Remote Sensing to Monitor Land Cover Change Pima County, Arizona

Report to the Pima County Board of Supervisors

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Cover: Oblique aerial photograph of the Bullock fire in the Catalina Mountains, courtesy of NASA.

Abstract

Pima County will use a variety of information sources to monitor changes in ecosystems at different time intervals and scales of resolution. The National Land Cover Dataset, derived from Landsat satellite images, will provide inexpensive and valuable data for detecting gross changes in vegetation and urban development throughout Pima County every five years, thereby meeting one of the monitoring objectives established by the Science Technical Advisory Team. This will be supplemented with in-house review of high-resolution digital aerial imagery, obtained by the Pima Association of Governments (PAG) every three years. The PAG imagery would be used to detect land use changes in and around urban reserves, where edge effects may be most pronounced, thereby providing a leading indicator of ecosystem change. These two sources of information, coupled with analyses using Pima County's tax assessor database, PAG land use, and locations of building permits, roads and sewers, will support Pima County's efforts to adapt its activities toward meeting the goals of the Sonoran Desert Conservation Plan (SDCP).

Introduction

Pima County spans two primary eco-regions in Arizona: the Sonoran Desert and the Apache Highlands (Figure 1). The natural vegetation of the Sonoran ecoregion in Pima County is dominated by vast tracts of somewhat sparse desert scrub with narrow linear patches of denser scrub and woodland along ephemeral stream channels. Varying soils and geological substrates, as well as diverse hydrological conditions, contribute to the landscape complexity of the Sonoran desert. The natural vegetation of the Apacherian ecoregion is even more varied: a mixture of desert scrub and grasslands, studded by montane "sky islands" harboring a rich mix of evergreen and deciduous forests and woodlands. The sky islands are part of a larger ecoregion that extends from the Mogollon Rim south into the Mexican states of Sonora and Chihuahua (Marshall et al., 2004).

Pima County has adopted a plan to conserve the natural and cultural heritage of the area. The biological goal of the Sonoran Desert Conservation Plan (SDCP) places emphasis on the retention of native biodiversity through maintaining

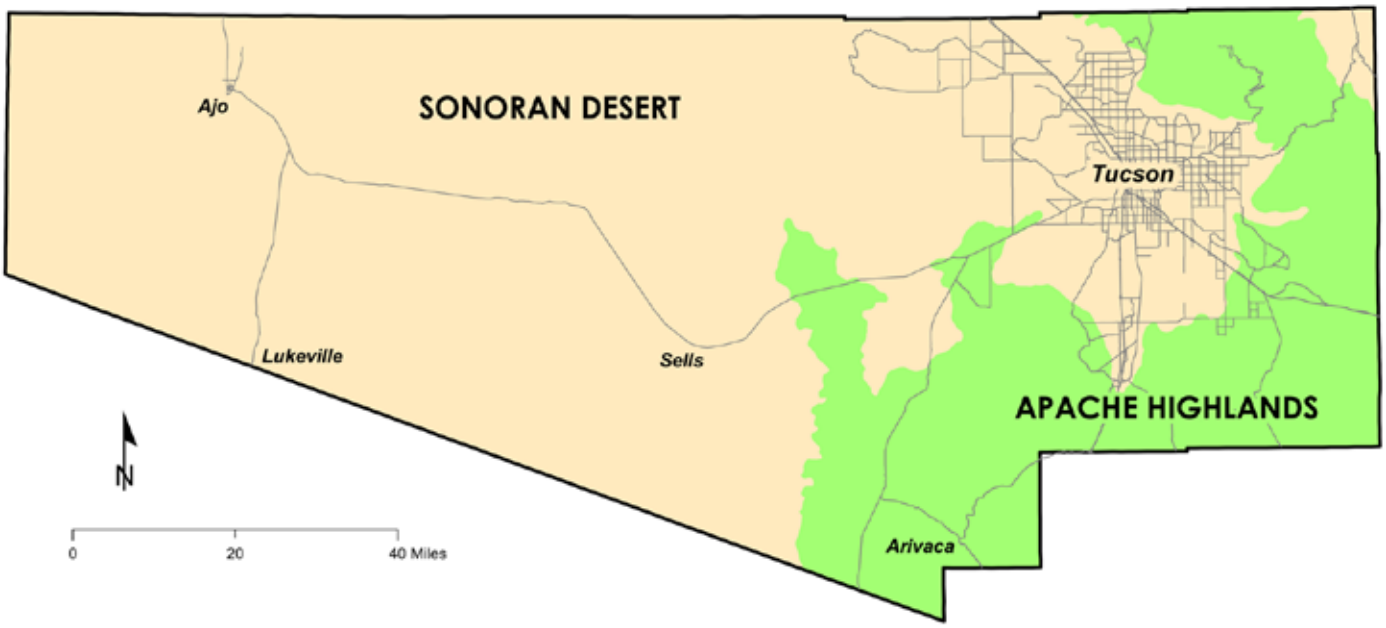


Figure 1. Ecoregional setting for Pima County

or improving ecosystem structure and function, rather than managing individual species. Our objective in developing the Pima County Ecological Monitoring Plan is to detect and quantify changes that can tell us whether Pima County is achieving the SDCP goal, and provide the County with information to direct land management actions including open space acquisitions, land and water resource management, infrastructure development and land use planning. The scope of Pima County's activities affects a wide and diverse area, ranging from high elevation forest lands in the Santa Catalina Mountains to low deserts near Ajo and Lukeville. Because of the diverse scope of Pima County's jurisdiction and actions, a broad view of landscape-scale ecosystem change is important.

The purpose of this report is to recommend appropriate types of ecosystem-level monitoring for the Pima County Ecological Monitoring Program. In 2006, the Science Technical Advisory Team (STAT) for the SDCP recommended that the scope of inference of the monitoring plan should be broad, not confined to the permit area or the committed lands alone (Appendix 1). Recognizing that resources for monitoring are and will be limited, the STAT proposed that remote sensing be used to monitor land cover as a means of tracking the loss of habitat on a gross scale due to land conversion. Furthermore, they recommended that the monitoring program should be phased: after an initial period of five years, all elements of the monitoring program will be assessed and modified to increase efficiency and effectiveness.

In accordance with STAT's guidance, this report will be focused on remote sensing techniques which can be used in the initial five-year monitoring period. Remote sensing of the landscape is an obvious tool to consider for a landscape as large and diverse as Pima County. Because the County's reserve system is highly fragmented and spatially distributed in various locations, remote sensing offers the promise of providing a broader context in which to view the forces operating upon reserves. A future report will address potential monitoring of vegetation using ground-based techniques.

Repeated measurements of *land cover* can be used to track changes in ecosystem structure and function, and measure direct impacts of development upon the land. Land cover refers to the biophysical aspects of the earth's surface or its immediate subsurface (McConnell and Moran 2000). Land cover is typically delineated into major categories such as types of natural vegetation (e.g., forest, shrubland, grassland) and the built environment such as urban development, agricultural fields, mine sites, and roads. Common measures of land cover include areal extent, the pattern of connectedness, or the diversity of cover types.

Land use encompasses both the activities on the land and the intent of the use (Turner et al. 1995). Figure 2 illustrates the difference between land cover and land use. For instance, the land cover classification of an area may be desert scrub, but the land use there could vary from park to active ranchland, and each could have very different and important conservation implications such as the potential for future subdivi-

Figure 2. Land cover types vary from left to right: Forest, barren, urban commercial, scrub. Land use types from left to right are all urban. More specifically, urban low-density residential, urban vacant, urban commercial, urban open space.

sion or mining. Typical measures of land use might include areal extent, length of linear infrastructure, or the number of points representing where particular land use activities occur. Mapping distinctions in the intent to conserve natural land cover is most important for our purposes.

Land use can be an excellent leading indicator of environmental condition and a major determinant of land cover (Meyer and Turner 1994). Further, the type, distribution, and extent of major land uses can foreshadow changes to the distribution and abundance of plant and animal species (Blair 1999; Hope et al. 2003; Hansen et al. 2005) or other parameters such as water quality (Soranno et al. 1996) that have important implications for maintenance of biodiversity and ecological health (Hansen et al. 1993) in Pima County (RECON 2007).

Changes in land use and land cover can reflect fundamental changes in the natural and built environments used by people and other animals. Runoff is particularly affected by change in land cover. Land cover metrics are useful because they respond quickly to change, such as fire and land conversion. At a global level, changes in land cover are used to detect patterns and extent of human disturbance, including habitat fragmentation. Watershed goals and species management goals sometimes have land cover standards to achieve for conservation. At a local level, changes in land use and landcover are also used for describing and analyzing purely social phenomena, such as urban land use trends or the effectiveness of land use policies.

Fundamentals of Imagery Analysis

Pima County will rely primarily on imagery obtained from aircraft and satellites to understand ecosystem changes across the breadth of our landscape. The spatial resolution of this imagery will vary from as high (fine) as 0.3 meters to as low (coarse) as 30 meters (approximately 100 feet), depending on the source. Figure 3 shows how resolution affects the ability to detect differences in land cover. Digital imagery is composed of a matrix of square cells called picture elements, or pixels, and its spatial resolution corresponds to the pixel size. High-resolution imagery will allow for smaller features to be distinguished than low-resolution imagery, but the increased data density generally imposes higher costs for analyzing the data.

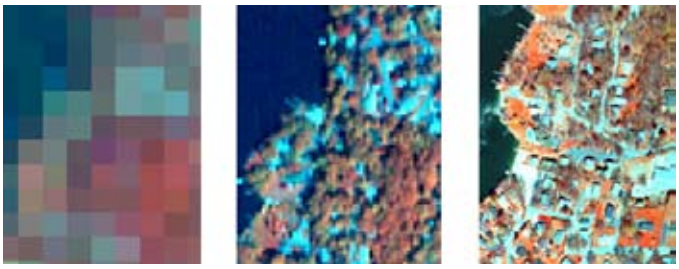


Figure 3. Image resolution affects detection of land features. This is the same image displayed at three different spatial resolutions. Left to right: Landsat resolution is based on 30-meter pixels; Ikonos has 4-meter resolution; airborne ADAR has 0.5-meter resolution. See http://clear.uconn.edu/projects/landscape/measuring/intro.htm for a good primer on remotely sensed imagery.

