Investigating Parcel Changes to Understand Historic Land Use in a Southwestern Watershed

A thesis submitted to the faculty of
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In partial fulfillment of
the requirements for
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Master of Arts

In

Geography: Resource Management and Environmental Planning

by

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San Francisco, California

Fall 2013

CERTIFICATION OF APPROVAL

I certify that I have read Investigating Parcel Changes to Understand Historic Land Use in a Southwestern Watershed by Charlotte Catherine Ely, and that in my opinion this work meets the criteria for approving a thesis submitted in partial fulfillment of the requirement for the degree Master of Arts in Geography: Resource Management and Environmental Planning at San Francisco State University.

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INVESTIGATING PARCEL CHANGES TO UNDERSTAND HISTORIC LAND USE

IN A SOUTHWESTERN WATERSHED

Charlotte Catherine Ely
San Francisco, California
2013

Long-term land use and land cover change pose critical challenges to sustaining healthy communities and ecosystems. In this study, a methodology was developed to use parcel data to evaluate land use trends in southeast Arizona's San Pedro River Watershed. Changes to parcel size are examined decade by decade, for two intervals: from 1882 to 2012, and from 1971 to 2012. Graphs are used to depict decadal parcel trends for both intervals. Parcel density maps additionally illustrate decadal trends for the 1971 to 2012 interval. The purpose of this study is to 1) improve and describe a methodology for evaluating land use trends using parcel data; 2) display land use trends in a portion of the San Pedro Watershed using parcel data; and 3) discuss the implications of the analysis for evaluating environmental impacts with modeling tools and for assessing effects as required by the National Environmental Policy Act.

I certify that the abstract is a correct representation of the content of this thesis

Chair, Thesis Committee　　　　　　　　　　Date

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Introduction

The San Pedro River is considered one of the last free flowing, undammed rivers in the American Southwest; it flows intermittently between two deserts and through two countries (Figure 1), supporting tremendous biodiversity and providing an important stopover along the central migratory flyway. Changes to ground- and surface water quality and quantity on both sides of the border have raised serious concerns about watershed sustainability. A particular focus in the Upper San Pedro River Watershed is long-term water supply reliability and impacts to the country's first National Riparian Conservation Area, the San Pedro Riparian National Conservation Area (SPRNCA). Despite pioneering water management approaches and collaborative partnerships, "the overall situation in the regional aquifer is not improving; rather, it continues to get worse" (USPP 2011).

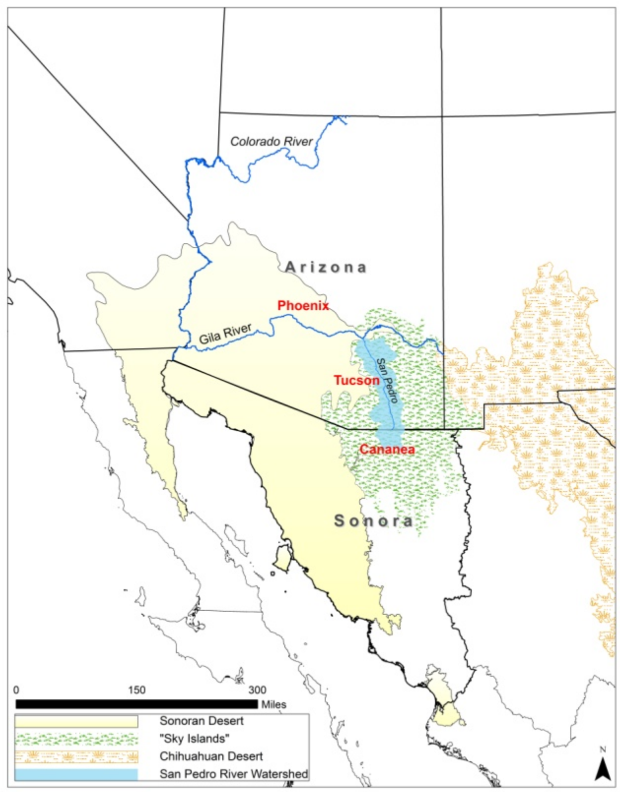

Figure 1: The San Pedro River flows 230 km (~142 mi) from its headwaters in Cananea, Sonora, Mexico to its confluence with the Gila River in Arizona. The watershed is within the Madrean Archipelago, also known as "Sky Islands." This area is one of the most biologically diverse in the world (Koprowski 2005, Skroch 2009). The geographic convergence of two major mountain ranges (the Rocky and the Sierra Madre) and two vast deserts form the foundation for ecological interactions found nowhere else (Skroch 2009). Hydrology data from USGS NHD; Administrative boundaries from AZTANA; Ecoregions from NHEERL; Mexican hydrology data & administrative boundaries from Kepner et al. 2003.

The impact of urbanization on the San Pedro River watershed is a significant driver of declining water quality and quantity (Nie et al. 2011). Yet, few researchers have analyzed the area's changing urban landscape. The purpose of this study is not only to show land use trends in a portion of the San Pedro River Watershed, but also to improve and describe a methodology that could be used to chronicle residential land use change in watersheds across the country.

When people use land, we change it, producing intended and unintended consequences, for good and for ill. Considered the single most important agent affecting ecosystems (Vitousek 1992, NRC 1993), human-induced land use change may have transformed as much as 83% of the earth's ice-free surface (Sanderson et al., 2002). Even as global temperatures rise and glaciers melt, the consequences of human modification of the earth's surface are anticipated to rival those of climate change (Vitousek 1994, Vorosmarty et al. 2000, Chapin et al. 2002, DeFries and Eshleman 2004, Brauman et al. 2007, Whitehead et al. 2009).

That land use change can negatively affect the environment is not a new concern. Geographers have studied and described the relationship between human activity and ecosystem degradation for some time. In 1864, George Perkins Marsh wrote Man and Nature; or Physical Geography as Modified by Human Action. Marsh warned that human actions had so altered the earth that it was "fast becoming an unfit home for its noblest inhabitant."

Man and Nature presented an apocalyptic vision and called for new policies and programs to protect and restore the land. A seminal text, it helped engender an American conservation ethic. Along with Rachel Carson's catalytic Silent Spring (1962) and later geographic works such as Man's role in Changing the Face of the Earth (1959), it also inarguably "heightened the environmental consciousness of the English-speaking world, and exerted unprecedented influence on the development of a unified approach to environmental issues" (Williams 1987).

One of the most sweeping policies to emerge from the environmental movement is the National Environmental Policy Act (NEPA). The law acknowledged "decades of environmental neglect that had significantly degraded the nation's landscape…" and would "create and maintain conditions under which man and nature can exist in productive harmony…" (NEPA, 1969, Sec. 101 (a)). NEPA requires all federal agencies to develop documents that describe the environmental impacts of proposed projects. The documents include analyses of a project's direct, indirect, and cumulative impacts.

> *Direct impacts* are "project impacts that occur in the same time and place" (Sec. 1508.8). For example, a wastewater treatment facility (WWTF) expansion project could change a land's use from agricultural to industrial by constructing additional treatment works on farmland adjacent to the existing plant.
>
> *Indirect impacts* are "reasonably foreseeable consequences that occur later in time or farther in distance" (Sec. 1508.8). For example, the same WWTF expansion project would accommodate an increase in a population that could result in changes to the community's pattern of land use, i.e. a transition from rural to urban.
>
> *Cumulative impacts* are "impacts that result from the incremental impacts of the action when added to other past, present, and reasonably foreseeable actions" (Sec. 1508.7). For example, the WWTF expansion project accommodating an

> increase in population would complement other projects supporting growth. A "connected action" (Sec. 1508.25) would be an increase in a community's drinking water supply. In the case of the San Pedro watershed, that would require expanding the capacity and/or number of wells. A potential cumulative impact could be decreased river flows caused by increased groundwater pumping.

Analyzing and, as possible, mitigating the consequences of direct, indirect and cumulative impacts require understanding the project's historical context. According to the CEQ, understanding the historical context is critical to a NEPA analysis because it will 1) establish an environmental baseline; 2) identify and assess trends; and 3) predict the effects of the proposed action (CEQ 1997, pg. 31). Evaluating management decisions using only current conditions would belie potential impacts (Covington and Moore 1992). Without knowledge of past projects and their consequences, a NEPA analyst cannot evaluate whether present management will lead to significant environmental impacts in the future.

Preferably, baseline conditions would be based on undisturbed environments. However, most environments have been impacted and modified by both modern and aboriginal humans (Swanson et al., 1993). Arguably, all environments could be described as "disturbed" or "produced nature" (Smith 1996). It is less important that a reference condition be "pristine" than that it be simply available and that subsequent changes to that baseline can be evaluated using consistent and measurable criteria.

Establishing land use baselines and assessing environmental impacts over time has been challenging. Before the launch of remote sensing satellites in the early 1970s, past and present conditions were compared using archival literature, historic maps and photography. Scholarship on vegetation change in the American West provides many examples (Humphrey 1958; Hastings and Turner 1965; Branson 1985; Grover and Musick 1990; Bahre 1991; Bahre and Shelton 1993; Turner et al. 2003). Many of these histories analyzed change by comparing matched photographs, a method called repeat photography (Figure 2).

