

High school student(s)

Sambo Dul, SCENE research intern 1999
Juan Gomez, Tempe HS 2000
Natalys Ter-Grigoryan, SCENE research intern 1999

Pre-college teacher(s)

Robert Atwood, Meyer Elementary 1999-2000
Renee Bachman, W.T. Machan Elem 1999-2000
Joyce Baldwin, Sacaton Middle School 1998-2000
Jim Barnette, Zedo Ishikawa Elementary 1999-2000
Paula Beacom, Lowell Elementary 1999-2000
Chuck Bell, Deer Valley HS 1999-2000
Wendy Blasdell, Mountain View HS 1999-2000
Dave Boomgaard, Brimhall Jr. HS 1998-2000
Carole Boling, W.T. Machan Elementary 1999-2000
Scott Bowling, Discovery Elementary 1998-2000
Sharlene Cardona, Falcon Hill Elem 1999-2000
Dave Carpentar, Meyer Elementary 1999-2000
Meg Davis, McKemy Middle School 1998-2000
Joelle Don de Ville, St. Mary's HS 1998-200
Ed Eberle, Dobson HS 1998-1999
Vickie Eberle, Sunridge Learning Center 1998-1999
Ann English, Desert Eagle HS 1999-2000
Tad Int-Hout, Desert Harbot Elementary 1999-2000
Michelle Fink, Meyer Elementary 1998-2000
Ann Flagg, EDU Prize 1999-2000
Gerry Foster, Mesquite HS 1999-2000
Scott Greenhalgh, Tempe Union HS 1999-2000
Janet Henderson, Deer Valley Mid Schl 1999-2000
Susie Huffaker, Meyer Elementary 1999-2000
Sue Johnson, The Family School 1999-2000
Teresa Krause, Mendoza Elementary 1998-2000
Larry Langstaff, Hendrix Jr. HS 1999-2000
Sharon Langston, Monte Vista Elem 1999-2000
Karen Lee-Price, Moon Mountain School 2000
Jim Little, Rhodes Jr. HS 2000
Marjorie McKenzie
Jim Manley, Stevenson Elementary 1998-2000
Mary Martine, Kiva Elementary 2000
Vickie Massey, Mendoza Elementary 1998-2000
Robert Meko, Stevenson Elementary 1998-2000
Stephanie Mihalic, Greenway Mid School 2000
Birgit Musheno, Desert Vista HS 1999-2000
Donna Palladino, Copper Canyon Elem 2000
Gary Patterson, Skyline HS 1999-2000
Kathleen Pelley, Evans Elementary 1998-2000
Trish Peters, Pueblo Elementary 1999-2000
Kris Rademacher, Desert Vista High School 1998-1999
Nancy Ragle, McKemy Middle School 2000
Lisa Randall, Stevenson Elementary 1998-2000
Linda Sargent, Mountain View HS 2000
Darlene Sitzler, Eisenhower Elementary 1998-2000
Mike Sliskovich, Supai Middle School 2000
Susan Soroka, McKemy Middle School 2000
Kara Steiner, Mendoza Elementary 2000
Joyce Sterret, Trevor Browne HS 1998-2000
Toby Tucker, Fountain Hills HS 1998-1999
Michelle Volk, Kyrene Aprende Mid Schl 1999-2000
John Wallace, Mountain View High School 1998-2000
Kimberly Wilson, Kyrene Pueblo Mid Schl 2000
Susan Wiseman, Arthur M. Hamilton Schl 2000

Volunteer Participants

Michelle Bagley, Bird Survey
Genine Baker, Bird Survey
Mike Baker, Bird Survey
Lois Bansberg, Bird Survey
Richard Bansber, Bird Survey
Barbara Barnes, Bird Survey
Millie Billotta, Bird Survey
Terry Brodner, Bird Survey
Joshua Burns, Bird Survey
Adam Burdick, Bird Survey
Eleanor Campbell
Evie Chadbourn, Bird Survey
Marty Chew, Bird Survey
Tillie Chew, Bird Survey
Marti Cizek, Bird Survey
Alta Marvin, Bird Survey
Nettie Meyers, Bird Survey
Carol McKernan, Bird Survey
Jane McNeill, Bird Survey
Cathy Merrill, Bird Survey
Grace Miller, Bird Survey
Sandra Mobley, Bird Survey
Carolyn Modeen, Bird Survey
Pete Moulten, Bird Survey
Roy Muehlberger, Bird Survey
Andrea Nesbitt, Bird Survey
Laurie Nessel, Bird Survey
John Nichol, Bird Survey
Maxime Parent, Bird Survey
Tom Partel, Bird Survey

