CENTRAL ARIZONA – PHOENIX LTER (DEB-9714833)
LAND-USE CHANGE AND ECOLOGICAL PROCESSES IN AN URBAN ECOSYSTEM OF THE SONORAN DESERT

Annual Progress Report, 1998-1999

(A somewhat condensed version was submitted to NSF via Fastlane, September 29, 1999.)

I. GENERAL INFORMATION ABOUT CAP LTER

The CAP LTER is a multifaceted project 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 this alters ecological pattern and process, and how changes in ecological conditions further influence human decision making. The overall approach will incorporate a hierarchical, patch-dynamics model for the metropolis as an ecosystem, but studies and models at smaller spatial scales and lower levels of organization are integral to this work.

Initial projects began in spring 1998, falling under the general categories of: 1) data synthesis (amassing, checking, formatting, and using existing data from municipalities, agencies, and governmental and nongovernmental organizations); 2) pilot projects for long-term monitoring (working out the details of methods, site selection, statistical characteristics of data sets, etc. for designing efficient and appropriate long-term monitoring projects); 3) experiments (both unique opportunities for one-time experiments and repeat surveys or experiments to compare with studies done 10 or 20 years ago); 4) developing frameworks for modeling structure and patch topology. This year's report provides updates and findings from our initial work and describes plans for the core long-term monitoring effort. Results from the data synthesis projects provide substantial resources for ongoing work; the long-term monitoring design is taking shape and a pilot project was conducted in spring 1999 to refine the protocols and procedures for a 200-point survey scheduled to begin in spring 2000; initial experiments have been completed or are being completed this summer; and work continues on developing frameworks for modeling structure and patch topology in the context of evolving GIS and remote sensing databases.

Initially, considerable effort went into ensuring open lines of communication and achieving maximal input from the large number of participating core scientists (>50). The All Scientists Council continues to meet monthly in a forum focusing on current research (open to interested parties); a Management Leadership Council meets occasionally to facilitate integration among teams; and an Executive Committee meets as needed (usually biweekly) to establish and review policy, as the primary search committee for postdoctoral hires, and to allocate resources. Integrating diverse research activities in the CAP LTER project will be achieved in some cases through internal dissemination of results and naturally evolving collaborations among project scientists. However, we recognize that deliberate steps to encourage integration are necessary. To this end, each summer we host a 1-day workshop or "summit" and each winter we hold a poster symposium presenting research results. This year nearly 50 attendees participated in a summer summit intended to explore the potential for integrating ecological variables into social science projects or vice versa. The 1999 (first annual) CAP LTER Poster Symposium featured John Magnuson (NTL LTER) as keynote speaker and 32 posters presenting research results. For the first two project years, 60 faculty, 4 outside scientists (e.g., from USGS and MAG), 7 postdoctoral scholars, 56 graduate students, 21 undergraduates (including REU students), 23 professional and office staff, 44 pre-college teachers, and 45 volunteers have been or currently are actively involved in CAP LTER projects. Project descriptions can be viewed on the CAP LTER Web site (http://caplter.asu.edu/).

II. HIGHLIGHTS OF RESEARCH ACTIVITIES FOR YEAR 2

Activities in Year 2 continued to center on acquiring requisite information for establishing a rational, spatially based monitoring program. We have acquired existing data to get a sense of the overall structure (including historic spatial patterns) of the CAP LTERstudy area, in order to define patch topology and long-term monitoring schemes and to construct initial materials budgets for the whole system. New data collection was undertaken where little previous information existed, as in populations, primary production, and organic matter dynamics. Modeling activities continued in concert with data synthesis and new data acquisition activities.

Several initial projects are nearly complete but will evolve into elements of core monitoring (urban water chemistry, primary production, organic matter storage and soil respiration, arthropod sampling). Some initial projects have investigated underlying dynamics likely to be key drivers of ecosystem processes and human-ecosystem interaction (e.g., describing urban growth patterns, uncovering the relationships between land cover and land use, defining the economic value of open space). Considerable effort was devoted to the design of a 200-point survey that will be implemented in spring 2000 and every 3-5 years thereafter. In spring 1999, we also embarked on an environmental risk study to create a composite hazards map of the metropolitan area and link it to socioeconomic variables. Ecology Explorers, our educational outreach program, has taken off in this second year and is attracting a strong following of teachers and students who are directly participating 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 initiated in 1998 and 1999. Figure 1 illustrates the location of our pilot sampling sites.

Remote Sensing and Patch Topology

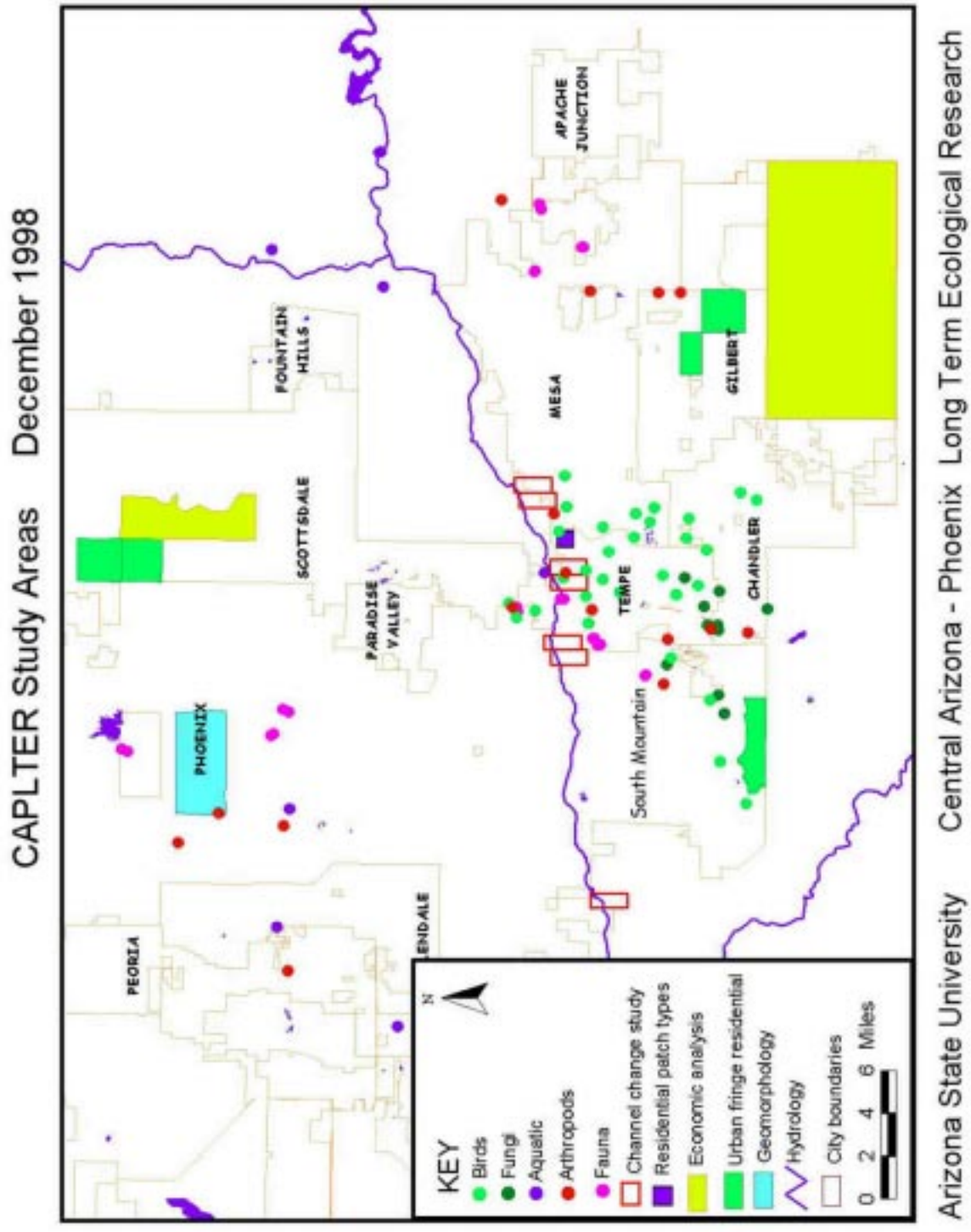
The definition of patch types and their distribution in the CAP LTER area is highly variable depending on individual project goals. Further, “patches” in a remote sensing context are limited to the resolution of the dataset being studied (in this case, 30 meters for Landsat TM) and may change with time. Therefore, this project involved completion of a land cover map, derived from remotely sensed data, for the region. Classified land cover information forms the baseline dataset for ecological, geological, and geographic models of spatial and temporal change used to investigate the urban environment. A Web site and data server has been created to provide these data to all CAP LTER scientists [http://elwood.la.asu.edu/grsl/maps/data_serv.html]. Work completed during the past year has built upon initial classification efforts that concentrated on an east central Phoenix-Tempe pilot study region. The aims of the pilot study were to demonstrate feasibility of the technique and refine the processing procedure. Expansion of the east valley pilot study was carried out in the last year using Landsat Thematic Mapper (TM) data collected during May and June 1993 as the base dataset for classification.

Ecological models generally require data in the form of land use rather than land cover. However, remotely sensed data record energy interactions with surface materials (land cover). This required the development of a correlation scheme to relate the land cover classification derived from TM data to the land-use units of interest to CAP LTER investigators. This dataset is now available to CAP LTER researchers at the Geologic Remote Sensing Laboratory's Web site. Refinement and error checking continue. In addition, a vegetation abundance image (NDVI) has been created by special request and placed on the GRSL site. Remote sensing activity will continue as a long-term project, making the transition from a pilot study.

Hierarchical Patch Dynamics Model

Modeling activities during Year 2 were development and refinement of the hierarchical patch-dynamics modeling (HPDM) framework for the CAP LTER, and hierarchical analysis of the CAP landscapes based on land cover and land-use data. Long-term goals and objectives include: 1) developing a land-use change model for Central Arizona - Phoenix; 2) adapting and evaluating patch-level ecosystem process models

FIGURE 1. CAP LTER 1998-99 SAMPLING SITES



appropriate for the CAP LTER project, and 3) linking patch-ecosystem models with the land-use change model to construct a hierarchical patch-dynamics model of Central Arizona - Phoenix (HPDM-CAP).

HPDM-CAP will be 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 will be developed for different land cover types. Upon reviewing a wide range of existing models of arid and semiarid ecosystems, we have identified two patch-level ecosystem models: the Patch AridLand Simulator and CENTURY. Based on these two models, we will develop different versions of patch-ecosystem models for the different land-use types in the study area. The patches may be vegetation remnants, shopping centers, residential areas, and golf courses. These models will provide information necessary not only for understanding fine-scale interactions between urbanization and ecology, but also 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 patches. At the regional (CAP) scale, we will build 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.

The following research questions are being addressed by this approach: 1) how can the historical changes in land-use pattern in the Phoenix metropolitan area be quantified?; 2) how will the land-use pattern in the Phoenix area change in future (50 to 100 years) with different scenarios of driving forces?; and 3) how will land-use change affect ecosystem processes (nutrient cycling), biodiversity measures (species richness of selected plant and animal groups), and other ecological properties (e.g., persistence of certain valuable species, invasion of exotics, water resources)? In Year 2 we completed the following:

- developed the hierarchical patch-dynamics modeling framework with specific implementation plans. Conducted a series of landscape pattern analysis at different spatial scales to capture and understand the structural characteristics of the study area;
- carried out spatial analysis with the historical land-use dataset to quantify the dynamic spatial pattern of urbanization;
- developed a cellular automaton/Markovian simulation model of land-use change;
- designed a method for validating satellite image land-cover classification; ordered supplemental digital imagery for land-cover classification validation; began to compile and format digital time series socioeconomic data; developed initial methods for determining the effects of scale and aggregation on the accuracy and representation of landscape patterns.