Figure 2: Landscape change from perennial grassland to mesquite woodland in a semi-arid rangeland (Santa Rita Mountains south of Tucson, Arizona) from 1903 (left) and 1941 (right) (from Kepner et al. 2002)

However, there are serious drawbacks in using this technique to assign change over this period of history. As some authors, e.g. Bahre (1991), point out, the field of view in older photographs is usually oblique and covers little total area, which limits their usefulness in determining change over large regional areas. Secondly, historic photographic series are usually separated by large periods of time. Lastly, repeat photography has largely been used for qualitative comparisons and little progress has been made in quantifying and characterizing change using this dataset (Kepner 2002).

Since the 1970s, remote imagery has increasingly been used to chronicle change. Integrating remote imagery, computer processing, and spatial analysis technologies with landscape ecology theory (a la Forman and Godron 1986, Risser 1984) has produced analyses that qualitatively and quantitatively describe land use change (Kepner et al. 2002, 2004). As displayed in the Upper San Pedro Watershed example (Figure 3), the researchers found a 414% increase in urban land cover between 1972 and 1997.

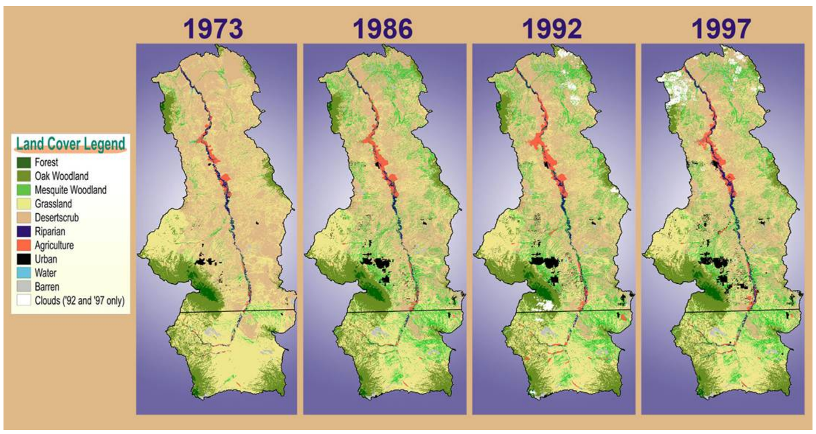

Figure 3: Land cover in the Upper San Pedro Watershed using Landsat MSS and TM (Kepner et al. 2002)

Trends analyses, in turn, can be used to project the potential future effects of a proposed action. Such predictive models have been used to develop alternative future scenarios, which can lead to a more robust comparative analysis of impacts relative to alternative courses of management action (Swart, Raskin and Robinson 2004). As an example, Burns et al. recently evaluated basin-wide impacts to water quality in the San Pedro, assessing various development scenarios from 2010 through 2100 (Burns et al. 2013). A decade prior, Steinitz et al. (2003) also developed robust futures analyses for the San Pedro watershed.

There are limits to how much change can be detected and subsequently projected using remote imagery. Satellite images, for example, vary in scale related to pixel size and spectral resolution, which can complicate the generation of cohesive and comprehensive mosaics. Furthermore, their availability is limited as the earliest Landsat imagery dates back only to 1972. While aerial imagery has been used to reconstruct landscape conditions prior to the launch of remote sensing satellites, georectifying and digitally interpreting such photographs also presents challenges, i.e. geospatial error, limited scope, and photos with varying spectral properties.

To the extent that these limitations hinder our ability to chronicle changes in settlement patterns, historic property records provide an opportunity to fill data gaps and complete a finer-scale analysis that can be used to corroborate relatively coarse mosaics. Historic property records can be used to follow the changing number and sizes of individual properties over time, effectively tracking changes in property density. From this analysis, we can deduce changes in land use, observing, for example, the subdivision of a former Spanish land grant into several thousand parcels, and the probable (although not inevitable) shift from a rural to suburban landscape. Extending further back in time and more consistent than census data[1], archival ownership records have been scarcely used in landscape studies. Yet, they represent a quantifiable indicator that can be readily incorporated into environmental histories and future analyses alike.

Geographers especially have found that such property records (i.e., parcel data) can provide valuable insight. In 1966, Norman J. W. Thrower's *Original Survey and*

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[1] While decennial census data is another source of information for historic population distribution and human settlement patterns, GIS-compatible information was not available prior to the 1990 census; furthermore, the "ever-changing" boundaries of GIS-compatible units (i.e. the tabulations areas: block groups, tracts, etc.) make it difficult to examine the same area year after year (Theobald 2001, Hammer et al 2003).

Land Subdivision: A Comparative Study of the Form and Effect of Contrasting Cadastral Surveys described, as his editor, Clarence Glacken, wrote, “an ancient and basic phenomenon, the way in which men have divided up their land.” Thrower compared two 100-square mile plots in Northwestern Ohio, examining two distinct ways of dividing land. Thrower’s primary purpose was to describe how contrasting cadastral surveys influenced a number of factors, such as road placement, settlement, methods of cultivation, taxation, etc..

However, he dedicated a few pages to the changing number and size of properties in the study area. Between 1875 and 1955, the number of properties in “Area S” increased 23% while their average size decreased 22%; the number of properties in “Area ‘U increased 52% while their average size decreased 34% (Table 1, Figure 3). Thrower relied on the “handsomely bound” county atlases and township maps. He laments that these primary sources are “a valuable and, perhaps, neglected source for historical-geographical studies” (Thrower 1966, pg 51).

	Area S		Area U	
Year	**1875**	**1955**	**1875**	**1955**
Number of Properties	712	875	305	465
Percent change	23%		52%	
Average Property Size (acres)	90	70	230	150
Percent change	-22%		-34%	

Table 1: Changing parcel patterns in Northwestern Ohio, 1875 & 1955

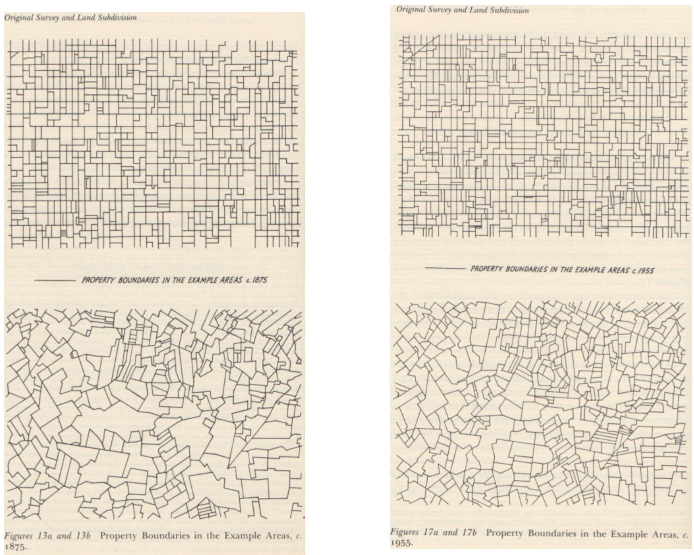


Figure 4: Hand-drawn maps from the Thrower study. "Area S" in 1875 (left) and 1955 (right) is show above; "Area U" in 1875 (left) and 1955 (right) is shown below.

With the exception of William M. Rodgers, whose work this study builds upon and whose approach will be detailed extensively in the methods section, the following few decades of geographic research appear[2] to have overlooked the use of parcel data to provide quantitative analyses. For example, William Preston's *Vanishing Landscapes* (1981) made modest use of parcel data to show the disposition of federal land and the subsequent subdivision of California's Tulare basin. While Preston writes that "land records are the earliest quantitative record…(and)…are very useful in the analysis of initial settlement" (104), he omits a detailed quantitative analysis of parcel changes over time. In the Corcoran and Pixley example shown on the next page, however, the changes can be derived from the figures themselves (Figure 5). In other words, parcel data cannot only be used to analyze "initial settlement," but also the progression of settlement.

[2] Using search terms such as parcel, subdivision, tax roll, assessor roll, land use, land use trends, geography, and/or historical geography, Google Scholar queries identified few relevant publications between 1950 and 1980.

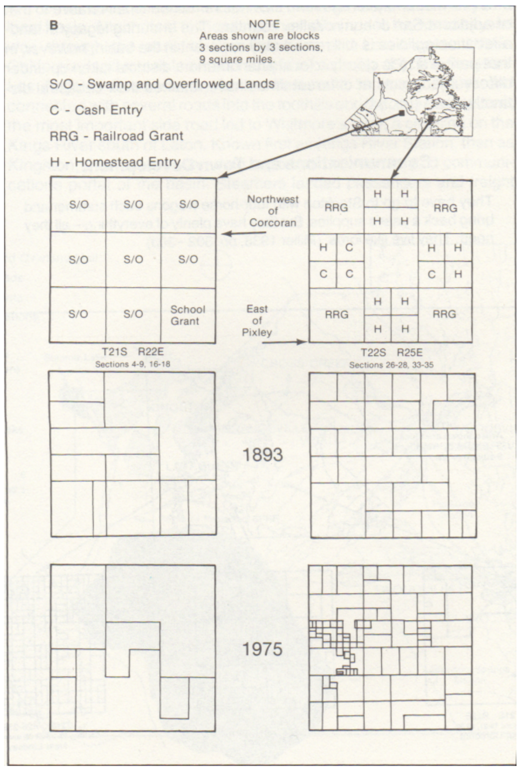


Figure 5: Parcels changes in the Tulare Basin. Between 1883 and 1975, the number of parcels in the Corcoran block decreased by 36%, from 11 to 7 parcels, while the number of parcels in the Pixley block increased 190%, from 29 to 84 parcels.