JoAnn Dalcin, Bird Survey
Newilda DeFrance, Bird Survey
John Delventhal, Bird Survey
Bix DeMaree, Bird Survey
Cliff Drowley, Bird Survey
Mildred Eade, Bird Survey
Vicki Eberle, Bird Survey
Amy Elsnic, Vertebrate Species Project
Herbert Fibel, Bird Survey
Dwayne Fink, Bird Survey
Anne Fischer, Bird Survey
Craig Fischer, Bird Survey
Dick Foegel, Bird Survey
Lori Ford, Bird Survey
Jim Forrest, Bird Survey
Jeanne Frieden, Bird Survey
Thomas Gaskill, Bird Survey
Alison Grinder, Bird Survey
George Hansen, Bird Survey
Elizabeth Hatcher, Bird Survey
Helen Haukland, Bird Survey
Meg Hendrick, Bird Survey
Ted Henricks, Bird Survey
Jan Hilton, Bird Survey
William Karl, Urban Lakes Study
Mark Malone, Bird Survey
Charlotte Mars, Bird Survey
Bill Peterson, Bird Survey
Stella Peterson, Bird Survey
Joan Powers, Bird Survey
Timothy Price, Bird Survey
Peg Purcell, Bird Survey
Beverly Rambo, Bird Survey
Jennie Rambo, Bird Survey
Linda Rawles, Bird Survey
Nancy Reed, Bird Survey
Diane Rhodes, Bird Survey
Steve Rissing, Bird Survey
Pat Roberston, Bird Survey
Arlene Scheuer, Bird Survey
Terry Schulte, Bird Survey
Linda Scharf, Bird Survey
Beverly Shaver, Bird Survey
Norm Shrout, Bird Survey
Jim Sommers, Bird Survey
Andree Tarby, Bird Survey
Lorraine Thompson, Bird Survey
Walter Thurber, Bird Survey
Juanita Valentyne, Bird Survey
Anita Van Auken, Bird Survey
Susie Vaught, Bird Survey
Cindy West, Bird Survey
Alice Williams, Bird Survey
Penny Wilson, Bird Survey
Marika Witenko, Bird Survey
Keith Yett, Bird Survey

Partner organizations:

Phoenix Urban Systemic Initiative: Collaborative Research

Three teachers from the USI who have served as Collaborative Peer Teachers(CPT) have joined the CAP LTER K-12 education program. By virtue of their training in inquiry-based learning and the national reforms in science and math, these teachers naturally facilitate the objectives of the CAP LTER project. In addition, Michael Lang, USI project director, has provided a list of all CPTs who might serve as future participants in the K-12 education program. Lang serves on the K-12/Informal Science Education Advisory Team.

Mesa Systemic Initiative: Collaborative Research

Two teachers from the MSI who have served as Collaborative Peer Teachers (CPT) have joined the CAP LTER K-12 education program. By virtue of their training in inquiry-based learning and the national reforms in science and math, these teachers naturally facilitate the objectives of the CAP LTER project. In addition, Bob Box, project director of the MSI, sits on the K/12/Informal Science Education Advisory Team.

Arizona Tribal Coalition, UT-CO-AZ-NM-Ru: Collaborative Research

Two teachers from the RS, who served as Collaborative Peer Teachers (CPT),have joined the CAP LTER K-12 education program (one from the Gila River Indian Reservation and one from the Salt River Pima-Maricopa Indian Community). By virtue of their training in inquiry-based learning and the national reforms in science and math, these teachers naturally facilitate the objectives of the CAP LTER project. The coalition also serves on our K-12/Informal Science Education Advisory Team.

Desert Botanical Garden: Facilities;Collaborative Research
The Desert Botanical Garden provides one of the collection sites for Ecology Explorers and also serves as one of our long-term sampling sites. A permanent, long-term monitoring, experimental plot was installed to measure net primary productivity as affected by human activities and to obtain the measurements needed to establish allometric relationships. We also initiated “focused field trips” to the DBG in Fall 1999. In addition, the DBG serves on our K-12/Informal Science Education Advisory Team.