Survey 200: Interdisciplinary Core Long-Term Monitoring Project for CAP LTER

The culmination of the CAP LTER start-up phase was the design of an extensive survey for the metropolitan area that can be repeated infrequently (every 3-5 years) and will encompass the continued growth of the city. Every effort was made to include both social and ecological variables in this sample and to identify the best design for statistical analysis. Survey 200 will form a core body of data to which other more spatially restricted but temporally detailed studies can be related. Thus, we plan more frequent and detailed monitoring on subsets of the core 200 sampling sites.

Survey 200 aims to quantify vegetation and built structure across the study area, characterize other essential ecological parameters (soil physical and chemical properties, microbial diversity, litter decomposition rates), and survey insects, birds, and human activities. In addition to collecting basic data on structure, key biotic variables, and human activity for the LTER project as a whole, the survey will provide a basis for scaling up plot- and site-specific studies, help integrate different disciplinary studies, and allow comparison with a similarly designed study in the Baltimore LTER.

The CAP LTER study area is ca. 6500 sq. km and encompasses most of Maricopa County. Sample point locations have been arranged using a tessellation-stratified design, whereby the study area was divided into

approx. 200 (4 x 4 km) grid squares. A sample point has been located at random in each grid square within a central urban area. Outside this central core, where development is sparse and there is a high proportion of undeveloped and vacant land, only every third grid square is sampled in the same random manner. The main survey will be conducted in a 17.4-m radius (900 sq. m) plot by a four-person field team that carries out a standard procedure to collect locational, structural, ecological, and social data. A pilot survey at 20 plots was conducted this spring; the main survey of all 200 plots will be conducted in spring 2000. The exact location of all plots is being determined and permissions to conduct the survey are being obtained.

Geosciences and Engineering

Three main projects in Geosciences and Engineering (supported from 97-99 by the Geosciences and Engineering Supplement) are studies of quaternary geomorphology of the Phoenix Basin, century-scale channel change in the Salt River, and a pilot project on the Tempe Town Lake/Rio Salado. In the quaternary geomorphology project, landscape development in the CAP LTER region is studied by compiling existing information and applying traditional and new geological mapping techniques. Landscape development over the last million years has determined the distribution of materials at the surface and in the shallow subsurface and has controlled the region's topographic form. These effects define the spatial and temporal context for the ecological relationships CAP LTER studies. The activity of the rivers that flow through the region dominates the area's recent geologic history. The Gila River (and its important tributaries, the Salt, Hassayampa, and Agua Fria Rivers) has existed as a major tributary of the Colorado River for the past 8-9 million years. Alluvial deposits filled the basin floor for much of the early and middle Pleistocene, followed in the late Pleistocene and early Holocene by a period of downcutting during which the drainages removed earlier alluvial material and formed a series of inset terraces. Climatically correlated changes in surface transport rates and sediment supply apparently drove this alternation of aggradation and entrenchment.

We are gaining an understanding of the development of the landscape by applying traditional and new geological mapping methods to document the distribution of materials and the relative ages of geologic events. One outstanding question involves the timing of landscape development. We have made good progress in our efforts to apply the tool of cosmogenic dating to establish numerical ages for the incision and aggradation events. We also are establishing GIS and remote sensing databases, important foundations for the multidisciplinary models central to the LTER project, created a bedrock geology map; and undertaken a high-precision gravity survey of the western alluvial fan flank of the White Tank Mountains, which will determine the depth-to-bedrock profile and allow us to create a three-dimensional interface. This information will allow for the calculation of sediment flux to better determine the geologic history.

Century-scale channel change project: The main research questions addressed in this investigation of the Salt and Gila Rivers are what are the spatial and temporal components of change in the functional surfaces of the Salt River in the Phoenix metropolitan area, and what are the causes of these changes? The general approach has been to use historical aerial photography supplemented with field investigations to track the geographic changes in the channel over the past 60 years and to use a GIS to create maps of the channel area showing the probability of encountering channel surfaces in any location. Causes of change were revealed through historical hydrology and hydraulic calculations. All the work has been completed and a manuscript is in press (Graf 2000).

Rio Salado/Tempe Town Lake Project: The City of Tempe is undertaking a large ecological, hydrogeological experiment. A new urban lake was created in the dry Salt River bed that runs through the center of the city. The lake is over 3.2 km long, about 320 m wide, has a surface area of about 100 ha, and contains about 2500 acre-feet of water. The geological/hydrogeological aspect of the study is to determine the effects of lake filling on local transient hydrological flow, formulate an improved 4D hydrogeological model of the area, and provide subsurface geophysical control for the geochemical and biological research efforts taking place in conjunction with this effort.

During spring 1999, a grid of approximately 50 stations for microgravity measurements was set up, and two complete surveys of the stations were completed to provide baseline data before the lake started filling

in early June. Determining changes in gravity to a level of 1-10 microgals (to 1-10 parts in 10^9 of the earth's ambient gravity field) will enable us to determine water levels in areas not covered by wells and aquifer porosity in areas that do have well coverage. As the new hydrogeological steady state becomes established, we have been regularly collecting gravity data to monitor transient flows and water levels. We also have measured nutrient and other chemical concentrations in lake, inflow stream, and ground waters since initial filling, as well as algal populations, biomass, and zooplankton. We view this project as an excellent microcosm of the entire CAP LTER, because this "urban experiment" involves all components envisioned in our conceptual scheme of urban ecosystems: land-use change, change in ecological conditions, human feedbacks, and geophysical and societal constraints and drivers.

Land-Use Change

One initial project of the land-use change team focuses on the morphology of the urban fringe. In addition, this team is involved in developing the CAP LTER GIS database through their collaboration with the Maricopa Association of Governments (MAG). Another project was to compile data on land-use change during the 20th century.

The urban fringe project tracked the spatial distribution of the expanding urban fringe between 1990 and 1997. A clear interpretation of data analyzed thus far is that every location is changing in metropolitan Phoenix. A donut spatial structure results. Although housing loss occurs in central locations, net residential densities increase at the urban fringe. A study of urban fringe morphology has also been conducted. Completed and ongoing research has investigated the amount, density, and spatial configuration of residential construction on the urban fringe using a GIS coverage of housing completions between April 1, 1990 and June 30, 1998. We have used these data to ask:

- whether and why certain communities have experienced infilling while others grow through the aggressive conversion of rural land and open space;
- how and why the wave of development on the urban fringe changes over time and space;
- how closely patterns of new housing construction track with agricultural land turnover

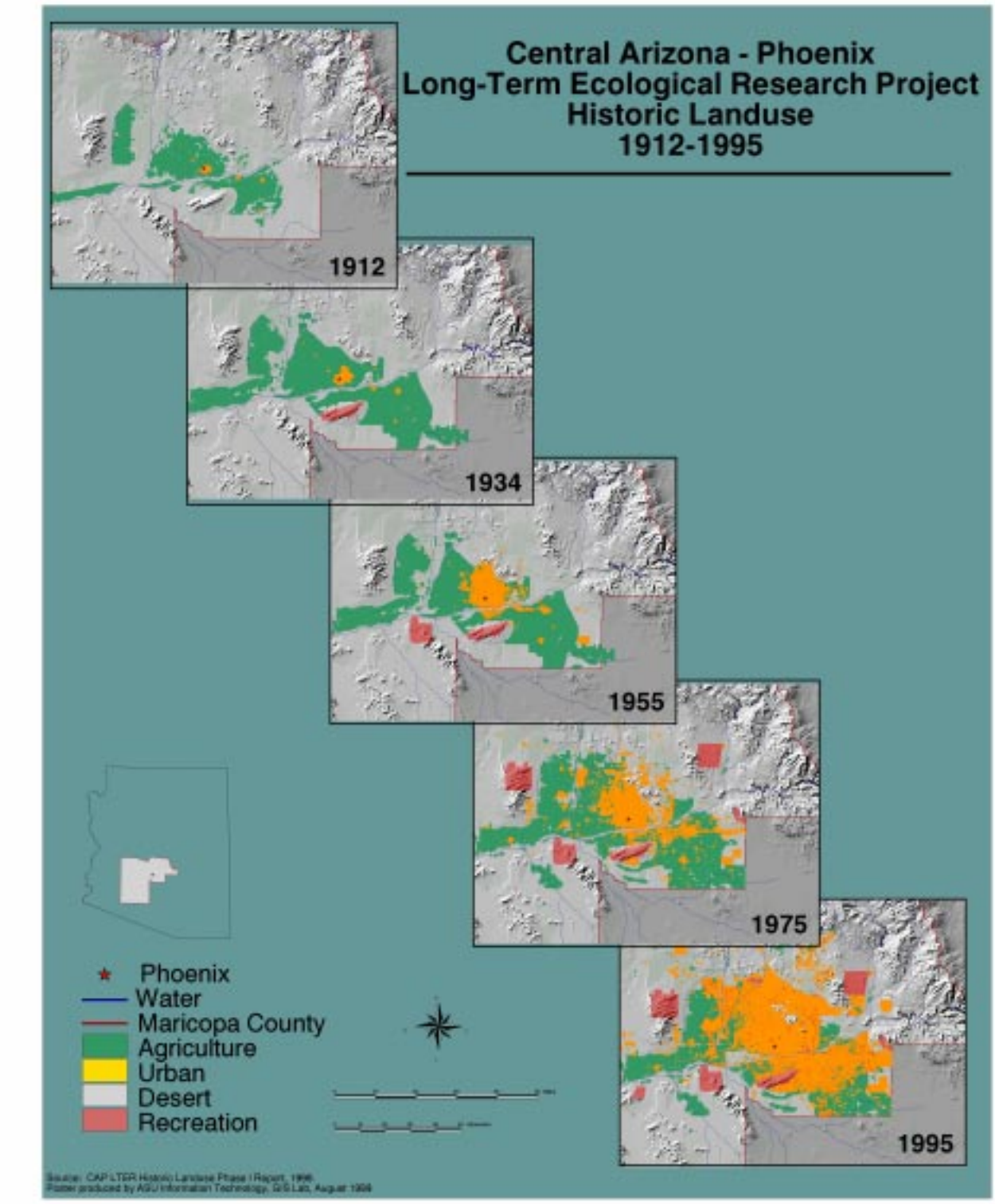
An outgrowth of a National Center for Ecological Analysis and Synthesis workshop on "Urban Modeling" was a model of the spread of housing at the urban fringe, developed by ecologists and borrowing from population diffusion models (Fagan et al., submitted). This model may be parameterized with data from the urban fringe project.

The historic land-use project has been approached in two phases. The goal of Phase I was to collect time series data about land-use development for the CAP LTER study area. During this phase, GIS software and diverse data sources were used to map the pattern of generalized desert, agricultural, recreational, and urban land uses for the Phoenix metropolitan area for the approximate time periods: 1912, 1934, 1955, 1975, 1995 (Figure 2). The goal of Phase II is to collect and map time-series data about land use in greater detail for individual study sites, approximately one square mile in area. Land-use classifications will be more detailed than those used for Phase I and similarly based on the modified Anderson classification system. Dates for land use will be for 1934, 1949, 1954, 1961, 1970, 1980, 1990 and 1995. The study sites correspond with the 200 sample sites being used for the Survey 200.