In the 1990s — likely coinciding with the integration of landscape ecology into geography and other disciplines (Farina 2006) — land use change studies began counting parcels. Rather than, as with the previously described research, including a parcel analysis as a minor component of a broader investigation, parcel data began to feature prominently. Research examining the loss of forestland, particularly, has employed parcel data to chronicle change.

An early example comes from the University of Boulder. In “Land Use and Landscape Change in the Colorado Mountains II: A Case Study of the East River Valley,” Theobald, Gosnell and Riebsame (1996) examined residential subdivision between 1964 and 1994. The authors employed landscape ecology principles to study not just changes in vegetation patterns (i.e. the land cover), but also changes to the "cultural landscape" (i.e. land use). Parcel data provided the foundation for the land use change analysis.

The study relied on three sources of data acquired form the County Assessor: 1) parcel maps, 2) subdivision plat maps, and 3) tax records. Theobald, Gosnell and Riebsame used the parcel data to track subdivision trends, and also to develop nine parcel-size classes. The authors then correlated the parcel classes to land cover classes (Table 2). Among other findings, they observed the 30-45 acre class (i.e. the "dramatically increasing" *ranchettes*) preferred the wooded valley slopes (e.g. aspen), a land cover class the authors identified as steadily declining.

Land area by land-cover type and parcel class

Ac: Ha:	0–.5 0–.2	.5–1 .2–.4	1–5 .4–2	5–10 2–4	10–30 4–12	30–45 12–18	45–100 18–40	100–500 40–202	500+ 202+	Total
Cover	Acres									
Alpine	0	0	0	0	0	0	0	49	0	49
Aquatic	0	0	1	1	0	0	16	64	17	98
Aspen	17	17	11	2	167	1,110	516	826	2,302	4,967
Mixed Conifer	0	0	0	2	22	1,221	413	931	1,502	4,091
Meadow	124	33	86	87	137	371	218	2,928	3,256	7,239
Mtn. Grass.	32	13	24	8	103	259	191	475	1,145	2,249
Mtn. Shrub	0	0	0	3	2	37	0	152	187	382
Non-veget.	0	0	0	0	0	0	0	3	3	7
Disturbed	0	0	0	0	7	2	0	91	27	127
Riparian	2	7	22	30	100	155	251	925	719	2,210
Sagebrush	126	38	151	147	569	2,367	1,528	4,558	7,838	17,322
Total	301	107	293	281	1,107	5,522	3,133	11,001	16,995	38,740

Table 2: Parcel and land cover classes from East River Valley study

Haines, Kennedy and McFarlane's "Parcelization: Forest Change Agent in Northern Wisconsin" (2013) provides a more contemporary example of integrating parcel data into a landscape ecology analysis. The authors also relied on County Assessor data to track parcel changes, and, as with the East River Valley study, then correlated parcel changes to landscape ecology metrics, such as Number of Patches (NP) for particular land cover classes (e.g. open space, forest). Table 3 shows that between 1938 and 2005, the number of private parcels increased 73.5% as the "developed" patch class increased 336.20%.

Parcels	Patch class	NP	TCA	LPI	FRAC_MN
1938 Fragmentation results					
n = 2,355	Open space	323	525	0.091	1.115
	Developed	265	77	0.024	1.066
	Forest	155	24,854	44.39	1.082
2005 Fragmentation results					
n = 4,087	Open space	229	298	0.069	1.115
	Developed	1,156	396	0.032	1.073
	Forest	280	22,553	25.753	1.094
1938–2005 Class metric percent change					
73.50%	Open space	−29.10%	−43.20%	−24.10%	0.10%
	Developed	336.20%	411.50%	31.70%	0.60%
	Forest	80.60%	−9.30%	−42.00%	1.10%

Table 3: Changes in parcels and land cover in Northern Wisconsin

Both the East River and Northern Wisconsin studies digitized and geo-referenced the parcel and subdivision plat maps for multiple years and then cross-referenced parcel sizes with the tax record. The East River study uses parcel data to track changes in parcel density over time, the Northern Wisconsin study to create incremental land use maps. Haines, Kennedy and McFarlane followed particular parcels back through time using "reverse parcelization," a methodology in which the researcher obtains a current digital parcel layer and then merges subdivided lots back into "parent" parcels, reconstructing land uses in 5 to 10-year increments.

As shown in Figure 6, reverse parcelization methodology chronicles parcel-by-parcel changes. Such an analysis requires investing considerable time. Kennedy and McFarlane estimate that using reverse parcelization to analyze the entire county surrounding their study area "would have consumed years" (Kennedy and McFarlane 2009). While using reverse parcelization methodology can provide great detail, the hefty time investment may limit a study's scope. The Northern Wisconsin study includes several thousand parcels within a 169,875-acre area. In comparison, using the to-be-detailed methodology, the San Pedro study area included and tens of thousands of parcels within a nearly million-acre area.

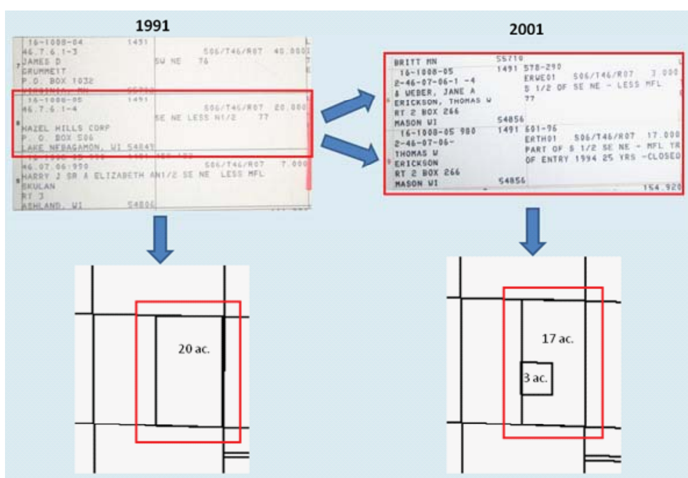


Figure 6: Illustration of reverse parcelization methodology (Kennedy and McFarlane 2009). Segments of the scanned 1991 and 2001 tax records appear above, and the parcel maps below.

The East River Valley and Northern Wisconsin studies provide representative examples of how geographers have used parcel data to examine land use change. Additional landscape ecology studies have completed analyses using very similar methods (Kliman and Erickson 1995; Drzyzga and Brown 2002; Alberti and Marzluff 2004; LaPierre and Germain 2005; Gosnella, Haggerty and Travis 2006; Compas 2007; Donnelly and Evans 2007; Ko and He 2011).

Of course, geography is not the only discipline studying parcels. Economists have developed spatial models using historic parcel data (Irwin, Bell and Geoghegan 2003). Urban planners have also incorporated parcel data into exurbanization research; Exparza and Carruthers (2000), for example, counted (but did not map) the increasing number of privately owned parcels in unincorporated Cochise County. Unlike landscape ecology research, these studies examined changes over relatively small periods.

Examining change over much longer time periods, environmental histories have long sought to describe how nature was and is organized (Worster 1990). The emerging field of "historical GIS" describes the geospatial technologies and analytical techniques historians are increasingly employing to "(tackle) the historical construction of space" (White 2008). For example, DeBats (2008) used the "often-neglected tax records" to map Alexandria, VA and Newport, KY in the 19th century. Donahue (2004) relied on tax records to analyze patterns of agriculture and inheritance in Concord, MA. The foundation of Heasley's *A Thousand Pieces of Paradise* (2003) was a huge GIS database, one of the "most important" components of which was the parcel layer (Rice 2013).

A Thousand Pieces of Paradise incorporated parcel data into an environmental history of the Kickapoo Valley using methods very similar to the landscape ecology approaches previously described. However, its analysis diverged considerably as Heasley's primary purpose was to chronicle modern property discourse by presenting an "ecological history of property and a cultural history of ecosystems" (Heasley 2003). Heasley's work provides a celebrated example of how historians are embracing GIS to reconstruct the past; it also reflects the field's growing emphasis on the complex interdependency of people and nature.

Modern environmental histories not only consider how nature has shaped human societies, but also how thoughts, actions and policies produce environmental change (White 1985). If considering how a federal action would produce change, environmental historians would no doubt present a thorough NEPA analysis, particularly because describing "cumulative effects" is an inherent component of their approach. When environmental historians describe how past events and processes have interacted to transform people and place, they describe the "cumulative" landscape. Historical geographer D.W. Meinig elaborates:

> To (the environmental historian) all that lies before his eyes is a complex cumulative record of the work of nature and man in this particular place…. the historian sees the particular cumulative effects of processes working upon the particular elements of this locality….Every landscape is an accumulation. The past endures; the imprint of distant forebears in survey lines, land parcels, political jurisdictions, and routeways… (Meinig 1979).