The Phoenix Zoo: Facilities; Collaborative Research
The Phoenix Zoo provides one of the collection sites for Ecology Explorers. We also worked extensively with the Zoo to develop a focused field trip relating to the bird survey. In addition, the zoo serves on our K-12/Informal Science Education Advisory Team.

Arizona Science Center: Facilities; Collaborative Research
The Arizona Science Center, under the leadership of Laura Martin, is a strong partner in our K-12 educational outreach programs. In particular, the Center has been a strong collaborator in the proposal, Down to Earth Science: Graduate Teaching Fellows in K-12 Education, submitted to NSF's directorate for Education and Human Resources. As part of the project, the Center would offer fellows, teachers, and students “focused field trips.” They would contribute staff time to develop exhibit “trails” to support what the students would be learning, help teachers guide students, and provide plantarium shows for each visiting group. The Center will participate in focusing student attention on exhibits that relate directly to long-term research. The Science Center also serves on our K-12/Informal Science Education Advisory Team.

Arizona Historical Society Museum: Facilities; Collaborative Research
The Historical Society has shown great interest in serving as a “focused field trip” site for our K-12 educational program. In particular, this site offers teachers a place where students can integrate social perspectives with the scientific data they are collecting (land use, cultural history, and demographics).

Southwest Center for Education and the Natural Environment: *In-kind Support; Facilities; Collaborative Research; Personnel Exchanges*
The Center for Environmental Studies (CES) and the CAP LTER K-12 education program partners with the Southwest Center for Education and the Natural Environment (SCENE), an organization that calls upon University expertise to provide science-based environmental education to the K-12 community. SCENE links ASU with broader community interests and further strengthens partnerships initiated in CES's other research and outreach activities. The CAP LTER K-12 education team works closely with SCENE to promote programs to teachers. Successful collaborations include: Science Connections, which has brought CAP LTER scientists into K-12 classrooms; Native Habitat Restoration, which has helped schools to create native habitat areas for use as outdoor learning labs and to test CAP LTER protocols; and Research Experiences for High School Students, which has brought gifted students to the ASU campus to work in labs or on field research projects associated with our long-term ecological research project.

Tonto National Forest: Collaborative Research
The Tonto National Forest actively participates in the CAP LTER project by allowing long-term sampling to take place on TNF land and by attending meetings of interest, including the monthly All Scientist Council Meetings. We are currently collaborating with the Sycamore Creek Riparian site to develop an environmental education program.

Arizona Public Service: In-kind Support; Collaborative Research
Louise Moskowitz, education program coordinator for APS, a publicly owned power company, has pledged to provide computer equipment and software to CAP LTER K-12 teachers whose schools have minimal computer support. In addition, the CAP LTER Education Liaisons inform teachers about the APS Teacher Venture Grant, as well as other educational opportunities offered through APS.

Maricopa Community Colleges: Collaborative Research
The MCC District, through the Urban Systemic Initiative, partners with CAP LTER on inquiry-based learning objectives. In addition, the District serves on our K-12/Informal Science Education Advisory Team.

Motorola: In-kind Support; Collaborative Research
Motorola has been an instrumental partner in CAP LTER outreach activities. Motorola continues to: 1) fund an educational liaison position; 2) design logos, exhibit displays, bookmarks, and associated communications materials for the Ecology Explorers program; 3) work with project staff to design and produce our newsletter; and 4) contribute in-kind contributions (computers, as well as design, production, and printing costs of the newsletters and other materials).

Salt River Project: Facilities; Collaborative Research; Personnel Exchanges
The Salt River Project (SRP) is a semipublic organization responsible for the management of water in the metropolitan area for public, industrial, and agricultural use. It is also one of two major electrical energy suppliers for the region. The CAP LTER project has a long-term research and outreach relationship with SRP, and they have been a crucial partner in a number of our pilot projects. SRP greatly facilitated the work of the Historic Land Use Team in Phase I of their study, which involved capturing desert, agriculture, and urban land uses for the Phoenix metropolitan area. SRP's involvement in this study helped to produce maps and tables of generalized land use for the years 1912, 1934, 1955, 1975, and 1995. In addition, SRP has contributed greatly to the nitrogen mass balance study by providing data on groundwater nitrate levels, daily flows in canals and laterals, and water deliveries and irrigated acreage at 240 “gates” within their system. They have also contributed data to a separate groundwater nitrogen mass balance project. Representatives from SRP attend our monthly All Scientist Council meetings and meet regularly with project scientists to discuss common concerns.

