Changes in Pima County, Arizona Land Cover 1992-2001

Report to the Pima County Board of Supervisors

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Pima County Administrator

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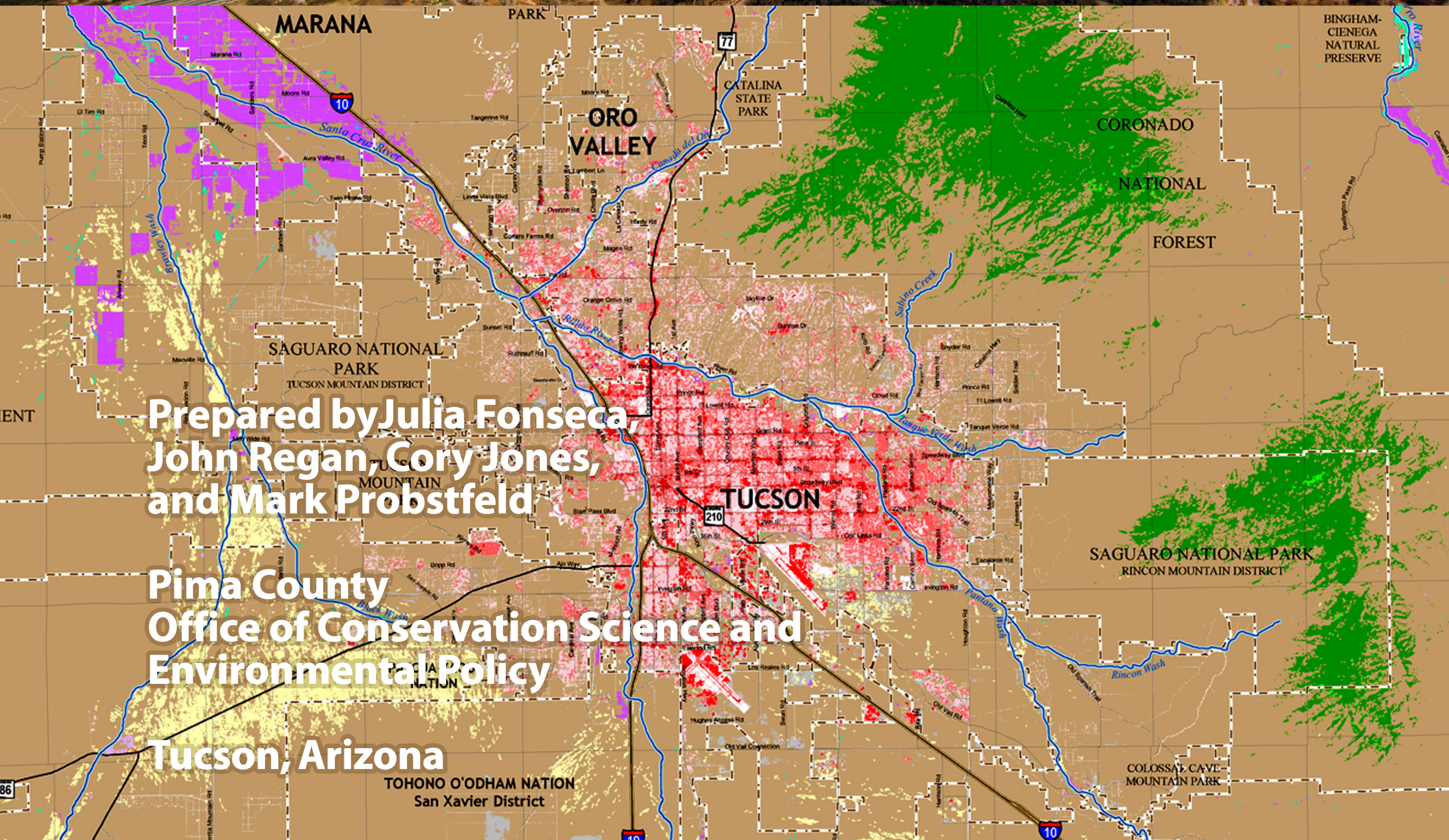

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Cover Photo

View from the Interstate 10 Pantano Interchange
toward Rincon Mountains, by Chuck Park

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ABSTRACT

A previous report recommended that land cover and land-use change be incorporated into the Pima County Ecological Monitoring Plan (Fonseca 2008). The monitoring plan, currently in the design phase, is being developed for habitat conservation purposes. Local, GIS-based measures of development based on tax assessor records do not provide direct measures of habitat loss. National Land Cover Dataset (NLCD) is the only monitoring program available at this time to provide independent assessments of habitat loss. This report develops the methods for using NLCD to report change by jurisdictions and land ownership by utilizing an existing dataset.

The NLCD indicates forested wetland area in Pima County has increased by 4803 acres (19%) from 1992 through 2001, even as the footprint of urban and industrial development has expanded. Most of the conversions in natural land cover to urban development (mean rate of change = 1,200 acres/year) occurred on private lands in eastern Pima County, while changes in land cover on federal and tribal lands have resulted from ecological processes such as fires and woody plant growth. Loss of natural vegetation cover to urban development based on NLCD is close to the rate of 1,357 acres/year that was projected for the initial ten years of the Pima County Multi-species Conservation Plan (RECON 2006; EIS 2003). Both rates are substantially lower than those that might be inferred from land consumption estimates derived from census data.

Background and Purpose

The ***Sonoran Desert Conservation Plan*** (SDCP) is a long-term, spatially explicit, regional effort to conserve the natural and cultural heritage of Pima County, Arizona. The biological goal of the Sonoran Desert Conservation Plan is 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 ecosystem structures and functions necessary for their survival.

Pima County's Office of Conservation Science and Environmental Policy is developing a monitoring plan (Pima County Ecological Monitoring Program; PCEMP) to support efforts to protect habitats for native plants and animals. Monitoring changes in the distribution and abundance of broad, landscape-level parameters such as land cover (e.g. vegetation or the built environment) are thought to be important to the effort (***Powell 2008***). Changes in land cover can portend changes in ecosystem services such as runoff and productivity that ultimately affect the quality of human and other animal life. Changes in cover may directly or indirectly affect habitat for species. Periodic reporting of changes in land use and land cover will be made as part of Pima County's Multi-Species Habitat Conservation Plan (MSCP).

Pima County monitors changes in land uses through tax assessor records, but knowing when and where removal of natural land cover is occurring is challenging. An index called the built environment has been used by Pima County and others as a proxy for reporting lands already converted from natural cover to the built environment (ESI 2003; RECON 2006). The minimum map unit for the built environment is the parcel. Parcel sizes range from less than one-tenth of an acre for some urban lots, to thousands of acres for parcels in wildland settings. There is a great deal of inherent uncertainty in representing habitat loss on larger parcels using parcel-based records. Years may elapse between when a parcel is considered built, and the actual removal of habitat. A parcel may be improved without significant removal of habitat or occupancy of the lot itself: for instance, sewer service may be extended along an adjacent road, or a well or septic tank installed. Even after occupancy, the vast majority of natural cover may be retained on larger parcels. For these reasons, the built environment index can be considered biologically conservation in that it overestimates direct losses of natural cover, and reports such losses at or in advance of the actual impacts.

Remote sensing is the appropriate tool for detecting change in land cover, yet such systems are costly and require sophisticated analytical methods that entail substantial delays in processing (Fonseca 2008). A consortium of federal agencies known as the Multi-Resolution Land Characteristics Consortium (MRLC) collects and processes Landsat satellite imagery to monitor changes to the nation's land cover. The data collected are known as the National Land Cover Dataset (NLCD). At this time, NLCD from 1992 and 2001 are available for Arizona, permitting comparisons across jurisdictional boundaries to investigate changes in the human-built environment and natural land cover.

A previous report recommended using the NLCD data, in conjunction with locally measures of land use change such as the built environment, to understand regional trends in land-cover change for the PCEMP (Figure 1, ***Fonseca 2008***). The purpose of this report is to analyze and interpret NLCD data from 1992-2001 to develop methods of analysis and reporting for the PCEMP and the Sonoran Desert Conservation Plan. This report is a partial contribution toward completion of habitat conservation grant P0012008005134 from Arizona Game and Fish Department.

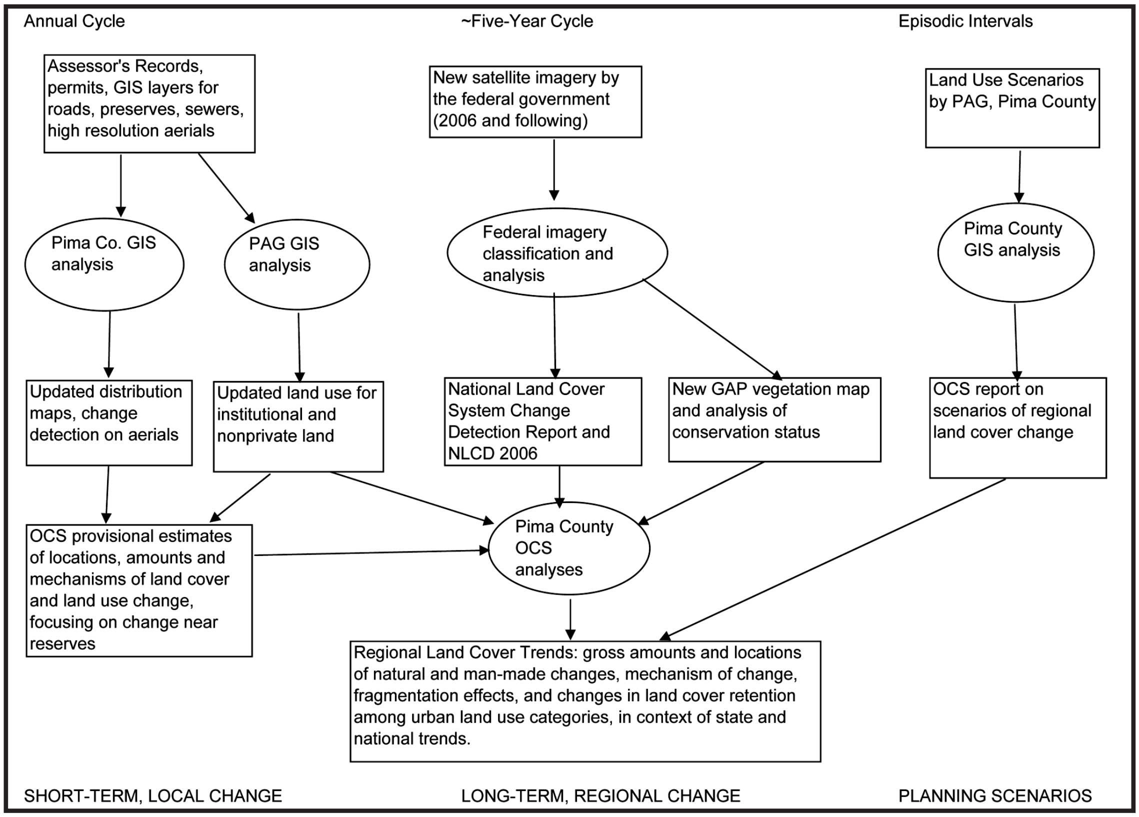


Figure 1. Proposed land monitoring cycles and products for the Pima County Ecological Monitoring Plan (Fonseca 2008).

