Journal of Conservation Planning Vol 5 (2009) 38 — 53

Development of a Parcel-based Density Analysis Tool to Evaluate Growth Patterns in Western North Carolina

Neil Thomas, Greg Dobson, Paul Dezendorf, Mark Cantrell and David Abernathy

Neil Thomas
President
Resource Data, Inc.
305 Westover Drive
Asheville, NC 28801
rdi@resourcedata.net
Phone: (828) 251-1658
http://resourcedata.net/

Greg Dobson
GIS Research Associate
National Environmental Modeling and Analysis Center
University of North Carolina Asheville
One University Heights
Asheville, NC 28801
gdobson@unca.edu
Phone: (828) 251-6973
http://orgs.unca.edu/nemac/

Paul K. Dezendorf, Ph.D.
Department of Mass Communications
University of North Carolina Asheville
One University Heights
Asheville, NC 28801
pdezendo@unca.edu
Phone: (828) 301-3860
http://www.unca.edu/

Mark Cantrell
Aquatic Fauna Recovery Specialist
U.S. Fish and Wildlife Service
160 Zillicoa Street
Asheville, NC 28801
Mark_A_Cantrell@fws.gov
Phone: (828) 258-3939
http://www.fws.gov/nc-es/

David Abernathy, Ph.D.
Geography/Global Studies
Warren Wilson College
PO Box 9000
Asheville, NC 28815-9000
dabernathy@warren-wilson.edu
Phone: 828-298-3325
http://www.warren-wilson.edu/external_index.php

ABSTRACT: Early identification of land use development patterns improves the ability of conservation planners to devise plans to mediate the effects of growth, educate elected officials and staff, and build public support. As a result, multiple approaches to measuring development have been created using the Census, remote sensing, and other sources. Conservation planning stakeholders in Western North Carolina including the U.S. Fish and Wildlife Service, academic institutions, and GIS consultants began in 2004 to develop a simple, generic, and low-cost measurement process based on cadastral data, the government maintained record of land parcels. The resulting Parcel-based Density Analysis Protocol (P-DAP) identifies spatial and temporal changes in land use patterns. P-DAP provides a set of subdivision metrics that relate directly to land use intensity. The P-DAP includes acquiring and removing anomalies in cadastral data; categorizing parcel sizes and identifying patterns of change; creating parcel density topologies; and developing presentation materials. The P-DAP produces fine-grained descriptions of parcel changes in any desired geographic area over time. The P-DAP results are easily integrated with other geographic-referenced data such as land use and land cover (LULC), elevation models, soil maps, and water resources. We observed that the shift in land use from less developed to more developed size classes occurred in advance of the rise in population density that followed. Parcels are subdivided, buildings and infrastructure are developed, and on average, the land is used more intensively. Similarly, as parcels are subdivided roads, utilities and other supporting infrastructure are installed. Parcel density (and mean parcel size) may be a better indicator of land use intensity especially in exurban areas than population density for many conservation planners. Population can only indirectly measure land use intensity and does not easily account for the impacts of non-residential commercial and industrial development, or vacation homes. Population influences on the land use intensity vary considerably because human behaviors vary culturally, socio-economically, and through personal choice. P-DAP provides a measure of land use intensity regardless of the population inhabiting the land. We also found other uses for the P-DAP such as computation of a "compaction ratio" that measures extent of land use for right-of-ways and thus provides a quick means of illustrating the impact of roads in a study area ranging from a small subdivision to an entire county. As a result, the inexpensive P-DAP approach to describing land use development patterns can benefit conservation planners and other organizations throughout the country.

Keywords: Conservation planning, geographic information systems, GIS, land use planning, parcel analysis, parcel compaction, parcel density, parcelization, land use intensity, sprawl, urbanization, P-DAP

INTRODUCTION

Sprawl, unplanned growth outside of organized support frameworks, is a national problem. One barrier to mediating the effects of sprawl is the limited understanding of land-use dynamics beyond the urban fringe as county level data aggregations poorly capture the dynamics of development (Theobald 2001); for example, subdivisions have a differential impact depending on type and size of subdivision (Compas 2007). Early identification of development patterns allows conservation planners to develop approaches to mediating the effects of growth such as the use of build-out scenarios, inform elected officials and staff, and build public support (Skibbe and Miller 2008, U.S. Department of the Interior 2007). As a result, various approaches have been developed to describe and predict land-use using information from the Census, remote sensing, and other sources (Agarwal et al. 2002, Gonzalez-Abraham et al. 2007, Merenlender et al. 2005). Beginning in the 1980s, planners began to use cadastral data, a comprehensive, uniform, continually updated database regarding the ownership and subdivision of parcels maintained by local governments **(**Barnes 2003, van der Molen 2001). In recent years, multi-county and regional efforts developed to use such data (Apfelbaum 2004, The Conservation Fund 2000, Fryberger, 2007).

Beginning in 2004 in the western region of North Carolina, conservation planning stakeholders identified cadastral data analysis as a potential solution for their lack of region-wide data and limited funds for research. Growth and sprawl in this area was similar to the problems faced in other areas of North Carolina (Brookings 2000). From the early 1990s onward, land development pressure came from retirees and second home purchasers; growth in tourism; business and industry expansion; and upgrading of the transportation network. The region overall is identified by characteristics associated with sprawl: available ground water, temperate climate, uncertainty about metropolitan growth, virtually no public transportation, decentralized population, and rugged terrain (Burchfield 2006). In addition to those factors, development on the region's steep slopes was a growing threat to the land as well as to the region's scenic mountain vistas. The region's 220 local government units offered very limited sources of data and almost no regional planning support. As a result, the conservation stakeholders involved with the development of the Parcel-based Density Analysis Protocol (P-DAP) sought land use analysis tools that would provide more timely and meaningful information regarding the pattern and extent of development in the region, especially in exurban areas, so as to better plan and to engage and educate elected officials and the public.

Conservation planning stakeholders sought to develop a simple, inexpensive, and reliable protocol that would provide high-resolution land use intensity information with scalability and comparability across government units as well as across natural and built environment boundaries (Buncombe County NC 2008a, Buncombe County NC 2008b, NC Secretary of State, Division of Certification and Filing 2008, NC Property Mappers Association, 2008). The stakeholders also sought to find metrics that directly and inexpensively measures land use intensity and change.