Imagery is created using sensors which detect light reflected from soil, vegetation or other material covering the earth. Each pixel contains a set of numbers representing the intensity of light (or other electromagnetic energy) reflected from the land surface in different wavelengths. The sensor determines the part of the spectrum which will be sampled. Sensors can detect not only visible light but also additional wavelengths not visible to the human eye. For instance, your digital camera uses sensors to record light in a range of wavelengths visible to humans. Different wavelengths appear as different colors. Satellite-derived land cover images typically also include information about wavelengths which are not visible to the human eye, particularly longer wavelengths from near-infrared to thermal-infrared (heat) energy. Near-infrared (NIR) wavelengths are especially useful for ecological monitoring, to discriminate among different types of cover, because reflectance in this range is so sensitive to the chlorophyll content of vegetation. Green plants reflect most of the NIR radiation striking them, while other objects reflect relatively little. Thermal infrared (TIR) reflectance can be used to examine variations in soil moisture content or study "heat island" effects in urban areas.

Widely available imagery sources provide specific combinations of spatial resolution and spectral characteristics. Some common imagery sources are listed in Table 1. The last one listed is the imagery funded by local governments through a contract with the Pima Association of Governments (PAG). This is the only type of imagery that is regularly acquired by local government or land managing agencies in our region. It is discussed in greater detail under land use.

After an image is acquired, there are a number of additional steps which must be taken to process and analyze the image.

Type of Imagery	Spatial Resolution	Wavelengths	Cost
AVHRR	1090 m	6 bands Visible-TIR	Free, or nominal
Landsat	30 m	7 bands Visible-TIR	Free, or nominal
Ikonos MSS	4 m	4 bands Visible and NIR	$25.20 / sq. km
Panchromatic	1 m	Visible only	
Quickbird MSS	2.44 m	4 bands Visible and NIR	$28 / sq. km
Panchromatic	0.6 m	Visible only	
PAG Aerials	0.3 m (1 ft)	(3 bands?) Visible	$77.22 / sq. km

Table 1. Imagery Characteristics. Costs cited are for new imagery (Jennifer Psillas, Pima County Natural Resources, Parks and Recreation; Sam Drake, Office of Arid Lands Studies)

These steps take additional time, money and considerable training to execute. For these reasons, the cost of utilizing remotely sensed imagery can be high, especially for Pima County's geographically dispersed reserve system, which spans a great variety of climatic and topographic settings.

The steps to make imagery useful often include:

1. Radiometric and/or geometric corrections to remove systematic errors
2. Georeferencing or orthorectification
3. Atmospheric correction
4. Image data processing for specific applications
5. Developing a classification system
6. Applying a classification system to the processed image
7. Accuracy assessment of the imagery classification
8. Change detection analysis using imagery from at least two different time periods

Step 1 is usually done by the data vendor, and step 2 may be done at additional cost. Steps 3-6 are usually done by the user, or by a separate vendor with those specialized skills. In some cases, steps 4, 5 and 6 are iterative, so that the classification accuracy can be improved. Fieldwork may be needed for step 7, unless higher resolution imagery or other source data are available to test and improve the accuracy of the classification. Step 8 occurs when a time series of imagery from the same location is available, and is sometimes performed by a different set of people than the other steps.

Land Cover in Pima County

There have been many separate efforts at characterizing Pima County's land cover (Fonseca, 1999). A consortium of federal agencies mapped Arizona in 1992 using various Landsat images and the Anderson Level 2 classification (Table 2). The Anderson classification (Anderson 1976) is widely used for land cover studies and primarily on the physiognomy (structure) of the vegetation and the distinction between urban, agricultural and industrial land uses in the built environment.

Connolly et al. (2000) used a combination of 1992 Landsat imagery and local land cover maps to estimate that approximately 355,605 acres in Pima County had been converted (lost) to urban, agriculture, or mining uses, with most losses occurring in the Tucson and Avra basins. The 1992 Landsat data were used to estimate the extent of urban, agricultural and mining land cover.

The environmental consulting firm RECON prepared a composite land cover map for the Sonoran Desert Conservation Plan (RECON 2000). It used the most accurate information that Pima County could compile at that time. The source data included site-specific investigations spanning many decades. Because the composite vegetation map was derived from various time periods, it cannot provide a suitable baseline for monitoring land cover change over time. Since then, new federal efforts have provided representations of land cover at the national scale.

National Land Cover Database

The National Land Cover Database is the current system used to describe land cover in the US (Horner et al. 2004) and serves as a basis for monitoring land cover change. Figure 4 shows the NLCD 2001 for Pima County. The processed, analyzed data for 2001 are available at no cost from the Multi-Resolution Land Characteristics Consortium (MRLC). Data is acquired at a resolution of 30 meters every 5 to 10 years and change can be resolved at a minimum of 1 acre (http://www.mrlc.gov/changeproduct.php). However, because of long processing times, results are not delivered back to users for years after the date of imagery acquisition.

The 2006 land cover data are being analyzed by MLRC, but have not yet been released. MRLC will compare imagery from 2001 and 2006 spectrally. Areas identified as changed

1. Urban or Built Up Land
11. Residential
11A. High Intensity Residential
11B. Low Intensity Residential
12. Commercial
13. Industrial
14. Transportation, Comm, Util
15. Indust/Commercial Complexes
16. Mixed Urban or Built-up Land
17. Other Urban or Built-up Land
17A. Urban/Recr'l Grasses
2. Agricultural Land
21. Cropland & Pasture
21A. Crops
21B. Pasture
21C. Fallow
22. Orchards, Vineyards, etc.
23. Confined Feeding Operations
24. Other Agriculture
3. Rangeland
31. Herbaceous Rangeland
32. Shrub/Brush
33. Mixed Rangeland
4. Forest
41. Deciduous Forest
42. Evergreen Forest
43. Mixed Forest
5. Water
51. Streams/canals
52. Lakes
53. Reservoirs
54. Bays/estuaries
6. Wetland
61. Forested (woody) wetland
62. Nonforest (herbaceous) wetland
7. Barren Land
72. Beaches
73. Other sand
74. Bare exposed rock
75. Strip mines/quarries/gravel pits
76. Transitional areas
77. Mixed barren lands

Table 2. Anderson Classification. Level 1 (shaded, single digit) and Level 2 (double digit) classes. Classes with letters are supplemented from the National Land Cover Database. From a National Park Service classification protocol (Townsend, 2006)

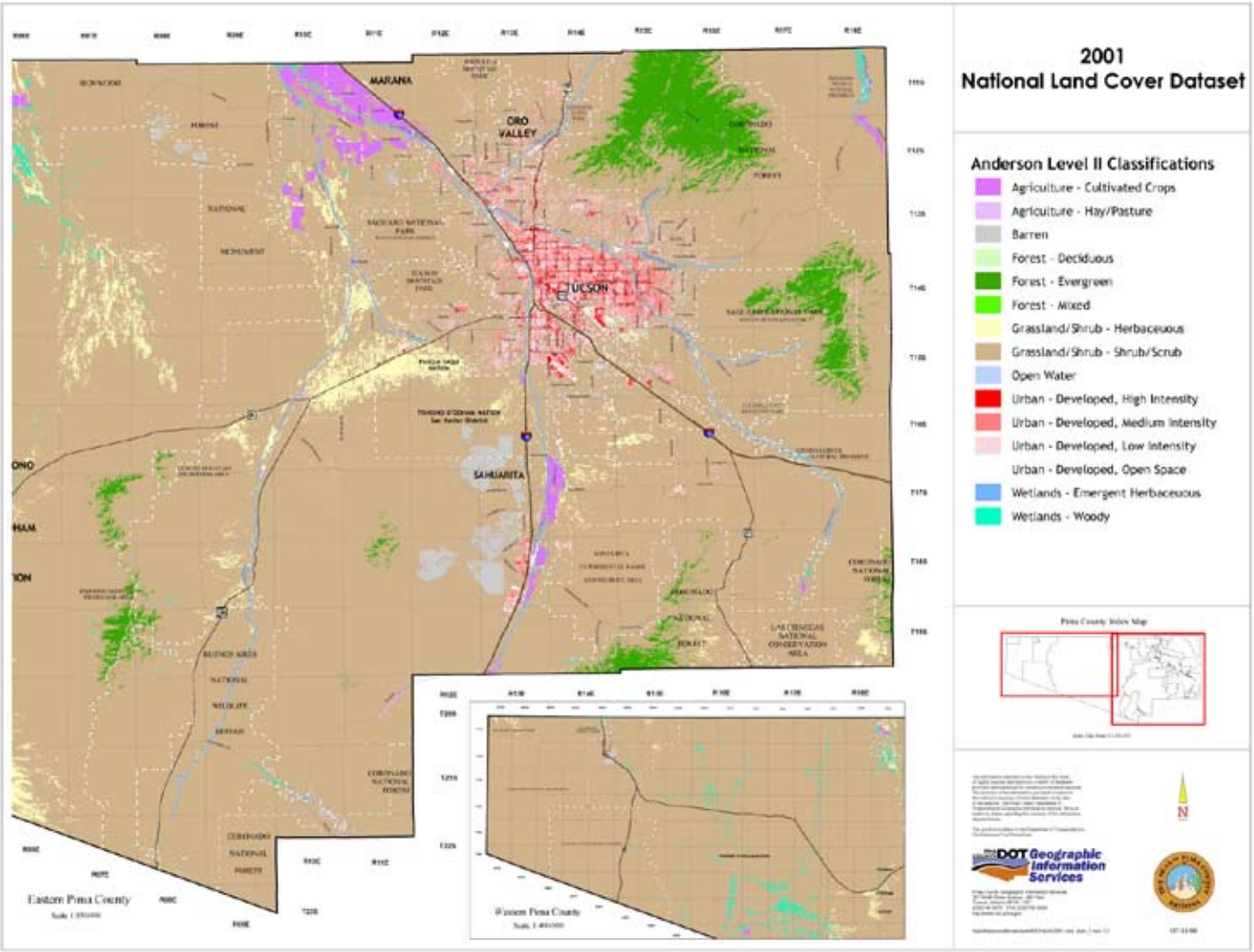


Figure 4. National Land Cover Dataset for eastern and western Pima County, displayed at Anderson Level 2.

will be extracted from the image sets and classified according to NLCD 2001 methods at Anderson Level 2. The 2001-2006 change detection, land analyses will be released to the public at no cost, however a timeline for completion is not yet available.

Pima County and its partners can use the NLCD to detect conversion of natural cover to urban and mining land uses, and to observe changes in the distribution and extent of bare soil, deciduous and evergreen forest, grassland/shrub and riparian "wetlands" (primarily mesquite bosques, broadleaf deciduous forests, and herbaceous seasonal wetlands combined).