Primary Production and Organic Matter Dynamics

We began pilot projects in spring 1998 on both primary production and organic matter that used the same design and sites . The design consists of six treatments with three replicates each for a total of 18 field sites. The treatments are: 1) undisturbed Sonoran Desert; 2) agricultural field; 3) xeriscape residential yard developed from desert; 4) xeriscape residential yard developed from agricultural field; 5) mesiscape residential yard developed from desert; and 6) mesiscape residential yard developed from agricultural field. Air temperatures are expected to be lower in a turf than in the crushed granite, and lower above concrete than

FIGURE 2. CAP LTER HISTORIC LANDUSE, 1912-1995



above asphalt pavement. Greater plant growth and productivity are expected in the cooler cover types and should be correlated with lower air temperatures. Finally, soil respiration was measured monthly at each site.

Initial estimates of standing biomass and total landscape canopy coverage were made in June 1998. Monthly mid-day gas exchange measurements were made at all 18 sites. At selected sites, diel gas exchange and plant water status patterns were measured every three months. Totalizing water meters were installed on landscape irrigation systems at 12 of the 18 sites to record landscape water volumes. Micrometeorological stations continuously monitored microclimate variables at four sites, one of each residential treatment type. Soils were analyzed for carbon and nutrients and are currently being analyzed for enzyme activity. Lastly, studies of water use efficiency (WUE) began that included: a greenhouse experiment to examine the effects of irrigation frequency on plant growth, gas exchange, and water use efficiency (completed) and a long-term monitoring research project in collaboration with the Desert Botanical Garden to study WUE at the landscape level (supported by non-LTER funds). For the latter, 14 landscape plots consisting of landscape trees, shrubs, and ground covers commonly found in Southwest landscapes were installed in May 1999. Landscape design aspects including species diversity and plant frequency in these landscape plots waere based on an analysis of the species diversity and plant frequency of primary productivity pilot project residential landscapes. WUE at various irrigation regimens and pruning frequencies will be evaluated over multiple years to test the null hypothesis that WUE is not affected by pruning or irrigation practices. In addition, microclimate in frequently and infrequently irrigated landscapes will be monitored to evaluate how landscaping practices affect microclimate, with data collection to begin in January 2000. Two interdisciplinary projects were initiated by the primary production team in Year 2. In one project, research was begun to examine how socioeconomic factors and community ordinances influence vegetation patterns (landscape plant choices) in four regionally diverse areas of greater Phoenix. Sampling protocols for this research were developed using the primary productivity pilot study sites. Survey questionnaires of residential homeowner landscape preferences were developed for distribution in fall 1999. Survey data will be correlated with landscape canopy coverage data obtained from aerial photography. This research represents a collaboration between plant ecologists and cultural geographers. Plant ecologists and climatologists collaborated on a second project that replicated research conducted in 1975-76 studying the effects of land use on microclimate along several commercial to rural land-use transects in the greater Phoenix metro area.

Populations

Populations research is focused on five 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). In addition, research and analysis has been done on scorpion sting data in the metropolitan area (see Findings).

The vascular plant studies have three 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. Work in Year 2 included:

- preparation of *The Phoenix Flora*, a database of vascular plant species with documented specimens for the CAP LTER area (http:/ls.la.asu.edu/herbarium/herb13.htm) and a re-survey of plant communities in desert remnant patches taken 20 years ago;
- four plant community surveys that examined how habitat fragmentation, caused by human alteration of the landscape, affects plant communities of a formerly continuous expanse of natural Sonoran Desert. Phoenix presents an especially useful arena through which to study this phenomenon, due to its many natural habitat patches (parks, undeveloped lands). In summer 1998, herbs were surveyed along previously established transects; the spring 1999 survey was confined to woody species only, due to very low rainfall.

This year a preliminary study was conducted to elucidate arbuscular mycorrhizal (AM) fungal diversity along a temporal transect (45 to 3 years since establishment) in residential landscaped areas (“yards”). Five

sampling sites were arrayed along a transect starting in the urban core of Tempe and extending south to the Phoenix urban fringe in Chandler. Rhizosphere soil samples had previously been collected from ash trees at each sampling site in June 1997. These soil samples were used to establish trap cultures to determine AM fungal species richness and composition. A study is currently being conducted to assess arbuscular mycorrhizal diversity and root colonization at the first 20 permanent sampling sites in the CAP LTER Survey 200 fieldwork. Three soil samples were collected in May 1999 from each sampling site. Roots were collected from each soil sample, to be stained for assessment of mycorrhizal root colonization. Soil samples will be evaluated for AM species composition, richness and abundance. Trap cultures will be established in the greenhouse to detect AM fungal species that were not sporulating at the time of sample collection.

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. Arthropods are logical choices for monitoring because: 1) they are diverse and thus provide a fairly quick picture of biological diversity; 2) they respond quickly to habitat/ disturbance/soil/vegetation changes and hence fit well with monitoring by other groups; 3) they are fairly easy to collect; 4) they represent a spectrum of feeding (trophic) levels, including decomposers, herbivores, predators, and parasites; and 5) they are important sociological, agronomical, economical and agricultural components of human altered habitats. Although several sampling methods will eventually be used to collect arthropods, for the pilot phase we settled on pitfall traps for ground/litter insects, as they are relatively low tech and easy to use. The project is documenting the abundance and distribution of ground arthropods in six different forms of urban land use (with four replicate sites each of: residential xeriscape, residential mesiscape, industrial/commercial property, agricultural field, urban desert-remnant parks, and desert parks on the fringe of metropolitan development). We are pitfall trapping arthropods at each of our 24 study sites for three days once each month. This design is an expanded and more comprehensive version of the Pilot Arthropod Monitoring study design from last year in that sampling is now being conducted at more sites throughout the metropolitan area with greater standardization in trap layout among sites. Habitat (land cover) data are also now being collected at each site. The objective of this study is to characterize arthropod assemblages as functions of land use and land cover in the Phoenix metropolitan area so as to be able to predict (and preserve) patterns of arthropod diversity with future urban development. Relationships among sites, land use, land cover, geographic location within the metropolitan area, and trophic position of captured taxa are among the topics under current investigation.

We also are in the process of comparing pollinator-insect community structure (species richness and abundance) in two seasons (late summer 1998 and spring 1999) among the four urban land-use types. Pollinator-insect community structure has not, to our knowledge, been compared among different forms of urban land use in Phoenix nor elsewhere. We are focusing on insects belonging to the order Hymenoptera, which perform the lion's share of pollination around the world. We are addressing three research questions: 1) how does the ratio of native Hymenoptera species to the exotic honeybee differ among natural desert, urban desert remnants, and residential areas that also have flowering plants?; 2) how does insect pollinator community structure (richness and abundance) differ among natural fringe desert, urban desert remnants, and residential areas?; and 3) how does insect pollinator community structure differ with different residential horticultural practices (xeriscaping with native plants vs. watered laws with exotic plants)? We used water traps to collect pollinators and surveyed vegetation at two spatial scales at each of our 32 study sites. We are currently processing the field samples.

The goals of the bird project are to document the changes in avian richness and abundance over time and space and determine the biotic/abiotic and socioeconomic/political factors that cause these changes. To accomplish these goals, we are conducting bird censuses in four key habitats in the CAP LTER study area. These habitats include: older residential neighborhoods, younger residential neighborhoods, remnant desert areas, and golf courses. Each site contains a 1 km transect (divided into ten 100-m segments) that is sampled 3 times per month. Hired birders count birds within 20m and 40m of each side of a transect within a 30-minute time period. In addition, using the same methodology, volunteers (60 people to date) are censusing birds in their respective neighborhoods across the study area. These volunteer data give a much better picture

of where birds are across the Valley. In addition to the transect method, two new data collection protocols, a bird point count and a backyard bird list, to collect data were established. These new procedures were established so that a wider variety of volunteers could be included into the LTER project (and provide valuable data).

Enhancing the bird project is a graduate student project comparing vertebrate communities in the "urban islands" of desert remnant buttes with buttes outside the metropolitan boundary. This study has provided baseline data that can be re-sampled over time to document future changes. These data can be used as possible predictors of how future urban growth will affect potential desert preserves, and which groups of species are most vulnerable to extirpation with continued urban growth. The work also collected data relevant to other LTER pilot projects (e.g., bird survey data within the urban matrix can be compared with the desert remnants to look for reciprocal influences, and herbivore abundance data can be analyzed by botanists conducting surveys on plant species diversity.

Transport and Retention of Materials

Several projects have been initiated in this area. A compilation and synthesis of existing data yielded a preliminary mass balance for nitrogen (mass balance project). Long-term monitoring of surface water inputs and outputs is underway, along with additional complementary studies: material transport from urban surfaces during storms; a synoptic sampling of canals; dry and wet atmospheric deposition; chemical and biological monitoring of urban lakes; and heavy metal analysis of lichens.

The goal of the mass-balance project is to develop preliminary mass balances for nitrogen and salts in the CAP LTER watershed. Among the key questions are: 1) What are the major sources and sinks for nitrogen in the ecosystem?; 2) What is the net retention of salts and nitrogen and where do they accumulate?; and 3) How have changes in population and land use (e.g., a shift from agricultural production to urban development) affected accumulation rates of these materials? The mass balances include external inputs, internal production, outputs, and accumulation. We hypothesize that accumulation in groundwater and the vadose zone is very large in relation to inputs. Because the accuracy of determining accumulation "by difference" will be low, we are also trying to determine groundwater and vadose zone accumulation rates directly. Year 2 was spent refining these estimates through synthesis of data from disparate sources such as pumping rates for 12,000 wells from Arizona Department of Water Resources groundwater records, concentration data for about 1,000 wells, obtained from the Salt River Project, USGS, and ADWR; census-track data; also to estimate demographics for nutrient uptake calculations; Arizona agricultural statistics; Arizona air pollution inventory; USGS water quality and flow records; USDA reports and data on food consumption, food waste, human nutritional requirements, and animal nutrition requirements; land cover data; chemical and flow data for all wastewater treatment plants in the area, including National Pollution Discharge Elimination System records, state water reuse permits, state groundwater recharge permits, MAG reports on water quality and landfills, and the University of Arizona "Garbage Project" statistics for garbage generation rates.

The surface-water monitoring project asks what fluxes of key nutrients, salts, and trace metals are imported to and exported from the CAP LTER urban areas in surface waters (rivers and canals) and what contribution do they make to the whole system mass balance? In addition, what are the spatial patterns of nutrient, salt, and metal transport in the urban ecosystem, and how do these fluxes change over time in response to increasing urbanization and climate variations? To quantify and monitor the annual surface water inputs and exports for the whole CAP LTER study area, a regular water-sampling program was established at seven key sites, to supplement and continue the database assembled by the USGS (NAWQA program). Sample collection followed the same basic procedure as the USGS NAWQA program. All analyses were done in triplicate, with the inclusion of quality-control samples at regular intervals. In addition to the routine monitoring, additional samples were collected at four of the storm flow sites during both winter and summer high flow events. We combined patch-specific studies of nutrient dynamics with data on transport in urban runoff, as a means of linking "patch-based" and "whole system mass balance" approaches.

The urban runoff study addresses three main questions: 1) are nutrient (C, N) export rates and interannual variability in nutrient export rates from the urban area greater or less than those from the surrounding desert?; 2) how will nutrient export and its variability change with continued urbanization?; and 3) what are the "hot spots" of nutrient and contaminant storage and contribution to export in the city vs. the desert? We predict temporal variability in exports will be less in urban than in desert watersheds, but we suspect that spatial variability may be higher in cities relative to surrounding desert watersheds due to greater heterogeneity in storage of materials and in surface infiltration capacity. Since 1992 the USGS has been studying urban storm water runoff in the Phoenix area, in order to determine the physical, chemical and microbial characteristics of storm water from drainage basins with residential, industrial, and commercial land use. Results showed that the proportion of impervious surface is the single most important variable in predicting the export of nutrients from small urban watersheds. Hence, in the past year the main focus of CAP LTER research has been to determine the role of urban surfaces in the storage and transport of nutrients in the urban biogeochemical cycle.