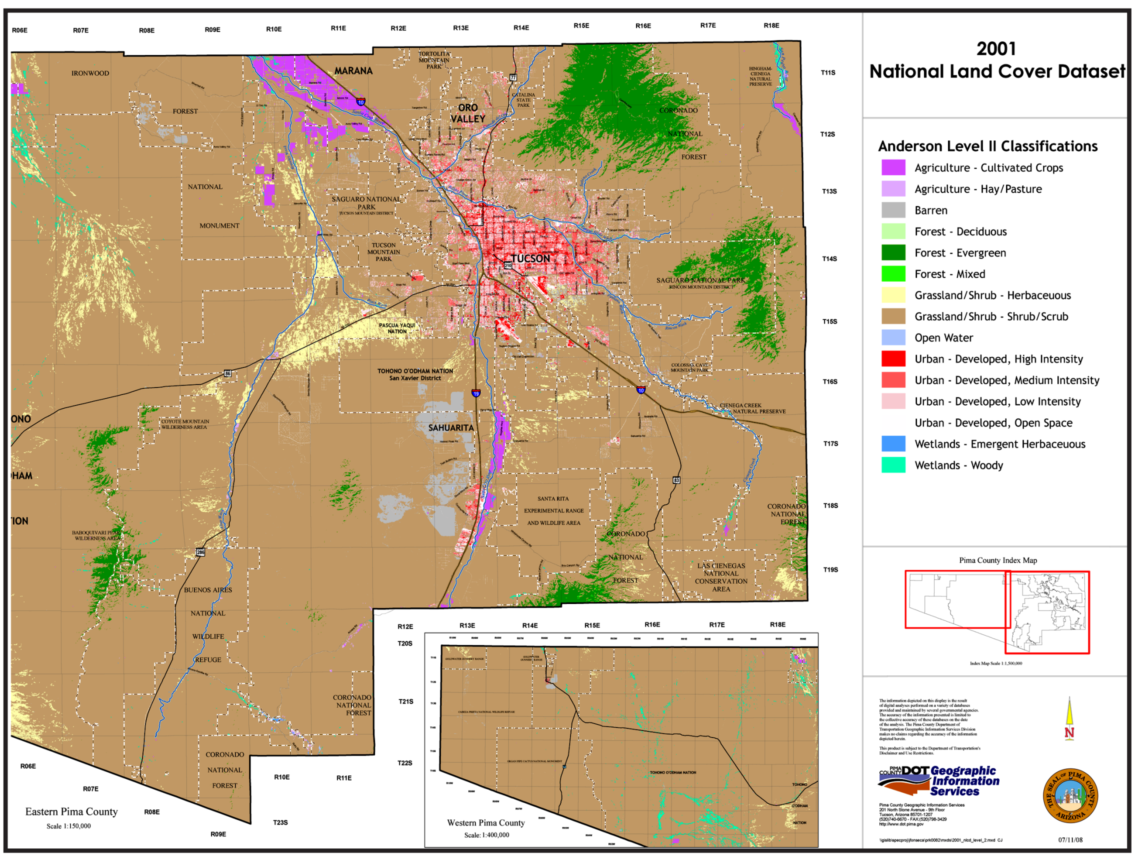


Figure 2. National Land Cover Dataset for eastern and western Pima County for 2001, displayed at Anderson Level 2.

METHODS

To begin our work, we obtained the NLCD 1992, NLCD 2001, and NLCD 1992-2001 change-detection data from the Multi-Resolution Land Characterstics Consortium (***MRLC***) website. NLCD uses the Anderson hierarchical classification system for land cover. At Anderson Level 1, the datasets distinguish between open water, urban, barren lands, forest, grassland/scrub, agriculture and wetland. At level 2, more detail is offered for each of these land cover types. The minimum mapping unit size is one acre, or approximately four 30-by-30 meter pixels. Figure 2 shows the NLCD 2001 for Pima County displayed at the Anderson Level 2 land cover classification. The time period for NLCD 2001 coincides with the intense data gathering effort for Pima County's Sonoran Desert Conservation Plan (SDCP).

The available change detection product for these datasets uses the Anderson Level 1 classification because of the limitations in the 1992 dataset as compared to 2001 (MRLC 2008). NLCD is currently analyzing changed from 2001 to 2006 at Level 2 (Xian, et al. 2007) but the change-detection product has not yet been released.

Diverse desert scrub vegetation types mapped in the Sonoran Desert Conservation Plan land cover are lumped together by NLCD 2001 with true grassland types into what is called the grassland/shrub class (Table 1). This comprises the dominant land-cover type for Pima County in the NLCD.

We compared vegetation mapping performed by Southwest ReGAP and riparian mapping performed during the SDCP to understand the NLCD wetland category. We combined the SWReGAP vegetation classification for Warm Desert Riparian Mesquite Bosques with Warm Desert Riparian Woodland and Shrubland and compared that to NLCD 2001's forested wetland category. Seventy-five percent of forested wetlands, as defined by NLCD 2001 overlapped with riparian forest classifications in SWReGAP. NLCD forested wetlands are restricted to highly mesic settings along major watercourses of central and eastern Pima County, whereas SWReGAP riparian also mapped onto uplands, especially along the periphery of the Baboquivari Range. Herbaceous wetlands mapped by NLCD 2001 correspond primarily with sacaton and other grass-like plants in the Cedar Creek/Arivaca drainage of Pima County.

Table 1. NCLD 2001 classfications for Pima County, Anderson Level 1

Class	Acres
Agriculture	31,381
Barren	58,882
Forest	134,535
Grassland/Shrub	5,454,651
Open water	837
Urban	169,183
Wetlands	30,016
No data	196
Total	**5,879,680**

Pima County Geographic Information Services (GInSo) analyzed the location of changes noted by in NLCD change-detection product relative to land ownership and land-use jurisdiction. These distinctions will be important for understanding the potential for adaptive management in future periods of reporting for the Pima County MSCP. A protocol for evaluating these changes was developed for this purpose (Appendix 1). Analyses were completed using the County assessor's parcel base layer from December 2001 and municipal boundaries from December 2001, respectively. Analyses for future periods would use updated information. GInSo updates parcel records daily.

Losses of natural vegetation cover to urban development are of great interest to the Pima County Ecological Monitoring Program as a proxy for loss of species habitats caused by activities within the scope of land-use authorities. A change was deemed natural land cover loss if the change was from forest, wetland, grass/shrub or open water to urban or barren. (NLCD's barren land classification includes both naturally bare land and land cleared for future urban development or used for mines and quarries). By including lands converted from natural to barren, development impacts may be over-represented by as much as 3,314 acres. If the change was from agriculture to urban, it was not considered a loss (conversion) of natural land cover, but a replacement of one developed cover type for another. Conversions occurring on state trust land or federal lands were also deemed as urban growth for the governing jurisdiction. Because municipalities have continued to annex land in Pima County, we decided to use annexation boundaries as they existed at the end 2001. This may result in underestimating urban development in unincorporated Pima County, but resolves the problem presented by not knowing the relative timing of annexation and development.

We reviewed the location of detected changes against higher-resolution aerial imagery from the time period 1995-2005, selected from the Pima County Internet ***mapguide*** site. Interpretation of aerial photographic imagery was used to validate whether the remotely-sensed change represents an actual land-cover change during that time period. We used corollary data layers from the Pima County GIS library and our understanding of local land-use change to inform the discussion of these changes below.

RESULTS

Barren lands in NLCD 2001 appear to encompass small, isolated, naturally occurring patches of bare soil or rock as well as large, continuous areas of mines and quarries (Figure 3). Thus, changes in barren lands could reflect natural processes of vegetation removal as well as expansion of industrial extraction.

A closer look at NLCD images for mapped agricultural areas shows that agricultural land cover is not monotypic. Instead, agricultural areas are comprised of pixels of agricultural land-cover mixed with grassland/scrub (Figure 2). Comparison with high-resolution color aerial photography shows the fine-scale intermixing of pixels of agriculture and grassland/shrub on tilled farmlands is an artifact of the NLCD imagery processing or in some cases reflects former agricultural lands which were in the process of transitioning back to natural cover types (Figure 3). In the Arivaca area of Pima County, some small areas of sacaton grassland were misclassified as agricultural land cover.

Some low-density rural and exurban development is mapped as natural land cover in NCLD 2001 (Figure 4), but both dirt and paved roadway disturbances associated with these types of developments are generally included in the urban land cover. Given the 30-meter resolution relative to the width of the roadway disturbance, pixellation is evident.

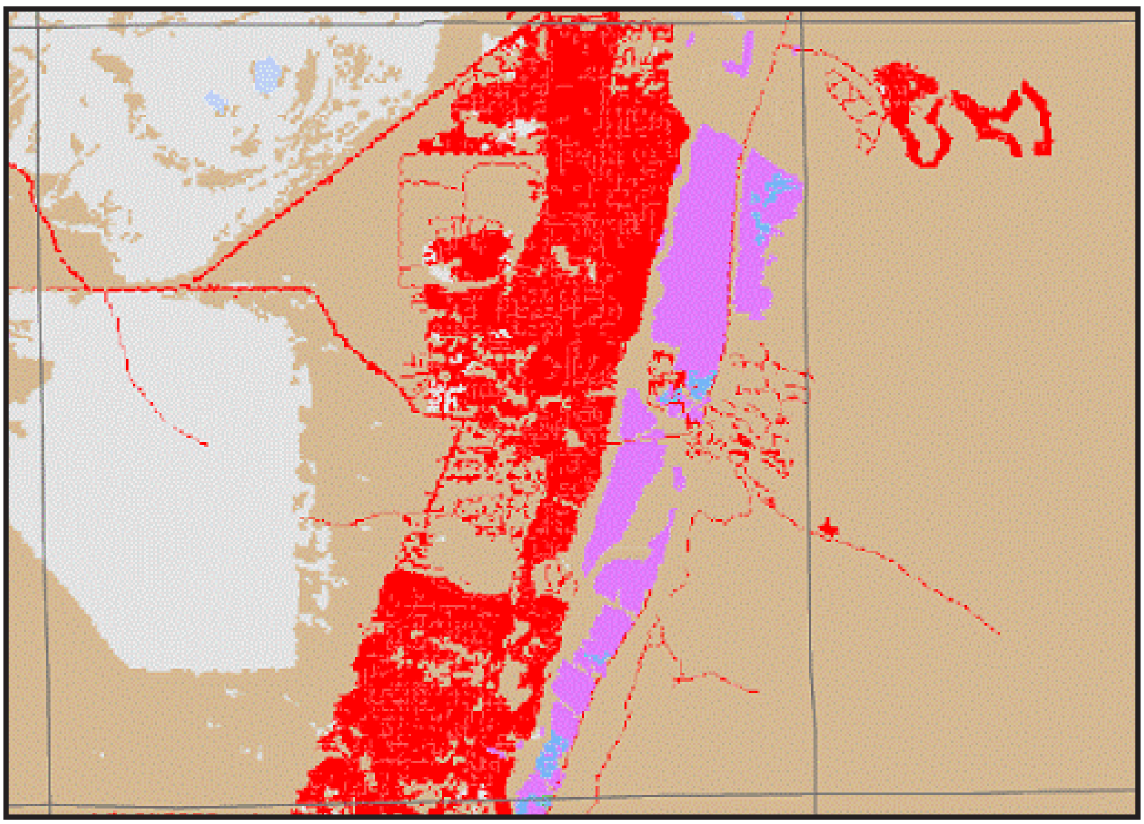


Figure 3. Green Valley and adjacent mines, NLCD 2001. Urban in red, barren lands in gray, agriculture (pecan groves) in magenta.