The NLCD can provide unique information on the conversion of natural land to urban development at the local, state and national level. There is no local program to detect or report acres of land cover altered by mining, agriculture or tribal activities. Therefore, NLCD's change detection product can provide a periodic, cumulative assessment of landscape changes for the Sonoran Desert Conservation Plan that is not otherwise available. NLCD data can also provide a metric for direct urban impacts upon land cover by each jurisdiction, independent of local agency development tracking methods discussed later in the report.

One of the most important drawbacks to using the NLCD are the long time lags between satellite acquisition and release

of the processed data to the public, which can exceed two years. These time lags mean that Pima County's can only use these data as a retrospective tools for landscape change—change that may no longer be occurring at the same rate or location. Such time lags may not be so vexing to the interpretation of landscape-level changes as it might seem at first glance. Changes in species and their habitat features may be apparent more quickly, but also change significantly from year-to-year, thereby making long-term trend detection difficult, except over longer time periods (see treatise on this subject in Powell 2008, in prep). The significance of trends in species or habitat will be informed by the history of land cover change. In addition, some ecosystem shifts are, by nature, slow, subtle, and often uni-directional such as the re-growth of forests or the incursion of shrubs into grasslands.

Pima County Geographic Information Systems (GIS) has analyzed change detected by the NLCD between 1992 and 2001 as a trial to test what types of change can be detected by this source of information. The results will be described more fully in an upcoming report (Fonseca et al., in preparation). Using GIS, Pima County can assess where change is occurring relative to various administrative and natural boundaries. Most land cover change during this time period occurred on private lands in eastern Pima County, primarily due to urbanization. By contrast, on federal lands most of the change was between forest and grassland/scrub, primarily due to forest fires, with little net loss of cover. NLCD data also shows trends in riparian forest cover that parallel those detected in other regions (Fonseca et al., in prep.) These types of changes in land cover may exert powerful influences upon ecosystem structure and function.

NLCD Strengths:
- nationally consisent monitoring
- detects removal of land cover
- detects gross change in vegetation structure
- change detection product available at no cost
- independent source

NLCD Weaknesses:
- imagery analyzed at infrequent intervals
- may not detect scrub-grassland shifts
- low-density ex-urban residential may be underestimated
- unreliable detection of agricultural change

Our analysis also shows that there are limitations, of course, to the usefulness of NLCD for detecting some land cover changes likely to occur in Pima County in the future. NLCD Level 1 cover types are very broad and relate primarily to gross changes in the vegetation structure and urbanization. It remains to be seen whether the Level 2 NLCD analyses for 2001 to 2006 will be able to detect natural conversions between desert scrub and grassland in our region, a vegetation shift that is of interest for understanding habitat suitability change. NLCD will not detect invasions by non-native grasses. NLCD data are also unreliable for detecting changes in the agricultural category, at least in a way that might be most meaningful for our project. The accuracy assessment is not complete, but is reported to range from 70% to 98% (USEPA, 2007).

In the eastern United States, the 30-meter resolution has proven to be unreliable for detecting low-density residential (LDR) development of one dwelling per one-half acre or less (Irwin and Bockstael, 2007). Low-density residential makes up a high proportion of total development in unincorporated Pima County. There is ample evidence to suggest indicate that low-density ex-urban development can greatly affect ecosystem structure and function as well as species richness (Maestas, et al, 2003; Lenth, et al. 2006). Detecting land cover change associated with this development is therefore important to the PCEMP. Our inspection of NLCD imagery indicates that many of the changes associated with LDR may go undetected at the 30-meter pixel resolution, such as partial removal or intensification of vegetation. However, the acreage of many of the direct impacts of roads associated with LDR upon land cover may be quantified with NLCD 2001 in Pima County due to lack of obscuring tree canopy (Figure 5). This idea would need further analysis to demonstrate feasibility.

The Anderson classification system used by NLCD is relatively stable. In general, however, land cover monitoring continues to evolve, and future changes in the classification algorithms and sensors can make year-to-year comparisons less accurate. The results should be examined for artifacts generated from changes in methods of detection rather than just actual changes on the ground. Any change detection product

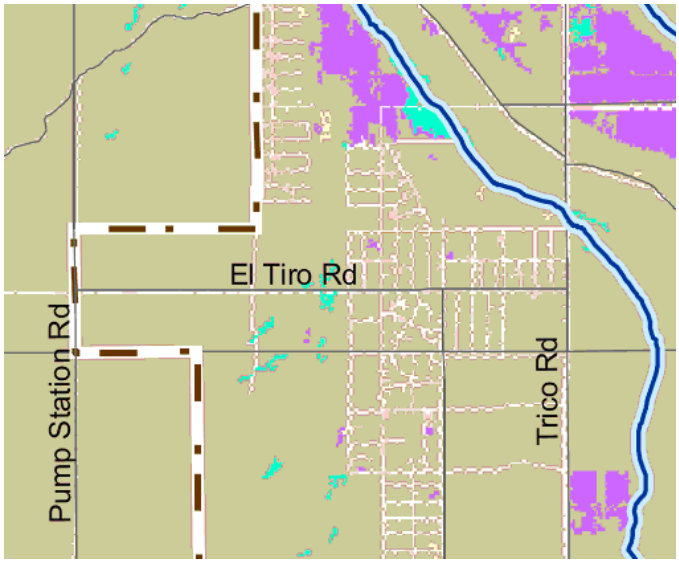


Figure 5. An area of low density residential ex-urban development as shown on NLCD 2001. Roads (called transportation corridors in the Level 2 classification) are white, low density residential is light pink. Actual residential footprint is more scattered than shown here, but the roadway network is largely accurate. Agriculture is purple, brown is shrub/scrub, and teal areas are woody wetlands. This area is bounded by Los Robles Wash (blue line) on the east and Ironwood Forest National Monument (white and brown dashed line).

released by NLCD should be reviewed against higher-resolution imagery or other Pima County GIS data sources to understand systemic biases.

GAP Vegetation and Other Land Cover Sources

Another federal effort is the Gap Analysis Program (GAP), which provides periodic assessments of the conservation status of native vertebrates and their habitats. Gap analysis itself is a scientific means for assessing to what extent native animals and their habitats are being protected. GAP has produced the new, regional land-cover maps, such as the Southwest Regional GAP land cover, (cite) as one tool for habitat analysis. The maps use the National Vegetation Classification System (NVCS) and landform information (e.g., elevation, slope, aspect) to classify natural and semi-natural ecological communities. Like the Anderson classification scheme, NVCS has a hierarchical structure, with the upper levels of the NVCS hierarchy being based primarily on vegetation structure (e.g. forest versus savanna and grassland)—such that these can be related ("crosswalked") to Anderson levels 1 and 2 in the NLCD. At the lower levels, the NVCS hierarchy relies on floristic characteristics, thus providing a finer scale understanding of the distribution of vegetation cover types than NLCD can offer. Agriculture and urban land cover types for GAP are derived and generalized from the NCLD. Recently burned areas are differentiated on the basis of Landsat imagery interpretation.

Updates to GAP vegetation maps could be used to detect large changes in the patterns and distribution of the natural vegetation cover types in Pima County if data analysis techniques are not greatly altered between iteration. GAP vegetation mapping cannot be relied upon for detecting shifts among several grassland and scrubland types in the Chihuahuan ecoregion, because a number of types are similar in terms of their spectral reflectance Lowry et al., in prep. And while GAP does define vegetation classification does include cover dominated by non-native plants, very little was actually captured for our area.

U.S. Geological Survey's Center for Earth Resources Observation and Science (EROS) is studying the types, rates and causes of land cover change using Landsat imagery at the ecoregional level during the time period 1973-2000. Their studies use Landsat and other sources to interpret land cover change at sample sites. Their study for our region is not yet available, and will not report information at the county level or constitute a monitoring program per se.

Burned areas have been mentioned as a potential type of land cover change worthy of monitoring (RECON, 2007). In Phase 1 of the Ecological Monitoring Plan development, participants did not rate fire or burned area monitoring as a high priority. Changes in land cover that result from fire are of more interest than the aerial extent of fire itself. While fire may not cause a land cover change, like floods, they represent an explanatory process. Various federal agencies compile fire histories for our area, and their data can be used, if necessary, to interpret land cover change detected by other means.

In conclusion, the NLCD can provide a regional context for monitoring changes in ecosystem structure in Pima County; it can detect some changes in vegetation structure that

would be costly and time-consuming to obtain, such as changes in distribution of forest cover and wet floodplain vegetation. However, because there will be long lag times between when the data are collected, analyzed, and reported in both NLCD and GAP, and there are inherent limitations in the reliability of the data, Pima County should not rely solely upon these federal sources to detect change in land cover. In particular, Pima County should seek other means to monitor loss of land cover and other effects associated with low-density development which is disconnected from the urban center, and small-scale changes within its reserve system. Suggestions for acquiring these data are highlighted in the next section.

Opportunities for Monitoring Land Use

The Pima County GIS Library includes over 1,100 GIS layers. GIS information is made available to the public and other agencies through the Internet at www.dot.pima.gov. Aside from the GIS library, users can also display and superimpose GIS layers via a MapGuide viewer, or download GIS information via FTP site.

The largest and most complex of the GIS Division's datasets is the Parcel layer, also called the Landbase. This data layer contains over 429,000 polygons representing property boundaries. Each one of those parcels has 73 attributes, including land ownership and a use code which can be related to land uses. Parcel use codes are updated every year for tax assessment purposes, but are often "blind" of land use information for parcels owned by authorities which are not taxed. Parcel boundaries are updated whenever parcels are split or legally subdivided, and thereby provide an indication of areas where land use intensity is likely to change. However, parcels may be split years or even decades before construction.

From a practical standpoint, one of the most important land-use attributes that Pima County should monitor is the protection afforded to natural cover by various state, federal and local measures. The formal name for this attribute is land stewardship. Changes on federal and state land stewardship are tracked by the GAP program mentioned earlier in this report. The GAP land stewardship classification recognizes differences between areas which have a biological conservation mandate, and those that do not. In addition, the security of the protective designation is used to classify stewardship. GAP's land stewardship coverage for Pima County was reviewed for this project and found insufficient for local use. GAP's land stewardship data is out of date and incomplete compared to local records for our area.

Pima County GIS maintains a "preserves" coverage that includes GAP classification as an attribute. This allows our local data on land stewardship to be displayed using the national classification system at a much finer, parcel-level, resolution, with much greater accuracy regarding the potential for future development. Protection levels are in a state of flux due to ongoing land acquisitions, exchanges, Congressional legislation, and state ballot measures. Pima County staff should continue to monitor changes in land stewardship and report changes to this attribute in its "preserves" GIS coverage. This information will be used in annual land use updates prepared by Pima Association of Governments (K. Zimmerman, personal communication.)