P-DAP addresses a large spectrum of subdivision metrics. Parcel density, mean parcel size, and compaction ratio (ratio between rights of way acreage and lot acreage) clearly identify land use patterns and land use intensity. As parcels are subdivided, buildings and infrastructure are developed, and the land is used more intensively. Similarly, as parcels are subdivided, roads, utilities and other supporting infrastructure are developed to support the smaller parcel sizes (Thomas et al. 1999; Thomas et al. 2000). Population measures, on the other hand, do not adequately or directly account for many intensive land uses including non-residential commercial and industrial development or vacation homes, to mention a few. Population counts are not sensitive to the higher resolution time frames required of planners these days. Remotely sensed regional LULC mapping is expensive, time consuming and often provides poor spatial (30 meter or greater) and temporal resolution.

P-DAP is a leading indicator of change. Parcels that are subdivided today may require a year or more before they are fully developed. Once a parcel is subdivided, the developer has a strong incentive to fully develop the properties to maximize the investment. On occasion subdivisions do fail, and parcels are recombined. P-DAP also captures this change. Neither population metrics nor land use, land cover (LULC) mapping are resolved spatially or temporally to track change at this resolution.

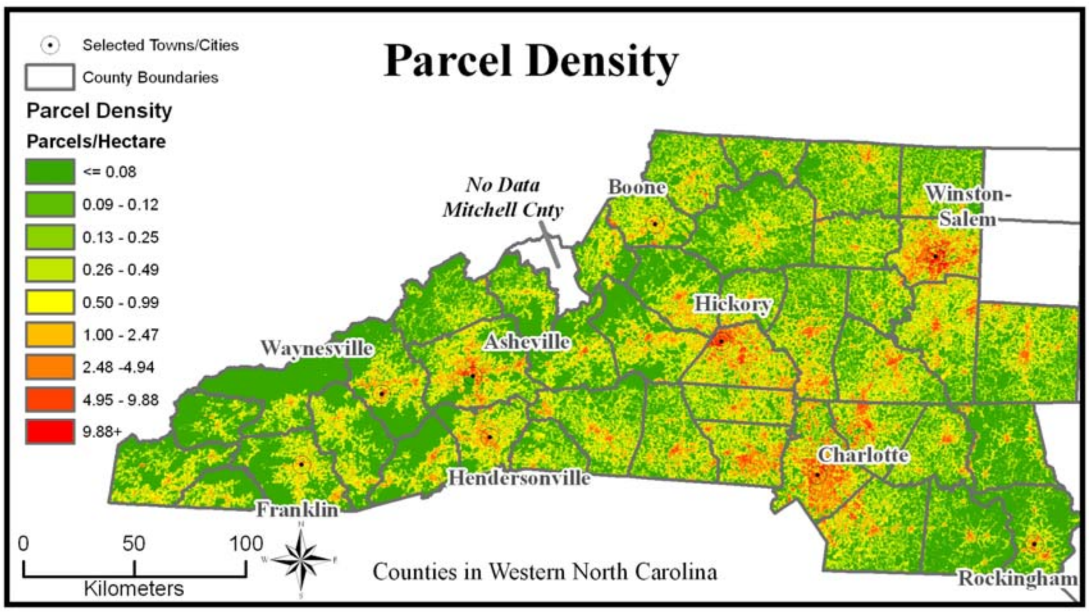
In addition, the stakeholders sought to create a process that would result in products that were easily understood by the public and elected officials as well as being easily customized for specific applications ranging from the analysis of hydrologic units to studies of the use of land for right-of-ways (ROWs). The P-DAP begins with the use of common quantitative software (such as MS Excel and Access) to organize and remove anomalies from publically available cadastral data. The process then creates parcel size categories based on local needs; these categories are used to analyze parcels in order to measure characteristics such as the degree of urbanization in a geographic area or the relative parsimony of ROW use among groups of subdivisions. Geographic Information System (GIS) software is used in turn to create a weighted center-of-parcel point for each parcel that allows calculation of continuous density functions and parcel density topologies. These topologies, or "density maps," provide a fine-grained picture of the range and change in parcel density in any desired geographic area. These density maps and the associated parcel size analyses can be integrated with a wide variety of conservation planning data such as water quality, soil loss, flood management, and habitat and fragmentation management and tracking.

METHODS

Study Area

The western region of North Carolina includes 43 counties covering approximately 49,053 square kilometers (18,939 square miles) with an estimated population of 3,918,882 in 2005 (TIGER GIS Data 2005) (Figure 1). The region includes such natural resources as the Great Smoky Mountains and the Blue Ridge of the southern Appalachian Mountains as well as portions of the most visited National Park in the country. Major land holders include the Eastern Band of the Cherokee Indians, Great Smokey Mountains National Park, Blue Ridge Parkway, state forests and parks, and wilderness areas as well as locally protected areas. Figure 1 illustrates the wide range of parcel density in the 43 counties of Western North Carolina.

FIGURE 1 This parcel density topology for the 43 counties in Western North Carolina in 2006 visually conveys the wide range of parcel densities from very low densities in natural areas on public lands to very high densities in urban areas such as the city of Charlotte.



The P-DAP process is a six step process as shown in Figure 2, page 43.

Step 1. Data Collection

The P-DAP process begins with the acquisition of cadastral data from local governments. This data is available in many jurisdictions in digital form and in most cases without any cost.

Step 2. Data Cleaning

A host of minor issues should be reviewed when the data is processed. Data anomalies such as duplicate parcels and multi-part parcels should be identified and adjusted. It is helpful to know if large public/conservation lands are present, and rights of way configurations should be assessed. Parcel coding consistency (tax use, ownership, etc) is generally not a major problem because only parcel centroids and size measurements are utilized in P-DAP analysis. The resulting data consistency allows for inexpensive processing and provides reliable data from dataset to dataset.

Step 3. Categorize parcels and create parcel size products

Parcels are then grouped into size classes. Parcel size classes are categories created as a measure of land use intensity; the classes provide a metric to characterize the current conditions within a particular study area. Parcel size classes are chosen based on the particular needs of the study and the conditions of the study area. The parcel size classes chosen in developing the P-DAP conformed to local, regional and national parcel-size classifications for environmental and ecological analysis.

The initial division into size classes began with defining parcels of 4.0 hectares (10 acres) or less as "high intensity" use. This size cutoff was chosen because 4.0 hectares is regarded as "high intensity land use" in the NRCS urban and developed land classification (NRCS 2000). After further examination of the data from watersheds in Western North Carolina, parcels from 4.0 to 12.1 hectares (10 to 30 acres) were classified as "medium intensity," and parcels larger than 12.1 hectares were considered "low intensity" based on the patterns of land ownership. The parcels of less than 4.0 hectares were then placed into sub-categories in order to allow a finer-grained view of changes. Size classes used in TR55 watershed models were selected for this range (http://www.mn.nrcs.usda.gov/technical/eng/references.html).