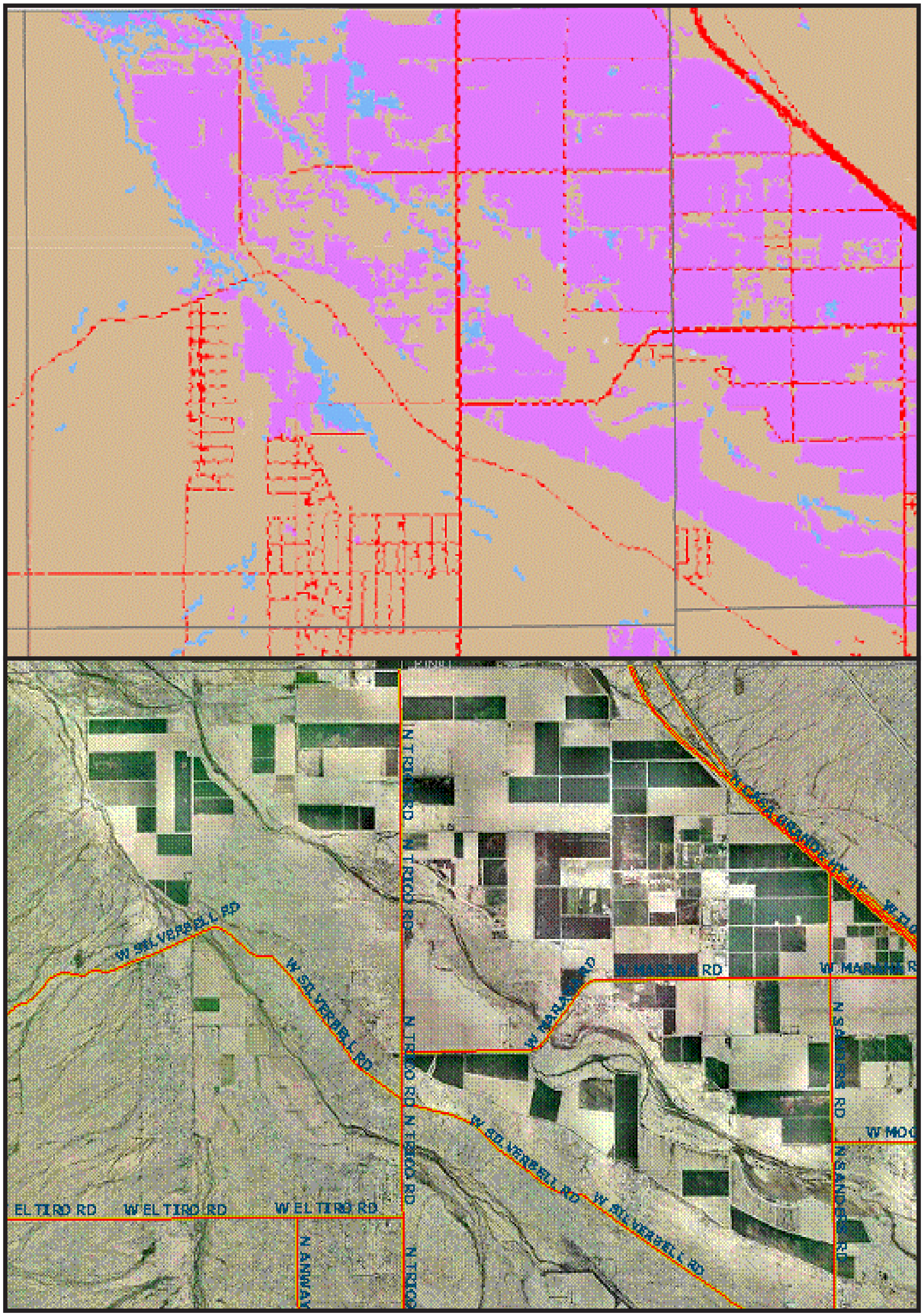


Figure 4. Top: NLCD 2001 image shows agriculture in magenta, grassland/shrub in brown, urban in red, wetlands in blue. Bottom: 2003 natural color orthophotography showing same area. NLCD captures unpaved as well as paved roads, and most agriculture, but abandoned farm fields present some classification problems (see arrow). Wetlands are primarily woody riparian vegetation.

LAND-COVER CHANGE AND OWNERSHIP

The vast majority (99.4%) of Pima County's land-cover did not change classification between 1992 and 2001. Most of the changes that did occur were conversions of grassland/shrub to urban (Table 2).

Table 2. Summary of Changes (Conversions) between Anderson Level 1 land-cover classes, 1992-2001.

CLASS	GAIN	LOSS	NET
Agriculture	5,802	5,479	322
Barren	3,409	0	3409
Forest	2,571	3,247	-676
Grassland/Shrub	6,973	25,669	-18,696
Open Water	250	318	-68
Developed	10,925	16	10,909
Wetlands	4,822	19	4,803

Most of the changes to land-cover detected by NLCD occurred in eastern Pima County. Appendix 3 identifies the ownership of land converted from one category to another during the 1992 and 2001 sampling periods of the NLCD.

The majority of change (17,498 acres) occurred on privately-owned lands, which are a minority of the total land ownership base of Pima County. Most of this change is attributed to conversion of natural land-cover types to barren, agriculture, or urban land-cover (Table 2, Appendix 1). Principally, areas of shrub/grassland were converted to urban uses. Urban land conversions are situated along (1) Mission Road south of Irvington near the Santa Cruz River, in the Tortolita bajada, (2) the Santa Cruz River valley north of Ina, in Marana's former agricultural lands, and (3) old Vail Road.

Federally owned, non-tribal, lands had the second highest area of change (6,580 acres). The majority of this change was from one natural land-cover type to another: forest to grassland/shrub, or from grassland/scrub to forest. Areas of former forest and shrub in the Rincon Mountains were converted grassland/shrub, likely by fires (***Swantek, et al.***, no date). There are almost no areas of forest loss in the Santa Catalina, Baboquivari or Sierrita Mountains during this same time period (1992-2001). Small, dispersed areas of forest gains are found in the Whetstone Mountain and Santa Rita Mountain units. These are likely caused by maturation of forest canopy in the absence of fire.

Tribal land change appears to be driven principally by natural factors and obscured by classification issues. We attribute the majority of change to have occurred in floodplains, where 1,684 acres of lands classified in NLCD 1992 as agricultural were converted to grassland/scrub, and 2,771 acres of grassland/scrub shifted to wetlands (riparian). A review of the 2001 Landsat imagery suggests that some of the apparent loss of agriculture to grass/scrub may be spurious, the result of corrections to the 1992 misclassification what was really desert scrub.

Land-cover on State Trust lands changed little in relation to their proportion of the land base. The majority of the change detected is attributed to agriculture gains (936 acres) in northern Pima County. This seems curious, given the moratorium on new agricultural expansion in the Tucson Active Management Area (AMA). When we look at the distribution of these purported agricultural gains, we see that much of what was recorded as an agricultural gain is the result of misclassification in 1992 or possibly shifts in irrigation states from dry and fallow in 1992 to wet and cultivated in 2001 (Figure 5). Some of the apparent losses (blue) in agricultural on State Trust land are the result of corrections in classification which occurred in the 2001 NLCD. Improvements made for the 2001 classification should reduce errors for the next monitoring period, 2001-2006.

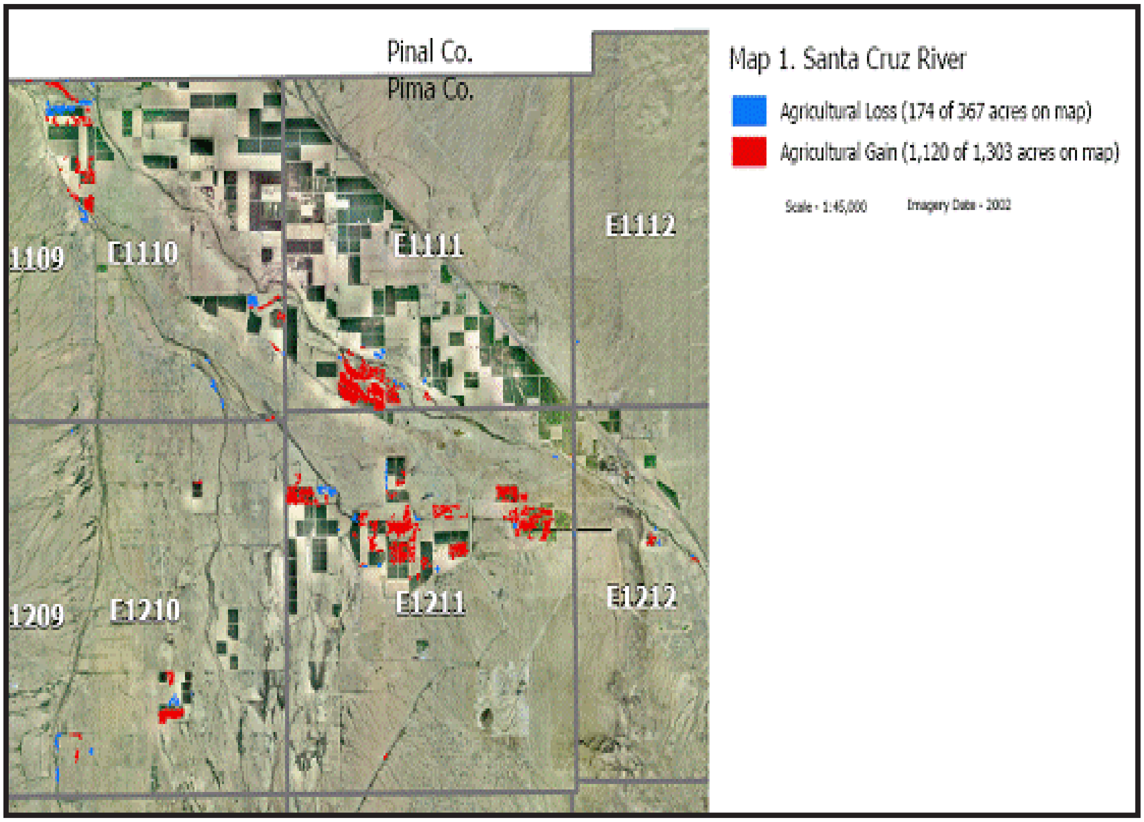


Figure 5. Locations of NLCD agricultural losses and gains on State Trust lands, superimposed on 2002 natural color imagery.

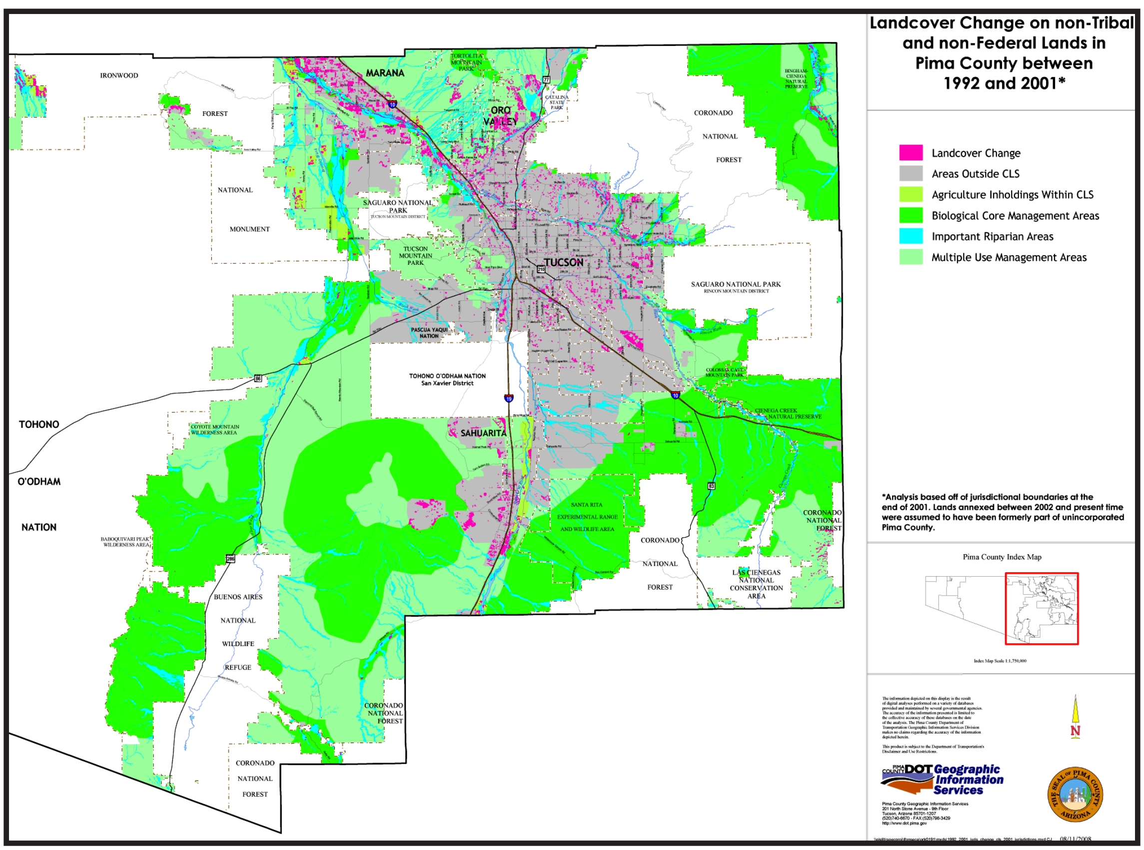


Figure 6. Location of conversion from natural to urban land-cover, 1992-2001.