PAG Land Use Monitoring

Pima Association of Government (PAG) characterizes urban land use for metropolitan jurisdictions. The methodology and categorization system was tested in 2005 and 2006; the 2007 dataset is the first complete dataset. Their protocol is attached as Appendix 2, and relies upon the parcel base as only one source of information. Their land use representation is updated annually to support the PAG travel and land use models. The primary strength of their system is that they classify land use for federal and institutional categories (and other categories) for which the parcel use codes are unreliable or absent. PAG land-use data can supplement the County parcel data to help classify remotely sensed data more accurately into urban density categories or to verify certain other man-made land cover modifications.

The removal of natural land cover by many other types of urban development is not tracked by local governments. Building permits can however be used to understand the distribution of development on a yearly basis. PAG compiles all of the building permit information for local government on an annual basis. Building permit locations are point locations: the total acreages of land affected by the permit cannot be derived from this source, nor from grading permits issued by individual jurisdictions. The building permit attributes include distinctions between single-family and multi-family dwellings, and between housing types, such as mobile homes versus townhomes. Building permits can be used to identify the location of development on an annual or cumulative basis. Figure 6 shows the data from 2007. Permits are issued for modification of existing structures, not just new construction. For the ecological monitoring plan, plots of building permits relative to county reserves might help identify "hot-spot" areas where indirect impacts are likely to intensify in the near-future.

PAG combines building permits with census information to establish residential densities, which could be useful for understanding indirect impacts of population growth on habitat. Census data are used to establish an estimate of the

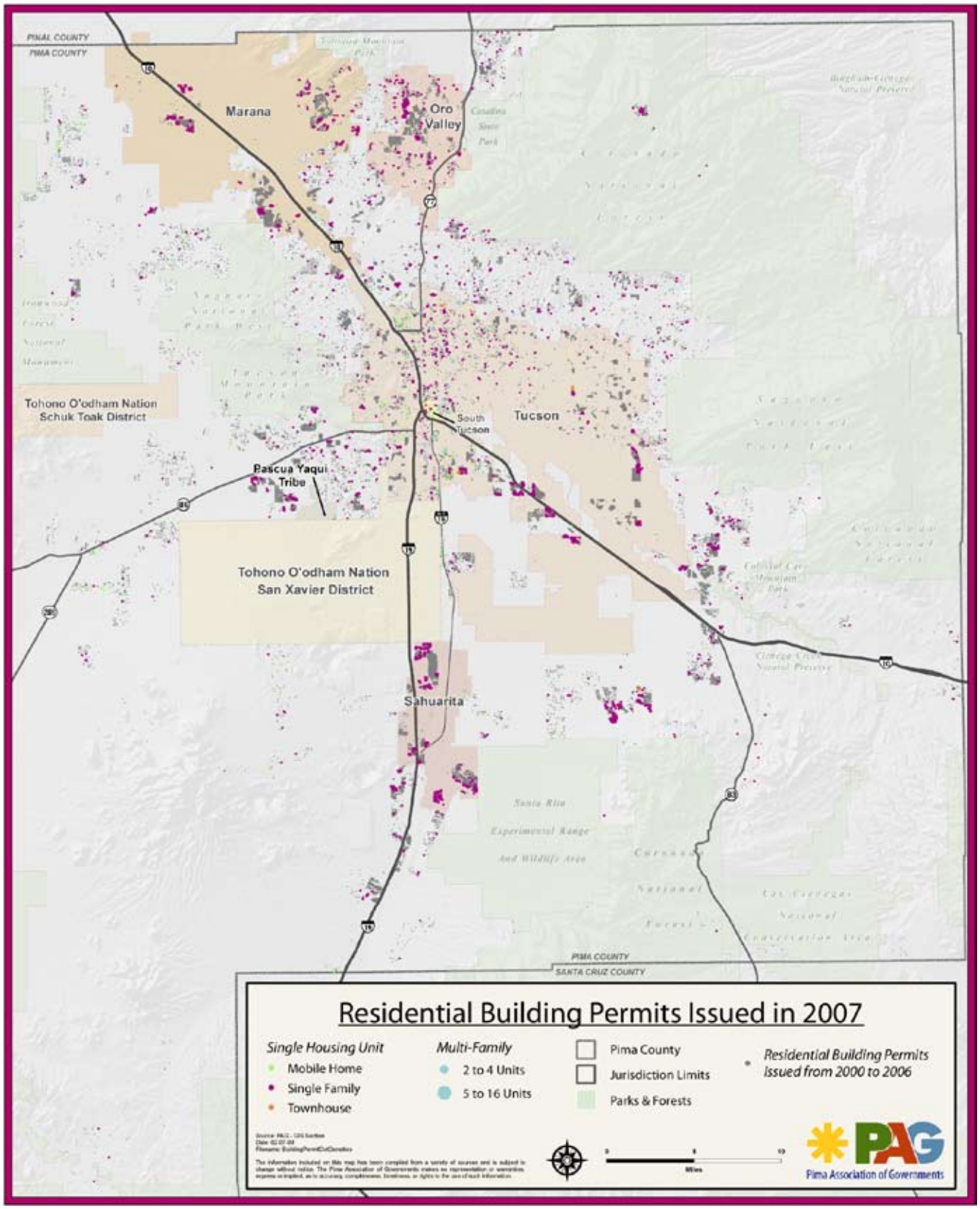


Figure 6. Development permits issued in 2007. Pima Association of Governments map. Colors represent types of housing permits.

number of housing units in 2000 per PAG residential land use polygon. Then, PAG adds the address-level building permits to estimate the number of housing units in the run year (e.g, 2007, 2008, etc.) per residential polygon (Kristin Zimmerman, personal communication, 2008). The polygon geometry and the land use codes do not change from year to year, just the attribute data associated with them. In essence, this process aggregates contiguous parcels with the same assessor use code together, and assigns these 'neighborhoods' a 2000 housing unit count and a current year housing unit count. Users can then derive neighborhood level densities from the count estimates.

PAG coordinates natural color aerial imagery acquisition for metropolitan Tucson. Imagery is acquired at approximately three-year intervals (2002, 2005, 2008). Figure 7 shows that the extent of the 2005 imagery. PAG 2005 imagery encompasses over 81,000 acres of Pima County's mountain parks, and the Cienega Creek Natural Preserve, Saguaro National Park West, Catalina State Park, and many of the small urban reserves. Around 118,000 acres of County reserves, primarily in the Rancho Seco, A7, Diamond Bell and Six Bar ranches, lie outside the 2005 imagery boundaries (Jennifer Psilla, personal communication).

At the 2-foot resolution of 2005 imagery, individual trees can be discerned, as well as wash bottoms, houses and trails (Figure 8). Future imagery acquisitions will be at 1 foot or better resolution. Because the primary purpose of the imagery acquisition is for planning and engineering urban infrastructure, PAG members have sought increasingly high horizontal and vertical accuracy, a trend which is increasing the unit cost and leading to decreases in aereal extent of coverage.

It is currently infeasible to obtain this imagery for all of the permit area, or even all of the County reserve system, each year. The three-year interval between imagery acquisition dates represents a compromise in terms of balancing the cost, accuracy and processing time. PAG imagery acquisition can be expanded beyond the metropolitan area. Increasing the spatial extent costs Pima County about $200 per square

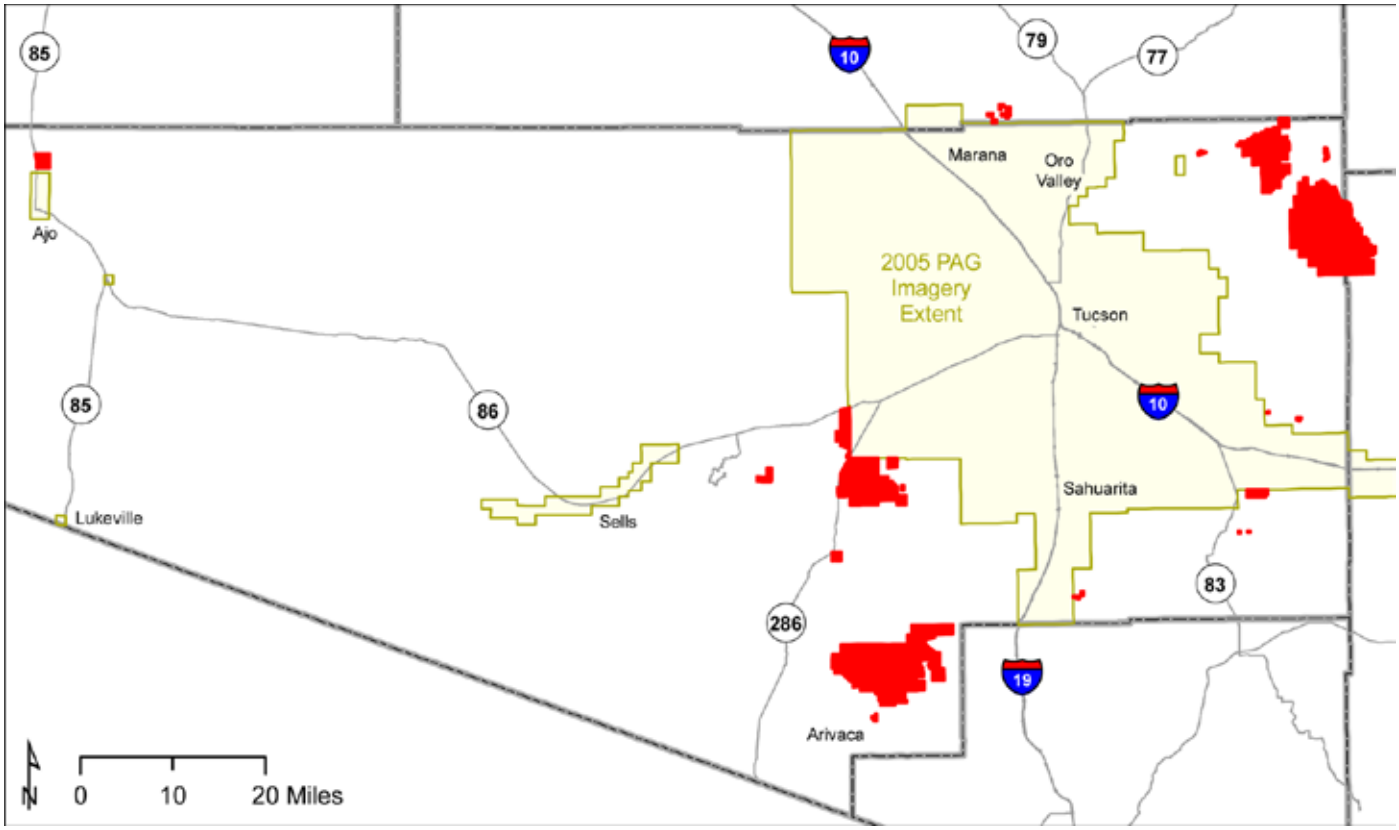


Figure 7. Extent of 2005 PAG imagery is outlined in beige, County reserves outside the photographic extent are shown in red.