The two main objectives of the atmospheric deposition project are to: 1) quantify the input of major nutrients and ions to the CAP ecosystem occurring in the form of wet and dry deposition; and 2) monitor changes in wet and dry deposition of major nutrients and ions over time. The driving research questions are: How important are atmospheric deposition inputs to the nutrient mass balances for N, C & P in the CAP ecosystem? What are the major sources of these materials (ie. soil-derived dust, vehicle exhaust emissions, other anthropogenic sources such as power generation facilities)? How are these inputs changing over space and time, in relation to land-use change across the study area? The approach involves sampling wet and dry deposition at a network of 10 collection sites, located to sample deposition in relation to the main air mass movements over the valley. To this end, five wet/dry bucket collectors (as used by NADP) are being sited within the developed urban area, four in desert outside the city and one collector at Organ Pipe National Monument in SE Arizona, which will serve as an unpolluted control site. Nine sites are co-located with existing air quality/deposition monitoring sites run by ADEQ, Maricopa County, NADP, NOAA AIRMoN or AZMET programs, while a tenth site is located in the Sycamore Creek watershed — site of a long-term desert stream study. We are currently collaborating with the NADP to establish our central Phoenix 'Supersite' (the location of intensive air quality monitoring by ADEQ) as part of the NADP network — the first specifically urban site of its kind in this program.

The Phoenix area features many small urban lakes artificially created to serve recreational, aesthetic, and flood control purposes. The lakes were constructed when a variety of water sources could be readily accessed by developers. Like construction of urban lakes, the monitoring of the lakes has been uncoordinated. Although some individual lake owner associations have conducted some level of lake monitoring over the years, little effort has been made to bring preexisting data sets together or to systematically investigate the lakes chemically or biologically. The objective of the study is to: determine how the chemistry, primary productivity, and algal populations in the urban lakes related to lake age, water source, and other urban lake features: and to assess if the urban lakes represent sinks for nutrients and contaminants.

To achieve the study objectives, six lakes were selected to maximize variations in age (urbanization) and water source. Monthly water sampling was initiated in fall 1998. Samples were examined monthly 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. The water samples were examined bimonthly for algal density and composition. The pollutants analyzed include Cu, Pb, Zn, Benzene, Toluene, Ethyl benzene, Xylene (BTEX), and Total Petroleum Hydrocarbons (TPHC). As of June 1999, six months of data have been collected.

Disturbance

A reconnaissance of the Phoenix area's fire services was conducted during Year 1 as a pilot project to a more complete study of urban fire ecology. This area is new to disturbance ecology; it is unlikely that a model of urban fire ecology exists. Phoenix has no history of a major wildfire, but is built and maintained

on industrial fire (internal combustion). This project centered on identifying the nature and location of quantitative and qualitative information that could be used in constructing an ecological history. A report has been prepared that describes the extant records and datasets. The report includes: statistics on physical fire obtained from local fire departments, county, state, federal, nonprofit, and other agencies, data from various air quality studies revealing emissions from combustion events in the region; records from city clerks revealing budget priorities and other municipal dynamics; and maps, charts, aerial photographs, and general plans from urban, county and state planning departments, nonprofit museums and other repositories.

Flood is the other major disturbance on which CAP LTER will focus. In collaboration with the USGS, we have begun a study to examine the transport of materials from urban patches to waterways during the intense, localized storms that characterize this region (see above). Their existing data, plus new studies initiated in summer 1998, will form the basis for comparison of urban, suburban, and desert catchments in terms of their yields of nutrients, organic carbon, and metals (see century-scale channel change project description, above).

Human-Environment Feedbacks

Two studies have been undertaken in this domain: economic value of open space in Year 1 (see 1998 report) and an environment risk assessment project in Year 2. 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, our research questions are: 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.

Information Management

Data Lab activities are detailed in the Information Manager's report at http://caplter.asu.edu/data/siteflash/CAPsiteflash99.htm. In summary, this year core catalog databases used for general project management were maintained and expanded, features were added to the bibliographic database that allow users to make and store selections of references for output as bibliographies, and an online, searchable metadata catalog for LTER data was added to the Web site (http://caplter.asu.edu/data).

Efforts continued to compile existing data relevant to CAP research. Data from Maricopa Associated Governments, Maricopa Flood Control District, USGS and ADEQ were acquired and converted to formats and/or projections compatible for use in LTER research. The original purpose of the pilot GIS database project was to quickly acquire GIS datasets currently available to support sampling decisions, initial pilot research startup, and general mapping needs for CAP LTER activities. Datasets from a series of community partners and commercial suppliers (listed in Products section) were acquired, converted to file formats used by LTER researchers, and re-projected to conform to the two standard projections used by CAP LTER. Compressed copies of all GIS files were created to provide remote download access, and copies of most GIS datasets are independently maintained on a Unix server at ASU's GIS lab. CAP LTER staff created metadata

descriptions of most imported datasets, and a relational database was designed to store metadata information for all spatial and non-spatial data. A Web site was created to display images of the primary GIS datasets compiled in this project. Framework GIS layers compiled during the first year was augmented by georeferencing

In addition, several Web products reach out to a more general audience. An interactive, map-oriented Web application provides search and display access to the bird survey project (http://caplter.asu.edu/po12). This tool developed expertise in core technologies such as Web-based mapping that will be reused in other projects. Text and graphics from the first CAP LTER poster conference held in January 1999 are available through our Web site, and the CAP LTER data lab provides database management and Web entry forms protocols for the Ecology Explorers program (http://caplter.asu.edu/explorers).

III. RESEARCH FINDINGS

Our efforts over the last two years have yielded findings that have significantly developed our long-term core monitoring strategy and fed into our effort to develop a Hierarchical Patch Dynamic Model (HPDM). We report on project findings below, following the categories described in the Research Activities section above.

Remote Sensing and Patch Typology

An error matrix was used to assess the accuracy of the land-use/land cover classification for each individual training region. This method is preferable to overall classification accuracy in which the accuracy of individual classes is unspecified. Inspection of the producer's and user's accuracy for individual classes indicates that natural material classes in general are more accurately discriminated by the minimum distance classification rule. Discrimination of the various urban and vegetation subclasses is poor (which contributes to a low overall accuracy of ~ 53%). This result is most likely due to the spectral similarity of these classes at Landsat resolution. Combining these subclasses into a broader class scheme (i.e., urban-agricultural-desert) improves the accuracy significantly. Poor classification accuracy for some of the classes is thought to be due to a combination of subpixel mixing and temporal variation between the 1993 Landsat data and the 1995 MAG land-use data. Spectral similarity of several of the land cover classes also contributes to misclassification. A more constrained classification rule (such as maximum likelihood) may discriminate classes more accurately, if appropriate training regions can be defined.

These findings are important as they indicate that accurate classification of explicitly defined land cover classes in an urban setting is difficult using relatively low resolution TM data. The use of ratio images as a classification base for urban environments is novel and has the added benefit of producing data that can be used to map soil variations directly. The MAG land-use data set was found to be problematic for accuracy assessment due to the correspondence of several land cover types to a single land use. The present work reveals, however, that TM data can be used effectively to determine more broadly defined land cover classes in arid-region urban areas.

Hierarchical Patch Dynamics Modeling

Major findings to date:

- Since 1912, the urbanized area in CAP has increased exponentially, accompanied by a drastic decrease in desert area.
- Urbanization has substantially increased the structural complexity of the CAP landscape. A higher fragmentation (smaller and more patches) and more regular (square or rectangular) patch shapes are hypothesized to characterize areas of higher human impact.

- The extent of urban area is linearly correlated with population size ($r^2 = 0.99$), suggesting that human population may be, at the regional scale, used as a surrogate variable to represent a suite of factors that have driven land-use changes in the past several decades.
- Topography does not seem to have limited urban expansion, meaning that while the city grows out, it also climbs up.
- One or more urbanization centers can be quantitatively defined using landscape metrics at different spatial scales. When different variables are used, the centers of urbanization may differ geographically.

Geosciences and Engineering

Data from historical aerial photographs analyzed with a GIS show that large-scale regional flood events and local human activities have driven river channel change on the Salt River in the Phoenix metropolitan area. Mapping functional surfaces such as low-flow channels, high-flow channels, islands, bars attached to channel banks, and engineered surfaces shows that, from 1935 to 1997, the relative areal coverage of these surfaces has changed. Flood events have caused general changes in sinuosity of the low flow channel, but islands have remained remarkably consistent in location and size, while channel-side bars have waxed and waned. The most important determinant of local channel form and process is sand and gravel mining, which in some reaches occupies more than 70% of the active channel area. The general location of mining is closely related to the location of the moving urban fringe which serves as a market for sand and gravel during construction. Quantitative spatial analysis of imagery supplemented by field mapping shows that for each location within the general channel area, it is possible to specify a probability of encountering a low flow channel or other fluvial features. Maps showing the distribution of these probabilities of occurrence reveal the most probable location and configuration of the channel as it occurred in the past. Some reaches have the low flow channel located persistently within a limited area as a result of bedrock or sinuosity controls, but other reaches dominated by flow separation or shallow gradient have almost no persistence in channel location from one flood to another.

Land-Use Change

Land consumption and absorption rates were compared for 13 cities in Maricopa County and the nature of urban growth in these communities was compared to the strictness of their land-use policies. Patterns of new housing construction are unrelated in any systematic way to official land-use policies. Although communities pay lip service to the need for more land-efficient urban growth, market forces trump public policy in determining the nature and the distribution of new housing development.

Likening the march of new residential development at the urban frontier to a “tidal wave”of new development, this research has updated a classic study of urban fringe morphology, but over a much shorter time frame and a much finer geographic scale. Findings show that the pattern of new development covers a surprisingly wide geographic area, especially at early stages of the growth cycle. As the growth cycle unfolds, new home construction takes place across a much narrower band of territory. While Hans Blumenfeld’s classic study of the urban fringe in Philadelphia showed that the crest of the wave of metropolitan expansion moved outward at the rate of one mile per decade during the first half of the 20th Century, recent expansion in parts of contemporary Phoenix occur at a rate of *one mile per year*. The pace and distribution of new housing construction are strongly related to the pace and distribution of agricultural land turnover. There appears to be little or no lag, as much of the urban fringe literature suggests, from the time land is taken out of agriculture until it is used for housing and other urban purposes.

Primary Production and Organic Matter Dynamics

Monitoring of patch transition types suggests that agricultural sites generally have the highest carbon assimilation and transpiration fluxes, whereas remnant desert sites have the lowest. Residential xeriscapes and mesiscapes do not differ significantly in these parameters, but land-use history does have some effect.

Data collected for the residential irrigation study show that water application volume is not related to residential yard design choice. The greenhouse experiment showed that irrigation frequency does affect plant growth, gas exchange, and WUE in some landscape plants. Frequency of irrigation did not affect total dry weight for Red Bird of Paradise, but frequently irrigated Blue Palo Verde had greater total shoot length and higher shoot and root dry weights than moderately or infrequently irrigated treatments. Preliminary data from microclimate transects indicate that land-use type affects temperature and dewpoint.

Populations

Vascular plants. Findings from the vascular plants studies include: 1) species listing of flora in the CAP LTER study area; 2) a preliminary data analysis of plant community surveys; 3) a habitat fragmentation study.

The Phoenix Flora species listing includes: scientific names of all native or established alien taxa (species, subspecies, varieties, forms, cultivars) and where each taxon is known to grow according to quarters and specific locations as described above; place names for the region; common names cross-referenced to families and scientific names for the layman; scientific and cultivar names of all taxa cultivated in the region; common names cross-referenced to families and scientific names; and a bibliography.