Environmental historians offer a germane perspective and Historical GIS a powerful suite of analytical tools that could be readily incorporated into NEPA analyses. While Cronon (1993) cautions that environmental histories cannot predict or prescribe, a greater understanding of, for example, the historical relationship between growth and watershed impacts would invariably aid future management decisions. We cannot predict the future, but we can learn from our past. And when we represent our past quantitatively, we can incorporate trends into increasingly scalable and comprehensive analysis tools.

Building a Historical GIS database is “slow, expensive, and frequently tedious” (Gregory and Ell 2007). Capturing parcel data would be one of many time-consuming steps in the database’s construction, possibly requiring, as exemplified, obtaining historic tax records as well as parcel maps that in turn must be scanned, digitized and geo-referenced. The methodology to be described may provide a more comprehensive and less cumbersome approach to acquiring and analyzing parcel data. Because of its relative simplicity, the proposed methodology could be particularly useful in NEPA analyses.

In this study, historic tax records were used to examine land use change over a relatively long period, from 1882 to 2012. This was accomplished by restricting the analysis to a portion of the Upper San Pedro River Watershed that was studied by the aforementioned William R. Rodgers, a University of Arizona graduate student in the mid-1960s. The study area encompasses the same rectangular section of the watershed Rodgers defined as the Upper San Pedro River Valley (Figure 7).

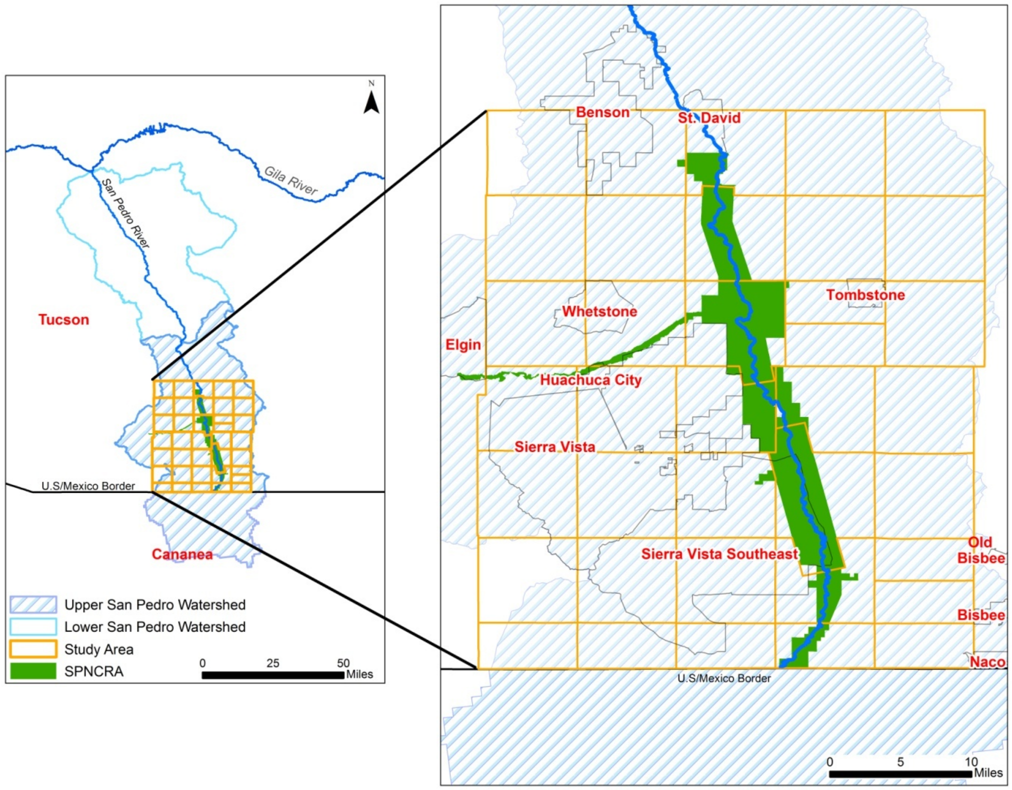


Figure 7: Location Map of the Study Area. The study area was defined using the Public Land Survey System (PLSS); the grid shows historic township boundaries. Also shown is the San Pedro Riparian National Conservation Area (SPRNCA). Administered by the U.S. Bureau of Land Management (BLM), SPRNCA protects approximately 64 km (~40 mi) of the river corridor. Hydrology data from USGS NHD; Administrative boundaries from AZTANA; PLSS boundaries from Cochise County; SPNCRA boundaries from Kepner et al. 2003.

Methods

At the age of 55, Brigadier General William M. Rodgers retired from the Army and enrolled in the Geography program at the University of Arizona. In 1965, Rodgers submitted his thesis, titled "Historical Land Occupance of the Upper San Pedro River Valley Since 1870." The study relied heavily on documents provided by the Cochise County Treasurer and Assessor. Rodgers described using Tax Rolls from 1882 through 1964 to analyze the changing extent, number, and acreage of parcels, decade by decade. He drew detailed landholding maps using the Public Land Survey System (PLSS). Figure 8 shows the 1900 and the 1964 landholding maps from Rodgers' study. The diagonal lines show how much of each section and how many of a Township's 36 640-acre sections were occupied for each of the years examined.

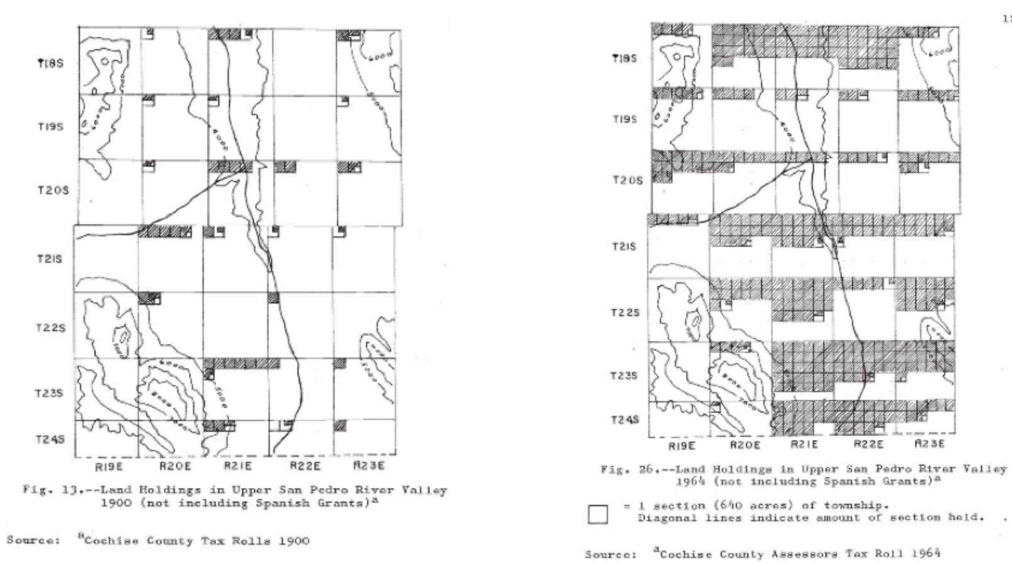
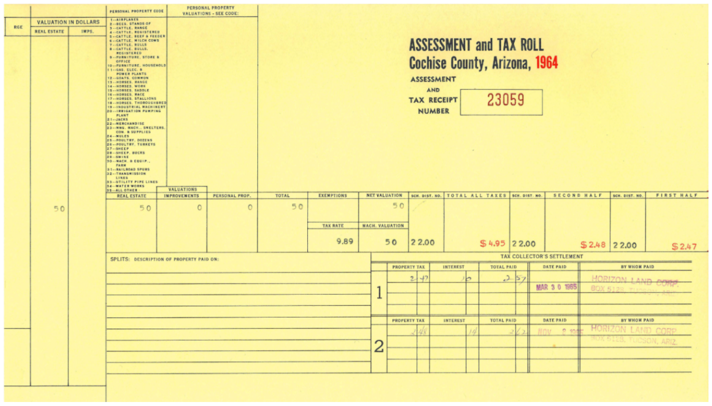


Figure 8: Landholdings in Upper San Pedro River Valley, 1900 and 1964 (Rodgers 1965)

The historic tax rolls are stored in large binders, organized by year and, from 1935 to 1970, by Tax Roll Number, which is also referred to as the Assessment Number. For example, the 1964 Tax Roll binder “35015 to 35441” contains all tax records with assessment numbers ranging from 35015 to 35441. Before 1935, the Tax Roll was organized by year and, alphabetically, by owner last name. Today, the binders are stored in the Cochise County Archives (Figure 9).

Figure 9: Cochise County Archives space savers (left) and the row containing the 1964 Tax Roll binders (right)

Each Tax Roll record provides an assessment number, the name and address of the owner, the taxes due, and, sometimes, the property’s legal description, acreage, and location, defined using PLSS coordinates (e.g., Township 21, Range 22, southeast quarter of Section 35) (Figure 10).