After identifying the desired parcel sizes, the cleaned parcel information was processed in an Access™ database. Fields were defined for each parcel record. These fields included the amount of acreage in that parcel (GIS_Acreage), the size class assigned to that parcel (SizeClass) and the rank of that size class (SizeClass Rank) (Figure 2). The "calculate geometry" function in ArcGIS™, was used to populate the GIS_Acreage field. A simple lookup table of size classes in Access™ was used via a database query to populate the SizeClass, and SizeClass Rank values. The SizeClassRank is used as a sort-key to keep the size classes in order. After the data was processed, simple Access™ queries allow production of a variety of parcel size products.

One parcel size product that the P-DAP developers found useful was an index of "parcel compactness." Parcel compactness is the total amount of space within parcels (excluding ROWs) divided by the total space of a study area (including ROWs). The parcel compactness index measures the relative parsimony in the use of ROW. The index can be used to easily compare the relative parsimony of ROW among subdivisions or municipalities.

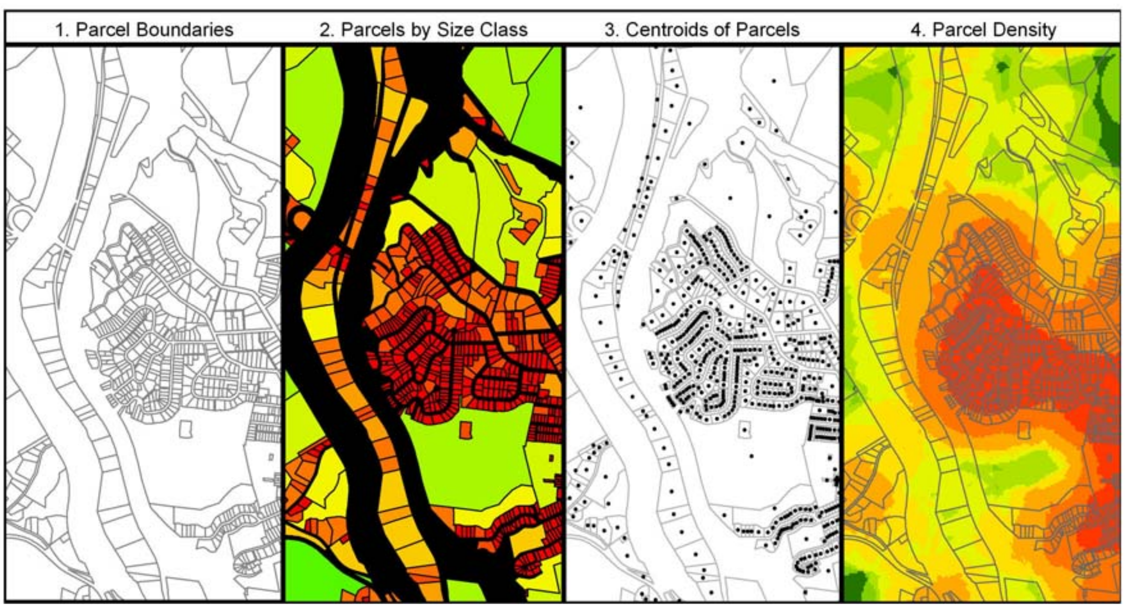
Step 4. Compute parcel densities and create parcel density products

Parcel density typologies describe the density of parcels as a function of the underlying parcel size. Figure 3, page 43, illustrates the process of moving from a cadastral map of parcel boundaries to a parcel density typology.

FIGURE 2 Summary of the actions required for P-DAP analysis.

Preparation	Step 1. Data Collection
	• Establish a routine for annual collection with minimal labor
	Step 2. Data Cleaning
	• Cross-reference to county maps for correcting individual errors
	• Make consistent coding for irregular uses such as condominiums
Process	Step 3. Categorize parcels and create parcel size products
	• Identify appropriate size classes for the study area
	• Place cleaned parcel information into database
	• Generate intermediate products such as “parcel compactness”
	Step 4. Compute parcel densities and create parcel density products
	• Identify desired size of search circles and grid cells
	• Compute center points of all parcels
	• Generate parcel density maps
	Step 5. Classify parcel density information into desired subsets
	• Create subsets as needed for various types of analysis
Presentation	Step 6. Develop presentation materials
	• Generate tables and charts to support density maps
	• Assemble materials into presentation packages

FIGURE 3 These four panels provide a graphic illustration of how cadastral information (in the first panel on the left) is used to compute and identify parcels by size classes (second panel); the third panel illustrates the computation of center points for each parcel and the final panel on the right illustrates a completed parcel density map.



The process of generating parcel density typologies begins with the identification of a center point for each parcel, the centroid (Panel 2 of Figure 3). A centroid is a mathematical term for the center of an object. In a circle-shaped parcel, the centroid is at the center. In a very irregular parcel, the centroid may not even be inside the parcel. While identifying centroids was once a laborious manual process, ArcGIS™ automatically converts a file with the parcels of interest into a file containing only the centroids. The centroids are then converted into a parcel density topology by use of the ArcGIS™ point density function. The point density function calculates density by counting the total number of centroids within a particular area and dividing by the area. In effect, the software centers a search circle on a given grid cell and counts the number of centroids in that circle. By dividing the number of points by the area within the circle, a "point density" is calculated at the center of the circle. The search circle is then moved to the next grid cell. By repeating this process for every grid cell in a particular area, a map of parcel density is produced.

The two variables in this step are the size of the search circle and the size of the grid cells. The size of the search circle determines the dynamic range of the density value. Larger search circles cover larger areas and thus extract broader and less detailed land use patterns; an infinitely large search circle produces a density map that is simply the average number of parcels per acre in the study area. Smaller circles cover smaller areas and thus emphasize more localized patterns. Increasing detail by decreasing the search circle size is self-limiting as the point data becomes highly influenced by those centroids in the immediate area. Our primary concern was the conversion of rural lands (over 12 hectares), to urban and build-up areas of less than 4.0 hectares. As a result, we chose a search circle of roughly 12 hectares that smoothed out some of the small parcel information but adequately captured the variation within the 0-to-12 hectare range of interest. Grid sizes are selected in a similar manner to search circle sizes. Increasing the grid size decreases the fineness of detail in the resulting map. Dropping the grid size below the level of the smallest parcel and other related data would provide no additional useful information to the models.