Figure 8. Trees, shrubs, roads, houses, small washes, and social trails can be distinguished in this high-resolution PAG 2005 color aerial available to the public at Pima County's Mapguide system. Black lines represent parcel boundaries. Pima County could use these digital images for change detection.

mile. In other words, around $40,000 per year would be needed to cover all of the reserves currently outside the 2005 baseline extent, for any given year. Additional funding was provided to PAG by Pima County to acquire 2008 imagery acquisition for A7 and Bar V Ranches. With additional funding, or a decrease in resolution, the extent could be enlarged in 2011 to cover these and other new acquisitions, but this course of action should be weighed against obtaining multispectral imagery from other vendors. For instance, it would be cheaper to acquire Quickbird multispectral images at $73 per square mile (Sam Drake, personal communication); for this investment, ecologists would receive both visible color and the near-infrared bandwidths. Infrared spectra, which would be useful for land cover/land use classification and urban heat-island studies, are collected by PAG's vendor, but PAG jurisdictions have not purchased these data. To process the PAG imagery for infrared would cost an additional $75,000, and would provide us with a very good sense of what portion of the land is occupied by the built environment. No monies were available to do this for the 2008 flight.

PAG imagery provides an unparalleled resolution, but any imagery would require classification or analysis to become information useful to monitoring land use. At present, Pima County has limited capacity to process remote sensing imagery. To fund a graduate student at University of Arizona to process and classify imagery might cost $20,000 (excluding software costs) and take a year to return meaningful results.

Until such time as the budget can fund multispectral image acquisition and analysis, interpreting the high-resolution PAG imagery to detect removal of natural land cover in County reserves would be one way to track habitat condition. County-managed lands should be foci for monitoring because they are where Pima County's ability to respond to ecosystem change is the greatest. Reserve management is part of the county's mitigation for habitat take elsewhere. The 2005 and 2008 PAG color imagery are suitable for examining change on small preserves located in urban and suburban settings, where edge effects would likely affect a greater proportion of the area. While natural land cover removal from County projects should be minimal within a preserve, it could occur through various approved or illegal activities: off-road vehicles, utilities, mines, vegetation manipulation by adjacent homeowners, trailhead development, and social trails. The resolution of the NLCD is too coarse to pick up some of these land-use effects. The 2005 and 2008 PAG imagery could be compared to detect land-use changes and loss of natural cover in and around the periphery of reserves.

County Parks staff could use the 2005/2008 photographic series detect change in within their areas of familiarity. This would take advantage of the human eye and brain, and could be effective in mapping human disturbances accurately than automated classification systems. Detecting land cover change in and around the periphery of a preserve could provide an information feed-back loop to land managers. A protocol for sampling and reviewing the imagery, and cataloguing and reporting the changes by different observers in a systematic way would be essential. "Virtual transects" could be established for review during successive years. Potentially, other free aerial photographic sources could also be pressed into service, if resolution was consistent. Initially, free ArcReader plug-ins, jpgs or Adobe pdfs could be used to record annotations by land managers. Jpgs or PDFs would require digitizing by GIS staff to transfer annotations to ArcGIS. Pima County GIS is exploring various options to conduct this type of analysis.

Fragmentation Analyses

Conversion of natural land cover can be regarded as a direct measure of wildlife habitat loss. Dispersed patterns of residential and commercial growth in the United States have raised ecological concerns about indirect impacts caused by fragmentation (breaking up wildlife habitat into smaller areas), and the spread of invasive exotic species (Theobald, 2001).

Pima County should apply some simple metrics of natural land cover unit size, configuration, and connectivity deemed relevant to a wide range of species, to examine the indirect effects of landscape fragmentation using the NLCD. Protocols are being formulated for fragmentation analyses by the National Park Service's Inventory and Monitoring Program, but these are mainly for forested areas outside the Sonoran Desert. Pima County will coordinate with NPS and others regarding protocols for fragmentation analyses.

Fragmentation by roads and sewers is also of interest due to its connection to the scope of County activities. Sewers facilitate intensification of land uses. Roads are of interest as a form of direct habitat loss, but more particularly roadways are associated with many indirect and cumulative effects upon habitat (Forman 2003). The 2001 NLCD transportation corridors cover type will be used as a baseline to measure direct habitat impacts. acres of change over time.

Successive versions of NLCD will be used to detect direct impacts across all jurisdictions, regardless of whether the transportation corridor is legal or illegal. In addition, Pima County will report extensions of County roads and sewer systems into the Conservation Lands System as a measure of the degree to which County infrastructure has fragmented the Conservation Lands System. The baseline for this will be July 2006 data. Pima County regularly updates its GIS to reflect sewer extensions and additions of County-maintained roadways.

In response to habitat considerations and other needs, some land use jurisdictions, including Pima County, have adopted "smart growth" approaches that tend to cluster development and encourage infill and redevelopment of urban areas (Pima County, 2001). Metrics relating to spatial configuration of regulated development types could be used to test the effectiveness of smart growth techniques or regulations, possibly using grant funding to support the work. This could be viewed as the inverse of examining habitat fragmentation, because here the growth patterns are the focus of investigation. While not central to our initial program development, studies of growth patterns could be an important complement to ecosystem monitoring, providing information useful to future land-use planning.

Proposed Land Cover and Land-use Monitoring Program

Existing staff with the Office of Conservation Science (OCS), within Pima County Natural Resources, Park and Recreation Department, would direct analyses of land use and land cover data for ecological monitoring. The Pima County Geographic Information System Division would be the primary data analyst. It is also possible that Pima County might choose to contract with individuals or agencies for supplemental analyses. Information and metadata is and would continue to be stored in the existing Geographic Data Library. Data collected by PAG and the federal government at no charge to Pima County would be used to supplement Pima County's information.

Figure 9 summarizes recommendations for the EMP. At the annual time scale, analysis would focus on detecting short-term change in land use at a high spatial resolution. At five-year intervals, determined by the availability of NLCD products, OCS would analyze regional change in land cover. Episodically, OCS would utilize land use projections to predict land cover change into the future. By looking forward as well as back, we would hope to produce information to inform urban land use planning, not just land management of the reserve system.

On an annual basis, Pima County GIS and PAG would maintain and update land use databases in preparation for later regional analyses. OCS would report changes to the GAP status due to land acquisitions, and report road and sewer basin extensions and major land use changes annually. OCS could look for land cover changes in and around the reserves

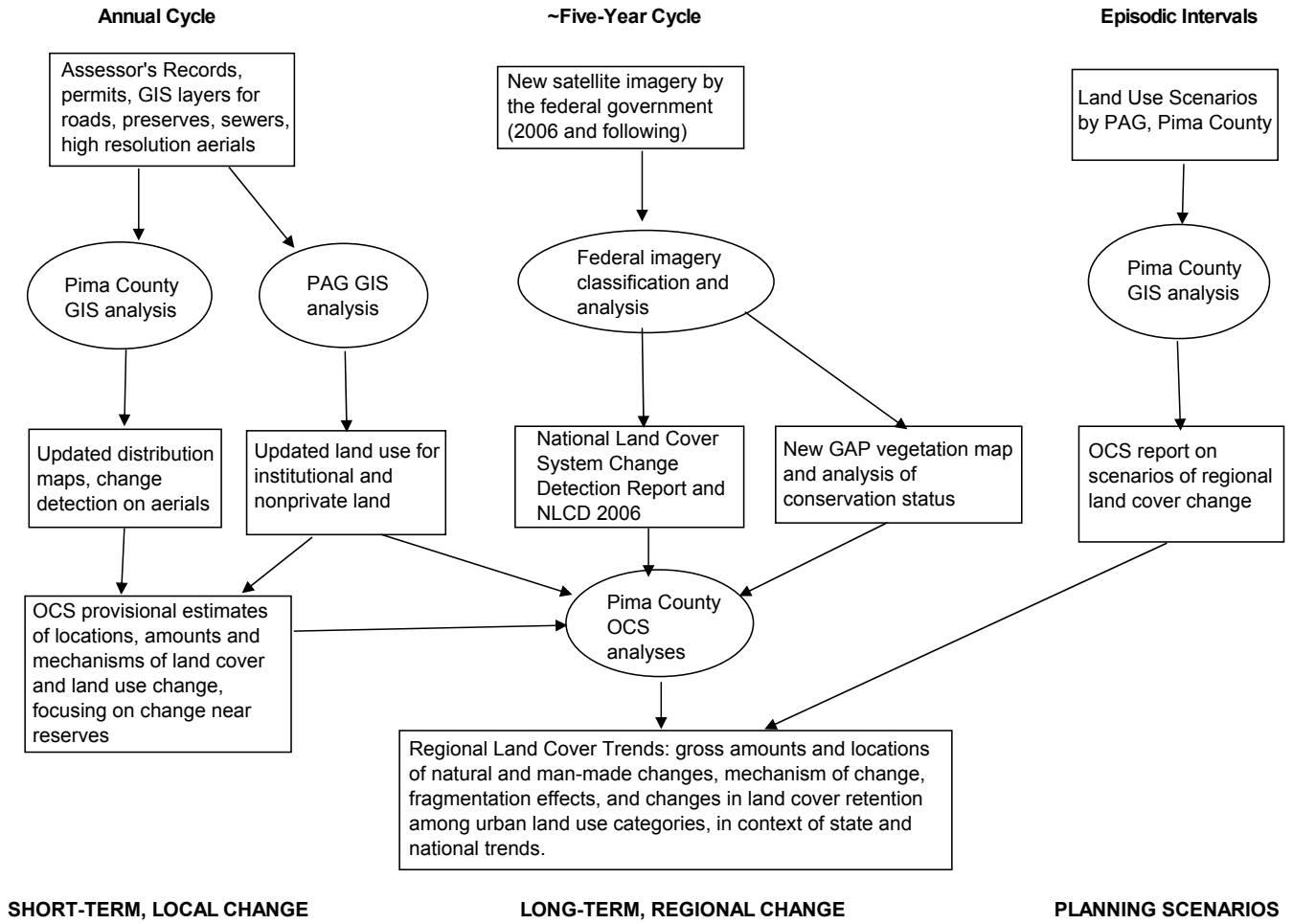


Figure 9. Proposed land monitoring program cycles and products would span temporal and spatial scales to give a complete picture of land cover change in Pima County.

using high-resolution aerial imagery. Depending on the success of investigations now ongoing, use of high-resolution aerial imagery to detect change might be limited to a few reserves each year, or if a more efficient and automated protocol could be developed, then the entire PAG imagery set could be analyzed. New imagery is available about every three years. Analyses would be limited by the geographic extent of the available high-resolution imagery, unless a specific funding source is provided.