ASSESSMENT and TAX ROLL
Cochise County, Arizona, 1964
ASSESSMENT AND TAX RECEIPT NUMBER 23059

PERSONAL PROPERTY CODE: 1--AIRPLANES; 2--BEES, STANDS OF; 3--CATTLE, RANGE; 4--CATTLE, REGISTERED; 5--CATTLE, BEEF & FEEDER; 6--CATTLE, MILCH COWS; 7--CATTLE, BULLS; 8--CATTLE, BULLS, REGISTERED; 9--FURNITURE, STORE & OFFICE; 10--FURNITURE, HOUSEHOLD; 11--GAS, ELEC. & POWER PLANTS; 12--GOATS, COMMON; 13--HORSES, RANGE; 14--HORSES, WORK; 15--HORSES, SADDLE; 16--HORSES, RACE; 17--HORSES, STALLIONS; 18--HORSES, THOROUGHBRED; 19--INDUSTRIAL MACHINERY; 20--IRRIGATION PUMPING PLANT; 21--JACKS; 22--MERCHANDISE; 23--MNG. MACH., SMELTERS, CON. & SUPPLIES; 24--MULES; 25--POULTRY, DOZENS; 26--POULTRY, TURKEYS; 27--SHEEP; 28--SHEEP, BUCKS; 29--SWINE; 30--MACH. & EQUIP., FARM; 31--RAILROAD SPURS; 32--TRANSMISSION LINES; 33--UTILITY PIPE LINES; 34--WATER WORKS; 35--ALL OTHER

PERSONAL PROPERTY VALUATIONS - SEE CODE:

RGE	VALUATION IN DOLLARS: REAL ESTATE	IMPS.
	50	

VALUATIONS: REAL ESTATE	IMPROVEMENTS	PERSONAL PROP.	TOTAL	EXEMPTIONS	NET VALUATION	SCH. DIST. NO.	TOTAL ALL TAXES	SCH. DIST. NO.	SECOND HALF	SCH. DIST. NO.	FIRST HALF
50	0	0	50		50						
				TAX RATE 9.89	MACH. VALUATION 50	22.00	$4.95	22.00	$2.48	22.00	$2.47

SPLITS: DESCRIPTION OF PROPERTY PAID ON:

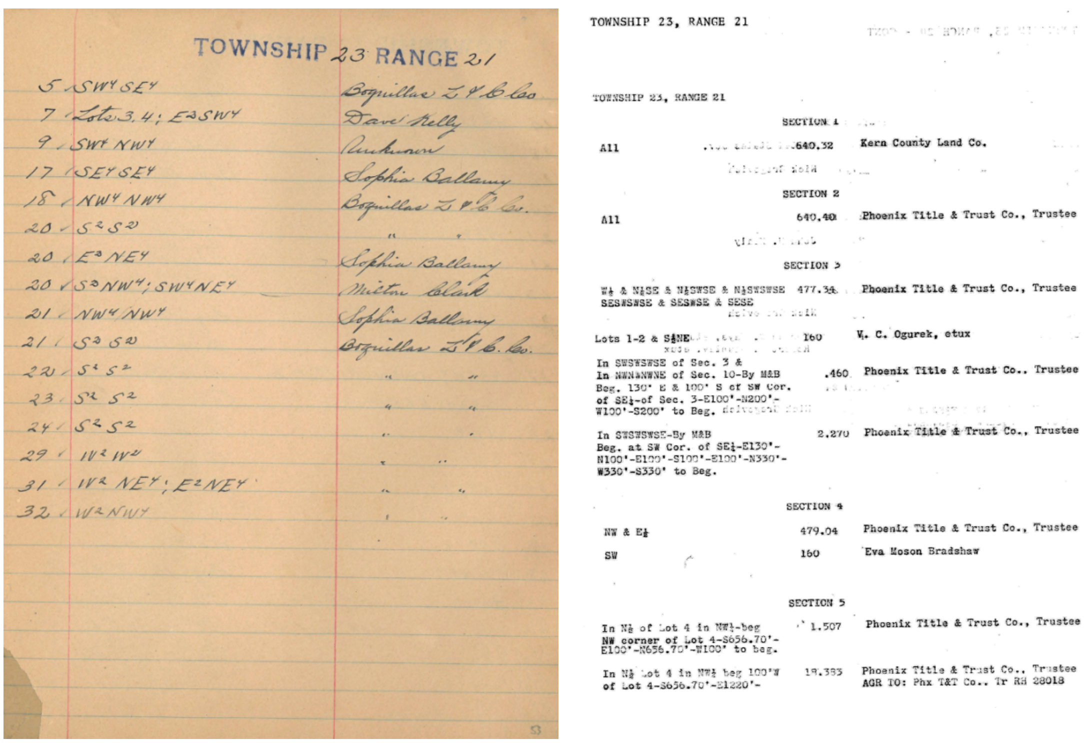
TAX COLLECTOR'S SETTLEMENT

	PROPERTY TAX	INTEREST	TOTAL PAID	DATE PAID	BY WHOM PAID
1	2.47	.10	2.57	MAR 30 1965	HORIZON LAND CORP. BOX 5128, TUCSON, ARIZ.
2	2.48	.14	2.62	NOV 2 1965	HORIZON LAND CORP. BOX 5128, TUCSON, ARIZ.

Figure 10: Scanned Image of 1964 County Assessor Tax Roll Record (Courtesy of Cochise County Archives, 2012)

If a property spanned multiple sections in multiple townships and/or ranges, the Tax Roll record - if complete - would list the acreage owned within each area (e.g. Township 21, Range 22, southeast corner of section 32, 160 acres; Township 22, Range 22, northern half of the northwest quarter of section 2, 80 acres). Rodgers was interested only in properties within the Upper San Pedro Valley, which he defined as Townships 18 through 24 and Ranges 19 through 23 (Figures 7 & 8). As the Tax Roll was not organized geographically and as many of the Tax Roll records had missing and/or incomplete acreage and location information, it seems more than likely Rodgers would have also relied on County plat books.

The County's oldest plat book dates from 1913, and the most recent from 1964. The plat books were organized by Township, Range, and Section. The properties within a given section were listed one by one and included only two additional pieces of information: who owned it and its acreage (Figure 11). There is no unique assessment number associated with each entry in the plat books. Rodgers would have needed to take great care in identifying an individual property. Since large properties consisted of land in multiple sections, ranges, and/or townships, the owner's name would appear multiple times in the plat books. Once Rodgers knew who occupied land in his study area, he would have been able to track that individual down in the Tax Roll and then accurately describe the acreage of a single property.



TOWNSHIP 23 RANGE 21

5	SW¼ SE¼	Boquillas L & C Co
7	Lots 3, 4; E½ SW¼	Dave Kelly
9	SW¼ NW¼	[illegible]
17	SE¼ SE¼	Sophia Ballamy
18	NW¼ NW¼	Boquillas L & C Co.
20	S½ S½	" "
20	E½ NE¼	Sophia Ballamy
20	S½ NW¼; SW¼ NE¼	Milton Clark
21	NW¼ NW¼	Sophia Ballamy
21	S½ S½	Boquillas L & C Co.
22	S½ S½	" "
23	S½ S½	" "
24	S½ S½	" "
29	W½ W½	" "
31	W½ NE¼; E½ NE¼	" "
32	W½ NW¼	" "

TOWNSHIP 23, RANGE 21

TOWNSHIP 23, RANGE 21

SECTION 1

All	640.32	Kern County Land Co.

SECTION 2

All	640.40	Phoenix Title & Trust Co., Trustee

SECTION 3

W½ & N½SE & N½SWSE & N½SWSWSE SESWSWSE & SESWSE & SESE	477.34	Phoenix Title & Trust Co., Trustee
Lots 1-2 & S½NE	160	W. C. Ogurek, etux
In SWSWSWSE of Sec. 3 & In NWNWNWNE of Sec. 10-By M&B Beg. 130' E & 100' S of SW Cor. of SE¼-of Sec. 3-E100'-N200'-W100'-S200' to Beg.	.460	Phoenix Title & Trust Co., Trustee
In SWSWSWSE-By M&B Beg. at SW Cor. of SE¼-E130'-N100'-E100'-S100'-E100'-N330'-W330'-S330' to Beg.	2.270	Phoenix Title & Trust Co., Trustee

SECTION 4

NW & E½	479.04	Phoenix Title & Trust Co., Trustee
SW	160	Eva Moson Bradshaw

SECTION 5

In N½ of Lot 4 in NW¼-beg NW corner of Lot 4-S656.70'-E100'-N656.70'-W100' to beg.	1.507	Phoenix Title & Trust Co., Trustee
In N½ Lot 4 in NW¼ beg 100'W of Lot 4-S656.70'-E1220'-	19.383	Phoenix Title & Trust Co., Trustee AGR TO: Phx T&T Co., Tr RH 28018

Figure 11: Scanned Plat Books entries showing landholdings in Township 23, Range 21 in 1913 (left image) and 1964 (right image) (Courtesy of Cochise County Archives, 2012)

Examining holdings in 1940, 1950, and 1964 would have required an additional step because, from 1935 to 1970 the Tax Rolls were organized by assessment number, not by owner name. In order to connect a property owner to a specific piece of property during those years, Rodgers likely referenced the "alpha indices," which are organized alphabetically by owner last name (Figure 12). Adjacent to the owner name, the alpha index lists the unique assessment number associated with that person's property. By referencing a given year's alpha index, Rodgers could have tracked down a Tax Roll record using the assessment number. To examine parcels in 1940, he may have done this as many as 325 times; for the year 1964, as many as 831 times. He did not describe his methods in detail, and they remain an impressive mystery - particularly for those years that lack plat books (before 1913) and Tax Roll binders (before 1886).