A preliminary data analysis of *plant community surveys* involved species-area curves and cluster analysis on subsets of the data. Adobe Dam Recreation Area, an outlying patch had the highest species density of the four pilot patches surveyed. This site had a more diverse herbaceous component, while woody species diversity was comparable with the other patches. A cluster analysis identified five community types.

Arbuscular mycorrhizal (AM) fungal diversity. Species richness of AM fungi was positively related to time since yard establishment. A gradual increase in the number of AM fungal species occurred over time in urban yards, with species richness matching or surpassing that previously reported for sampling sites in the surrounding Sonoran Desert. Individual trap cultures from trees in recently established yards averaged only three AM fungal species per trap culture compared to those from trees in yards established over 45 years ago, which averaged almost 10 species per trap culture. Species in the Glomaceae family were at all sampling sites. In contrast, no members of the Gigasporaceae family were detected at any site. Of the 12 AM fungal species detected, 11 were in the genus Glomus. All AM fungal species, except for Glomus macrocarpum, were small (#150 Fm); many were hyaline or white. Most detected species were previously seen in trap cultures from the surrounding Sonoran Desert.

Arthropods. Relationships among sites, land use, land cover, geographic location in the metropolitan area, and trophic position of captured taxa are among the topics under current investigation in this study. Results to date (analyzing data from residential xeriscapes, industrial/commercial property, agricultural field, and urban desert-remnant parks from April 1998-October 1998), the same average number of arthropod taxa were found in these types of land use, although more individuals were captured at industrial/commercial sites than elsewhere. However, taxonomic composition differed among land-use types. Predators and herbivores were most abundant in the agricultural sites, whereas scavengers were most abundant in desert-remnant and industrial sites, and detritivores were found primarily in residential yards.

Scorpions. Between 3000-4000 people report being stung by scorpions each year in the Phoenix area, but the frequency of stings is not distributed evenly across the metropolitan area. Certain areas of the region exhibit consistently higher numbers of scorpion stings. I overlaid data from the Phoenix Samaritan Regional Poison Center about the number of scorpion stings per ZIP (postal) Code onto a Geographic Information System coverage of land use in the Phoenix metropolitan area. Using regression and correlation analyses, the types and amounts of land use among ZIP Codes that differed in the number of scorpion stings were compared. The number and geographic location of scorpion stings in the Phoenix metropolitan area were reflected in the presence and abundance of some forms of urban land use. In particular, density of single-family homes and proximity to undeveloped open space were good predictors of the frequency of stings.

Birds. Censusing is going quite well, and some analyses have been completed. Species composition differs markedly from season to season and site to site; over 180 species have been identified to date across the Valley. Notably, many migrating species have been sighted during the spring and fall migration period and the Peach-face Lovebird, an exotic parrot that seems to be breeding in the Valley, has been frequently sighted. Many indigenous species, which normally have low population numbers, have been recorded in the surveys. However, these sightings are infrequent and a long-term data set (at least 4 years) is needed to establish whether these species are truly using certain urban areas. This long-term urban data set will be the first of its kind and will allow researchers to answer many questions. After detecting the areas that attract particular species, satellite images, high aerial photography, and vegetative ground surveys will be used to study the effects of landscape structure on avian populations.

Habitat fragmentation has strong effects on summer breeding and wintering bird species as well as small-bodied mammals and reptiles. Migrant birds show little response to habitat fragmentation. These findings represent some of the first data on wildlife responses to habitat fragmentation in an urban context. The urban matrix presents a unique environment that facilitates some species movements between remnant habitat patches, while restricting others. The fast-growing field of urban ecology has so far focused on the responses of individual species to urban growth, not on whole communities. This study provides baseline data and methods for how whole communities respond to urban growth over time.

Transport and Retention of Materials

A preliminary nitrogen mass balance has been constructed for the city. The key findings are as follows:

- Human-mediated imports and fixation account for 90% of total N inputs.
- The largest single source of fixed nitrogen entering the ecosystem is combustion, (N^2 becomes Nox), which is about twice as large as all fertilizer inputs.
- We have no idea where Nox emissions go. If atmospheric N is deposited within the ecosystem, it would represent a major source of N that may contribute to surface or groundwater contamination. Atmospheric N fertilization would likely alter the species composition of natural plant communities. Finally, N deposition would stimulate growth of natural vegetation, possibly increasing fire danger during wet years (when the growth of natural vegetation is greatest).
- Only 4% of wastewater N (16×10^6 kg/yr) is exported from the system via surface water outlet; 71% is exported as N^2 by denitrification; 9% becomes biosolids that are recycled on agricultural land; 5% becomes dry salts produced by evaporation of cooling water for a nuclear power plant; and 9% is reused or recycled as effluent.
- Very roughly, "new" sources of N to groundwater include (in 10^6 kg/yr): excess fertilizer (approx. 7.1), septic tank leacheate (1.4), recharged effluent (0.12), effluent reused for irrigation (approx. 1.4), manure leaching (approx. 2.9), for a total around 12×10^6 kg/yr. Upward pumping removes about 11×10^6 kg/yr from the aquifers. However, much of the pumped groundwater is used for irrigation of cropland. Because much of it is contaminated with nitrate (often >> 10 mg/L), we hypothesize that irrigation water provides N in considerable excess of crop requirements. If this is true, much of the N in irrigation water is recycled to the aquifer, resulting in net positive accumulation of N in the aquifer.
- For the entire ecosystem, volatilization removes about 30% of inputs, accumulation accounts for 20%, total export accounts for 12%. The big uncertainty is the fate of combustion-derived Nox, about 30% of all inputs. Nox produced within the system is either deposited to the terrestrial system or exported.
- From USDA surveys on food consumption and food waste, we have found that protein consumption in excess of RDA requirements and wastage of food are equivalent to the amount of protein required for humans. Thus, we produce around twice as much protein (or N) as we consume. This contributes greatly to nitrogen pollution throughout the country through higher fertilizer use, greater manure production, and more human waste generation.

- Nitrate distribution in groundwater is not well predicted by the cumulative input of agricultural N fertilizers in the overlying land surface. Vertical and horizontal mixing of groundwater is a likely major factor obscuring a simple relationship between these variables.
- In soils samples obtained during well drilling in the Buckeye Irrigation District, leachable nitrate was a small fraction of total soil N. Furthermore, cumulative fertilizer input was small relative to the total N storage in the vadose zone (30-80 feet). The large soil N storage terms leads to the hypothesis that changes in the near-surface soil environment that would promote mineralization and nitrification (e.g., irrigation) may release substantial quantities of nitrate, even without fertilizer use.

Nutrient monitoring. Major nutrient concentrations were significantly higher at the output sites downstream of the city than at the input sites. For example, nitrate concentration was 2-14 mg/L at output sites compared to <0.01 to 0.2 mg/L at the input sites. Phosphate, ammonium, total-N, and total-P concentrations also differed between input and output sites, whereas dissolved organic carbon (DOC) showed much less difference in concentrations between sites. Large changes in chemistry occurred downstream from a wastewater treatment plant (91st Ave. site), where effluent accounted for up to 100% of streamflow.

The pH ranged widely between sites, from just below 7 at the 91st Ave outlet to 8 to 9.5 downstream. Major cations, particularly Na, Ca Mg, and SO_4 showed a general trend of increasing concentrations with distance downstream, but were also useful in highlighting the input of highly saline groundwaters to the river channel from underlying aquifers downstream from the 91st Ave outlet.

Urban runoff. The aims of the research were to measure the surface loadings of major nutrients on impervious asphalt parking lot surfaces embedded in different land uses (desert, industrial, commercial, residential). Parking lot surfaces were chosen, as they contribute significantly to urban storm runoff. Just before the monsoon season, in summer 1998, a rainfall simulator was used to produce 5-minute rainfall events (intensity equivalent to 6.2 inches/hr) from which runoff was collected from 8-10 small (0.29 m^2) circular plots and analyzed for major nutrients (C, N, P) and selected trace metals (Cu, Pb, Zn). The variability in surface loadings was examined with respect to land use, traffic type and density, surface slope, pavement condition, and distance to the nearest curb. The nutrient loading data were also compared with results obtained for a similar experiment carried out on an undisturbed natural desert soil surface. Results showed that both nutrient and trace metal loadings (particularly of ammonium, nitrate, particulate C, and Zn) on asphalt parking lot surfaces varied considerably between site types. Dissolved nutrients, Zn, and particulate C correlated significantly with pavement condition; nitrate and Zn also differed significantly with traffic type. Most striking were the results for dissolved nitrogen loadings on asphalt (average for nitrate was 151.3 mg/m^2) compared to desert soil (0.82 mg/m^2). Such enhanced N-deposition in the urban setting may be largely attributable to increased deposition from Nox emitted from vehicle exhausts (see mass balance findings). Soluble reactive phosphorus showed no such differences.

Atmospheric deposition. Data from the existing NOAA/AIRMoN program, a CAP LTER desert site 10 miles east of the city, shows that dry N deposition rates were between 1.37 and 1.67 kg/ha/yr for the period 1992-1994. This flux was predominantly in the form of HNO_3 vapor, which has deposition fluxes 50-100 times higher than those for NO_3^- If applied to the entire study area, this rate represents an estimated dry deposition input of 1.7 – 2.1 x 10^6 kg N/yr to the system. Atmospheric inputs to the whole ecosystem are likely to be higher, because reported dry deposition rates from the midwest show that N deposition rates increase towards urban centers.

Urban lakes. Lake chemistry, especially specific conductance and nutrients, and biology (algal biomass and species composition) differ appreciably among lakes and appear to be primarily related to feed water source. Priority pollutants were typically not detectable in lake waters.

Disturbance

Urban fire ecology. Traditional urban fire history is narrowly humanistic and dominated by “big fire” disaster stories and institutional narratives centered on heroic firefighters. Our research effort centered on identifying the nature and location of quantitative and qualitative information that could be used in

constructing an ecological history. This effort involved statistics on physical fire obtained from local fire departments, county, state, federal, non-profit, and other agencies; data from various air quality studies revealing emissions from combustion events in the region; records from city clerks revealing budget priorities and other municipal dynamics; and maps, charts, aerial photographs, and general plans from urban, county and state planning departments, as well as non-profit museums and other repositories of information. The data compilation is complete and available through the CAP LTER archives.

The Sonoran Desert is not an easy ecosystem to study long-time fire activity using stratigraphic methods, due to limited charcoal and carbon deposition and the fact that the Phoenix area in particular has so disturbed most "natural" sites, the quantitative data to create not only a model but provide the variables necessary for a long-term comparative study, must be centered on human records. At this stage in the research process, locating basic fire statistics was deemed the most crucial task and received the most attention. Extant municipal, state, and federal data, despite chronological and geographic "holes," provide a statistical baseline for fire incidents going well back into this century. In addition, air quality studies dating to 1971 provide an excellent statistical baseline for charting combustion events and the effects of rapid urban growth, or the effects of "industrial fire," over the last 25-plus years. Fire, air quality, and vehicle statistics might lead the study in the direction of an ecologic model, although incorporating historical geography is a likely tact. The latter method becomes even more applicable considering the extensive available records and maps on historical land use and the progression of human distribution patterns.