Arizona Dept. of Environmental Quality: Facilities; Collaborative Research
ADEQ has been a primary partner in collaborative proposals submitted to the EPA's EMPACT program that seek funding to provide Phoenix communities with real-time environmental information (in this case, air quality information). In addition, one of the main sites for the CAP LTER atmospheric deposition study is located at ADEQ's SuperSite. As part of their involvement in the study, ADEQ measures concentrations of airborne pollutants.

U.S. Geological Survey: Facilities; Collaborative Research
The USGS collaborated with the Historic Land Use Team in Phase I of their study, which involved capturing desert, agriculture, and urban land uses for the Phoenix metropolitan area. Their involvement helped to produce maps and tables of generalized land use for the years 1912, 1934, 1955, 1975, and 1995. As part of our long-term water monitoring project (WMP), we are monitoring several USGS NAWQA sites in our goal of measuring the chemistry of surface waters upstream, downstream, and within the Phoenix metropolitan area. CAP LTER scientists are also collaborating with the USGS on studies of water quality and storm sampling. Lastly, data from USGS has been acquired and converted to formats and/or projections compatible for use in LTER research.

City of Phoenix: Facilities; Collaborative Research
The City of Phoenix has issued blanket permission for CAP LTER to conduct fieldwork in the city's extensive park system, including at South Mountain Park. The urban fringe infrastructure project, which is in its initial phase, has obtained permission from the City of Phoenix to use water and sewer infrastructure information in the form of paper plats and electronic files. In addition, representatives from various city agencies have served as information resources to CAP LTER project personnel.

City of Scottsdale: Collaborative Research
The City of Scottsdale has entered into an agreement with CAP LTER to conduct a nutrient limitation study at Indian Bend Wash. The study is expected to yield useful data that may help in the management of algal growth. In addition, representatives from the Environmental Management have served as information resources to CAP LTER personnel, as well as partners in numerous grant proposals.

The City of Tempe: Collaborative Research
The City of Tempe has partnered with CAP LTER in the nitrogen balance study, particularly in allowing access to stormwater retention basins and to non-retention areas for purposes of sampling soil and stormwater. In addition, city representatives have served as information resources to CAP LTER personnel.

U.S. Dept. of Agriculture: Collaborative Research
The USDA/Maricopa County Cooperative Extension Service provided curriculum materials for the CAP LTER summer internships and acts as a resource to participating teachers.

U.S. Forest Service: Facilities; Collaborative Research
The USFS has granted us access to numerous locations in the Tonto National Forest. Locating sampling sites on land adjacent to the city has enabled us to establish control sites for monitoring ecological variables.

Flood Control District of Maricopa Co.: Collaborative Research
We are collaborating and sharing data with the Flood Control District in projects related to storm hydrology and stormwater chemistry.

Arizona State Land Dept.: Facilities; Collaborative Research
The Land Department has been very helpful in providing CAP LTER access to areas under their jurisdiction. In addition, project scientists have collaborated with land department personnel on a study of insect communities on creosote bushes.

Pueblo Grande Museum: Collaborative Research
The museum serves on our K-12/Informal Science Education Advisory Team.

Tempe Union High School District: Collaborative Research
Teachers and students from this district (and those below) participate in the following Ecology Explorer activities: 1) summer internships for teachers; 2) scientist visits to classrooms; 3) data entry into the Ecology Explorers Web site; 4) opportunities to participate in CAP LTER poster sessions and regional science fairs; and 5) schoolyards as sites for gathering CAP LTER ecological data.

Tempe Elementary School District: Collaborative Research
Teachers and students from this district participate in Ecology Explorers.

Peoria Unified School District: Collaborative Research
Teachers and students from this district participate in Ecology Explorers.

Deer Valley High School District: Collaborative Research
Teachers and students from this district participate in Ecology Explorers.

Glendale School District: Collaborative Research
Teachers and students from this district participate in Ecology Explorers.

Phoenix Elementary School District: Collaborative Research
Teachers and students from this district participate in Ecology Explorers.

Creighton School District: Collaborative Research
Teachers and students from this district participate in Ecology Explorers.

Phoenix Union High School District: Collaborative Research
Teachers and students from this district participate in Ecology Explorers.

Mesa Public Schools: Collaborative Research
Teachers and students from this district participate in Ecology Explorers.

Fountain Hills High School District: Collaborative Research
Teachers and students from this district participate in Ecology Explorers.