Figure 12: 1964 Alpha Index to Assessment and Tax Roll

However he obtained the data, the result was an analysis of the changing number and size of properties over an 80-year period. Rodgers not only described where people settled within the watershed, but how large those settlements were.

The acreage of a property can provide insight into how the land was used, especially when coupled with additional data. For example, Rodgers also documented the changing cattle population decade by decade. To analyze the changing trends in the size of landholdings, he grouped properties into four categories: 0 to 159 acres, 160 to 319 acres, 320 to 999 acres, and 1000 acres and up.

These size categories not only refer to the PLSS (i.e., a 640-acre section divided by 4 equals 160 acres), but probably to the Homestead Acts. The original 1862 Act granted 160 acres, or a quarter of a section. Later iterations increased the allotted acreages. The 1909 amendment, for example, increased the size of homesteads to 320 acres in western (i.e. arid) states (BLM 2013). For each year he examined, Rodgers counted the number of landholdings within each category, calculated their sum acreage, determined what percentage of all holdings the sum acreage represented, and, lastly, established the average property size in each category. Figure 13 shows the tables and hand drawn pie charts for the years 1940, 1950, and 1964.

TABLE IV

CATEGORIES OF LAND HOLDINGS IN UPPER SAN PEDRO RIVER VALLEY BY NUMBER, ACREAGE, PERCENTAGE OF TOTAL HOLDINGS, AND AVERAGE SIZE 1930-1964[a]

Year	Acreage of holdings	No.	Acreage	% of all holdings	Average size of holdings in acres
1940	0-159	123	10,127	4.1	81
	160-319	71	13,820	7.2	194
	320-999	100	46,180	24.0	462
	1000+	28	122,137	50.9	4,362
	Sp Grants	3	51,572	21.5	
	Total	325	243,836		
1950	0-159	244	7,593	2.7	31
	160-319	47	8,383	3.5	178
	320-999	65	31,644	14.7	579
	1000+	40	151,409	59.0	3,785
	Sp Grants	3	51,572	20.1	
	Total	399	256,601		
1964	0-159	674	14,297	5.1	21
	160-319	73	14,672	5.2	201
	320-999	47	26,660	9.5	567
	1000+	34	175,188	62.0	5,153
	Sp Grants	3	51,572	18.2	
	Total	831	282,389		

Source: [a]Cochise County Tax Rolls 1940-1950, Assessors Tax Roll 1964

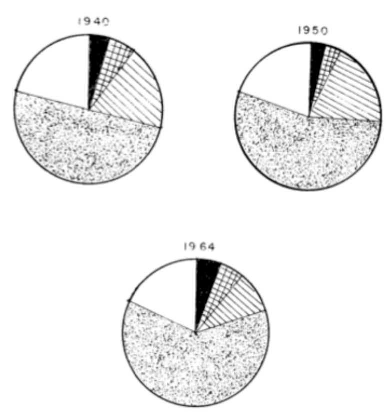


Fig. 28.--Privately Owned Land in Upper San Pedro River Valley by Size of Holdings 1940-1964[a]

0-159 acres
320-999 acres
Spanish Grants
160-319 acres
1000+ acres

Source: [a]Cochise County Tax Rolls 1940-1950, Assessors Tax Roll 1964

Figure 13: 1940, 1950, and 1964 summary of acreage changes in Upper San Pedro River Valley (Rodgers 1965)

The number of properties (column 3, i.e. the column with the heading “No.,” in Figure 13) does not represent the total number of landholdings within the watershed during that time; rather, it appears to be the sample size Rodgers used. His thesis is quiet on this matter. The difficulty in establishing every unique property's location and size likely prevented Rodgers from obtaining the true total. He calculated "percentage of all holdings" (column 5) using "Total Acreage" (column 4, last rows for each year examined). The pie charts at right display this calculation. For example, in 1964, the properties greater in size than 1,000 acres covered a cumulative acreage of 175,188; the total acreage of all properties at that time was 282,389; the "percentage of all holdings" for properties of that size was 62%, i.e. (175,188/282,389)*100.

Today, the Cochise County Information Technology (IT) Department has mapped each property using customized Geographic Information System (GIS) software, thus simplifying the tasks of displaying, querying, and analyzing land use trends. The IT Department provided a geodatabase that contained property information for the entire county. The geodatabase included the precise geographic location and size of each landholding. With this information, all properties within the study area, i.e., all those properties with their "centroid" within Townships 18S though 24S, and Ranges 19E through 23E, could be identified. Figure 14 shows the landholdings within the study area for the year 2012. Including mining parcels, there are 37,360 individual properties.

In order to complete the survey that Rodgers began, the same analysis was performed for the 2012 data. The 37,360 properties were grouped into the four size categories. The number of properties within each category were counted, the sum acreage calculated, the percentage of all holdings determined, and the average property size established (Table 4).

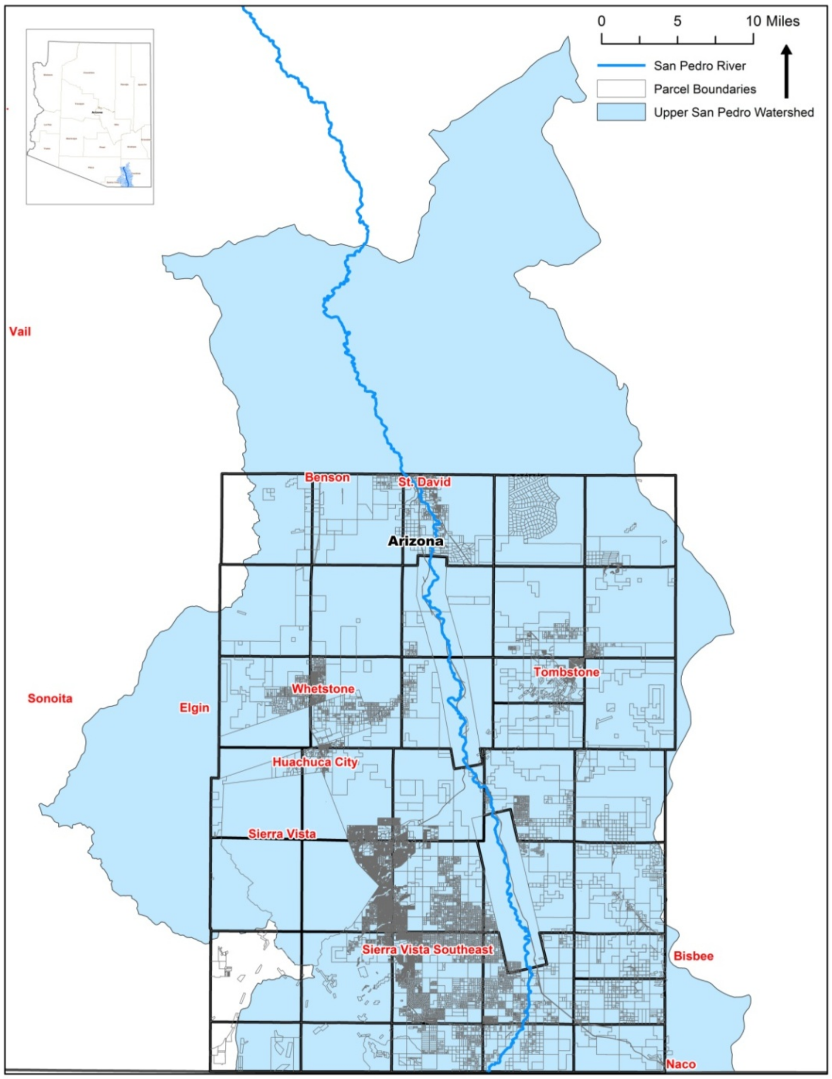


Figure 14: Parcels within the Study Area, 2012. Parcel data provided by Cochise County IT department; Hydrology data from USGS

Rather than, as Rodgers did, calculate "percentage of all holdings" using "Total Acreage," "Number of Holdings" was used instead. Figure 14 displays the results of those calculations for 1940, 1950, 1964 and 2012. With the goal of continuing Rodgers' decade-by-decade analysis, parcel data was obtained for 2001, 1991, 1981 and 1971. However, the parcel record for those decades was not available in the same format as the record for 2012. 2011 marked the first year the County mapped all parcels using GIS software. To analyze the previous decades and map the changes, an alternative approach was needed.

Categories of Land Holdings in Upper San Pedro River Valley by Number, Acreage, Percentage of Total Holdings, and Average Size in 2012.