As NLCD change detection products are released by MRLC, Pima County GIS would analyze gains and losses in land cover types throughout Pima County and the OCS would attempt to explain why the changes occurred in the context of available research and ancillary data by others. More specifically, Pima County's integrated GIS enables a much better understanding of changes detected by the National Land Cover Datasets than is afforded in most other jurisdictions of the country. By utilizing a combination of Landsat and high-resolution imagery, coupled with unique GIS datasets already tracked by Pima County, the ecological monitoring program (EMP) could understand changes occurring multiple scales of analysis.

An advantage of utilizing the NLCD would be to enable the OCS to put county-level observations within a state and national context. If warranted, the NLCD could be particularly valuable when investigating declines of Priority Vulnerable Species by looking at fragmentation of species' habitat due to changes in regional land cover. Changes in land cover retention within built-out areas could be examined to detect post-construction trends. Progress toward conserving plant communities and species habitat would be reported by OCS.

Periodically OCS would like to examine scenarios for future land cover change that involve different development assumptions This would probably be done in conjunction with land use planning needs, either for County Comprehensive Plan updates or other purposes. In all likelihood, these analyses would be restricted to eastern Pima County, where most of the land cover change relative to Pima County operations occurs.

Products

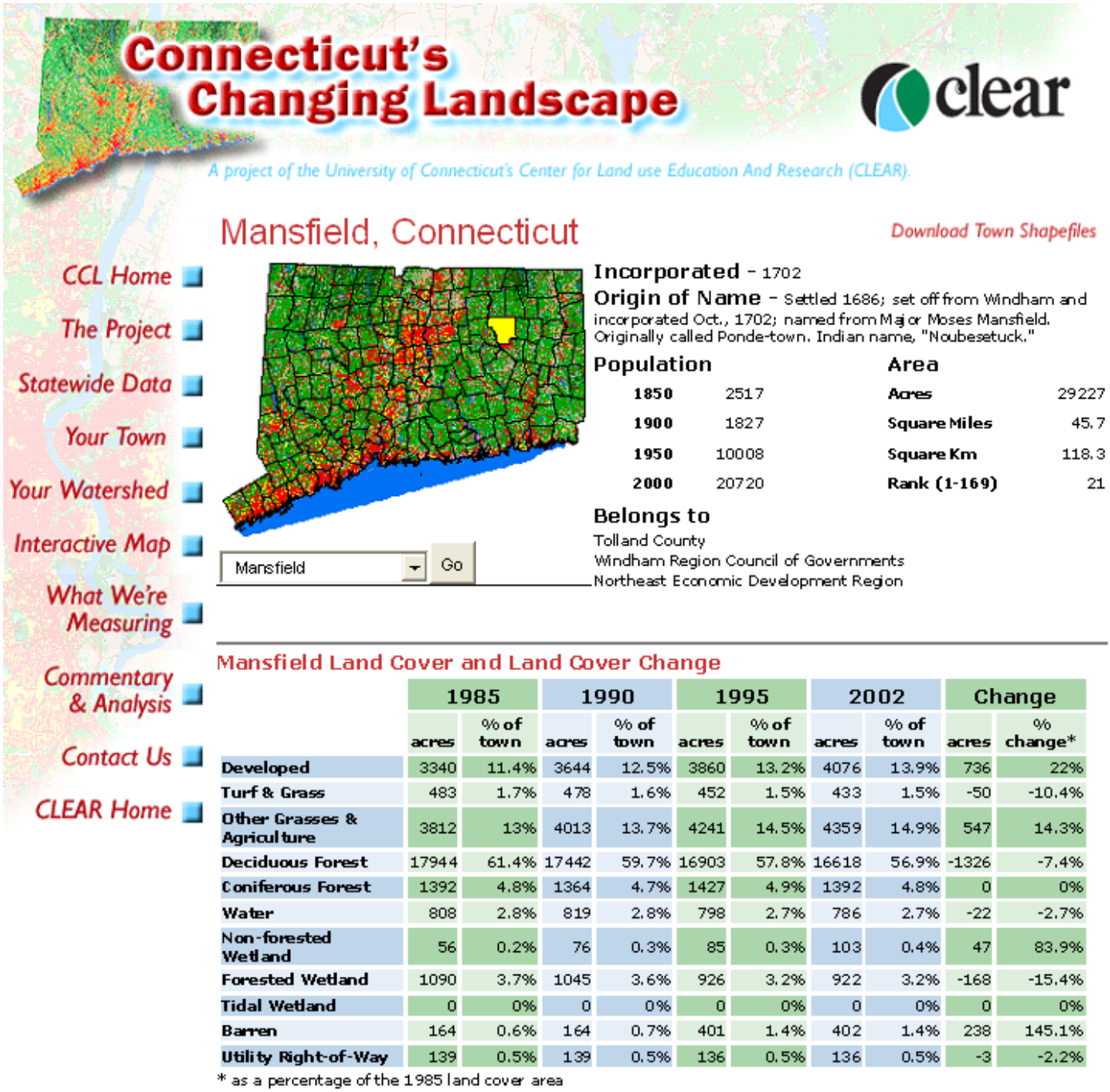
The final product would be a report called Regional Land Cover Trends, which would integrate analyses of local and federal data on land cover change with a prognosis for potential future land cover change based on at least one short-term (5- to 10-year) scenario of private, state, and federal land use change. This report would be geared toward identifying issues relevant to adapting the scope of Pima County operations to meet SDCP biological goals.

The proposed land cover and land use monitoring could address questions of interest to those outside the County reserve management system. Some ancillary uses of land cover/land use data might include answering questions such as:

1. How does Pima County's land utilization for residential subdivision development compare with national trends?
2. What percentage of a given watershed is impervious cover versus forest cover versus desert scrub, and how has this changed over time?
3. Are abandoned agricultural fields and sand bars in major watercourses revegetating naturally?
4. How many acres of mined lands are in Pima County and where has revegetation succeeded?
5. What is the long-term consequence of forest fire on regional land cover?
6. What is the overall acreage of roadways in a given jurisdiction?
7. Does the pattern of Pima County's urban expansion fit a given model?
8. Was a particular ordinance effective in altering the configuration of new development?

Ultimately, it would be desirable to provide information about Pima County's changing landscape in a user-friendly manner to the public and other SDCP land-managing partners via the Internet. One model might be University of Connecticut's land cover change project, which reports land

cover and population change by township and watershed boundaries (Figure 10). Pima County and Connecticut are similar in scale.



	1985		1990		1995		2002		Change	
	acres	% of town	acres	% of town	acres	% of town	acres	% of town	acres	% change*
Developed	3340	11.4%	3644	12.5%	3860	13.2%	4076	13.9%	736	22%
Turf & Grass	483	1.7%	478	1.6%	452	1.5%	433	1.5%	-50	-10.4%
Other Grasses & Agriculture	3812	13%	4013	13.7%	4241	14.5%	4359	14.9%	547	14.3%
Deciduous Forest	17944	61.4%	17442	59.7%	16903	57.8%	16618	56.9%	-1326	-7.4%
Coniferous Forest	1392	4.8%	1364	4.7%	1427	4.9%	1392	4.8%	0	0%
Water	808	2.8%	819	2.8%	798	2.7%	786	2.7%	-22	-2.7%
Non-forested Wetland	56	0.2%	76	0.3%	85	0.3%	103	0.4%	47	83.9%
Forested Wetland	1090	3.7%	1045	3.6%	926	3.2%	922	3.2%	-168	-15.4%
Tidal Wetland	0	0%	0	0%	0	0%	0	0%	0	0%
Barren	164	0.6%	164	0.7%	401	1.4%	402	1.4%	238	145.1%
Utility Right-of-Way	139	0.5%	139	0.5%	136	0.5%	136	0.5%	-3	-2.2%

* as a percentage of the 1985 land cover area

Figure 10. Screen print of a web-accessible data report for land cover monitoring. Such an application would be desirable for Pima County by informing residents of land-cover changes by jurisdiction or watershed.

Summary Recommendations

1. The NLCD 2001 should be used as a regional baseline for monitoring land cover change across jurisdictions in Pima County, realizing that other datasets may be better for applications at finer scales.

2. Pima County should prepare a sample report based on the 1992-2001 NLCD to develop the protocols for using the NLCD 2001-2006 change detection product (when it is available) to analyze and report land cover change.

3. The NLCD 2001-2006 change detection product should be examined (when available) to determine its usefulness for detecting shrub-grass conversions.

4. Pima County should develop methods to detect changes in the distribution and intensity of low-density residential exurban development using a combination of building permits, NLCD and roadway data.

5. Pima County should explore and compare methods for detecting land-cover change within its urban reserves, and develop a sampling plan. Initially, this will consist of in-house experiments using visual review by County staff and trials of supervised classification of PAG high-resolution imagery for selected reserves.

6. Pima County should monitor and report changes in land use, ownership, and the extensions of County roads and sewers as leading indicators of land cover change.

7. Pima County should continue maintaining the "preserves" layer and monitoring changes in GAP land stewardship status in the entire area.

8. Pima County should explain land cover data in reports and if possible, provide simple change-analysis tools on Pima County's Internet site that report changes by geographic areas meaningful to the public (see below)

This report outlines products and procedures for assessing land cover change and provides suggestions for combining this information with land-use and fragmentation metrics for a complete picture of landscape change in eastern Pima County. This information will form a critical foundation for the Pima County EMP. Like all broad-scale change detection, the effects of land cover change will also be expressed as changes in other landscape elements that are important for the structure and function of the Sonoran Desert ecoregion, most importantly water resources, soils, plants, animals, etc. The choice of these elements is currently underway and will be the subject of future reports.