Land-cover Change by Jurisdiction

This analysis examined conversion of natural land-cover types to the urban classification. Jurisdictional boundaries included federal and state trust lands.

Most of the loss of natural cover occurred through urban development of grassland/shrub in unincorporated Pima County (Table 3). Marana and Oro Valley also expanded into areas formerly classified as grassland/shrub. Tucson and South Tucson contributed relatively little to loss of natural land-cover, 24 and 2 acres respectively. South Tucson is mostly developed already, and 122 acres of Tucson's 146 acres of urban development occurred on former agricultural lands.

The distribution of natural land-cover conversion to urban development in non-federal, non-tribal land is shown in magenta in Figure 6. Most of the development in unincorporated Pima County during this time-period occurred in the Catalina foothills, the southern Tortolita piedmont, and in Green Valley. This figure includes the category of agriculture to urban land conversion mapped in blue, most of which occurred in Green Valley and the Tanque Verde Valley.

The distribution of urban growth relative to Conservation Lands System (CLS) for the Sonoran Desert Conservation Plan was also analyzed (Appendix 3). CLS guidelines for rezonings and other discretionary land-use decisions of the Pima County Board of Supervisors constrain the footprint of future development in many parts of unincorporated Pima County. The guidelines had not been adopted by any jurisdiction during the period 1992-2001, but Pima County did put rezoning guidelines into effect in 2002. During 1992 through 2001, most urban development occurred either outside the CLS or in areas of multiple-use management. However, from a biological perspective, urbanization in or near riparian areas is of concern. Urbanization of natural land-cover within Important Riparian Areas designated in the Sonoran Desert Conservation Plan causes habitat loss and imposed new stressors upon the CLS category with the greatest intended development restriction (Table 4). Urbanization of former agricultural lands within these areas diminishes the potential for natural or assisted recovery of native vegetation along watercourses.

No urbanization of NLCD wetlands occurred in any jurisdiction. The only forest loss, of two acres, occurred within the City of Tucson. This may represent conversion of an artificially-wooded urban lot, because naturally occurring forests in Tucson city limits are exceedingly rare. In Oro Valley, one acre of open water was converted to urban.

Table 3. Natural Land-cover Conversion to Urban Development (acres; 1992-2001) based on National Land-cover Dataset and 2001 Jurisdictional Boundaries

Jurisdiction	Marana	Oro Valley	Sahuarita	South Tucson	Tucson	Uninc. Pima County	All Jurisdictions
Conversion	1,129	1,860	185	2	24	3,894	7,094

Table 4. Existing urbanization 1992-2001 in areas later classified as Important Riparian Areas (IRA).

Jurisdiction	Marana	Oro Valley	Sahuarita	South Tucson	Tucson	Uninc. Pima County	All Jurisdictions
Loss of Ag in IRA	0	0	0	0	14	16	30
Loss of Grass /Shrub in IRA	58	14	0	0	0	92	164
Totals	58	14	0	0	14	108	194

NLCD 2001 also contains information about the distribution of impervious cover and canopy cover by jurisdiction, watershed or other areas of interest (Table 5). Comparable data will be available for 2006 (Xian, et al. 2007).

Tucson's acreage of canopy cover is much higher than the jurisdictions of Marana, Oro Valley, Sahuarita or South Tucson. Unincorporated Pima County's canopy cover is affected by the distribution of natural forest, but this is unlikely to be the case for other jurisdictions.

Unincorporated Pima County and Tucson have the bulk of impervious cover, but South Tucson has the highest percentage of impervious cover (Table 6).

Table 5. Number of acres in each Canopy Cover range by jurisdiction, Eastern Pima County, 2001

	0%	**1-5%**	**6-15%1**	**6-25%**	**26-100%**	**TOTAL**
MARANA	51,181	5	24	52	225	**51,487**
ORO VALLEY	17,685	0	1	45	169	**17,900**
UNINC. PIMA COUNTY	1,534,534	6,671	13,727	23,603	43,848	**1,622,382**
SAHUARITA	8,161	0	11	169	866	**9,207**
SOUTH TUCSON	630	0	0	0	0	**631**
TUCSON	139,051	2	20	843	2,422	**142,338**
TOTAL	**1,751,241**	**6,678**	**13,783**	**24,713**	**47,530**	**1,843,944**

Table 6. Percent Impervious Cover in 2001 by jurisdiction, Eastern Pima County

	0%	**1-5%**	**6-10%**	**11-20%**	**21-100%**	**TOTAL**
MARANA	46,274	691	717	1,092	2,713	**51,487**
ORO VALLEY	12,307	537	0	756	3,880	**17,900**
UNINC. PIMA COUNTY	1,542,576	11,741	8,344	11,835	47,886	**1,622,382**
SAHUARITA	8,086	150	180	213	578	**9,207**
SOUTH TUCSON	16	5	14	46	550	**631**
TUCSON	78,332	1,906	2,203	5,350	54,547	**142,3388**
TOTAL	**1,687,590**	**15,030**	**11,879**	**19,292**	**110,154**	**1,843,944**

DISCUSSION

When viewed on a land-cover basis, independent of ownership, the dominant change in NLCD land-cover is the loss of 25,669 acres of grassland/shrub land-cover (Table 2). As shown in Appendix 2, over 10,000 acres of urbanization came at the expense of loss of grassland/shrub cover. Wetland cover increased, while barren and open water classes experienced net declines.

While some change in the agricultural land is the spurious result of misclassification, around 2001 there was expansion of tribal agriculture in Avra Valley. During this time, some agricultural land clearing also occurred along in the valley of the San Pedro River and along the Santa Cruz River near San Xavier del Bac.

Key Statistics	Acres
Gross change to Agriculture	**5,802**
Net change to Agriculture	322
Gross change to Urban	**10,925**
Net change to Urban	10,909
Gross (and net) change to Barren	**3,409**

The change in forested cover is smaller, but significant given that the total amount of forested land covers only 2.2% of the County. Over 3,000 acres of forest cover was lost, but over 2,000 acres were gained. Most of this flux represents the dynamic between forest and grassland/scrub states caused by fires and natural re-growth. Because the immagry was taken prior to the 2002 and 2003 catastrophic fires in the Santa Catalina Mountains, we expect to see considerable change in forested cover in the next iteration of this analysis.

The 19% increase in wetland cover is perhaps the biggest surprise. Recall that wetlands include areas of herbaceous, shrub or forest types found in low-lying areas with high soil moisture. In our areas, "wetlands" include woodland and forest of mesquite or broad-leafed deciduous trees. The increases in mapped wetlands appear to have occurred in riparian areas. Much of the apparent growth in wetland cover occurred within low-elevation floodplains within the Tohono O'odham Nation, far from urban development; but, gains also occurred along the effluent-dominated Santa Cruz River. In all, 4,822 acres of "wetland" increase was mapped, and only 19 acres were lost.

Could the gain be the spurious result of seasonal differences in moisture-content of vegetation and soils between the 1992 and 2001 imagery? In Arizona, there are tremendous changes in the amount of land surface covered by leaf area before and after the monsoon season. To investigate this possibility, we looked at the ***metadata*** (MRLC 2000) from the images used in the NCLD 1992. Arizona is covered by no more than 18 Landsat Thematic Mapper (TM) scenes. The general NLCD procedure is to: (1) mosaic the scenes and classify them using unsupervised clustering, (2) interpret and label the clusters using aerial photographs as reference data, (3) resolve the labeling of confused clusters/classes using ancillary data source(s), and (4) incorporate land-cover information from other data sets and perform manual edits to augment and refine the "basic" classification developed above. The MRLS used two seasonally distinct TM mosaics: a leaves-on version derived from pre-monsoon (April-June) images from 1988-1992 and a leaves-off version during and after the monsoon (August-October 1988-1993). The MLRC metadata indicates that they also relied on GAP, U.S. Fish and Wildlife Service National Wetland Inventory, U.S. Geological Survey land-cover/land use data and proximity to streams and rivers to separate wetland classes. These NLCD procedures reduce the likelihood that the observed change is solely the result of seasonal differences in the soil moisture and leaf condition in the imagery.

Could the increase in wetlands represent the maturation of forest canopy that had established prior to 1992? Most of this gain came from areas which were previously classified as grassland/shrub. To examine this possibility more closely, we mapped the areas of increased wetland in Pima County and reviewed high-resolution aerial imagery (Figure 7). We reviewed Pima County Regional Flood Control District's 1:12,000 contact aerial photographs for the Santa Cruz River dated 1988 and 1994 and visually compared those to August 2001 imagery on Pima County's internet—accessible through ***mapguide***. August 2001 imagery shows large increases in riparian woodland occurred in the mapped locations during that time period. Even tiny patches of broad-leafed trees