St. Mary's High School: Collaborative Research
Teachers and students from this district participate in Ecology Explorers.

Gilbert High School District: Collaborative Research
Teachers and students from this district participate in Ecology Explorers.

Gila River Community Schools: Collaborative Research
Teachers and students from this district participate in Ecology Explorers.

Salt River Pima-Maricopa Indian Community: Collaborative Research
Teachers and students from this district participate in Ecology Explorers.

Maricopa County Parks and Recreation Department: Collaborative Research
Our K-12 education program has entered into a full partnership with the MPRD's Desert Outdoor Center, an environmental education facility located at Lake Pleasant, in the Sonoran Desert north of Phoneix. CAP LTER scientists have established collections sites at the center, where staff will integrate K-12 protocols into their program. Data will be input onsite, in their computer facility. For teachers involved in CAP LTER research, data collected from this rural site will allow for comparisons to their urban schoolyard sites.

Arizona Geographic Alliance: Collaborative Research
The Arizona Geographic Alliance, coordinated by the ASU Geography Department, provides teacher workshop materials for our teacher internship program. The alliance also serves on our K-12/Informal Science Education Advisory Team.

AZ Collaborative for Excellence in Preparation: Collaborative Research
ACEPT, on the ASU campus, advises our K-12 outreach program on inquiry-based materials for teacher internships. The collaborative also serves on our K-12/Informal Science Education Advisory Team.

Office of Youth Preparation: Collaborative Research
The Office of Youth Preparation at ASU, serves as an advisor to the CAP LTER K-12 program for developing inquiry-based materials for teacher internships. The OYP also serves on our K-12/Informal Science Education Advisory Team.

Arizona School Services through Education Technology: Collaborative Research
ASSET, located at ASU, serves on our K-12/Informal Science Education Advisory Team.

Office of Research Publications: Collaborative Research
This ASU office publishes a 4-color magazine, *Chain Reaction*, as well as science books and materials related to the Sonoran Desert ecology for the K-12 community. These materials were provided to the CAP LTER teacher workshops. The collaborative also serves on our K-12/Informal Science Education Advisory Team.

Maricopa Association of Governments: Collaborative Research
MAG, consisting of the 24 incorporated cites and towns within Maricopa County, 2 Indian communities, and Maricopa County, has been an integral partner to the CAP LTER project. They have supported the project by supplying GIS information and data that they use to support their regional planning eforts. Rita Walton, MAG's policy and information manager, works with the Land Use Change Team and was co-author of a CAP LTER study on land consumption and absorption rates. MAG continues to collaborate on CAP LTER investigations into growth planning, land-use projections, open space implementation, and environmental programs.

Arizona Department of Water Resources: Collaborative Research
The ADWR collaborated with the Historic Land Use Team in Phase I of their study, which involved capturing desert, agriculture, and urban land uses for the Phoenix metropolitan area. Their involvement in this study helped to produce maps and tables of generalized land use for the years 1912, 1934, 1955, 1975, and 1995.

Other collaborators:
The following businesses/organizations/agencies have given the CAP LTER project permission to conduct long-term monitoring of ecological variables on their sites:

- Arizona Department of Environmental Quality
- Arizona Public Service
- Arizona Department of Transportation
- Arizona State Land Department
- Arizona State Parks
- City of Phoenix
- City of Chandler
- City of Scottsdale
- City of Tempe
- Desert Botanical Garden
- Duncan Family Farms
- Flood Control District of Maricopa County

Honeywell
Insight Enterprises
Intel
Maricopa County Department of Environmental Services
Maricopa County Parks and Recreation Department
Morrison Brothers Ranch
Rogers Brothers Farms
Salt River Project
Sonoma Farms, Inc.
Tempe Union High School District
Tonto National Forest
Town of Fountain Hills
US Forest Service
US Geological Survey
Valley Lutheran Hospital
Dobson Ranch Homeowners Association
Dawn Lake Homeowners Association
Las Brisas Homeowners Association
Val Vista Lakes Community Association
Ocotillo Homeowner Association

Appendix A. CAP LTER Projects

*Lead PI listed first, student research associates in parentheses (), techs/field assts. in brackets [], *italics* indicate former participants in ongoing projects