Step 5. Classify parcel density into desired subsets

The parcel density is then classified into desired subsets that reflect the particular conservation planning interests for the study area. For example, one of the major concerns in the development of P-DAP was the rate of change in landscape from rural to urban. As a result, we chose to take our continuous data from Step 4 and reclassify it into two subsets, the densities representing parcel sizes larger than 4 hectare (10 acres) and parcels representing densities of less than 4 hectares. This approach provided for two discrete categories to map and track change, resulting in a regional index that can be applied to any study unit within the region. In other settings, a gradient break-point other than 4 hectares (10 acres) may be chosen to accommodate specific needs such as habitat size for a specific species.

Step 6. Develop presentation materials

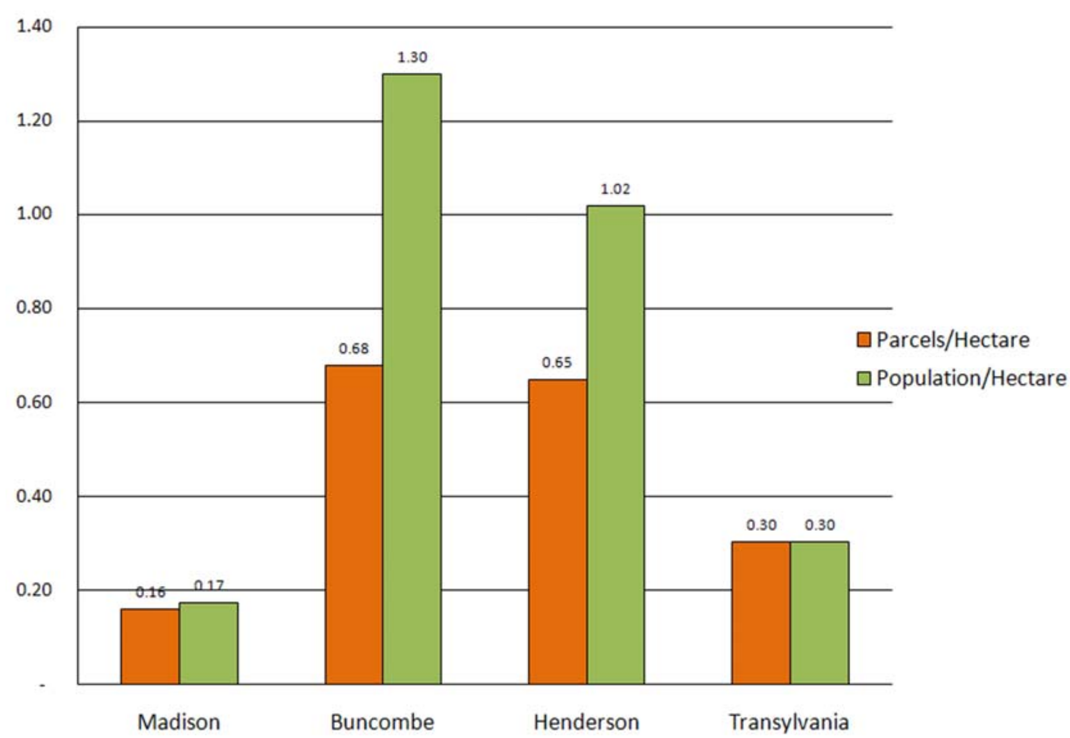
Tables, charts and maps from parcel analysis and parcel density analysis provide powerful visual tools for illustrating a range of spatial and temporal patterns. The maps are based on property parcels, and thus lend themselves to easy comprehension by the general public. In a similar manner, the parcel size products, such as percentage of ROWs or new parcels being created in steep slope areas, are similarly intuitive. In practice, assembling groups of tables, charts, and parcel density maps into packages aimed at specific audiences or issues was found to be more effective than use of either maps or charts and tables separately.

RESULTS

The examples given below demonstrate the ability of P-DAP to provide fine-grained analysis of the range of parcel density in a study area as well as describe changes over time in a clear and compelling manner. The first example illustrates the ability of P-DAP to measure a range of density and changes in parcels over time in the four counties of a Western North Carolina Council of Government (COG). The P-DAP is then applied in more detail to one of the COG counties. These two perspectives, range of density and change over time, are then applied to compare and contrast municipalities within Buncombe County. The strength and limitations of the P-DAP are then demonstrated by application to four hydrologic units within Buncombe County.

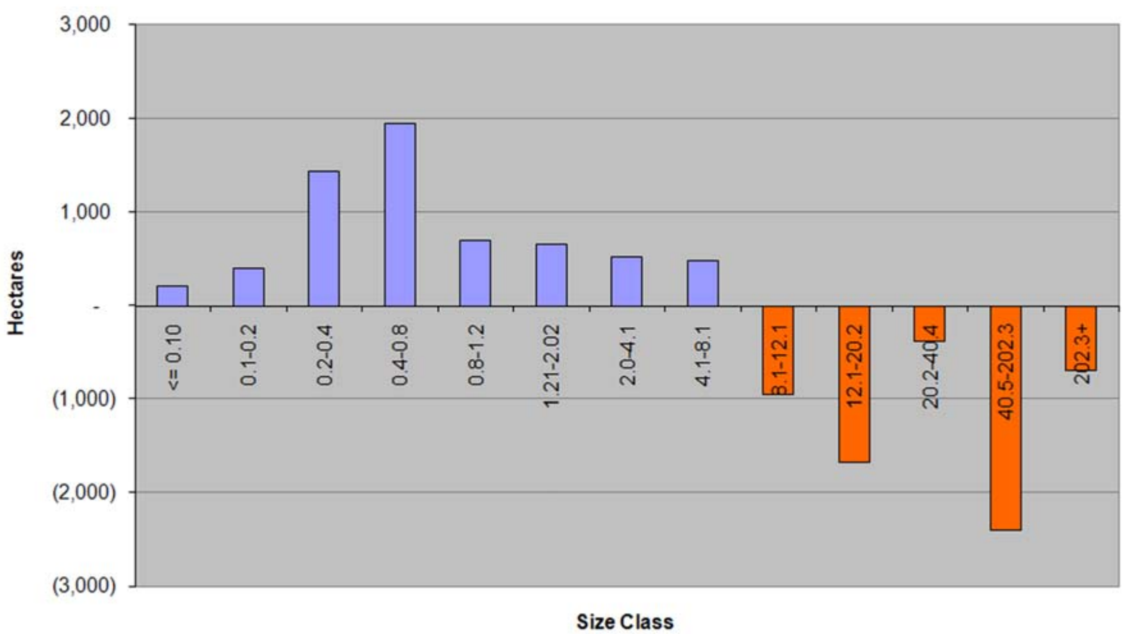
The P-DAP was initially pilot tested in the Land-of-Sky COG that includes the counties of Buncombe, Henderson, Madison, and Transylvania. Figure 4 illustrates a typical P-DAP product illustrating a range of spatial densities across the COG. The northern-most county, Madison, is a rural county but shows urban buildup along a north-south Interstate corridor. Henderson County includes both large farming areas as well as a dense retiree population. Transylvania County is characterized in part by the highest percentage of public lands (44%). Buncombe County is the most densely populated county with its urban center, Asheville. Parcel density values are generally lower than population density for any specific area. In Transylvania County however, the two densities are identical. In more urban counties the differential is greater as more people are crowded into fewer parcels (apartments and multi-unit housing) which are reflected in Figure 4. Beyond a certain parcel density the additional population only marginally affects the ecological landscape (EPA 2008, Hess et al. 2007). Parcel density (and mean parcel size) may be a better indicator of land use intensity than population density (Suen, I. 2005).