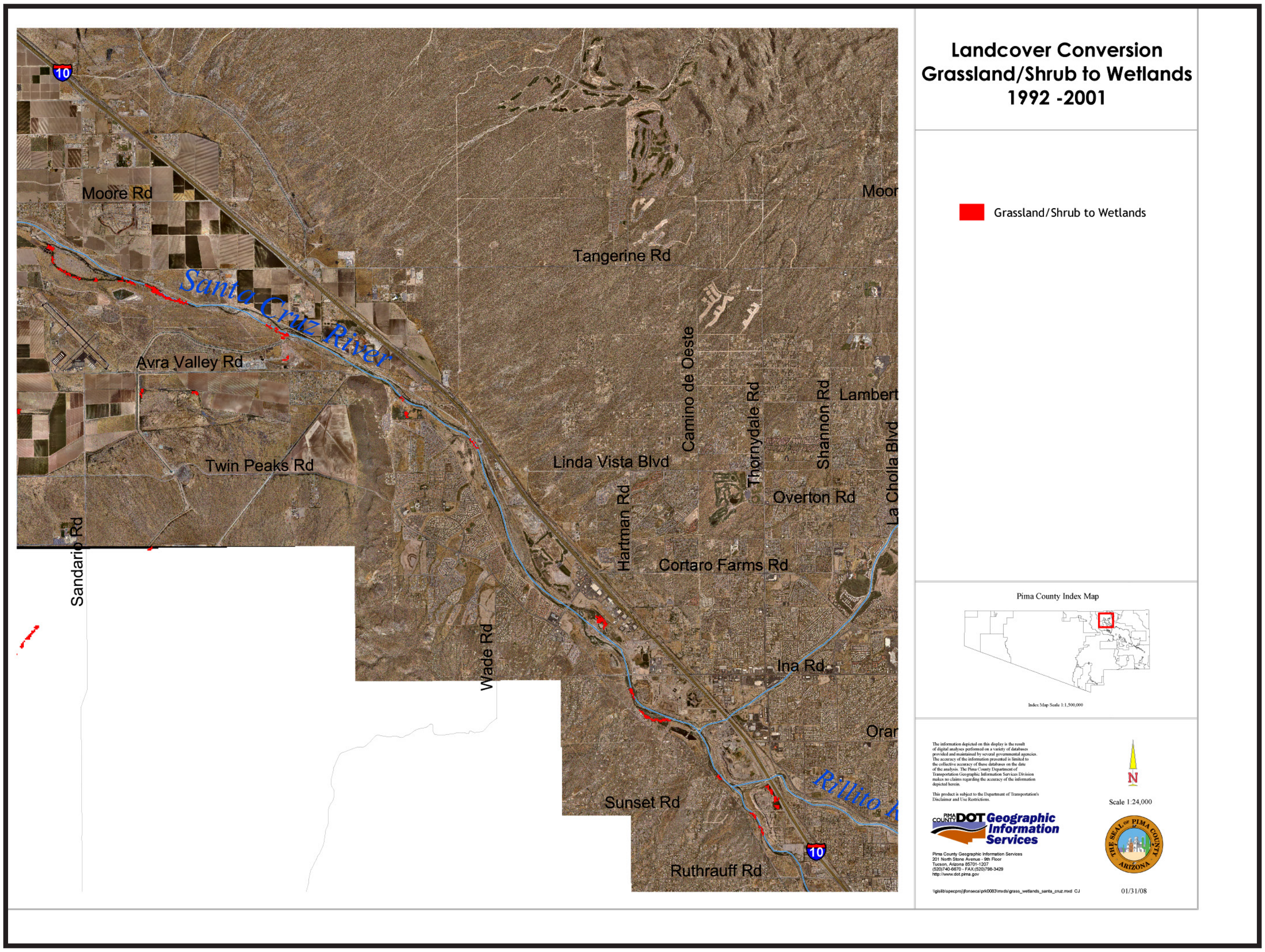


Figure 7. Red areas represent conversions from grassland/shrub to wetlands along the effluent-dominated Santa Cruz River.

which existed in gravel-pit ponds and channels are correctly mapped as wetland in the NLCD 2001 product. Several independent efforts have verified the increased acreage of riparian woodland along the Santa Cruz River (Baker 2000; Galyean 1996). One apparent error, a nascent pecan grove that was mapped wetland, is still consistent with the ability of this change-detection product to identify new forested "wetlands".

We also note that one area of mapped increase along Cienega Creek corresponds with a long-term photographic monitoring station. Figure 8 represents the observed change in this point from 1988 to 1998, a time period marked by growth of cottonwood saplings into a forest with an herbaceous understory. Importantly, the period from 1977 to 1993 had above average rainfall. However, the total increase in wetland is likely smaller at this location, as some of the gains are the result of correction to the 1992 misclassification.

The "developed" category increased by 10,909 acres. No local monitoring data are available to estimate the actual "footprint" for urban development on a yearly basis and therefore the NLCD provides a unique data source for this information. As previously mentioned, parcel-based tax assessor records do not account for undeveloped areas within a parcel. Pima Association of Governments (PAG) collects geo-referenced

Figure 8. Cienega Creek just upstream of Davidson Canyon. 1988 and same location in 1998. (Photographs by Julia Fonseca and David Scalero)

building permit locations from individual jurisdictions. There is no way to sum the total acreage of land disturbance from the building permit data. Also, none of these methods track the area disturbed for infrastructure projects such as airports, railroads, state and local roads, etc.

A total of 111 acres of County-owned land having natural cover converted to developed, according to this data source, of which 108 acres were previously classified as grassland/shrub. Again, the County maintains no independent record of loss of natural cover due to development against which these numbers may be compared. About 8,744 acres of private land were developed, again mostly from the grassland/shrub category. Development includes areas of urban turf and trees or constructed materials such as asphalt, concrete, buildings, etc. Tucson has over 2,000 acres of land with canopy cover in excess of 25%. South Tucson has the highest proportion of impervious cover in its jurisdiction.

The increased in the developed category, as estimated from NLCD's analysis of spectral reflectances, is 52% lower than land consumption estimates based on population growth and household density. Census data show that between 1990 and 2000, Pima County's population grew by 176,866 persons. Given Pima County's household size in 2000 was 2.47 persons (***U. S. Census Bureau***), ten years of new growth would be estimated to occupy an estimated 71,606 housing units, which is very close to the number of new permits issued from 1990-1999 (76,130 permits; PAG). Of these, approximately 86% were single-family housing, including mobile homes (PAG 2008). If all the units were new single-family dwellings, and all were placed in relatively low-density suburban (3,000 units per square mile) housing on natural areas, then the footprint of new development would be approximately 21,000 acres.

Factors which may account for the difference between projected land consumption based on housing density and the lower results from NLCD are the slightly different time periods represented, the potential for population increase to be absorbed by existing housing stock or urban infill projects, and what might be called the "low density residential problem." In the eastern U.S., NLCD estimates of development were found to under-represent development which occurs at levels of one dwelling per one-half acre or less (***Irwin and Bockstael, 2007***). This occurs because tree canopy obscures many small homes and roads in rural settings. In our more arid landscape, this factor may not constrain NLCD detection. Roadways and homes associated with low-density rural development are seldom obscured by vegetation. Many, but certainly not all, roads and roofs in exurban developments have high spectral contrasts from natural land cover (see Figure 3). Clay tile roofs are an exception (Phil Guertin, *personal communication*).

The NLCD development classification and mapping is more precise than using County parcel-based classifications for understanding the actual footprint of development. If a home or a mine is placed on a parcel, the entire parcel will be classified as developed for the purposes of Pima County tax records. The parcel base cannot be used to identify the portion of the parcel that may remain undisturbed.

Finally, the barren lands category increased by 3,409 acres, primarily from areas formerly mapped as grassland/shrub. If forested wetlands increased, then why would barren lands increase? High-resolution aerial photographs reveal that some of the newly barren areas correspond with expansion of existing mines. In addition, some of the barren land corresponds with graded areas not classified as developed, but which are in the process of being developed. None of the barren lands which existed in 1992 are shown as changed pixels by 2001 because those mechanically disturbed areas in 1992 were absorbed into the urban class definition for 2001 NCLD (***MRLC***, no date).

Comparison with Regional Trends

Federal agencies are using satellite imagery from 1973 to 2000 to report on land-cover and land use change in the U.S. Preliminary results from the Southwestern ecoregions of the Sonoran Basin and Range, the Madrean Archipelago and the Chihuahuan Deserts seem to indicate that change is "infrequent and occurs mostly within the grass/shrub, agriculture, and mining classes (***Ruhlman, et al., 2008***)." Our findings from the more limited NLCD set in Pima County show large increases in forested wetlands, principally mesquite woodland and cottonwood-willow riparian forests.

Though small in extent, changes in woody wetlands are important leading indicators of regional trends in biodiversity. These highly productive riparian forests and woodlands harbor much of the plant and animal diversity in the southwestern United States. Regional increases of woody riparian growth have been independently noted along many river systems in the Southwestern U.S. (Webb and Leake 2005; Webb et al., 2007; Jones, et al., 2008). In the conterminous U.S., freshwater wetland extent increased during the time period 1998 to 2004, based on remote sensing (***USFWS, 2005***). Most of the gains resulted from the creation of numerous freshwater ponds associated with agricultural conservation programs. Freshwater forested wetlands increased by 1.1% overall, and several Arizona-based samples showed gains in wetlands (USFWS, 2005).

Pima County's urban development occurs in the context of an emerging "Megapolitan" area that stretches from Sierra Vista to Prescott ***Morrison Institute 2008***). NLCD development claimed an average of 1,212 acres of natural land-cover per year. Based on census of population growth from 1990 to 2000, this means that natural land-cover was converted at a rate of one acre for every 14.6 new residents, or 0.0685 acres per person. Rates of removal of natural land-cover appears to be far lower than the land consumption rate of 0.272 acres/person reported for Tucson based on 1990 census urbanized areas and population (***Kolankiewicz and Beck, 2001***). The same source estimated mean land consumption of 4,538 acres per year for the period 1970 to 1990.

For various reasons, the "footprint" of urban encroachment upon natural land cover, as measured by NLCD, should not be conflated with these census-based measures. The U. S. Census Bureau defines urbanized areas as the central city and its contiguously developed suburbs. These data include much interstitial undeveloped land that could be natural land-cover by NLCD (see Figures 2 and 4 for examples) Census-derived land consumption rates are typically used to measure rural to urban land-use change, often called "sprawl". Intensification of land use within the urban land-cover class is also not included in the 0.0685 acres per person rate we calculate using the NLCD data. The NLCD change product defines the urban class as a mix of constructed materials such as roads and houses with vegetated areas such as golf courses, parks and other developed settings (MRLC no date). It includes development far from the urban areas.

NLCD estimates of the rate of urban development impacts are similar to those in the land use projections conducted for the Pima County Multi-Species Conservation Plan (RECON 2006; ESI 2003), though the configuration (Figure 6) is quite different. The model used for the MSCP projected a rate of development impact of 1,357 acres per year for the planning area for the first ten-year period. The MSCP projection included impacts inside and outside the reserve design, irrespective of jurisdiction.

NLCD estimates in Pima County could be a useful measure of direct habitat losses, whereas Pima County's parcel-based estimates (Figure 1, first column) might better represent the indirect losses which occur as a consequence of human occupancy. NLCD could also support habitat fragmentation analyses for individual species; the 30-meter grid size is the same resolution as uniformly available slope and climate data often used in state, local and national habitat studies. It would be more difficult to use parcel-based GIS data for fragmentation analysis, primarily because of inherent uncertainties in what is actually developed in the exurban and low-density rural residential categories, though road-based analyses are an alternative.

THE FUTURE OF THE NLCD

Periodic monitoring of changes in the nation's land-cover are expected to continue. Various federal agencies are currently undertaking analysis of 2006 satellite imagery. According to the ***Multi-Resolution Land Characteristics Consortium***, imagery from circa 2001 and 2006 is being compared. Areas identified as change have been extracted from the image sets and classified according to NLCD 2001 methods. The classified change areas will be integrated into the NLCD 2001 to produce NLCD 2006. In short, NLCD 2001 will serve as the base map for NLCD 2006. When it is complete, it should allow us to discriminate change in a greater variety of cover classifications than was previously possible. For example, changes in types of urban cover should be evident, and examination of changes in impervious cover and canopy cover will be possible (Xian, et al. 2007)

In order for the NLCD to continure to be useful over time, the federal agencies in the MRLC must continue to use the same procedures and sensor technologies over time, or at least develop procedures for crosswalking information as new technologies become available. If there is no commitment to a monitoring approach, changes in sensor technology or methods may erode the potential for detecting landscape change.

If the NLCD is to be more useful to state and local governments such as Pima County, we have the following recommendations:

1. Turn-around time for change-detection product needs to be reduced. A lag-time of five years occurred between the NLCD 2001 imagery and the release of the 1992-2001 change detection set. No state-wide summary report on change has been made available as yet from the MRLC.

2. Better methods for discriminating unirrigated agriculture from natural land-cover types are needed for more reliable estimates of shifts between these two categories. Use of seasonal changes in greenness could help resolve this at the national level.

3. Discrimination between naturally barren and artificially barren land-cover is essential for understanding changes in watershed condition. Use of seasonal images and corollary datasets will help at the national level.

4. If changes in methods or sensors occur, MRLC should completely document these, including values and formulas. Also description as to what degree these changes would compromise interpretations, which can be drawn from the change-detection products, would be helpful.

We have the following recommendations for Pima County's Ecological Monitoring Program:

1. Independently analyze the developed land category in NLCD 2001 using a subset of Pima County to understand the capabilities of current NLCD methods to classify urban lands accurately.

2. Develop rapid, in-house assessment procedures that could be used in conjunction with PAG high-resolution imagery to detect land conversion that would be compatible with NLCD 2006 and beyond.