No	Team	Title	Project Type	Participants*	Start Date	Status
1	DB	Establish pilot GIS database	Data synthesis	Fry, McCartney, Wu, Wentz (Gao, Maruffo, Swanson, Wells)	Fall 97	Completed
2	DB	Using Remote Sensing to Define Patch Typology	One time	*Ramsey*, Christensen, Hope, Burns, Wu, Gober (Stefanov)	Fall 97	Ongoing
3	LU	Urban Fringe Morphology	One time	Burns, Gober, Walton, Knowles-Yanez (James, Blevins)	Spring 98	Completed
4	DB	Modeling: Initial Structure and Work on GIS	Data synthesis	Wu (Luck)	Spring 98	Ongoing
5	GE	Century-scale Channel Change	One time	Graf (Roberge)	Spring 98	Completed
6	GE	Quaternary Geomorphology Study and Data Synthesis	One time	Arrowsmith (Robinson, Wood, Holloway)	Spring 98	Completed
7	NU	Nutrients and Data Synthesis, Mass Balance	Data synthesis	Hope, Baker, McCartney (Ying, Lauver, McPherson)	Spring 98	Completed
8	NU	Aquatic Core Monitoring (Continuation of NAWQA)	Long term	Hope, Grimm, Baker (Edmonds)	Fall 97	Ongoing
9	NU	Lichen Resurvey with Heavy Metal Analysis	Repeat experiment	Gries, Nash, Getty (Zschau, Zambrano)	Spring 98	Completed
10	PO	Pilot Arthropod Sampling	Long term	Faeth, Fagan, McIntyre, Shochat, (Rango) [Tseng, McKelvy, Stuart]	Spring 98	Completed
11	PO	Plant Survey of Current Vegetation	Data synthesis	Scheiner (Stiles)	Spring 98	Ongoing
12	PO	Bird Survey with Data Synthesis	Data synthesis	*Hostetler*, Katti, *Pearson*, *Ohmart*, Deviche [Stuart, Rambo, Hulen, Lemmer, Bachman]	Spring 98	Ongoing
13	ED	Ecology Explorers	Long Term	Staley, *Lindauer*, Elser, Williams, Kyle (*Hale, Rogers*, Sumners)	Fall 97	Ongoing
14	OM	Comparison Among Residential Patch Transition Types; Before-After	One time	Martin, Brazel, Burns (Stabler, Peterson, Blank)	Spring 98	Completed
15	DI	General Model of Urban Fire Ecology	One time	Pyne (Schmieding, Ammerman)	Summer 98	Completed
16	GE	Historic Records of Climate in Valley	One time	*Balling*	Spring 98	Not conducted
17	LU	Hohokam Canals as Multi-Use Facilities	One time	Spielmann, Rice (*Sonderegger*)	Spring 98	Pending
18	HU	Economic Analysis, Open Space	One time	Hogan, Ormiston (Becker)	Spring 98	Completed
19	LU	Historical Land Use Database	Long term	Redman, *Knowles-Yanez*, Fry, McCartney, Keane (*Moritz,* Reid, Hoppman) [Smith]	Summer 98	Ongoing
20	GE	Multi-Temporal Remote-Sensing Data Acquisition for CAP LTER Land Cover/Land Use Monitoring and Modeling	Data synthesis	Ramsey, Wu, Burns, (Stefanov)	Summer 98	Completed
21	PP	Above and Below Ground Estimates of Urban Plant Biomass	Repeat experiment	Klopatek, Klopatek	Summer 98	Not conducted
22	PO	Assessing Biodiversity of Arbuscular Mycorrhizal Fungi	Repeat experiment	Stutz, Martin (Cousins)	Summer 98	Ongoing
23	PO	Vertebrate Species Composition of Remnant Desert Islands within Urban Phoenix	One time	Ohmart, Clark	Summer 98	Completed
24	NU	Urban Lakes: Recipient Systems for Nutrients and Contaminants	Long term	Sommerfeld (Compton, Hunter, Case) [Holland, Myers, Bradbury, Walters, Karl]	Summer 98	Completed
25	PO	Scorpions in Urban Environments	One time	McIntyre	Fall 98	Completed
26	PO	Effects of Urban Horticulture on Insect Pollinator Community Structure	One time	*Hostetler*/McIntyre [sample collection: Compton, Hope, Stabler, Naegeli, Rango, Rissing, Stefanov, Stiles, Walters, Wells, Williams, Zhu, Bradbury, Holland, Meyers; taxonomic id, Minckley]	Fall 98	Completed
27	PO	Survey 200	Long term	Redman, Grimm, Hope, Gries, Carroll, Zhu, McCartney (Stabler, Stiles) [Rosales, Myers, Clary, Lemmer, Budet de Jesus, Paine, Tseng, Walters, Kochert] other: Martin, Green, Scheiner, Brazel, McIntyre, Faeth, Nelson, Burns, Katti, Shochat, Stuart, Rainey	Spring 99	Ongoing
28	NU	Urban Storm Runoff		Hope, Naegely, Grimm	Spring 99	Completed
29	LU	Are Microclimates Sustainable on the Urban Periphery of Phoenix, Arizona?	One time	Brazel (Anderson)	Fall 98	Ongoing
30	GE	Decade-Scale Change by Channel Eng: The Rio Salado (Tempe Town Lake) Project--Hydrogeologic component	One time	Arrowsmith, Tyburczy (Fergason)	Fall 98	Completed
31	NU	Atmospheric Deposition	Long term	Hope, Grimm, Anderson [Clary, Paine, *Holland, Bradbury*] (*Boone*)	Fall 98	Ongoing