Human-Environment Feedbacks

Environmental risk study. Our major findings are: 1) Large-quantity generators are shifting from central locations toward the periphery. In 1960, industrial plants that generated large amounts of waste were concentrated along major transportation corridors. By 1996, with the development of interstate highways and expansion of Sky Harbor Airport, large-quantity generators have moved somewhat from locations near the center of Phoenix toward the periphery. 2) Large-quantity generators are more likely to be located in less affluent areas with higher proportions of non-white population. The outcome variable of interest here is simply whether or not a census tract contains at least one facility that is listed in the 1996 TRI. Such large-quantity generators are significantly more likely to be sited in census tracts with lower income and higher proportions of African Americans, Hispanics, and Native Americans. 3) Greater volumes of hazardous emissions are found in less affluent areas with higher proportions of non-white population. In this analysis the outcome variable is the total weight of hazardous material released rather than the presence or absence of a TRI facility. Using the same 1996 data, there is a significant negative correlation between the volume of material released and the median income level and proportion white population in the census tract. 4) When the relative toxicity of releases is taken into account by using weights provided by the EDF, a more pronounced shift from center to periphery is observed and the relationship between emissions and sociodemographic characteristics is sharply attenuated, even reversed. The most notable sites of weighted releases are outside the central zone that had been the core of industrial activity and toxic air releases. The correlation between weighted releases and the median income level and proportion white of the census tract are now positive and non-significant, where they had been negative and significant for unweighted aggregate releases.

IV. RESEARCH TRAINING

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 their students, and high-school student interns.

Although in the early stages, the project has already involved six NSF-funded REU students who gained research training via summer projects integral to CAP LTER. Such training opportunities are likely to

increase as the project becomes more established. Undergraduate students have benefitted 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, geology, biology, and civil and environmental engineering have delivered additional training through graduate course designed around CAP LTER activities.

Five postdoctoral associates have taken leadership roles in the research and outreach activities of the CAP LTER. They interact with each other, participate in planning meetings with the co-directors and project managers, work with faculty participants and team leaders, and collaborate with graduate students. They are integral to the research and field experience of CAP LTER and receive training in interdisciplinary collaboration, graduate student supervision, and data analysis and presentation techniques.

Monthly All Scientists' Council meetings provide opportunities for cross-discipline 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.

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 for more information). During fall 1998 and spring 1999, two high-school students were 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 the resources of the CAP LTER and incorporate urban ecological issues and data into their classrooms. We reach out to the K-12 community in a program called Ecology Explorers 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 with12 schools in 1998, Ecology Explorers has expanded to include 29 schools and 41 teachers. Popular summer workshops and internships have engaged numerous teachers in our schoolyard sampling protocols for the vegetation survey, ground arthropod investigation, bird survey, and plant/insect interaction study, and the canal sampling study. This summer, 19 teachers from 10 school districts collaborated with18 CAP LTER faculty members and technicians. The internships, which

lasted from one week to one month depending on the project, allowed the teachers to participate in a research project and learn how to collect and analyze data. The teachers also met with our two education liaisons to develop lesson plans and curriculum and to share their experiences with other teachers. A two-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. A database has been constructed for teachers and students to enter collected data on the Web (http://caplter.asu.edu/explorers).

Through teacher evaluations and discussions, teachers have reported that they have a better understanding of ecological research, students' enthusiasm for 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.

Our education liaisons also work closely with the Southwest Center for Education and the Natural Environment (SCENE) to implement other environmental education programs. Contacts have been made with many members of the environmental education community, and joint programs are being developed. For example, a sampling protocol has been developed with the Desert Outdoor Education Center to allow students to collect data at a Sonoran Desert site to compare with their urban sites; the Arizona Historical Museum is creating similar activities in their desert riparian area; and we are involved in SCENE's Native Habitat Project to use sampling protocols to monitor changes in schoolyard ecology as native habitats are developed at schools.

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 has generated many presentations to school groups and to participants of Ecology Explorers workshops. Examples were constructed from data posted on the bird population Web site (http://caplter.asu.edu/po12) to show teachers how to search for patterns of species distributions and develop hypotheses to explain these patterns. The Center for Image Processing in Education (Tucson, Arizona) is working with us to create a GIS lesson plan for students that uses this interactive Web site.

At the university level, elements of the work from the remote sensing and patch typology team have been incorporated into Department of Geology 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 this summer.

CAP LTER public outreach activities were not limited to educational audiences. As an example, we were contacted by a consortium interested in establishing a central database to track raptor electrocutions that occur in Arizona. Representatives from the CAP LTER bird survey and data lab met with representatives from the Salt River Project, Arizona Public Service, Liberty Wildlife Rehabilitation Foundation, Western Area Power Authority, and Western Power to discuss housing the database at ASU; future meetings will address funding and organizational issues.

Urban fringe team members visited, sought feedback, and shared results with colleagues at the City of Phoenix and Maricopa Association of Governments. In June 1999, they participated in a Morrison Institute "brain trust" of local university, business, and government leaders to identify the forces driving our region's growth and development patterns. These researchers were invited to participate in a Morrison Institute-Brookings Institution project on urban growth. This effort will articulate closely with CAP LTER research on urban fringe morphology.

An overview of the pilot project "Back Yard Ecology" was published in *Southwest Home Horticulture*, by the Arizona Nursery Association. Homeowner associations have embraced the urban lakes project and are providing information about lake operation and management. 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.

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 important 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 CAP LTER projects. This project 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 classification of the Maricopa County region 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. 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.

Studies from the domains of engineering, geography, and geology are contributing to our understanding of urban ecology. The river channel change study has demonstrated that classic concepts of fluvial geomorphology provide the basis for analysis, management, and policy for modern American rivers, but that modified theory is necessary because urbanization and upstream dams alter physical processes in rivers. To date urban stormwater runoff has been very much the preserve of engineers. This work brings an ecological approach to the field and should in time reveal important new insights and understanding into the contributory factors to urban stormwater pollution. The main accomplishment of the nutrient monitoring program to date is to continue the long-term sampling begun by the NAWQA program, providing both a source of basic water chemistry data for the study site and information with which to design future LTER monitoring efforts. The urban lakes study will provide 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.

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 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 work done here is also serving as a prototype for upcoming ASTER algorithm development. Data from ASTER will provide global coverage in the visible, short wave infrared and thermal infrared portions of the spectrum at spatial resolutions of 15 to 90 meters/pixel. The Geologic Remote Sensing Laboratory at ASU is responsible for acquiring data from over 100 of the world's fastest growing urban centers and producing near real-time land-cover classifications two 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 affects on various trophic levels of vertebrates have varied top down influences on plant species within a fragment. The data shows that negative affects on plant communities may be predicted by the rabid 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 patch transition types study answered preliminary questions about urban plant ecology and allowed us to revise these questions to include long-term monitoring considerations. The database of urban horticultural ecology research is lacking. Because our work is somewhat unique to both horticulture and ecology, our work offers a useful bridge between the two 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 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.).

Contributions to Human Resources Development

The CAP LTER is 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, geology, plant biology, and sociology.

Our Ecology Explorers program (more details are provided below and in the Research and Education section of this report) 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, they have designed new courses to accommodate CAP LTER research interests. For example, the Biology Department offered a seminar in urban ecology in the first year of the project, and this year the river channel change project contributed to the education of 30 graduate students in botany, zoology, biology, agriculture, planning, geology, and geography by combining the research 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 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.

Ecology Explorers enhances the teaching and learning of science, inquiry-based learning, and critical thinking skills in the K-12 realm. Two schoolyard supplements 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 canal sampling efforts.

Contributions beyond Science and Engineering

By taking the long-term view of complex issues that defy simple explanation, CAP LTER is striving to understand the social, economic, and biological forces that drive these processes, not simply the circumstances we find ourselves into today. 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.

Our preliminary data on residential landscaping practices and water use offers the potential for research based on questions with practical applications in urban ecosystem management.

The habitat fragmentation study has implications for the design of parks in fast-growing urban areas. Urban planners require data on how to maximize wildlife species and numbers in parklands while balancing the needs of a growing population. This project is generating suggestions involving the design and siting of parks and preserves, their recommended size for maximizing species, and the most compatible surrounding land uses. Furthermore, the impact of various surrounding land uses on wildlife diversity and abundance in parks, an area of concern with very little empirical data, is also being addressed. Planners will be able to use this data to plan compatible land uses in and around future parkland. The public is increasingly concerned about the decline of wildlife, especially birds, as cities expand and encroach upon previous natural areas. This project outlines the kinds of wildlife most at risk of being displaced from urban growth and habitat fragmentation and the landscape factors responsible for this risk. The ability to preserve wildlife species in an urban setting has quality-of-life implications for the local community. Birdwatching has exploded in the last decade into a major recreational activity. The use of bird feeders and birdbaths in resident's backyards attests to the public's desire to observe wildlife in urban and suburban settings. If we can address the particular needs of various wildlife species in these settings, we can balance quality-of-life values with continued growth.

The scorpion study has implications beyond mere description of scorpion occurrences in Phoenix. The study determined the circumstances under which scorpions are abundant (and potentially problematic) in urban settings. Because scorpions from Arizona have been accidentally imported into urban areas in Nevada

and Texas (thought to have occurred in the transport of construction materials), this topic is of growing concern. It is also representative of the more general phenomenon of how anthropogenic changes to landscapes may impact the abundance and distribution of organisms. Project results are useful to potential homebuyers by informing them about areas at higher risk for scorpion encounters and may be helpful to land-use planners and urban developers in the cost-benefit analysis of deciding how and where future development in Phoenix should occur. One recommendation for future development is to consider how high-density housing (> 6 dwellings per acre) may minimize human-scorpion encounters. We hope that the results of the pollinator study will facilitate future urban design and development for preserving of pollinating insects and their important ecosystem functions in Phoenix and elsewhere in the Southwest.

Several management concepts arise from the nutrient synthesis project. The concept of holistic nutrient budgets will eventually form a new paradigm for regulatory agencies, and this project demonstrates the utility of this approach. For example, defining specific contributions to groundwater N make it possible to develop innovative, inexpensive, and effective control strategies. The concept of "source control," now being developed for controlling N pollution by reducing protein wastage and overconsumption has major implications for national N control strategies.

The urban storm runoff study could result in advances in controlling stormwater quality. Streams receiving urban runoff are required to be monitored by the environmental branch of the Flood Control District of Maricopa County for their National Pollution Discharge Elimination System (NPDES) program. NPDES permits must be obtained to control the quality of stormwater discharged into streams and determine if the quality of streams that receive urban runoff is degraded. CAP LTER research should impact our understanding of stormwater pollution and it amelioration.

Another area that promises a significant contribution is in the growing field of environmental equity. This year we began an environmental risk study, a new, integrative style of research situated at the intersection of social and natural science, ethics and policy. To date, the study has demonstrated that analyses relying on the presence of large-quantity generators or on the volume of toxic releases can be misleading; it is essential to account for toxicity of releases. Because it is situated in Phoenix, it offers a valuable contrast to other studies of environmental equity that tend to be sited in the Northeast or South. Finally, by studying the shift of industry from center to periphery (and from traditional industries to new industries), the study adds a forward-looking dimension to environmental equity literature. Our most striking result, comparison of weighted and unweighted releases, suggests "clean" new industry may harbor significant environmental hazards.

Other project findings and products that will benefit a broader audience: CAP LTER databases; Ecology Explorer student research protocols; listings of metropolitan fire records; data about the local environment and aspects of historical changes in artificial lakes; and photo images of urban lake algae for students and homeowners.

VII. PRODUCTS

Publications in refereed journals

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Four CAP LTER Supplements: "CAP LTER Schoolyard Ecology Supplement" ($15,000); "CAP LTER Collections Supplement" ($50,000); "CAP LTER General Supplement" ($50,000); "CAP LTER REU Supplement" ($15,000). Long Term Studies Program, National Science Foundation, 1998-1999. N. Grimm and C. Redman, Co-PIs.

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"Assessing Impacts of Residential Community Ordinances on New Urban Landscape Vegetation Patterns" ($5,000). International Society of Arboriculture, 1999-2001. C. Martin and K. Peterson, PIs.