3. Do not solely rely on NLCD for non-tribal agriculture gain/loss information. Parcel-based tax codes and in the future, ADWR crop survey data, can be used for defining active agriculture and for checking the reliability of NLCD classifications.

4. At the local level, identify and track the fate of abandoned agricultural lands. How many and where are these really are converting to natural land-cover versus urban development?

Conclusions and Acknowledgements

Natural land-cover conversion rates due to urban development were approximately 1,200 acres per year, based on NLCD. This is a substantially lower rate than census-based "sprawl" estimates would provide but similar to the rate projected for the Pima County Multi-species Conservation Plan. Urbanization is primarily affecting the loss of grassland/shrub types, but not wetlands. Wetland and forest land-cover change is primarily driven by natural factors, however cities such as Tucson have replaced native desert scrub with thousands of acres of artificially wooded land. Forested wetlands, a riparian habitat type which helps to sustain much of Pima County's biodiversity, appear to have increased during this time period. This change would not have been detected using local methods now available. NLCD also provides unique data on the distribution of tribal agriculture and type conversions due to fire.

Using the NLCD change-detection product as the sole source of information about habitat loss would fail to take into consideration the indirect impacts of urbanization such as habitat fragmentation, exotic species and other issues. The release date and methods used for NLCD products is also outside Pima County's control. We therefore affirm our previous recommendation to complement NLCD estimates with local GIS-based approaches for monitoring land-use change.

We thank Brian Powell, the principal editor for this report, and Andrea Fowler, who formatted the report. Manabendra Changkakoti, Richard Grimaldi, Greg Saxe and others also helped to improve the manuscript.

References

ESI Corporation 2003. Pima County Economic Analysis, Section 10 Permit. Sonoran Desert Conservation Plan. County Administrator's Office.

Fonseca, J. 2008. Remote Sensing to Monitor Land Cover Change. ***Multi-Species Conservation Plan Update***. Pima County Administrator's Office.

Galyean, Ken 1996. Infiltration of Wastewater Effluent in the Santa Cruz River Channel, Pima County, Arizona. U. S. Geological Survey Water-Resources Investigations Report 96-4021. Tucson, Arizona.

Irwin, E. G. and N. E. Bockstael 2007. ***The evolution of urban sprawl***: Evidence of spatial heterogeneity and increasing land fragmentation. Proceedings of the National Academy of Sciences, 104:52, December 26. Accessed September 20, 2008.

Jones, K. B., C.E. Edmonds, E.T. Slonecker, J.D Wickham, A.C. Neale, T. G. Wade, K. H, Ritters, and W. G. Kepner 2008. Detecting changes in riparian habitat conditions based on patterns of greenness change: A case study from the Upper San Pedro River Basin, USA. Ecological Indicators 8 (1): 89-99.

Kolankiewicz, L. and R. Beck 2001. Weighing Sprawl Factors in Large US Cities. Published by NumbersUSA.com. http://www.sprawlcity.org/studyUSA/USAsprawlz.pdf . Accessed September 21, 2008.

Multi-Resolution Land Characterization Consortium 2000. National Land Cover Data, Arizona. Version 09-06-2000. http://gis.esri.com/library/userconf/proc97/proc97/to200/pap196/p196.htm , Accessed September 20, 2008.

Morrison Institute 2008. ***Megopolitan: Arizona's Sun Corridor***. Accessed September 20, 2008.

Pima Association of Governments 2008. ***Housing***. Accessed September 21, 2008.

Powell, B. 2008. Pima County Multiple Species Conservation Plan Monitoring Program: Recommended Approach. ***Report*** to the Pima County Board of Supervisors, Office of Conservation Science, Pima County Natural Resources, Parks and Recreation. Accessed September 21, 2008.

RECON 2006. Pima County Multi-species Conservation Plan. Sonoran Desert Conservation Plan. County Administrator's Office.

Ruhlman, J. L. Gass, and B. Middleton 2008. Comparison of Contemporary Land-Cover Trends among the Sonoran Basin and Range, Madrean Archipelago, and Chihuahuan Deserts Ecoregion in Proceedings of a USGS Workshop on Facing Tomorrow's Challenges Along the US-Mexico Border. ***U.S. Geological Survey Circular 1322***. Accessed September 20, 2008.

Swantek, P.J., W. H. Halvorson, and C.R. Schwalbe, no date. ***The Use of GIS and the Internet for Analyzing Fire History of the Sonoran Desert: A Regional Approach in Arizona***. Accessed September 20, 2008.

Turner, Raymond, 2003. ***Pima County's Withdrawal from Its Past***. Sonoran Desert Conservation Plan. County Administrator's Office.

U. S. Census Bureau 2008. ***State and County Quickfacts***. Accessed September 21, 2008.

U. S. Fish and Wildlife Service 2005. ***Status and Trends of Wetlands in the Conterminous United States 1998 to 2004. Accessed September 11, 2008***.

Webb, R. H. and S. A. Leake 2006. Ground-water surface-water interactions and long-term change in riverine riparian vegetation in the southwestern United States. Journal of Hydrology 320: 302-323.

Webb, R. H., S.A. Leake, RM Turner, and D. Oldershaw 2007 The Ribbon of Green: Change in Riparian Vegetation in the Southwestern United States. Tucson, Arizona: University of Arizona Press.

Xian, G., C Homer, and J. Fry 2007. A Prototype of Updating National Land Cover Dataset by Using Landsat Imagery. American Geophysical Union, ***Fall Meeting abstract #B23F-05***. Accessed November 20, 2008.

APPENDIX 1. PROTOCOL FOR JURISDICTIONAL COVER ANALYSIS I (Provide acreage analysis of developed, impervious, and canopy cover on non-tribal, non-federal lands based on 2001 jurisdictional limits based on NLCD datasets)

Author: Cory Jones
Date: August 2008

Project 1: PRK0198 - 2001
Project 2: (PRK0201) methods can be found further below

DETERMINING JURISDICTIONS IN 2001

1 - USE "ERASE" GP TOOL TO GET PIMA COUNTY LANDS THAT AREN'T GIS ISLANDS

INPUT = "PIMA_ALL"
ERASE = "LIM_ALL"
OUTPUT = "COUNTY_BOUND_LIM_ALL_ERASE"

2 - ADD FIELD TO "COUNTY_BOUND_LIM_ALL_ERASE" LAYER CALLED "NAME"

3 - ATTRIBUTE FIELD WITH "PIMA COUNTY" VALUE

4 - USE "MERGE" TOOL TO ADD THE RESULTING FEATURES FROM "COUNTY_BOUND_LIM_ALL_ERASE" TO "LIM_ALL"

INPUT1 = "LIM_ALL"
INPUT2 = "COUNTY_BOUND_LIM_ALL_ERASE"
OUTPUT = "LIM_ALL_NO_TRIBAL_NO_FEDERAL"

5 - DELETE FEATURES FROM "LIM_ALL_NO_TRIBAL_NO_FEDERAL" REPRESENTING FEDERAL OR TRIBAL LANDS

6 - ADD FIELD TO "LIM_ALL_NO_TRIBAL_NO_FEDERAL" LAYER CALLED "JURIS2001" (STRING, 50)

7 - ATTIBUTE "JURIS2001" FIELD WITH "PIMA COUNTY" VALUE FOR FEATURES USING THE FOLLOWING SELECT ROUTINE

SELECT FEATURES FROM "LIM_ALL_NO_TRIBAL_NO_FEDERAL" WHERE "EFF_DATE" LIKE '200%'
REMOVE FEATURES FROM CURRENT SELECTION WHERE "EFF_DATE" LIKE '2001%'

8 – ATTRIBUTE "JURIS2001" FIELD WITH "PIMA COUNTY" WHERE "NAME" = 'SANTA RITA EXPERIMENTAL RANGE'

CANOPY COVER DATA LAYER PROCESSING

1- DOWNLOAD DATA SET FROM http://www.mrlc.gov/nlcd_multizone_map.php

2- PROJECT .IMG FILES TO OUR COORDINATE SYSTEM

3 - CLIP RASTER DATASET TO PIMA COUNTY BOUNDARY (canopy5_122706_ProjectRasterClip.img)

4 - RECLASSIFY CANOPY DATASET AS FOLLOWS;

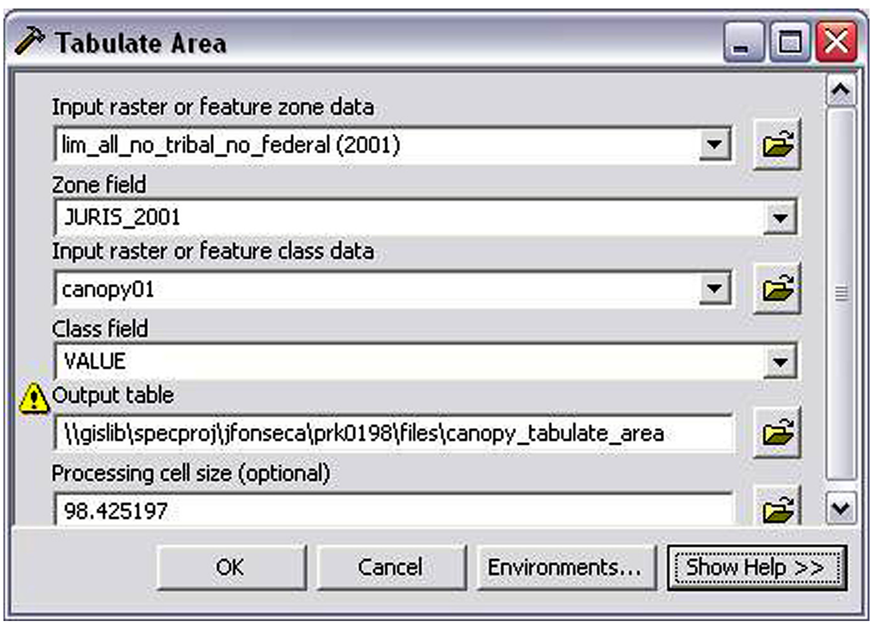
Reclassify into 6 classes (method = manual)

Old Value	New Value	Break Value
0	0	0
0-5	5	5
6-15	15	15
16-25	25	25
26-100	100	100
101-127	No Data	127

NAME DATASET CANOPY01

5 - USE "TABULATE AREA" IN ARCTOOLBOX->SPATIAL ANALYST TOOLS->ZONAL TO CALCULATE AREA OF EACH CANOPY CLASS WITHIN JURIS2001 FIELD OF "LIM_ALL_NO_TRIBAL_NO_FEDERAL"

EXAMPLE: (USE FOR IMPERVIOUSNESS AND LANDCOVER AS WELL, REPLACING CANOPY01 WITH IMPERV01 AND LCOVER01 RESPECTIVELY)



6 - FROM ARCMAP EXPORT RESULTING TABLE AS A .DBF (canopy_Tabulate_Area.dbf)

7 - OPEN RESULTING .DBF IN MS EXCEL AND CONVERT TO .XLS FORMAT AND DRESS UP TO LIST PERCENT CANOPY COVER BY JURISDICTION

MULTIPLY VALUE / 43560(SQ. FEET TO ACRES CONVERSION)

IMPERVIOUSNESS DATA LAYER PROCESSING

1- DOWNLOAD DATA SET FROM http://www.mrlc.gov/nlcd_multizone_map.php

2- PROJECT .IMG FILES TO OUR COORDINATE SYSTEM

3 - CLIP RASTER DATASET TO PIMA COUNTY BOUNDARY (impervious5_091406_ProjectRa_Clip.img)

4 - RECLASSIFY IMPERVIOUSNESS DATASET AS FOLLOWS;

Reclassify into 6 classes (method = manual)

Old Value	New Value	Break Value
0	0	0
0-5	5	5
6-10	10	10
11-20	20	20
21-100	100	100
101-127	No Data	127