32	HU	Environmental Risk	Long term	Bolin, Hackett, Pijawka, Sadalla, van der Leeuw, Nelson (Brewer, Mtranga, Sicotte)	Fall 98	Ongoing
33	PO	Backyard Bird Survey	Long term	*Hostetler*, Katti, Shochat, *Pearsom. Ohmart*, Deviche [Stuart, Rambo, Hulen, Lemmer, Bachman]	Spring 98	Ongoing
34	PO	Point Count Bird Censusing	Long term	*Hostetler*, Katti, Shochat, *Pearsom. Ohmart*, Deviche [Stuart, Rambo, Hulen, Lemmer, Bachman]	Summer 98	Ongoing
35	NU	Canal Study	One time	Grimm, Hope (Roach)	Summer 99	Completed
36	PO	Bruchid Beetle Study	Long term	Craig (Wallace)	Spring 98	Ongoing
37	LU	Spatial/Temporal Change of Climate/Air Quality in Relation to Urban Fringe Development	One time	Brazel, (Selover, Vose)	Summer 99	Ongoing
38	GE	Prediction Model of the Presence of Bedrock Pediments vs. Alluvial Slopes	One time	(Applegarth) Dorn, Brazel	Spring 00	Ongoing
39	LU	Urban Fringe Infrastructure Morphology	One time	Burns, Nelson (Sun)	Spring 00	Ongoing
40	HU	A River Used to Run Through It: Water Use and Flooding in Phoenix	One time	Honker	Spring 00	Ongoing
41	HU	Phoenix Area Social Survey		Harlan, Nelson, Hackett, Sadalla, Bolin, Pijawka, Hogan, Rex, Kirby	Spring 00	Ongoing
42	LU	Gender and Racial/Ethnic Inequality in Postindustrial Urban Labor Markets: A Spatial and Sectoral Analysis of Employment Changes	One time	Nelson, Harlan (Sicotte, LaBianca)	Spring 00	Ongoing
43	HU	Dynamic Political Institutions and Water Policy in Central Arizona - Phoenix	One time	Krutz (Serignese)	Summer 00	Ongoing
44	NU	Nutrient Transport and Retention in Urban Watersheds	One time	Grimm, Boyers, Hope, Zhu, (Roach, Jennerette, Coppola, Dillard, Zachary)	Spring 2000	Ongoing
45	HU	Social Area Analysis	One time	Nelson, Martin	Summer 00	Ongoing
46	PO	The Effects of Urbanization on Reproduction in Birds	One time	Katti, Deviche	Summer 00	Ongoing
47	PO	Plant Species Richness Patterns in the CAP LTER Area (initially part of project 11)	Data synthesis	Pinkava, Landrum, (Damrel)	Spring 98	Completed
48	PP	Effects of Urban Ground Cover on Microclimate and Landscape Plant Performance (initially part of project 14)	One time	Day, (Vining Mueller)	Spring 98	Completed
49	LU	Land Use Effects on Temperature and Humidity along a Urban-Rural Transect Gradient (initially part of project 14)	One time	Martin, Brazel (Stabler)	Summer 98	Completed
50	OM	Soil CO_2 Flux and Enzyme Activity Under Two Patch Type Conversions (initially part of project 14)	One time	(Oleksyszyn) Green	Spring 98	Completed
51	PP	Landscape Water Use Efficiency (initially part of project 14)	One time	Stabler, Martin	Spring 98	Completed