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Ramsey, M.S. "Urban Remote Sensing Analysis: The Phoenix LTER Project." 15th ASTER Science Team Meeting, Tokyo, Japan. June 1998.

Redman, C.L. "Humans as Part of Ecosystems." 125th Anniversary Symposium, Yellowstone National Park, Bozeman, MT. May 1998.

Stutz, J.C., and C.A. Martin. "Arbuscular Mycorrhizal Fungal Diversity Associated with Ash Trees in Urban Landscapes in Arizona." Phytopathology 88:S86. American Phytopathological Society/Entomological Society of American Joint Meeting, Las Vegas, NV. November 1998.

Wu, J. "The Hierarchical Patch Dynamics Modeling Framework for the CAP LTER." LTER Model Regionalization Workshop, San Diego, CA. December 1998.

Wu, J. and O.L. Loucks. "Hierarchical Patch Dynamics and Scaling." International Workshop on Scaling & Modelling in Forestry: Applications in Remote Sensing & GIS, Universite de Montreal, Canada. March1998.

Wu, J. and J.F. Reynolds. "Developing Models Across Multiple Scales Based on Hierarchy Theory." International Conference on Complex Systems Modeling, New Orleans, LA. July 1998.

1997 Grimm, N.B. "Opportunities and Challenges in Urban Ecological Research." International LTER meeting, Taipei, Taiwan. November 1997.

Community Outreach Presentations and other Miscellaneous Activities

1999 Clark, K., and R. Ohmart. "Vertebrate Species Responses to Fragmenting Habitat in an Urban System." The 4th International Symposium on Urban Wildlife Conservation, Tucson, AZ. May 1999.

Hostetler, M.E. "CAP LTER Avian Study in Phoenix, Arizona." Maricopa Audubon Society, Phoenix, AZ.

March 1999.

Hostetler, M.E. "CAP-LTER Avian Study in Phoenix, Arizona." Birders Anonymous, Sun City West, AZ. April 1999.

Hostetler, M.E. "Notes from an Urban Ecologist: The CAP LTER Project in Phoenix, AZ." Grand Canyon University. Phoenix, AZ. February 1999.

Hostetler, M.E. "How Birds Respond to Urban Growth and Habitat Fragmentation." Arizona Aviculturist Society Monthly Meeting, Phoenix, AZ. March 1999.

Shears, B.L. "Potential Collaborative Research with the CAP LTER." Rocky Mountain Stations Management Team Meeting. Fort Collins, CO. January 1999.

Stefanov, W.L "Using Remote Sensing to Define Patch Typology" Guest Lecture for the Arizona Geographic Alliance, Tempe, AZ.

Teacher's Workshop on Plant Diversity, July 1999. The workshop educated a group of grade school teachers on plant ecology.

Several presentations (about the bird project) were given to community groups and local clubs (Maricopa Audubon Society, the Birders Anonymous Club, and to a birding group from the Sportsman Club), Phoenix, AZ.

Hosted visit and field trip of Neal Lane (NSF Director) to study site (LTER participants: N. Grimm, R. Arrowsmith, M. Ramsey, J. Edmonds)

Presentation of CAP LTER mission and goals to municipal and state agencies, governments, corporations, etc. (C. Redman, N. Grimm, R. Arrowsmith, and others)

Knowles-Yánez, K., and E.K. Burns. "The Changing Urban Fringe." Arizona Planning Association, Phoenix, AZ. October 1998.

Lindauer, P., and M. Elser. "K-12 Teachers and Students Involved in Central Arizona - Phoenix Long-Term Ecological Research." Arizona Science Teacher Association Conference, Mesa, AZ. October 1998.

Redman, C. "Students, Teachers, and Environmental Science in the Coming Decade." Keynote presentation at the Arizona Science Teachers' Association Conference. Mesa, AZ. October 1998.

Redman, C., and B. McDowell. "Urban Ecology: Interdisciplinary Science for a Sustainable Future." ASU's 60th Anniversary Celebration of Graduate Education. Tempe, AZ. November 1998.

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

1999 "Ranch Part of Survey to Keep Track of Fine Feathered Friends." *The Dobson Ranchers' Roundup*."

Dye, L. "City Life is for the Birds." *Dye Hard Science*. ABCNEWS.com, April 7, 1999. http://abcnews.go.com/sections/science/DyeHard/dye990331.html.

Hostetler, M.E. 1999. "Birds in Urbanized Environments." *The Quivira Coalition Newsletter: Sharing Common-Sense Solutions to the Rangeland Conflict*, Santa Fe, New Mexico. January 1999: 2(2).

Martin, C., and L.B. McDowell. 1999. "Back Yard Ecology." *Southwest Home Horticulture*, Arizona Nursery Association (ANA).

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Hathaway, J. "ASU, Valley Get NSF Funding for First Long-term Study of Urban Ecology." *CLAS (College of Liberal Arts and Science) News*, Arizona State University, Tempe, AZ. Spring 1998:.1,11.

Hathaway, J. "Research Class Uncovers Shift in River Dynamics." *ASU Insight*, Arizona State University, Tempe, AZ. July 10, 1998:1, 6.

"Keeping Watch Over Arizona's Future." Special Edition of *ASU Insight*, Arizona State University, Tempe, AZ. Vol 19, No. 20. p. 3.

McDonald, K.A., "Ecology's Last Frontier: Studying Urban Areas to Monitor the Impact of Human Activity." *Chronicle of Higher Education*, February 13, 1998: A1, A18-A19.

Parlange, M. 1998. "The City as Ecosystem." *BioScience* 48:581-585

Ruber, I. "Worlds Apart: Phoenix is One of Two Cities to Receive Federal Ecology Research Fund." *The Business Journal*, Phoenix, AZ. January 16, 1998:17, 20.

"Scorpions: our Uninvited Guests." *The Arizona Republic*, Phoenix, AZ. Interview with N. McIntyre), October 12, 1998.

Webester, G. "Is your Home in a Scorpion Zone?: Stinging Report Shows Valley's High-Risk areas." *The Tribune*, Phoenix, AZ. September 16, 1998.

1997 Durband, D. and J. Hathaway. 1997. Six-Year NSF Study to Probe Phoenix-Area Ecology. *ASU Insight*, Arizona State University, Vol 18, No. 17, October 24, 1997:1,7

"Center for Environment Studies." Great Communities, Special Edition of *ASU Insight*, Arizona State University, Tempe, AZ. October 23, 1997:2

Kaiser, J. (ed.) 1997. "Ecologist to Study Life in the Fast Lane." *Science* 278:375

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Van Der Wert, M. "Valley's Urban Ecology in Focus." *The Arizona Republic*, Phoenix, AZ. October 20, 1997:1

Internal Publications, Reports, and Presentations

1999 Graf, W. L., L. Aben, L. Amoroso, S. Anderson, J. Armstrong, J. B. Bartley, V. Beauchamp, J. Cox, J. Curro, B. Dveris, J. Edmonds, S. Fairchild, K. Fergason, M. Fonstad, C. Gomes, R. Hall, M. Henze, G. Hilley, J. Johnson, H. Johnson, J. Keane, C. Levine, S. McGuire, C. O'Day, E. Prud'homme, R. Richter, J. Roach, M. Roberge, N. Villa, R. Vose, Z. Washburn, J. Welter, and M. Zoldack. 1999. Hydraulics and history: channel change on the Salt River in the Phoenix metropolitan area. As part of the Central Arizona - Phoenix Long-Term Ecological Research Project. Tempe: Center for Environmental Studies, Arizona State University.148 pp. [Student- and faculty-created book containing preliminary results of research]

Watkins: "What is Geography and GIS?" CAP LTER Education Program Workshop, Arizona State University, Tempe, AZ. May 1999.

1998 Arrowsmith, R. taught two courses that were inspired by and contributed to CAP-LTER research and student training: Advanced Field Geology, Spring 1998
http://www.public.asu.edu/~arrows/advfield/flyer.html)

and Desert Surface Processes and Quaternary Geomorphology seminar, Fall 1997 (http://www.public.asu.edu/~arrows/DesertGeomorphflyer.html).

Graf, W.L., S. Brinegar, F.C. Chuang, J. Edmonds, P.H. Figueredo, A. Gehling, A. Hargrove, J. James, J. Moreau, G. Morrisey, M. Roberge, H. Stenner, H. Triplett, R. Vose, L. Waite, and K.K. Williams. 1998. Recent channel changes in the Salt River, Phoenix, Arizona. As part of the Central Arizona - Phoenix Long-Term Ecological Research Project. Tempe: Center for Environmental Studies, Arizona State University. 107 p.

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Historic Land-Use Team. 1998. Phase I Report on Generalized Land Use. Tempe: Center for Environmental Studies.

Redman, C.L. Phoenix: "The Ecology of a City." Leadership Breakfast, College of Liberal Arts and Sciences, ASU Downtown Center, Phoenix, AZ. March 1998.

Bibliographies

Urban ecology (result of graduate seminar, Fall 1997)

Urban climatology (result of graduate seminar, Spring 1998)

Urban heat island (compiled by W. Thomas, climatology project)

Theses and dissertations, in progress and completed

Clark, K. (M.S., Biology, Ohmart): "Vertebrate species composition of desert islands in urban Phoenix."

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

Edmonds, Jennifer (PhD., Biology, Grimm): "Understanding linkages between dissolved organic carbon quality and microbial and ecosystem processes in Sonoran Desert riparian-stream ecosystems."

Holloway, S. (M. S., Geology, Arrowsmith): "Proterozoic and quaternary geology of Union Hills, Arizona."

McDowell, B. (M.S., Plant Biology, Martin): "The urban forest and microclimate: interactive and feedback effects on CO2 and water cycling."

McPherson, N. (Completed M.S., Civil and Environmental Engineering, Baker): "Fate of 50 years of fertilizer N applications in the Phoenix ecosystem."

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

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

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

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

Stefanov, W. L. (Ph.D., Geology, Christensen): "Investigation of semiarid hillslope soil development using mid-infrared spectroscopy."

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

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

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

Zschau, T. (M.S., Plant Biology, Nash): "Spatial and temporal air pollution pattern of select heavy metals in Maricopa County, Arizona."