An effective land cover monitoring program would utilize both remotely-sensed information and ground-based measures. This report covers only remote sensing. Remote sensing alone would be insufficient for detecting change in certain fine-scale ecological processes or habitat features of significance to Pima County's ecological monitoring plan. Monitoring for land cover and land use change will be complemented by ground-based methods for detecting changes in vegetation and other habitat features. This will be the subject of future reports.

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Appendix 1. Science Technical Advisory Team Memorandum [Excerpted]

Date: February 21, 2006

To: C. H. Huckelberry, Pima County Administrator

From: William Shaw, Chair, Science Technical Advisory Team

Subject: Biological Monitoring Program (Adopted by STAT on February 17, 2006)

PURPOSE & CONTEXT:

This memo is intended to serve as the work plan and guidance document on how Pima County will develop the biological ("effectiveness") Monitoring Plan for both the Pima County Multi-Species Conservation Plan (MSCP) and Sonoran Desert Conservation Plan (SDCP). Biological monitoring will support the Adaptive Management Plan of the MSCP and will inform the community about the County's progress in meeting the goals of the SDCP.

We propose the basic three steps of the biological monitoring program are:

1. Developing the Work Plan (this memo). This establishes the fundamental goals and objectives, and guides the development of the Monitoring Plan.
2. Developing the Monitoring Plan. This establishes the process and monitoring protocols that will be followed.
3. Implementing the Monitoring Plan. This is the actual measurement of selected parameters, using the protocols established in step 2.

While acknowledging that the monitoring program will be adaptive in order to best respond to circumstances, needs and new knowledge, we nevertheless stress the need for fundamental, guiding principles as described herein.

As a point of clarification, monitoring as discussed in this memo refers to biological (i.e., "effectiveness") monitoring and not to compliance monitoring. Compliance monitoring is also a requirement of Permit issuance, and will serve to demonstrate that the legally defined terms and conditions of the Section 10 Permit are being met. As such, compliance monitoring is in essence an accounting exercise, whereas biological monitoring seeks to determine if the HCP is successfully achieving its goals. The compliance-monitoring program will be developed in a separate forum.

GOAL AND OBJECTIVES FOR MONITORING BIOLOGICAL ELEMENTS OF THE SONORAN DESERT CONSERVATION PLAN

BIOLOGICAL GOAL: *To ensure the long-term survival of the full spectrum of plants and animals that are indigenous to Pima County through maintaining or improving the habitat conditions and ecosystem functions necessary for their survival.*

BIOLOGICAL MONITORING GOAL: *To determine if the biological goal is being accomplished.*

The biological monitoring program will be designed to accomplish these objectives:

- Provide reliable information on the status and trends of natural resources in Pima County, with a focus on measuring the most relevant, powerful, and cost-effective parameters; and to

- Detect and quantify changes in ecosystem structure and function in order to inform adaptive management, by monitoring changes over time in a hierarchical manner. Monitoring will occur on three basic levels or scales, each of which will use different tools and measures, appropriate to the scale, and will provide different types of information:

1. **Regional Landscape Level:** Monitor land cover changes on a landscape scale (i.e., County-wide) using remote sensing imagery.
2. **Ecosystem Level:** Monitor key parameters of vegetation communities (i.e., structure, composition, distribution) and riparian and water resources to detect changes that affect components of the ecosystem.
3. **Species Level:** Monitor selected species, suites of species, such as land birds, or aquatic species where they are efficient indicators of change at a higher hierarchical level (e.g. community structure and function) or where the status and trend of individual species require specific attention.

CRITICAL BIOLOGICAL MONITORING ELEMENTS:

Our recommendation is that the scope of inference should be broad, not confined to the permit area or the committed lands alone. Because of the scope and complexity of the biological elements of the SDCP, the potential parameters that could be monitored are nearly infinite. Recognizing that resources for monitoring are and will be limited, we propose the monitoring plan be structured around the following four elements, with their supporting questions and basic importance:

Top Four Biological Monitoring Elements:
Land Cover: Question: How is land cover changing and what are the implications for biodiversity in Pima County? Importance: To track the loss of habitat on a gross scale due to conversion from natural cover to urban, agriculture or mining uses. Monitoring should be based on remote sensing data to track the magnitude and spatial distribution of change in the major land-cover types throughout Pima County.
Vegetation composition: Question: How are vegetation communities changing and what are the implications for biodiversity in Pima County? Importance: To detect change in the structure (e.g., conversion of grasslands to shrublands) and composition of vegetation communities, including invasive plant distribution. Utilize ground-based monitoring in key plant communities. Include semi-desert grasslands and saguaro-mixed cactus associations because of their national and local significance.
Riparian and Water Resources Question: How are riparian systems and groundwater levels changing and what are the implications for biodiversity in Pima County? Importance: Most of the vulnerable species in Pima County are aquatic or have riparian associations and urbanization, agriculture, and mining are associated with increased water use and changes in hydrology. Also, this monitoring will assist in determining whether or not restoration efforts are meeting success criteria. Detect change in springs, streams and shallow ground water areas, riparian vegetation, and gross changes in hydrologic patterns. Utilize measures such as groundwater levels, stream flows; spring flows, and aerial extent of riparian vegetation.

Land birds, Aquatic Vertebrates, and selected species.
Question: How are bird and aquatic vertebrate and invertebrate populations changing, and what are the implications for biodiversity in Pima County?
Importance: As a measure of environmental health, monitor distribution and abundance of selected species known to track environmental changes closely. Detect invasions of non-native vertebrates (fish, frogs) and invertebrates (e.g., crayfish, snails) thought to be detrimental to populations of native species. Note: Species specific monitoring may be performed to inform ecosystem structure and function elements of the monitoring plan.

PHASING:

We intend for the monitoring program to be phased, beginning with an emphasis on broad, powerful, and cost-efficient parameters that establish robust baselines for assessments that can be repeated indefinitely over time. After an initial period of 5 years, all elements of the monitoring program will be assessed and modified to increase efficiency and effectiveness for conservation of vulnerable species.

[end of excerpt]

Appendix 2. Land Use Mapping Protocol for Pima Association of Governments

Summary

The PAG 2008 existing land use shapefile represents July 1 land uses and residential densities in Pima County. There are approximately 50,000 polygons in this dataset. It builds on the USE code collected by the Pima County Assessor's office, aggregates geographically continuous parcels with the same land use code (e.g., individual residential lots are aggregated into one 'neighborhood'), removes gaps in the parcel base by 'growing' surrounding land uses, and estimates mid-year residential density using address level building permits issued by Pima County, the City of Tucson, the City of South Tucson, the Town of Oro Valley, the Town of Marana, and the Town of Sahuarita and Census 2000 data.

Methodology

Geocode Residential Building Permits

1. Create Address Locator using adcounty downloaded at same date of paregion (e.g., ~July 1, 2008).
2. Create Address Locator using adparcel downloaded at same date of paregion.
3. Add unique ID field to original permit table and make a copy of it.
4. Delete all fields except unique ID and address if necessary.
5. Geocode to adcounty
6. Select and export all features with Score >74. Name file with adcounty.
7. Switch Selection.
8. Export selection to dbf.
9. Geocode dbf to adparcel.
10. Export all features with Score > 74. Name file with adparcel.
11. Switch selection to see if record count of un-geocoded addresses is acceptable. If not geocode to paregion either with an address locator or manually. If it's a limited number sometime it's easier by hand.
12. Merge adcounty and adparcel exports. Add addresses that matched paregion if applicable.
13. Join back to original table.
14. Check for duplicate IDs and compare totals to original table.

Note: Do not geocode to stnetall or any other feature that would create points in the right of way. This is too inaccurate and does not allow location selection of paregion for the purposes of recalculating PAGLUCODE to work properly.

All residential building permits should fall within a parcel.

Prep Input Shapefiles

All input shapefiles are current as of July 1, 2008.

paregion

Part I

1. Use the same **exact** file for land use inventories, update in model.
2. Remove unnecessary fields from paregion. This is most easily done by turning the unwanted fields off and exporting to a new file. Designate and keep this file unchanged and in a safe place because it is the same file to be used for the land use inventories, update in model.
3. Join the PAGLUCODE table to the exported paregion based on the USE field. The PAGLUCODE field must be an integer type. Note: this table can change over time. No USE value is equal to PAGLUCODE 999

Part II

* Some building permits fall into parcels that do not have a residential PAGLUCODE. This occurs because of paregion update lag (see important note). This code must be changed to account for these new building activities.

1. Add EXLU with the final Residential building permits to ArcMap.

2. Select and create 2 layers from permit points by PAGTYPE = MF and PAGTYPE = (SFR, MH, TWN). Name layers accordingly.

3. Select by location EXLU that contain MF. Create layer from EXLU selection.

4. Select all non-residential PAGLUCODE values and recalculate PAGLUCODE to 165

5. Repeat process for SFR,MH, TWN and convert PAGLUCODE to 101

Important Note: The selection tool is finicky with large datasets. Make sure areas of 10-15 acres which are obviously non-residential features are not selected when recalculating PAGLUCODEs. Bad selections are also due to paregion update lag on new subdivisions. Do not over-write code on National Parks Forest, Monuments, rights of way, etc. This is why it is important to use the same exact paregion file.

pima_all

1. Add field PAGLUCODE and calculate field = 617

PAG major roads inventory

1. Add field GRIDCODE that is equivalent to PAGLUCODE

PAG land use inventories

1. Put in a file geodatabase in a feature dataset called Input.

2. Create two other feature datasets called Output and Intermediate.

Build the Current Year EXLU Features (using ArcGIS Model Builder)

This first step creates a single feature class of all the land use inventories. They must be added in a particular order so more detailed coverages do not over-write less detailed coverages. For example casinos should be updated after Indian Reservations because they are on reservations. The Update tool does not create overlapping topology. It performs erases and appends in one step.

1. Use the Update tool (required ArcInfo license) to "merge or append" the below listed inventories in order from A to AA. Name the output with its associated letter for convenience and save under feature dataset Output.

   A) ASLD Grazing

   B) Indian Reservations

   C) Military

   D) Open Space

   E) Post High School schools

   F) Airports

   G) MTLUS industrial

   H) MTLUS office

   I) MTLUS streetside commercial

   J) MTLUS shopping centers

   K) Casinos

   L) Hospitals

   M) Lodging facilities

   N) K-12 schools

   O) Active landfills

   P) Eldercare facilities

   Q) Prisons

   R) Dedicated government

   S) Special events

   T) Transit centers

   U) Mines

   V) Utilities

   W) RV/Mobile Home parks

   X) Multifamily residential

Y) Washes

Z) CAP

AA) Railroads

BB) Paregion (same as used for inventories)

CC) pima_all

(Note: See Attachment A for inventory description and detailed methodology on how each inventory dataset was constructed.)