FIGURE 4 This figure illustrates the wide variety in mean parcel density and population density in the Land-of-Sky COG's four county region. Parcel density provides a more direct measure of land use intensity than population density.



A second analysis was carried out on Buncombe County to evaluate the rate of subdivision of parcels. By converting a portion of the Buncombe County parcel size class information from the initial analysis into a bar graph, a striking visual display was created for public presentations as shown in Figure 5. Over a period of about 8 years, 257 larger parcels were subdivided into over 16,000 smaller parcels while approximately 243 hectares (600 acres) were converted into ROWs. This represents a shift of over 6,000 hectares (15,000 acres) from less developed to more developed size classes. On an average, 1161 hectares (2870 acres) have changed from rural to urban each year during this period. By using this statistic, it is possible to estimate how quickly a county, a municipality, a watershed, any summary unit, will take to convert all of its rural lands into urban lands. In Buncombe County, the historical rate suggests that it will take about 60 years to convert all of the private rural lands into private urban land, although the economy and other factors can speed up or slow down this process.

FIGURE 5 Changes in parcel acres by class size are shown from 2000 to 2008 in Buncombe County; the increase in the number of small parcels is shown by the upward bars on the left of the graph and the corresponding decrease in larger parcels by the downward bars on the right.



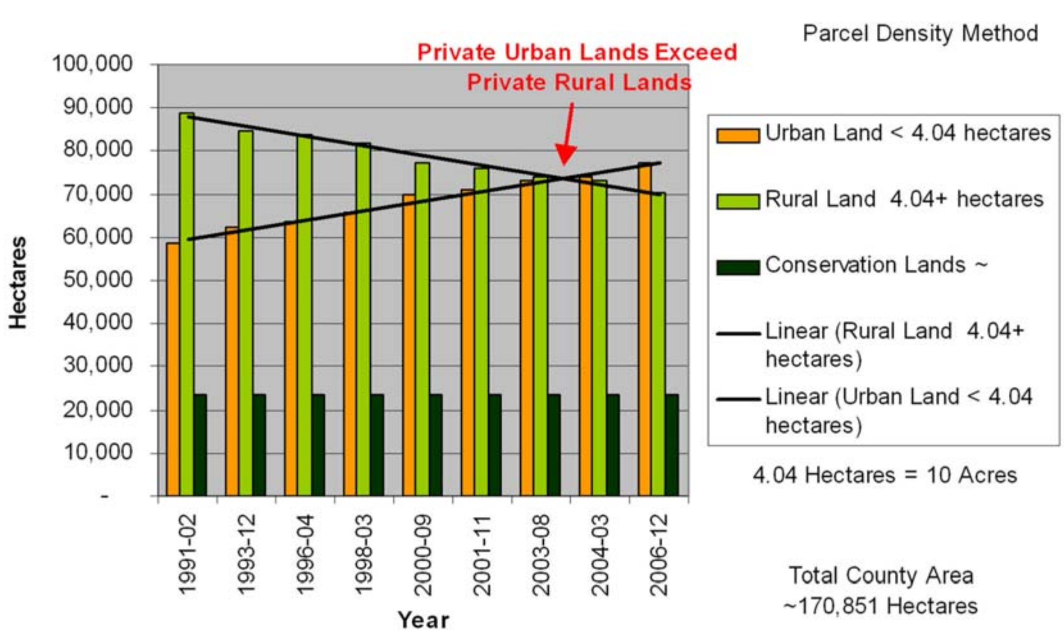
In Figure 6, the trend lines identify the point in time where private urban land acreage begins to exceed private rural lands in the county. This is a key milepost in the county's urbanization process. Another milepost might be the point in time when private rural lands are reduced below that of the public lands.

As well as analyzing the change in the largest parcels, the P-DAP can be well used at the other end of the density range to compare urban areas. The six municipalities within Buncombe County span a range from the City of Asheville's 114 square kilometers (44 square miles) of urban development to the tiny Town of Montreat's 9 square kilometers (3 square miles). In Figure 7, page 48, the table in the first section provides parcel data for each of the six municipalities as well as the amount of unincorporated land in the county and for the county as a whole. The second section provides parcel size data, and the third section parcel density data.

Differences between Woodfin and Asheville, which adjoin each other, as shown in Figure 7, illustrate not only the overall difference in size but also the internal differences regarding parcelization. Woodfin, for example, has larger mean parcel sizes in part because it incorporated landfills, former prisons, and other large facilities. The table and bar chart illustrate the ability of the P-DAP approach to quickly provide useful information that is understandable by the general public and elected officials.