Acreage of Holdings	*Number of Holdings*	*Total Acreage*	*% of all holdings*	*Average size (ac)*
0-159	36,891	142,231	98.74%	3.86
160-319	170	36,489	0.46%	214.64
320-999	209	110,499	0.56%	532.78
1000+	90	464,278	0.24%	5158.65
Total	37,360		100%	

Table 4: 2012 Land Holdings Analysis (Data Courtesy of Cochise County IT Department, 2012)

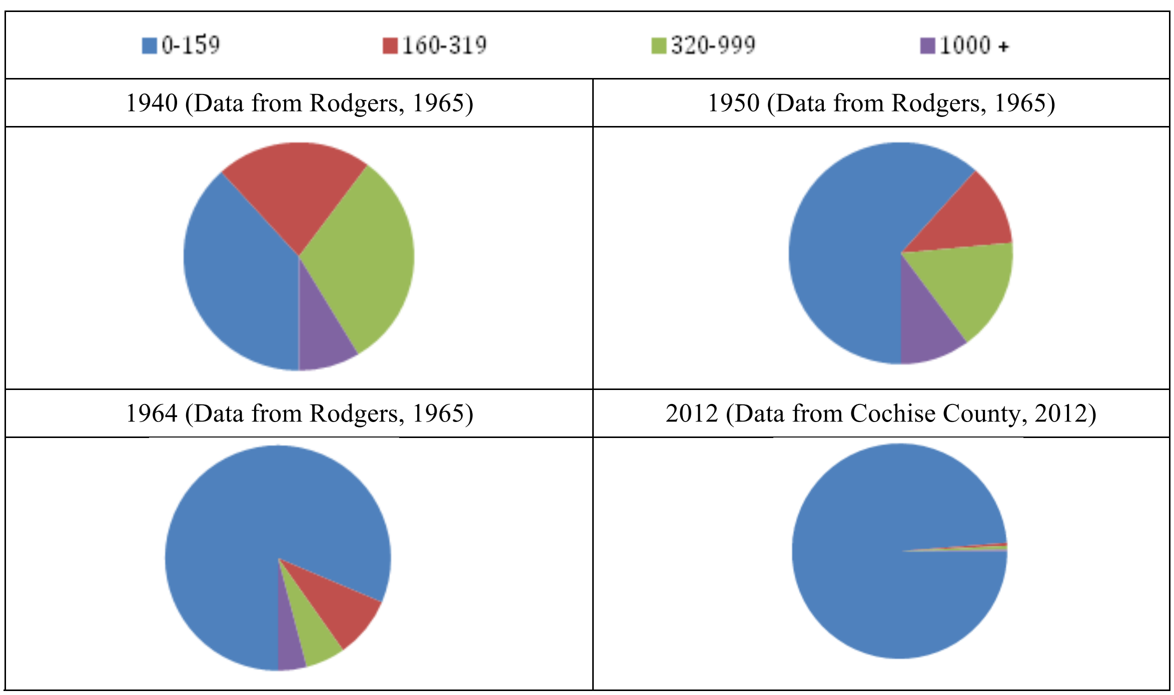


Figure 15: Percentage of all holdings using “Number of Holdings” for 1940, 1950, 1964 and 2012. For example, in 2012, there were 90 properties as large as 1,000 acres or more, and a total of 37,360 properties: (90 /37,360)*100= 0.24%.

By 1965, each record in the Cochise County Tax Roll possessed two unique identifiers: the assessment number and an Assessor Parcel Number (APN). The APN is a unique identification number used in a system of tracking parcels called an “Assessor Map-based” system. Under this system, the assessment map itself is incorporated into the parcel identifier (IAAO 2012). The parcel identifier (e.g. the APN) refers to three units. For Cochise County, these three units are the book, the map, and the parcel number. Within the study area, each “book” possesses a unique three-digit number (e.g. 101, 102); generally its area coincides with old PLSS designations, often covering the same area as two or more townships. To identify which books fall within the study area, Microsoft Excel’s MID function was used to isolate the first three characters of every unique property’s APN in the 2012 dataset. Excel’s “remove duplicates” function then revealed the unique numbers. Excluding mining parcels, there are 17 books.

Within each book are multiple “maps,” which represent a smaller geographic area and possess a unique two-digit number, 1 through 99. Combining the “book” number with a “map” number gives the “book-map” number. There are a total of 541 book-maps within the study area (Appendix A). However, parcel data were not collected for every book-map, for several reasons, including that some book-maps lie within federal or state lands that do not contain residential parcels. For example, the Coronado National Forest and the U.S. Army’s Fort Huachuca together encompass over four dozen book-maps (Appendix C). Furthermore, parcel data were not collected from the same number of book-maps every year. In 1971, parcel data were collected from 325 book-maps; from

398 in 1981; from 415 in 1991; from 420 in 2001; and from 427 book-maps in 2012. This is because not all book-maps have always contained parcels. As the number of housing developments increased, so did the number of book-maps containing residential parcels.

Finally, the "parcel number" refers to a specific piece of real property within a book-map. A parcel number is generally a three-digit number (e.g. 001). If the property has been subdivided multiple times, a letter may be added (e.g. 001A or 001B). A typical APN would be "10101001" (i.e., Book 101, Map 01, Parcel number 001). While the Tax Roll began including the APN in 1965, it wasn't until 1971 that it began to be organized by the APN rather than the assessment number. For example, the 1971 Tax Roll binder "101-01-001 to 106-39-149" contains all tax records for parcels 10101001 through 10639149. In other words, in 1971, the County began organizing the parcel records geographically. Each book and book-map refers to a specific area (Figure 16). Some books are not shown in Figure 16 because the study area contains relatively small portions of their area not visible at the map's resolution.

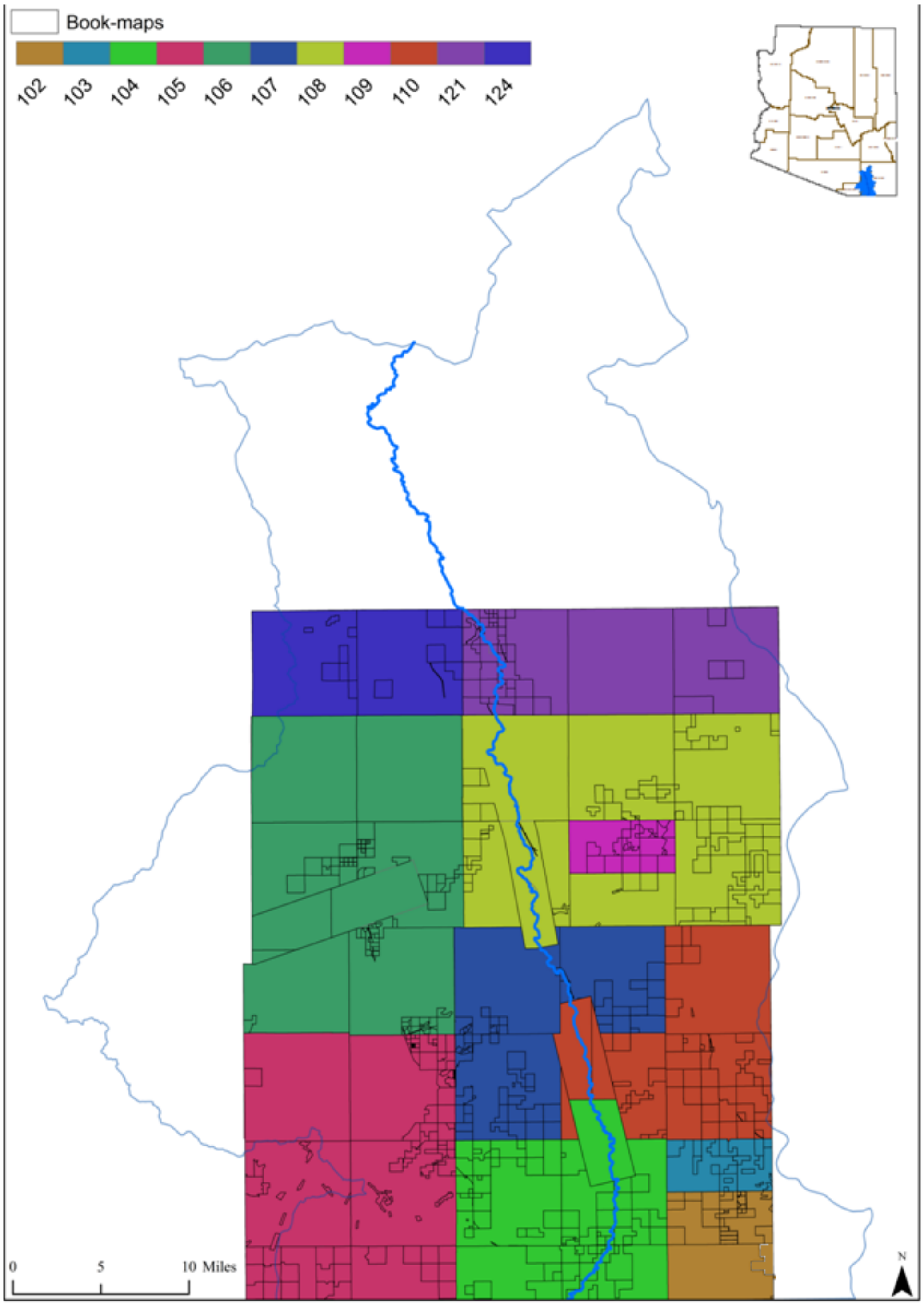


Figure 16: Books and Book-maps in the Study Area (Book-Map data provided by Cochise County IT department; Hydrology data from USGS NHD)

With improved mapping technologies and the County's use of more modern book keeping procedures, the acreage analysis Rodgers made for 1882 through 1964 could be completed for 1971 through 2012. Additionally, detailed maps illustrating parcel density trends could be constructed. To analyze and display parcel density in the study area, the changing number of residential parcels within relevant book-maps for one year of each decade were tracked. The first dataset is from 1971, as it marked the first year the Tax Roll was organized by APN, and the remaining datasets are from the subsequent decades (1981, 1991, 2001, and 2012).