6. Make sure there are no features without a PAGLUCODE. If there is, populate it with correct code or delete it if appropriate.
7. Clip CC to pima_all and name EXLU
8. Input EXLU into ET Geowizards tool: Explode Multi Part Features, name as EXLU_2008

Create new model of raster tools. Spatial Analyst is needed for this step.

9. Convert EXLU to grid with the Feature to Raster tool. Field is PAGLUCODE. Name output GRID and put in working geodatabase. Output cell size is 10.
10. Use the Shrink tool on GRID. Name output SHRINK and put in working geodatabase. Number of cells is 75. Zone values are 617 and 999.
11. Weird but necessary step. Use the Resample tool to create SHRINK2 that has a cell size of 5.
12. Convert SHRINK2 to polygon using Raster to Polygon tool. Check the simplify polygons box. Name output EXLU_YEAR (ex: EXLU_2008) in Output feature dataset.
13. Run Update tool on EXLU_YEAR with major roads inventory.
14. Run Check Geometry tool.
15. Run Repair Geometry tool if necessary.
16. Add field LUCode that is equivalent to the GRIDCODE field.

Sweet, the Existing Land Use layer is ready!!

Attribute the Current Year EXLU Features with Current Year Residential Density (using two Python Scripts)

Part I

This tool is used to assign dwelling units (DUs), households (HHs), and household population to a land use theme for the BASE YEAR, typically the year 2000 for which a census block group databases is available. The tool does NOT affect the input land use theme -- all results will appear in the COPY, which is written to the same directory as the source. The tool REQUIRES there to be an input existing land use theme containing polygons with appropriate land use codes AND a census block group theme source. The tool will overlay the two creating an identity theme so that we know for each census block group which residential polygons are resident in it. The tool then assigns census data to those polygons, apportioning on the basis of area. However, the method also attempts to assign DUs and HHs to each residential polygon in a way so as to prevent very large residential polygons from absorbing everything in the block group at the expense of other small residential polys.

Part II

This tool will UPDATE residential data in a land use shape file that you have already created with census 2000 base data, using a point file of lagged residential building permits as a source. The update can be applied periodically over time and as needed to keep the land use database current. DUs appearing in the permits file are added to those already in the land use theme. HHs and population are then estimated for them, using occupancy rates and household size averages that appear in the census block shape file.

Attachment A. Land use inventory construction methodology

Land Use Inventories Used in 2008 Existing Land Use Dataset

(Note: Every attempt was made to update and accurately portray the actual physical extent of each feature and the PAGLUCODE attribute. Other attribute data are less reliable.)

LAYER	DESCRIPTION	SOURCE	FEATURE CREATION METHOD NOTES
Airports	Publicly accessible airports (TIA, Ryan, Marana)	previous year's inventory plus any new	select paregion that "have their centroid in" old inventory, create centroid from old inventory; join selection to centroid to populate name & address; merge individual shapes then explode
ASLD Grazing	AZ State trust owned lands that are leased for grazing	Most recently available AGIC datasets: "alott" and "own"	own is CATEGORY = State Trust; project datasets to match paregion; select parcels and copy, paste and trim to appropriate boundaries to create paregion rectified boundaries, PAGLUCODE = 750 for Agriculture and Ranching; dissolve by PAGLUCODE; explode multi part features
Dedicated Gov't	Lands owned by local, state, and federal governments	PCLIS bldg_gov, firestat, library, police, postoffi, cotparc, parcpima, related websites	combine bldg_gov, firestat, library, police, postoffi tables to create one large table to geocode to adcounty; make sure records have correct PAGLUCODE, name address, check cotparc, parcpima and websites to find new records to add, or update cot with parc then update with new combined final shape; attribute with new PAGLUCODE; dissolve by PAGLUCODE then explode OR do select by location paregion "that have their centroid in" old inventory and find new records to add from datasets and websites
Indian Reservations	Lands held in trust by the Pascua Yaqui and TON Tribes	PCLIS limjuris	select paregion that "have their centroid in" exported Indian boundaries from limjuris, copy paste and trim remaining parcels for complete coverage; dissolve, explode; PAGLUCODE = 821
Landfills	Active landfills	previous year's inventory, PCLIS lfil_ex	select paregion that "have their centroid in" old inventory, create centroid from old inventory; join selection with centroid to populate name & address; merge individual shapes then explode, check jurisdiction websites, and lfil_ex "status = open" for additional records
Mines	Active mineral and sand/gravel mines	previous year's inventory, PCLIS mines and mines and mines_act	select paregion that "have their centroid in" old inventory, create centroid from old inventory; join selection with centroid to populate name & address; copy, paste and trim for complete coverage, check for new records in updated county datasets merge individual shapes then explode,
Open Space	Lands dedicated to active and passive open space	PCLIS preserve, park_all, golf	select paregion that "have their centroid in" old inventory, create centroid from old inventory; join selection with centroid to populate name & address; copy, paste and trim for complete coverage, check for new records in updated county datasets, merge individual shapes then explode, attribute PAGLUCODE by dataset
Prisons	Detention facilities (all ages)	previous year's inventory	select paregion that "have their centroid in" old inventory, create centroid from old inventory; join selection with centroid to populate name & address; copy, paste and trim for complete coverage, check for possible new records, merge individual shapes then explode, attribute PAGLUCODE
Special Events	Special events and tourist destinations (e.g., TCC, Rodeo Grounds)	previous year's inventory, county and tucson websites, metro atlas Downtown (Map C)	select paregion that "have their centroid in" old inventory, create centroid from old inventory; join selection with centroid to populate name & address; copy, paste and trim for complete coverage, check for possible new records, merge individual shapes then explode, attribute PAGLUCODE
Transit Centers	SunTran transit centers (Rondstat, Tohono T'dai, Laos)	previous year's inventory	select paregion that "have their centroid in" old inventory, create centroid from old inventory; join selection with centroid to populate name & address; copy, paste and trim for complete coverage, check for possible new records, merge individual shapes then explode, attribute PAGLUCODE
Multifamily Residential	attached dwelling units (dpx, tpx, qpx, twn, condo, apt, assisted living, boarding house)	previous year's inventory, plus any new (sources for new include building permits, MTLUS, appropriate pargion use code)	select paregion that "have their centroid in" old inventory, create centroid from old inventory; join selection with centroid to populate table; copy, paste and trim for complete coverage, check for possible new records, merge individual shapes then explode, attribute PAGLUCODE = 165

LAYER	DESCRIPTION	SOURCE	FEATURE CREATION METHOD NOTES
Lodging	hotels, motels, bed/breakfast, resorts	previous year's inventory, plus any new (sources for new include building permits, MTLUS, appropriate pargion use code)	select paregion that "have their centroid in" old inventory, create centroid from old inventory; join selection with centroid to populate table; copy, paste and trim for complete coverage, check for possible new records, merge individual shapes then explode, attribute PAGLUCODE
Major Roads	estimated width of major roads	PCLIS stnetgdb	Query out major roads (MAJOR ROAD = Y), calculate total number of lanes per record (if Direction_of_travel = "Both Directions", total number of lanes = 2*LANE_CAT, if DIRECTION_OF_TRAVEL = 'One Way' or 'One-way reverse', total number of lanes = LANE_CAT. Buffer each feature accordin to number of lanes. (2 lanes= 26 ft buffer, 3 lanes = 32 ft buffer, 4 lanes = 38 ft buffer, 6 lanes = 68 ft buffer). Dissolve on STREET_NAME. PAGLCODE = 616, except I-10, I-19, State Roads =615. Clean topology (overlaps), dissolve again, clean gaps including highway interchanges, dissolve again.
RV/MH Parks	Recreational vehicle/mobile home parks	previous year's inventory, plus any new (sources fo new include appropriate paregion use code)	select paregion that "have their centroid in" old inventory, create centroid from old inventory; join selection with centroid to populate table; copy, paste and trim for complete coverage, check for possible new records, merge individual shapes then explode, attribute PAGLUCODE = 161
Major Washes	major water courses	PCLIS wash_maj	delete all records where WASH_NAME = null. PAGLUCODE = 730.
K-12 Schools	private, charter, and public k-12 schools	previous year's inventory, plus any new (sources for new include Tucson Book of Lists, AZ Daily Star school survey, AZ Dept of Education enrollment report, PCLIS schools)	select paregion that "have their centroid in" old inventory, create centroid from old inventory; join selection with centroid to populate table; copy, paste and trim for complete coverage, check for possible new records, merge individual shapes then explode
MTLUS_IND	MTLUS Industrial facilities, >5000 sq ft	MTLUS 3Q report, Table 6.1A	select paregion that "have their centroid in" old inventory, create centroid from old inventory; join selection with centroid to populate table; copy, paste and trim for complete coverage, check for possible new records, update vacancy/occupancy attributes, merge individual shapes then explode
MTLUS_STSIDECOM	MTLUS Strip commercial located along selected corridors	MTLUS, original source date was 2006.	select paregion that "have their centroid in" old inventory, create centroid from old inventory; join selection with centroid to populate table; copy, paste and trim for complete coverage, check for possible new records (if updated list is obtained), update vacancy/occupancy attributes, merge individual shapes then explode
MTLUS_OFFICE	MTLUS Office facilities, >5000 sq ft	MTLUS 3Q report, Table 5.1a	select paregion that "have their centroid in" old inventory, create centroid from old inventory; join selection with centroid to populate table; copy, paste and trim for complete coverage, check for possible new records, update vacancy/occupancy attributes, merge individual shapes then explode
MTLUS_SHOPCTR	MTLUS Shopping centers, >25,000 sqft	MTLUS 2Q report, Table 8.1	select paregion that "have their centroid in" old inventory, create centroid from old inventory; join selection with centroid to populate table; copy, paste and trim for complete coverage, check for possible new records, update vacancy/occupancy attributes, merge individual shapes then explode
Cap Canal	Above ground Central AZ Project Canal	PCLIS cap	Digitized physical extent of canal based on PCLIS cap feature overlaid on orthophoto. Geometry does not change from year to year.
Casinos	Actively operated casinos	Tribal/casino websites	Digitized physical extent of casino boundary based on orthophoto. Add/edit as changes occur.
Railroad Lines	Major railroads and spurs	PCLIS railroad	Digitized physical extent of lines based on PCLIS railroad feature overlaid on orthophoto. Geometry does not change from year to year.