NAME DATASET IMPERV01

5 - USE "TABULATE AREA" IN ARCTOOLBOX->SPATIAL ANALYST TOOLS->ZONAL TO CALCULATE AREA OF EACH CANOPY CLASS WITHIN JURIS2001 FIELD OF "LIM_ALL_NO_TRIBAL_NO_FEDERAL"

6 - FROM ARCMAP EXPORT RESULTING INFO TABLE AS A .DBF (imperv_tabulate_area.dbf)

7 - OPEN RESULTING .DBF IN MS EXCEL AND CONVERT TO .XLS FORMAT AND DRESS UP TO LIST PERCENT CANOPY COVER BY JURISDICTION
VALUE / 43560 (SQ. FEET TO ACRES CONVERSION)

LANDCOVER DATA LAYER PROCESSING

1- DOWNLOAD DATA SET FROM http://www.mrlc.gov/nlcd_multizone_map.php

2- PROJECT .IMG FILES TO OUR COORDINATE SYSTEM

3 - CLIP RASTER DATASET TO PIMA COUNTY BOUNDARY (landcover5_3k_022007_ProjectRasterClip.img)

4 - RECLASSIFY LANDCOVER DATASET AS FOLLOWS;

Reclassify into 6 classes (method = manual)

Old Value	New Value	Break Value	Field Value
0-20	No Data	20	Other (Unused in this analysis)
20-21	21	21	Developed, Open Space
21-22	22	22	Developed, Low Intensity
22-23	23	23	Developed, Medium Intensity
23-24	24	24	Developed, High Intensity
24-30	No Data	30	Other (Unused in this analysis)
30-31	31	31	Barren Land
31-127	No Data	127	Other (Unused in this analysis)

NAME DATASET LCOVER01

5 - USE "TABULATE AREA" IN ARCTOOLBOX->SPATIAL ANALYST TOOLS->ZONAL TO CALCULATE AREA OF EACH CANOPY CLASS WITHIN JURIS2001 FIELD OF "LIM_ALL_NO_TRIBAL_NO_FEDERAL"

6 - FROM ARCMAP EXPORT RESULTING INFO TABLE AS A .DBF (landcover_Tabulate_Area.dbf)

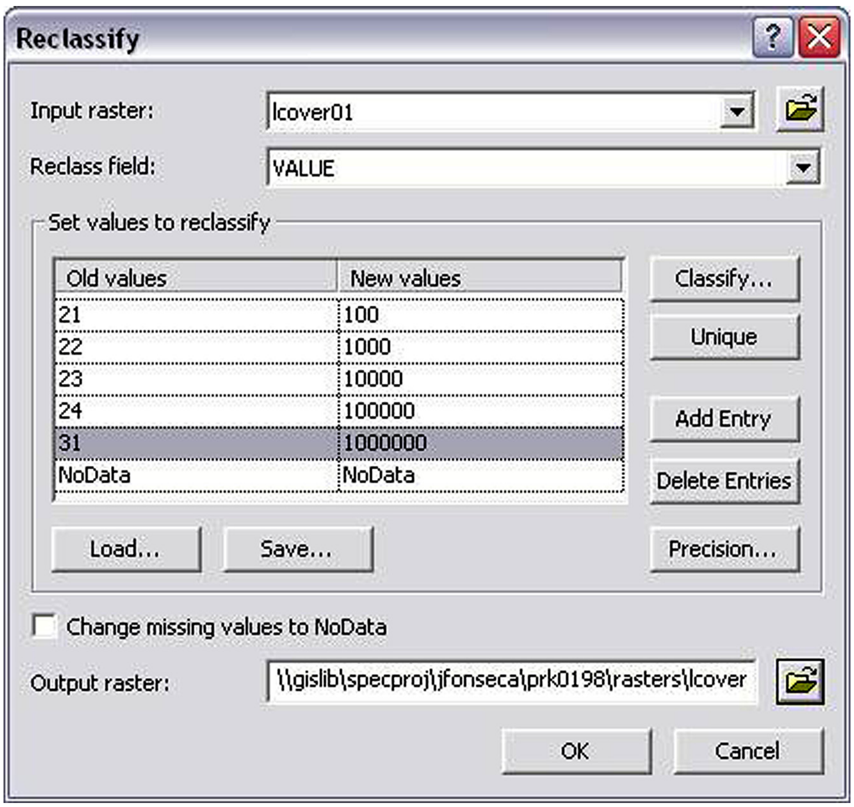
7 - OPEN RESULTING .DBF IN MS EXCEL AND CONVERT TO .XLS FORMAT AND DRESS UP TO LIST PERCENT CANOPY COVER BY JURISDICTION
VALUE / 43560 (SQ. FEET TO ACRES CONVERSION)

Project 2: PRK0201 - 2001 Jurisdiction Cover Analysis II (Further refine analysis to provide acres of NLCD development intensity categories across the imperviousness and canopy covers by 2001 jurisdictional limits)

CANOPY COVER AND DEVELOPMENT DATA LAYER PROCESSING

1 – RECLASSIFY LCOVER01 AS FOLLOWS;

Old Value	**New Value**	**Field Value**
21	100	Developed, Open Space
22	1000	Developed, Low Intensity
23	10000	Developed, Medium Intensity
24	100000	Developed, High Intensity
31	1000000	Barren Land



SAVE DATASET AS LCOVER01_2

2 – USE RASTER CALCULATOR TO ADD THE VALUES OF LCOVER01_2 & CANOPY01 [lcover01_2] + [canopy01]

SAVE DATASET AS LC_CAN01

THE RESULTING CLASSIFICATIONS ARE;

Value	**Field Value**	**Special Note**
100	Developed, Open Space, 0% Canopy Cover	

105	Developed, Open Space, 1-5% Canopy Cover	
115	Developed, Open Space, 6-15% Canopy Cover	
125	Developed, Open Space, 16-25% Canopy Cover	
200	Developed, Open Space, 26-100% Canopy Cover	
1000	Developed, Low Intensity, 0% Canopy Cover	
1005	Developed, Low Intensity, 1-5% Canopy Cover	
1015	Developed, Low Intensity, 6-15% Canopy Cover	
1025	Developed, Low Intensity, 16-25% Canopy Cover	
1100	Developed, Low Intensity, 26-100% Canopy Cover	
10000	Developed, Med Intensity, 0% Canopy Cover	
10005	Developed, Med Intensity, 1-5% Canopy Cover	
10015	Developed, Med Intensity, 6-15% Canopy Cover	
10025	Developed, Med Intensity, 16-25% Canopy Cover	
10100	Developed, Med Intensity, 26-100% Canopy Cover	
100000	Developed, High Intensity, 0% Canopy Cover	
~~100005~~	~~Developed, High Intensity, 1-5% Canopy Cover~~	~~NO CATEGORY EXISTS~~
~~100015~~	~~Developed, High Intensity, 6-15% Canopy Cover~~	~~NO CATEGORY EXISTS~~
100025	Developed, High Intensity, 16-25% Canopy Cover	
100100	Developed, High Intensity, 26-100% Canopy Cover	
1000000	Barren Land, 0% Canopy Cover	
1000005	Barren Land, 1-5% Canopy Cover	
1000015	Barren Land, 6-15% Canopy Cover	
1000025	Barren Land, 16-25% Canopy Cover	
1000100	Barren Land, 26-100% Canopy Cover	

3 – TO ENSURE UNIQUE FIELD NAMES FOR THE TABLE YOU WILL CREATE IN THE NEXT STEP, IT IS NECESSARY TO RECLASS THE CALCULATED RASTER ABOVE. SAVE THE FILE AS LC_CAN01_2

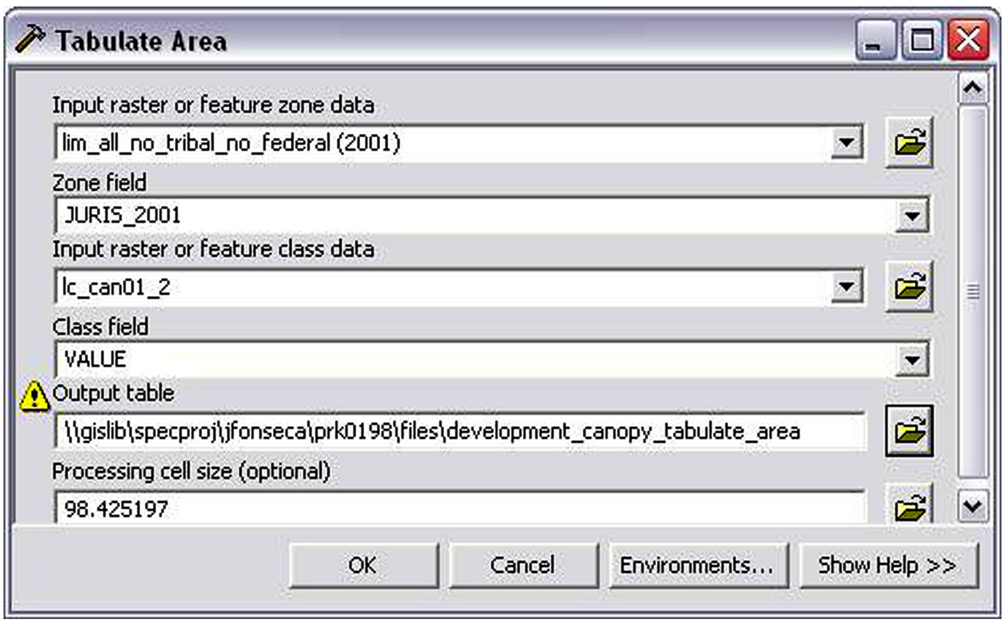
Old Value	New Value	Special Note
100	1	
105	2	
115	3	
125	4	
200	5	
1000	6	
1005	7	
1015	8	
1025	9	
1100	10	
10000	11	
10005	12	
10015	13	
10025	14	
10100	15	
100000	16	
~~100005~~		~~NO CATEGORY EXISTS~~

~~100015~~	~~NO CATEGORY EXISTS~~
100025	17
100100	18
1000000	19
1000005	20
1000015	21
1000025	22
1000100	23

4 - USE "TABULATE AREA" IN ARCTOOLBOX->SPATIAL ANALYST TOOLS->ZONAL TO CALCULATE AREA OF EACH CANOPY AND DEVELOPMENT
CLASS WITHIN JURIS2001 FIELD OF "LIM_ALL_NO_TRIBAL_NO_FEDERAL"

NAME THE INFO TABLE "DEVELOPMENT_CANOPY_TABULATE_AREA"

EXAMPLE: (USE FOR IMPERVIOUSNESS AS WELL, REPLACING LC_CAN01 WITH LC_IMP01 RESPECTIVELY)



5 - FROM ARCMAP EXPORT RESULTING INFO TABLE AS A .DBF (development_canopy_tabulate_area.dbf)

6 - OPEN RESULTING .DBF IN MS EXCEL AND CONVERT TO .XLS FORMAT AND DRESS UP TO LIST PERCENT CANOPY COVER AND DEVELOPMENT CATEGORY BY JURISDICTION **DIVIDE VALUES BY 43560 (SQ. FEET TO ACRES CONVERSION)**

IMPERVIOUSNESS COVER AND DEVELOPMENT DATA LAYER PROCESSING

1 – USE RASTER CALCULATOR TO ADD THE VALUES OF LCOVER01_2 & IMPERV01 [lcover01_2] + [imperv01]

SAVE DATASET AS LC_PERV01

THE RESULTING CLASSIFICATIONS ARE;