Collections

Urban arthropod collection (under development, M. Tseng)

Flora of Phoenix (herbarium)

Datasets

Dataset	Description	Status
LTER Produced		
Aquatic Core Monitoring Dataset	relational database, ArcView coverage of CAP LTER project sample area: AQUATIC CORE MONITORING	In Prep
Arthropods Dataset	relational database, ArcView coverage of CAP LTER project sample area: ARTHROPODS	In Prep
Bird Survey Dataset	relational database, ArcView coverage of CAP LTER project sample area: Birds	In Prep
Channel Change Dataset	ArcView coverage	In Prep
Dairy Farm Locations	Dairy farm locations	In Prep
Economic Analysis Dataset	ArcView coverage of CAP LTER project sample area: Economic Analysis	In Prep
Fungi Dataset	ArcView coverage of CAP LTER project sample area: Fungi	In Prep
Historic Climate Dataset	relational database, ArcView coverage of CAP LTER project sample area: Climate	In Prep
Nutrients and Data Synthesis Dataset	ArcView coverage of CAP LTER project sample area: Nutrients	In Prep
Plant Survey Dataset	relational database, ArcView coverage of CAP LTER project sample area: PLANTS	In Prep
Quaternary Geomorphology Dataset	ArcView coverage of CAP LTER project sample area: Geomorphology	In Prep
Residential Patch Types Dataset	ArcView coverage of CAP LTER project sample area: Residential Patch Types	In Prep
Student Participation Dataset	ArcView coverage of CAP LTER project sample area: Students	In Prep
Urban Fire Ecology Dataset	ArcView coverage of CAP LTER project sample area: Urban Fire Ecology	In Prep
Urban Fringe Morphology Dataset	ArcView coverage of CAP LTER project sample area: Urban Fringe Morphology	In Prep
Urban Lakes Dataset	ArcView coverage of CAP LTER project sample area: Urban Lakes	In Prep
Lichens Resurvey Dataset	ArcView coverage of CAP LTER project sample area: Lichens	In Prep
Vertebrates Dataset	ArcView coverage of CAP LTER project sample area: Vertebrates	In Prep
Land-Use change in Phoenix: Phase I	Generalized Land Use 1975	Online
Land-Use change in Phoenix: Phase I	Generalized Land Use 1912	Online
Land-Use change in Phoenix: Phase I	Generalized Land Use 1934	Online
Land-Use change in Phoenix: Phase I	Generalized Land Use 1955	Online
Land-Use change in Phoenix: Phase I	Generalized Land Use 1995	Online
Hohokam Canals Dataset	ArcView coverage of CAP LTER project sample area: Hohokam Canals	In Prep
Phoenix Flora Database	Vascular Plant Herbarium, ASU	Online
Acquired		
ADEQ Well Monitoring Database		
ADEQ Wastewater Reuse, Recharge, and Discharge		
Digital Elevation Model	1:250000 scale Digital Elevation Model of CAP LTER study area	Public
1993 Landiscorp Aerial Photos	Landiscorp Aerial Photo CD	Restricted
Digital Elevation Model	30-Meter Digital Elevation Model	Public
ALRIS GIS coverages for Arizona	Bureau of Mines Minerals Availability System (MAS) dataset	Restricted
ALRIS GIS coverages for Arizona	Spring locations in Arizona	Restricted
ALRIS GIS coverages for Arizona	Point locations of various cities and towns	Restricted
ALRIS GIS coverages for Arizona	Point data for the Census landmarks	Restricted
ALRIS GIS coverages for Arizona	Statewide coverage of Indian reservation land in Arizona	Restricted
ALRIS GIS coverages for Arizona	Geologic fault formations in Arizona	Restricted
ALRIS GIS coverages for Arizona	Geologic formations in Arizona	Restricted
ALRIS GIS coverages for Arizona	Major soils and some minor soils groups	Restricted
ALRIS GIS coverages for Arizona	Township and range grid lines	Restricted
ALRIS GIS coverages for Arizona	Incorporated city boundaries	Restricted
ALRIS GIS coverages for Arizona	US congressional districts	Restricted
ALRIS GIS coverages for Arizona	Individual county and an appended statewide coverage	Restricted
ALRIS GIS coverages for Arizona	Arizona Actual Vegetation, 1993	Restricted
ALRIS GIS coverages for Arizona	Arizona's natural vegetation	Restricted
ALRIS GIS coverages for Arizona	Hydrologic unit code areas	Restricted

ALRIS GIS coverages for Arizona	Interstate highways	Restricted
ALRIS GIS coverages for Arizona	Irrigated lands in Arizona in the early 1960s	Restricted
ALRIS GIS coverages for Arizona	Lakes in Arizona	Restricted
ALRIS GIS coverages for Arizona	Public Land Survey system data (Township, Range and Section), land ownership and county	Restricted
ALRIS GIS coverages for Arizona	Arizona's natural vegetation	Restricted
ALRIS GIS coverages for Arizona	7.5-minute quadrangle boundaries	Restricted
ALRIS GIS coverages for Arizona	Riparian vegetation associated with perennial waters	Restricted
ALRIS GIS coverages for Arizona	School districts	Restricted
ALRIS GIS coverages for Arizona	Hydrography consisting of linear features, i.e. streams	Restricted
ALRIS GIS coverages for Arizona	Bureau of Land Management, U.S. Forest Service, National Park Service, and Fish & Wildlife Service	Restricted
ALRIS GIS coverages for Arizona	State boundary coverage	Restricted
Landsat TM data	Landsat TM scene for Central Arizona Phoenix LTER study area, spring 1993	Public
MAG Urban Atlas	exlu95 - 1995 existing land-use map	Restricted
MAG Urban Atlas	dsrtsp	Restricted
MAG Urban Atlas	dvlp - development	Restricted
MAG Urban Atlas	edist - education districts	Restricted
MAG Urban Atlas	genplan - general land-use plan	Restricted
MAG Urban Atlas	magstrt - MAG Street layer	Restricted
MAG Urban Atlas	marblock	Restricted
MAG Urban Atlas	emp - employment demographics	Restricted
MAG Urban Atlas	exlu90 - 1990 existing land-use map	Restricted
MAG Urban Atlas	mpa96	Restricted
MAG Urban Atlas	pinblock	Restricted
MAG Urban Atlas	raz96	Restricted
MAG Urban Atlas	rez98q2 - 1998 reservation layer	Restricted
MAG Urban Atlas	rez96q2 - 1996 reservation layer	Restricted
MAG Urban Atlas	rez97q2 - 1997 reservation layer	Restricted
MAG Urban Atlas	ctract - census tract information	Restricted
Maricopa County Flood Control District	Administrative boundaries	Restricted
Maricopa County Flood Control District	Arizona boundary	Restricted
Maricopa County Flood Control District	Boundaries	Restricted
Maricopa County Flood Control District	City boundaries	Restricted
Maricopa County Flood Control District	Lunch areas	Restricted
Maricopa County Flood Control District	Maricopa County boundary	Restricted
Maricopa County Flood Control District	Photo 1993 locations	Restricted
Maricopa County Flood Control District	Planning boundaries	Restricted
Maricopa County Flood Control District	Pnlfcd boundaries	Restricted
Maricopa County Flood Control District	Boundaries	Restricted
Maricopa County Flood Control District	Project boundaries	Restricted
Maricopa County Flood Control District	Quadrangle boundaries	Restricted
Maricopa County Flood Control District	Sht_bnd boundaries	Restricted
Maricopa County Flood Control District	Supervisory boundaries	Restricted
Maricopa County Flood Control District	Boundaries	Restricted
Maricopa County Flood Control District	Hospitals	Restricted
Maricopa County Flood Control District	Landfill areas	Restricted
Maricopa County Flood Control District	MAG Land -use classification	Restricted
Maricopa County Flood Control District	Cultural	Restricted
Maricopa County Flood Control District	Cultural	Restricted
Maricopa County Flood Control District	Population	Restricted
Maricopa County Flood Control District	Solid waste disposal	Restricted
Maricopa County Flood Control District	Structural	Restricted
Maricopa County Flood Control District	Floods	Restricted

Maricopa County Flood Control District	FP FCD Floods	Restricted
Maricopa County Flood Control District	FEMA	Restricted
Maricopa County Flood Control District	Hazardous zones	Restricted
Maricopa County Flood Control District	RM FCD	Restricted
Maricopa County Flood Control District	RM FEMA	Restricted
Maricopa County Flood Control District	SPWBLN1	Restricted
Maricopa County Flood Control District	Spwbln2	Restricted
Maricopa County Flood Control District	Floods - Spwbln2	Restricted
Maricopa County Flood Control District	Floods - Spwzn2	Restricted
Maricopa County Flood Control District	Floods - Swe_fcd	Restricted
Maricopa County Flood Control District	Floods - Swe_fema	Restricted
Maricopa County Flood Control District	Floods Spwbln3	Restricted
Maricopa County Flood Control District	Floods - Xs_fcd	Restricted
Maricopa County Flood Control District	Elevation points	Restricted
Maricopa County Flood Control District	Elevation index	Restricted
Maricopa County Flood Control District	Ele_ln	Restricted
Maricopa County Flood Control District	iso10-93	Restricted
Maricopa County Flood Control District	iso12-78	Restricted
Maricopa County Flood Control District	iso1-93	Restricted
Maricopa County Flood Control District	iso2-100	Restricted
Maricopa County Flood Control District	iso24-10	Restricted
Maricopa County Flood Control District	iso24-2	Restricted
Maricopa County Flood Control District	iso24-25	Restricted
Maricopa County Flood Control District	iso24-50	Restricted
Maricopa County Flood Control District	iso2-78	Restricted
Maricopa County Flood Control District	iso2-80	Restricted
Maricopa County Flood Control District	iso2-93	Restricted
Maricopa County Flood Control District	iso6_10	Restricted
Maricopa County Flood Control District	iso6_100	Restricted
Maricopa County Flood Control District	iso6_2	Restricted
Maricopa County Flood Control District	iso6_25	Restricted
Maricopa County Flood Control District	iso6_5	Restricted
Maricopa County Flood Control District	iso6-72	Restricted
Maricopa County Flood Control District	iso7-92	Restricted
Maricopa County Flood Control District	iso8-54	Restricted
Maricopa County Flood Control District	iso8-63	Restricted
Maricopa County Flood Control District	Natenv	Restricted
Maricopa County Flood Control District	ls24-100	Restricted
Maricopa County Flood Control District	Obser_gg	Restricted
Maricopa County Flood Control District	Rainfall GG	Restricted
Maricopa County Flood Control District	Repeater	Restricted
Maricopa County Flood Control District	Soil	Restricted
Maricopa County Flood Control District	Vegetation	Restricted
Maricopa County Flood Control District	Assr. book	Restricted
Maricopa County Flood Control District	Centroid	Restricted
Maricopa County Flood Control District	Parcels	Restricted
Maricopa County Flood Control District	State land	Restricted
Maricopa County Flood Control District	DR INQ	Restricted
Maricopa County Flood Control District	Drntocln	Restricted
Maricopa County Flood Control District	Drtocpt	Restricted
Maricopa County Flood Control District	Hydrology	Restricted
Maricopa County Flood Control District	Hydrology MP	Restricted

Maricopa County Flood Control District	Lakes	Restricted
Maricopa County Flood Control District	Watershed	Restricted
Maricopa County Flood Control District	Envrntr	Restricted
Maricopa County Flood Control District	Agricultural areas	Restricted
Maricopa County Flood Control District	Industrial areas	Restricted
Maricopa County Flood Control District	Thalweg position	Restricted
Maricopa County Land Ownership Data	Cultural	Restricted
USGS Digital Raster Graphics	Digital Raster Graphic	Public
USGS Digital Orthophoto Quadrangle	Orthophoto	Public

VIII. PARTICIPANTS

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. We will initiate '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 site for Ecology Explorers. We will initiate 'focused field trips' to the zoo in Fall 1999. 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 stong 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, hrough 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 eductional liaison position; 2) design logos and associated communications materials for the Ecology Explorers Web site; 4) work with project staff to design and produce our newsletter; and 5) contribute in-kind contributions (computers, as well as design, production, and printing costs of the newsletters).

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 SRP has been a crucial partner in a number of our pilot projects. In particular, 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. Representatives from SRP attend our monthly All Scientist 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 Aquatic Core Monitoring project, we are monitoring several USGS NAWQA sites. CAP LTER scientists are also collaborating with the USGS on studies of water quality and storm sampling.

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. In addition, representatives from various city agencies have served as information resources to CAP LTER project 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 Cty. Parks and Recreation Dept.: 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 Collab. 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 four-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, two 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
City of Phoenix
Duncan Family Farms
Flood Control District of Maricopa COunty
Honeywell
Insight Enterprises
Maricopa County Department of Environmental Services
Maricopa Parks and Recreation Department
Morrison Brothers Ranch

Rogers Brothers Farms
Salt River Project
Sonoma Farms, Inc.
Tempe Union High School District
Tonto National Forest
US Forest Service
US Geological Survey
Valley Lutheran Hospital
Town of Fountain Hills
Dobson Ranch Homeowners Association
Dawn Lake Homeowners Association
Val Vista Lakes Community Association
Ocotillo Homeowner Association
Ross Management Inc.