Figure 7 illustrates how ROW contributes to the difference between the mean parcel size computed in the parcel data analysis and the parcel density analysis which is shown in the right hand column marked "Difference in mean parcel size methods." In the case of the Town of Woodfin, the difference is less than a quarter of an acre in the mean size of parcels between the two types of analysis. This expected difference occurs because the

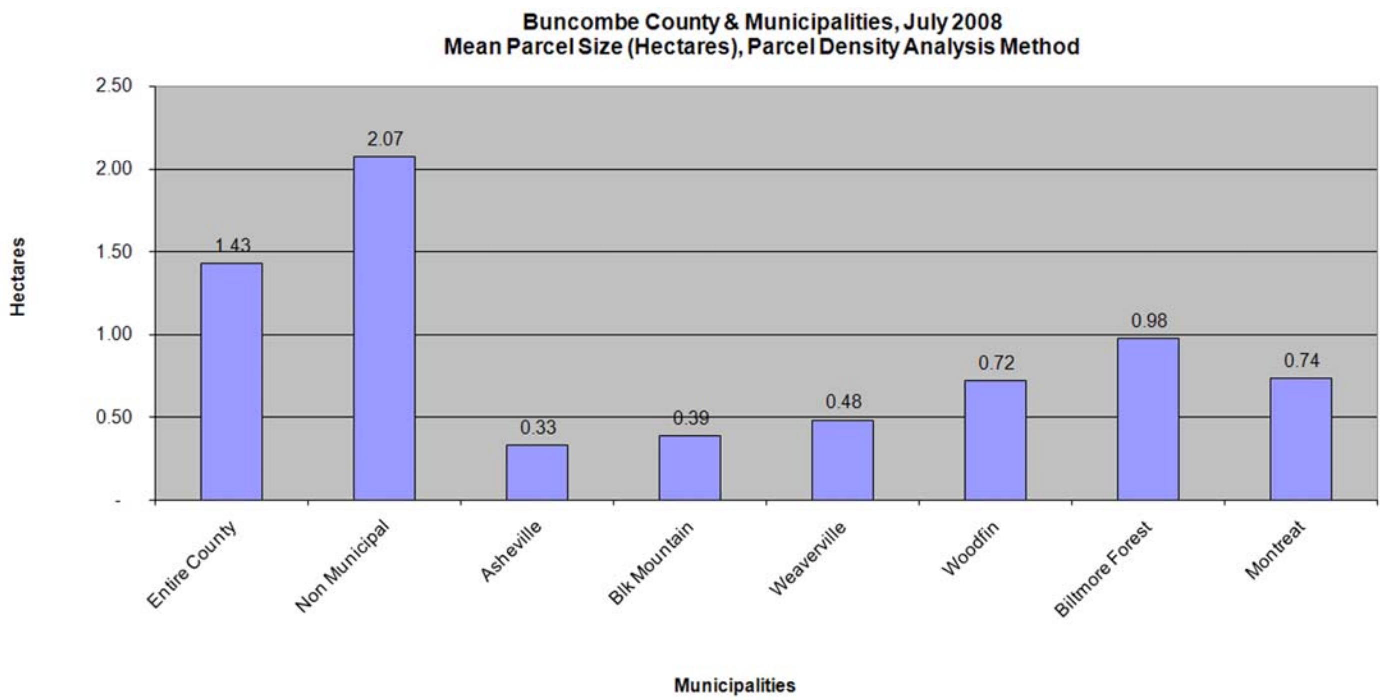
FIGURE 6 This figure illustrates the changing relationship between urban and rural lands resulting from parcelization in Buncombe County from 1991-2008; from 1991 on the left to 2006 on the right, rural lands are reduced while urban land increase until their relationship reverses between 2003 and 2004.



density data incorporates the ROW area into its mean while the parcel data does not. The error with larger parcels comes about due to the size of the search radius in computing density; the wider the search radius, the less accurate the local data.

Parcel analysis also can be used to compute a "compaction ratio" that measures extent of land use for ROW. A very high compaction ratio, say 95%, indicates land where little taxable (usable) land has been lost to ROW while a low number, typically 85% or less in these four counties, indicates a higher percentage of taxable land lost to ROW uses. In conservation planning, this provides a quick means to illustrate the impact of roads in a study area ranging from a small subdivision to an entire county.

FIGURE 7 This figure illustrates the differences in parcel density among the six municipalities in Buncombe County as of July 2008.



Municipal Boundaries			Parcel Data Summaries					Parcel Analysis			Density Analysis			Difference in Mean Parcel Size Methods
Boundaries	Bnd Hectares	Bnd Acres	Parcel Hectares	Parcel Acres	Parcel Count	ROW Hectares	ROW Acres	Compaction Ratio	Mean Parcel Size (hectares)	Mean Parcel Size (acres)	Mean Parcel Density	Mean Parcel Size (hectares)	Mean Parcel Size (acres)	Den Analysis - Parc Analysis (Mean Parcel Size (hectare)
COUNTY (All Parcels)	170952	422,433	160,807	397,362	119,614	10,146	25,070	94%	1.34	3.32	0.28	1.43	3.54	0.09
NON MUNICIPAL	153,188	378,535	146,218	361,313	73,082	6,970	17,223	95%	2.00	4.94	0.20	2.07	5.13	0.07
CITY OF ASHEVILLE	11,440	28,268	9,580	23,673	35,150	1,859	4,594	84%	0.27	0.67	1.22	0.33	0.82	0.06
TOWN OF BLACK MOUNTAIN	1,727	4,269	1,510	3,731	4,603	218	538	87%	0.33	0.81	1.05	0.39	0.95	0.06
TOWN OF WEAVERVILLE	862	2,129	789	1,949	1,881	73	180	92%	0.42	1.04	0.84	0.48	1.19	0.06
TOWN OF WOODFIN	2,273	5,616	2,001	4,944	3,174	272	672	88%	0.63	1.56	0.56	0.72	1.78	0.09
TOWN OF BILTMORE FOREST	755	1,866	Parcel Boundaries for these towns are not coincidental with Municipal Boundaries. As a result parcel data can not be summarized for these towns								0.41	0.98	2.41	NA
TOWN OF MONTREAT	708	1,750									0.55	0.74	1.82	NA

A P-DAP analysis of four of the watersheds in Buncombe County in Figure 8, page 50, demonstrates how parcel density provides a direct means to examine spatial differences in parcelization. For example, the North Fork watershed is significantly less parcelized than the county mean, as well as less than the three other watersheds. A large portion of this watershed is in conservation land. Significant changes in the parcelization of this watershed are evident on the bar chart, from a mean parcel size (MPS) of about 12 hectares (30 acres) to a current MPS of about 9.3 hectares (23 acres). The presentation allows easy comparison such as of the more urban watersheds (East Asheville, Bee Tree, Black Mountain) with mean parcel sizes ranging from 0.64 hectares (1.58 acres) to about 2.3 hectares (5.8 acres) to the mean parcel sizes of the City of Asheville 0.33 hectares (0.82 acres) and the county as a whole 1.4 hectares (3.54 acres). Comparison of the North Fork and East Asheville watersheds results in a finding that the North Fork's mean parcel size is almost 25 times larger than the East Asheville watershed that is adjacent to the rapidly expanding City of Asheville.