Value	Field Value
100	Developed, Open Space, 0% Impervious Cover
105	Developed, Open Space, 1-5% Impervious Cover
115	Developed, Open Space, 6-10% Impervious Cover
125	Developed, Open Space, 11-20% Impervious Cover
200	Developed, Open Space, 21-100% Impervious Cover
1000	Developed, Low Intensity, 0% Impervious Cover
1005	Developed, Low Intensity, 1-5% Impervious Cover
1015	Developed, Low Intensity, 6-10% Impervious Cover
1025	Developed, Low Intensity, 11-20% Impervious Cover
1100	Developed, Low Intensity, 21-100% Impervious Cover
10000	Developed, Med Intensity, 0% Impervious Cover
10005	Developed, Med Intensity, 1-5% Impervious Cover
10015	Developed, Med Intensity, 6-10% Impervious Cover
10025	Developed, Med Intensity, 11-20% Impervious Cover
10100	Developed, Med Intensity, 21-100% Impervious Cover
100000	Developed, High Intensity, 0% Impervious Cover
100005	Developed, High Intensity, 1-5% Impervious Cover
100015	Developed, High Intensity, 6-10% Impervious Cover
100025	Developed, High Intensity, 11-20% Impervious Cover
100100	Developed, High Intensity, 21-100% Impervious Cover
1000000	Barren Land, 0% Impervious Cover
1000005	Barren Land, 1-5% Impervious Cover
1000015	Barren Land, 6-10% Impervious Cover
1000025	Barren Land, 11-20% Impervious Cover
1000100	Barren Land, 21-100% Impervious Cover

2 – TO ENSURE UNIQUE FIELD NAMES FOR THE TABLE YOU WILL CREATE IN THE NEXT STEP, IT IS NECESSARY TO RECLASS THE CALCULATED RASTER ABOVE. SAVE THE FILE AS LC_IMP01_2

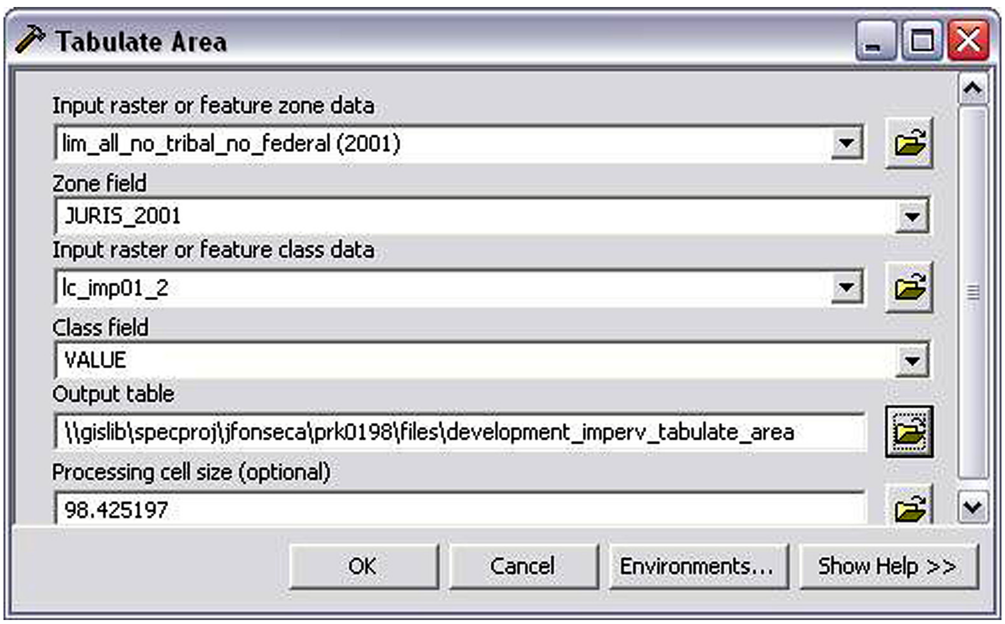
Old Value	New Value
100	1
105	2
115	3
125	4
200	5
1000	6
1005	7
1015	8
1025	9
1100	10
10000	11
10005	12
10015	13
10025	14

10100	15
100000	16
100005	17
100015	18
100025	19
100100	20
1000000	21
1000005	22
1000015	23
1000025	24
1000100	25

3 - USE "TABULATE AREA" IN ARCTOOLBOX->SPATIAL ANALYST TOOLS->ZONAL TO CALCULATE AREA OF EACH IMPERVIOUSNESS AND DEVELOPMENT
CLASS WITHIN JURIS2001 FIELD OF "LIM_ALL_NO_TRIBAL_NO_FEDERAL"

NAME THE INFO TABLE "DEVELOPMENT_IMPERV_TABULATE_AREA"

EXAMPLE:



5 - FROM ARCMAP EXPORT RESULTING INFO TABLE AS A .DBF (development_imperv_tabulate_area.dbf)

6 - OPEN RESULTING .DBF IN MS EXCEL AND CONVERT TO .XLS FORMAT AND DRESS UP TO LIST PERCENT IJMPERVIOUS COVER AND DEVELOPMENT CATEGORY BY JURISDICTION **VALUE / 43560 (SQ. FEET TO ACRES CONVERSION)**

Appendix 2. National land-cover Dataset 1992-2001 Change Detection Summary

NLCD CLASS	ACRES
Agriculture	25,580
Agriculture to Barren	91
Agriculture to Forest	4
Agriculture to Grassland/Shrub	3,970
Agriculture to Open Water	4
Agriculture to Urban	347
Agriculture to Wetlands	1,066
Barren	55,473
Forest	131,964
Forest to Agriculture	223
Forest to Barren	3
Forest to Grassland/Shrub	2,886
Forest to Urban	7
Forest to Wetlands	128
Grassland/Shrub	5,447,678
Grassland/Shrub to Agriculture	5,570
Grassland/Shrub to Barren	3,125
Grassland/Shrub to Forest	2,566
Grassland/Shrub to Open Water	242
Grassland/Shrub to Urban	10,566
Grassland/Shrub to Wetlands	3,599
No Data	196
Open Water	587
Open Water to Agriculture	8
Open Water to Barren	186
Open Water to Forest	1
Open Water to Grassland/Shrub	89
Open Water to Urban	5
Open Water to Wetlands	30
Urban	158,258
Urban to Barren	4
Urban to Grassland/Shrub	12
Wetlands	25,192
Wetlands to Grassland/Shrub	16
Wetlands to Open Water	4
TOTAL	**5,879,679**

APPENDIX 3.

JURISDICTION, CLS CLASSIFICATION, AND NLCD LANDCOVER CHANGE TYPE	ACRES	Total Development	Natural Land Conversion
MARANA – AREAS OUTSIDE CONSERVATION LANDS SYSTEM — AGRICULTURE TO URBAN	29		
MARANA – AREAS OUTSIDE CONSERVATION LANDS SYSTEM — GRASSLAND/SHRUB TO URBAN	708		
MARANA – BIOLOGICAL CORE MANAGEMENT AREAS — GRASSLAND/SHRUB TO URBAN	7		
MARANA – IMPORTANT RIPARIAN AREAS — GRASSLAND/SHRUB TO URBAN	58		
MARANA – MULTIPLE USE MANAGEMENT AREAS — GRASSLAND/SHRUB TO URBAN	356	1,158	1129
ORO VALLEY – AREAS OUTSIDE CONSERVATION LANDS SYSTEM — AGRICULTURE TO URBAN	30		
ORO VALLEY – AREAS OUTSIDE CONSERVATION LANDS SYSTEM — GRASSLAND/SHRUB TO URBAN	1,564		
ORO VALLEY – AREAS OUTSIDE CONSERVATION LANDS SYSTEM — OPEN WATER TO URBAN	1		
ORO VALLEY – BIOLOGICAL CORE MANAGEMENT AREAS — GRASSLAND/SHRUB TO URBAN	5		
ORO VALLEY – IMPORTANT RIPARIAN AREAS — AGRICULTURE TO URBAN	0		
ORO VALLEY – IMPORTANT RIPARIAN AREAS — GRASSLAND/SHRUB TO URBAN	14		
ORO VALLEY – MULTIPLE USE MANAGEMENT AREAS — AGRICULTURE TO URBAN	4		
ORO VALLEY – MULTIPLE USE MANAGEMENT AREAS — GRASSLAND/SHRUB TO URBAN	276	1,895	1860
PIMA COUNTY – AGRICULTURE INHOLDINGS WITHIN CONSERVATION LANDS SYSTEM — AGRICULTURE TO URBAN	9		
PIMA COUNTY – AGRICULTURE INHOLDINGS WITHIN CONSERVATION LANDS SYSTEM — GRASSLAND/SHRUB TO URBAN	0		
PIMA COUNTY – AREAS OUTSIDE CONSERVATION LANDS SYSTEM — AGRICULTURE TO URBAN	115		
PIMA COUNTY – AREAS OUTSIDE CONSERVATION LANDS SYSTEM — FOREST TO URBAN	3		
PIMA COUNTY – AREAS OUTSIDE CONSERVATION LANDS SYSTEM — GRASSLAND/SHRUB TO URBAN	3,288		
PIMA COUNTY – BIOLOGICAL CORE MANAGEMENT AREAS — GRASSLAND/SHRUB TO URBAN	12		
PIMA COUNTY – MPORTANT RIPARIAN AREAS — AGRICULTURE TO URBAN	16		
PIMA COUNTY – IMPORTANT RIPARIAN AREAS — GRASSLAND/SHRUB TO URBAN	92		

PIMA COUNTY – MULTIPLE USE MANAGEMENT AREAS — AGRICULTURE TO URBAN	6		
PIMA COUNTY – MULTIPLE USE MANAGEMENT AREAS — GRASSLAND/SHRUB TO URBAN	499	4,040	3894
SAHUARITA – AREAS OUTSIDE CONSERVATION LANDS SYSTEM — AGRICULTURE TO URBAN	10		
SAHUARITA – AREAS OUTSIDE CONSERVATION LANDS SYSTEM — GRASSLAND/SHRUB TO URBAN	183		
SAHUARITA – AREAS OUTSIDE CONSERVATION LANDS SYSTEM — OPEN WATER TO URBAN	1		
SAHUARITA – IMPORTANT RIPARIAN AREAS — AGRICULTURE TO URBAN	0		
SAHUARITA – IMPORTANT RIPARIAN AREAS — GRASSLAND/SHRUB TO URBAN	0		
SAHUARITA – MULTIPLE USE MANAGEMENT AREAS — AGRICULTURE TO URBAN	7		
SAHUARITA – MULTIPLE USE MANAGEMENT AREAS — GRASSLAND/SHRUB TO URBAN	11	203	185
SOUTH TUCSON – AREAS OUTSIDE CONSERVATION LANDS SYSTEM — AGRICULTURE TO URBAN	12		
SOUTH TUCSON – AREAS OUTSIDE CONSERVATION LANDS SYSTEM — GRASSLAND/SHRUB TO URBAN	2	14	2
TUCSON – AREAS OUTSIDE CONSERVATION LANDS SYSTEM — AGRICULTURE TO URBAN	92		
TUCSON – AREAS OUTSIDE CONSERVATION LANDS SYSTEM — FOREST TO URBAN	2		
TUCSON – AREAS OUTSIDE CONSERVATION LANDS SYSTEM — GRASSLAND/SHRUB TO URBAN	21		
TUCSON – BIOLOGICAL CORE MANAGEMENT AREAS — AGRICULTURE TO URBAN	2		
TUCSON – BIOLOGICAL CORE MANAGEMENT AREAS — GRASSLAND/SHRUB TO URBAN	1		
TUCSON – IMPORTANT RIPARIAN AREAS — AGRICULTURE TO URBAN	14		
TUCSON – IMPORTANT RIPARIAN AREAS — GRASSLAND/SHRUB TO URBAN	0		
TUCSON – MULTIPLE USE MANAGEMENT AREAS — AGRICULTURE TO URBAN	14		
TUCSON – MULTIPLE USE MANAGEMENT AREAS — GRASSLAND/SHRUB TO URBAN	1		
	19	146	24
		7309.2357	**7094**