DISCUSSION

The conservation stakeholders who contributed to the P-DAP development initially sought an inexpensive, simple means of tracking development in watersheds by focusing on cadastral data. Cadastral data is high quality, publicly available, and updated on a regular basis. In addition, cadastral data provides a means to identify potential impacts on the land based on the intensity of land use. Analysis of cadastral data brings an understanding of the potential increases in infrastructure needs such as development and maintenance of roads, garbage service, water and sewer services, energy, and communications services and their impacts on the natural and environmental systems.

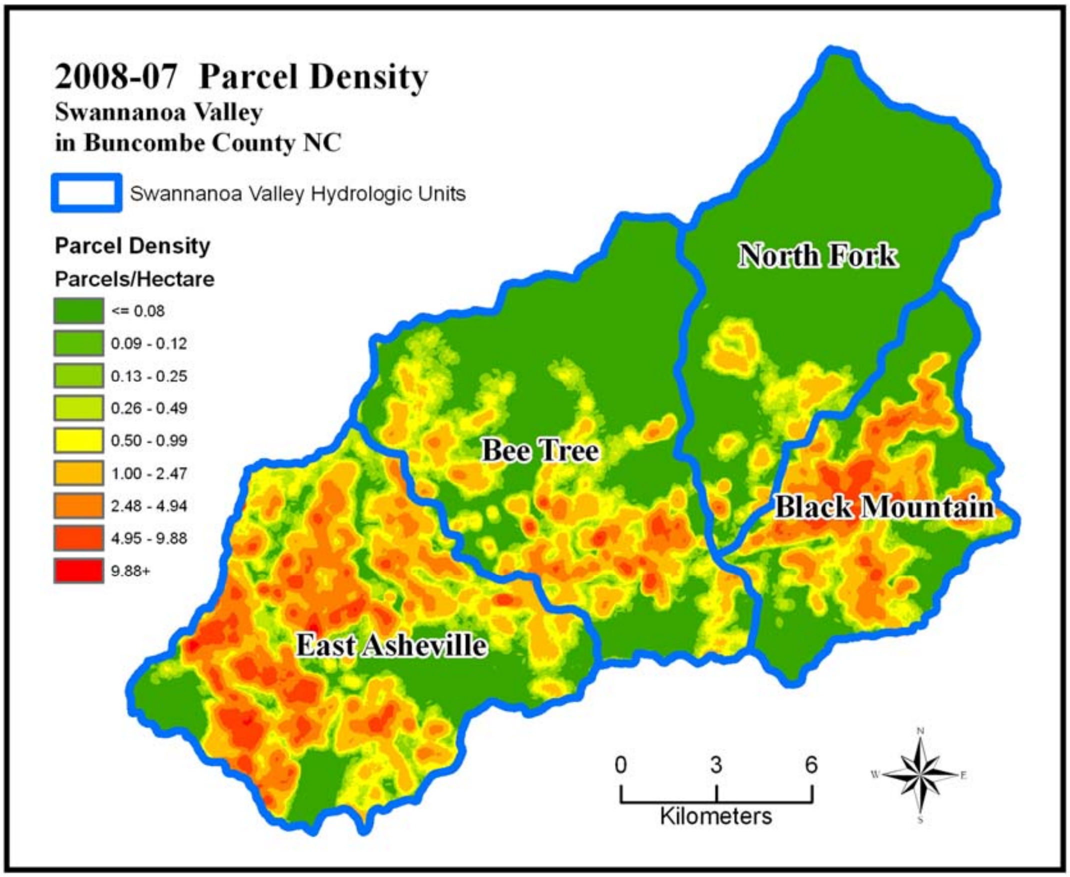
One of the advantages of focusing on cadastral data is the rapid increase in the amount of digitized data due to increase in GIS technology and decrease in data storage costs. In Western North Carolina, COGs are discussing acquiring the digital cadastral data from their members and creating COG-wide digital archives that in turn would be merged into regional archives, thus facilitating P-DAP analysis of large areas of North Carolina. Given that the P-DAP by its nature allows direct comparison among governmental units due to the commonality of cadastral standards, a P-DAP analysis for most of North Carolina appears feasible in the near future. The excluded areas – those lagging in adoption of digital cadastral information – are likely to be converted in the near future.

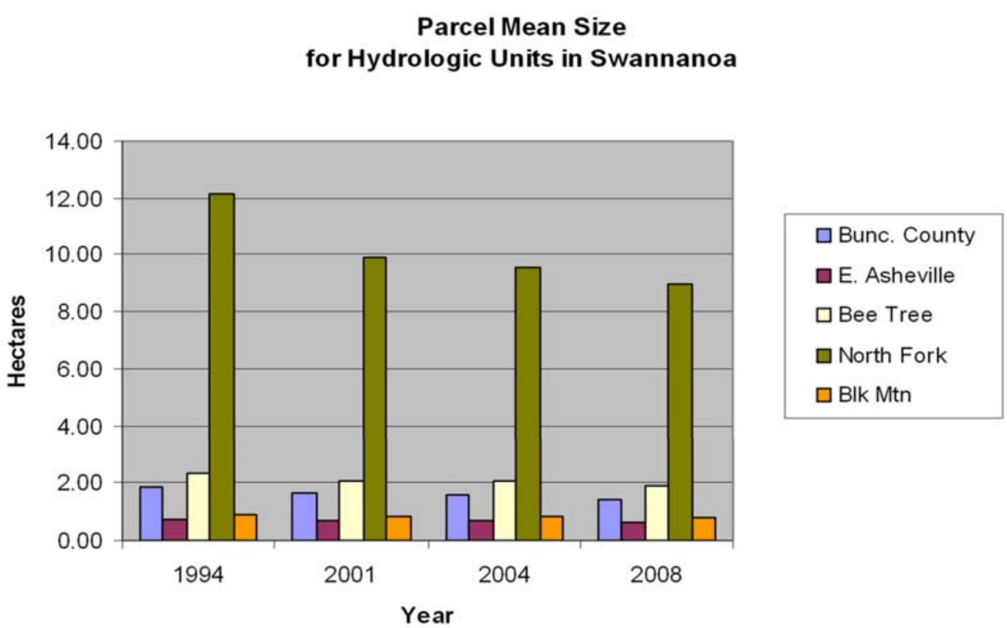
As the protocol developed, it became clear that the P-DAP was applicable across a broad range of settings, as shown in the Results section. The effort broadened to create a generic parcel density analysis approach that would measure development over all surface area by converting current parcel size information into spatial data sets. The final version of P-DAP was found to cover landscape change in a timely manner, at a parcel resolution, and with small data acquisition and processing costs. This is particularly important in Western North Carolina, a region that has moved from near wilderness into an urban landscape without developing a corresponding ability to understand and plan for the effects of that change.

The P-DAP also appeared to be a better indicator of land use intensity than population density. Parcel density is a direct measure of land use intensity. As parcels are subdivided, lots are developed, demand for access and services increases, the land is generally taxed at a higher rate, and the land is used more intensively. Annual change in parcel density is thus a leading indicator of land use condition. Parcel density also is easily updated (annually), the resolution of the data is parcel specific, and the metrics are easily and inexpensively calculated and developed.

Population and LULC measurements tend to be lagging indicators, do not provide the same resolution, and are relatively expensive compared to P-DAP metrics. Population measures do not adequately or directly account for many intensive land uses including non-residential commercial and industrial development or vacation homes, to mention a few. Population counts are not sensitive to the higher resolution time frames required of planners these days. Remotely sensed LULC mapping

FIGURE 8 This Swannanoa Valley parcel density map illustrates the pattern shifts across each of the four hydrologic units; the graph depicts how the parcelization rates differ between the four hydrologic units from 1994 to 2008.





is expensive, time consuming and often provides poor spatial (generally 30 meters or greater) and temporal resolution. As a result, we believe that P-DAP metrics are a better indicator of land use intensity than population density or LULC metrics.

The P-DAP is also able to generate measures for specific issues in a study area. For example, the P-DAP allows computation of a “compaction ratio” that measure the extent of land use for rights-of-way in order to provide a means of illustrating the impact of roads in a study area ranging from a small subdivision to an entire county. Compaction ratios are a useful tool for generating public discussion regarding the appropriateness of land use planning decisions; the ease at which these can be computed using the P-DAP approach calls a much wider use.

One of the major advantages to using parcel density topologies was found to be the elimination of the "edge effect." For example, Census data is not easily integrated with watersheds. However, parcel density data created using the P-DAP approach allows direct measurement within a wide variety of study area boundaries such as counties, Census boundaries, watersheds, sewer districts, topographies, geologies, and wildlife habitats. The P-DAP approach also allows use of a variety of land density metrics. For example, the U.S. Department of Agriculture Natural Resources Conservation Service (NRCS) considers parcels of 4.0 hectares (10 acres) or less as "urban and built-up areas" (NRCS 2000). Also included are tracts of less than 4.0 hectares that are completely surrounded by urban and built-up land. The P-DAP results using the 4.0 hectares metric also can be used to update less timely measures such as LULC maps.

Another P-DAP advantage is the ability to use generic, commonly available software rather than proprietary or highly sophisticated applications. Much of the P-DAP work was carried out by undergraduate interns. They found few problems in learning and applying the programs involved. For small conservation planning organizations with limited budgets, P-DAP offers a feasible method to monitor change with their existing software and help from students in local schools.

The P-DAP shortcomings are self-evident. The process measures parcel size changes, and not the actual impacts to the natural environment. However, current research is testing the relationship between parcel density and impervious surface. Also, local conservation planning organizations will be familiar enough with their own study areas to know whether subdivided farms, for example, are actually being turned into home sites. The P-DAP also requires local knowledge in order to determine what types of analysis would most effectively measure land use changes in a particular study area. For example, what size of search circles and grid cells are most appropriate in generating parcel density typologies? What categories should be chosen to sort parcels by size? How long a period should be covered in time-series analysis?

Given the relative advantages of P-DAP, adoption by large numbers of counties, or an effort by a single group to do P-DAP analysis of large portions of the state is likely to lead to adoption of the technique at a state level. One result might be a statewide index of the landscape condition as derived from parcel density calculations and presented as mean parcel size for counties, municipalities, hydrologic units, census units, and many others. With some refinements, the urban area raw data can be used to annually update high and low density urban lands of local and regional land use maps including the Gap Analysis Program (GAP), which provides regional assessments of native vertebrate species and land management activities. Adoption of the P-DAP protocol also is likely to be hastened by the rapidly increasing emphasis on sustainability and "green" development, as the tool provides a low-cost and standardized approach to measuring urban sprawl and efficiency of land use, especially when done in conjunction with other measures.

CONCLUSION

P-DAP allows a relatively simple, inexpensive, and direct conversion of cadastral data into tabular, chart, and map presentation materials that are effective in educating the public as well as elected officials and their staffs about land use changes. Pilot testing also found that the P-DAP approach could be made relatively routine and inexpensive to implement. Data can be gathered quickly and inexpensively, and analysis of the data requires knowledge of Access™ and simple GIS software. After the initial data acquisition and development of the analysis process, annual maintenance of the system is a relatively simple process.

The P-DAP also allows for the derivation of specific analyses tailored to particular situations. Using P-DAP analysis, a development index for hydrologic units could be constructed that would provide a surrogate for impervious surface measurements. There are likely relationships between parcel density and other environmental gradients.

As a result, the P-DAP appears to be a valuable tool for conservation planners seeking an index to development, particularly in situations where the rate of change is rapid, the area involved is large, and resources to support development models and other sources of data are limited.

ACKNOWLEDGEMENTS

The authors would like to thank the Asheville Office of the U.S. Department of the Interior, Fish and Wildlife Service, whose funding for the "Watershed Based Development Index Project" provided the initial funding for development of the P-DAP. Additional support for further analysis and dissemination was provided by the University of North Carolina Asheville's National Environmental Modeling and Analysis Center as part of the Renaissance Computing Institute Engagement Center.

Support for the P-DAP was also provided by Margo Flood, Director, and Phillip Gibson, Project Manager, of the Environmental Leadership Center at Warren Wilson College, Swannanoa, NC. The authors also extend thanks the project interns including Kelly Johnson, Rachael Briggs, and Rebecca Davanon from Warren Wilson, and Carolyn Fryberger and Leo Klausmann from UNCA. Support for the UNCA interns was provided by Brandie L. Fariss, Ph.D., Department of Environmental Studies. The land records staff in the Western North Carolina counties provided invaluable support in interpreting land records and GIS cadastral data. Steve Apfelbaum and Jason Carlson of Applied Ecology Services also provided additional assistance related to the use of parcel and road metrics.

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