Collecting data for 1971, 1981, and 1991 required tracking not just the APN, but also the antiquated assessment number. While the assessment number assigned to a unique property changes every year and while it does not include geographic information, following the assessment numbers proved to be useful. Assessment numbers advance numerically. The first tax record within the first Tax Roll binder for any given year is "1" and each record follows in succession. To count the number of parcels within a particular book-map, one must note the assessment number at the beginning of a book-map (e.g. 1621 for book-map 10201 in the year 1971), flip through the Tax Roll binder's pages, note the last number (e.g. 1628), and calculate the difference (for this example, 8). In this way, the changing number of parcels within particular book-maps for the years 1971, 1981, and 1991 were tracked. Figure 17 shows a segment of the first page of the 1971 Tax Roll record. Appendix D provides example records for 1971, 1981, and 1991.

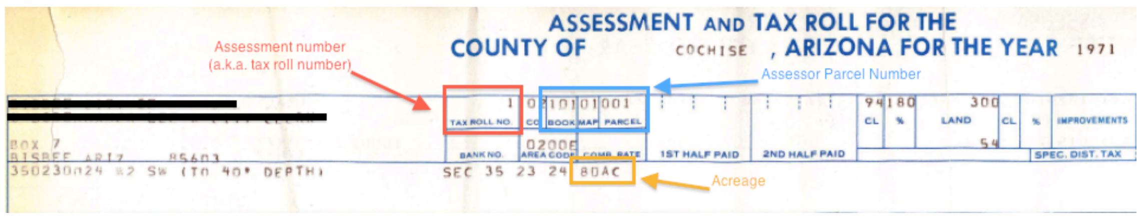


Figure 17: Segment of scanned 1971 Tax Roll Record (Courtesy of Cochise County Archives, 2012). Identifying annotations added.

To obtain acreage data the years 1971, 1981, and 1991, unique parcels were randomly selected from the dataset. Microsoft Excel's RandBetween function was used to generate the random sample of assessment numbers for properties within the study area. Those particular properties were located in Tax Roll binders, and their parcel size recorded. This was done for 1% of parcels for each year: In 1971, 99 of 9,035 parcels were sampled; in 1981, 183 of 18,016 parcels were sampled; and in 1991, 228 of 22,786 were sampled. For properties within subdivisions, the acreage was almost always omitted from the Tax Roll. For these properties, parcel size was assumed to be a generous 0.25 acres, which is the size of a "suburban" housing unit, as defined by the Integrated Climate and Land Use Scenarios (ICLUS) (USEPA 2009).

The County began maintaining the Tax Rolls electronically in 1996. The IT Department was easily able to provide a spreadsheet listing all the properties within the study area for the year 2001. There were 29,319 parcels. However, obtaining the acreage information for those properties was not as easy. The legal descriptions were missing. The County compared the 2001 list of parcels to a 2002 list. Where APNs matched, the parcel size from the 2002 data was ascribed to the 2001 data. Using this method, the County extracted acreage data from the legal descriptions of over 10,000 parcels.

As with the Tax Roll records from 1971, 1981, and 1991, the 2001/2002 records for properties within subdivisions almost always lacked acreage information. The 2012 data were used to determine the acreage of parcels within subdivisions. Where the APNs matched, the 2012 subdivision acreage was ascribed to the 2001 parcels. For the remaining properties within subdivisions, parcel size was assumed to be 0.25 acres. Eventually, nearly 97% (or 28,308) of the parcels in the 2001 dataset were assigned acreage.

Having determined the number and sizes of parcels throughout the study area and within particular book-maps for 1971 through 2012, the acreage analysis not only picked-up where Rodgers left-off but could also be incorporated into to more contemporary investigations, such as ICLUS. The four acreage categories used in the Rodgers study reflect the splitting and combining of original homesteads, and the regional shift from a largely rural and agricultural to a more suburban and service-based community and economy. Examining land use trends using ICLUS Housing Density (HD) categories further refined the analysis, and expanded its utility.

The ICLUS project dataset has been identified as ideal for projecting watershed-wide development into the future because its national-scale HD scenarios are consistent with the Intergovernmental Panel on Climate Change Special Report on Emissions

Scenarios (Nakicenovic and Swart, 2000). ICLUS uses four categories for HD representing rural, exurban, suburban, and urban land-uses (Bierwagen et al. 2010; USEPA 2009; USEPA 2010).

Density Category	Acres Per Housing Unit	Housing Units Per Acre	Hectares Per Housing Unit	Housing Units Per Hectare
Urban	<0.25	>4	<0.1	>10
Suburban	0.25-2	0.5-4	0.1-0.81	1.23-10
Exurban	2-40	0.025-0.5	0.81-16.19	0.06-1.23
Rural	>40	<0.025	>16.19	<0.06

Table 5: Explanation of ICLUS Housing Density (HD) Categories. ICLUS uses changes in HD to project changes in impervious surface cover, which can be used to examine impacts to water quality.

Decade-by-decade parcel data were analyzed using the ICLUS HD categories to create maps illustrating parcel concentration changes over time. The Cochise County book-map dataset included book-map area in square meters. The area of each book-map was converted to acres, and then divided by the number of parcels within that particular book-map. For each decade, the book-maps were then classified as urban (less than 0.25 acres/parcel), suburban (0.25-2 acres/parcel), exurban (2-40 acres/parcel), or rural (more than 40 acres per parcel), resulting in five distinct maps (Figures 20-24). For book-maps with no associated residential parcel data (e.g., Fort Huachuca, the Coronado National Forest, book-maps encompassing undeveloped land, etc.), the number of parcels per acre was assumed to be zero, i.e., rural because those book-maps contained fewer than 0.025 housing units per acre.

Results

Between 1971 and 2012, the number of residential parcels within the study area increased from 9,035 to 36,511. Although the rate of increase follows a nearly linear trajectory (dashed line in Figure 18), the rate of increase was the highest between 1971 and 1981 (898 parcels/year), lower but still high between 1971-1981, 1981-1991, and 1991-2001 (477 to 654 parcels/year), and increasing but smaller rate in 2001 through 2012 (18 parcels/year). Between 1971 and 2012, the average parcel size dropped from 37.98 to 8.01 acres.

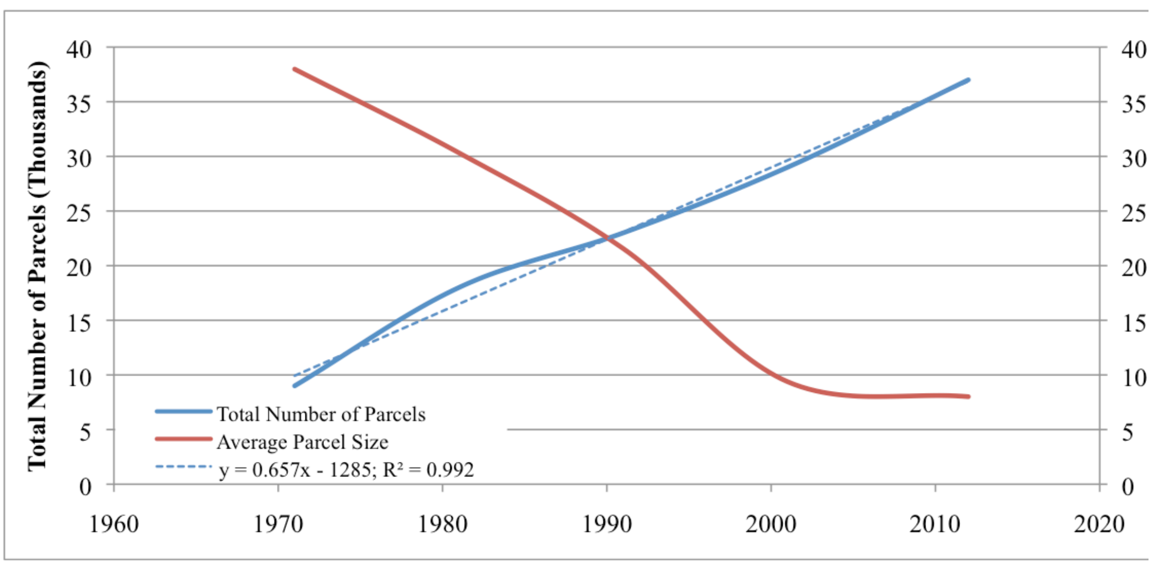


Figure 18: Decadal Changes in Total Number of Parcels & Average Parcel Size for 1971-2012

Parcels with an area of 159 acres or less increased by almost 10% over the 41-years, representing nearly 99% of all parcels by 2012. Figure 19 incorporates data from the Rodgers study to show acreage trends over the last 130 years. Between 1882 and 2012, the number of parcels with an area of 159 acres or less jumped from 16.98% to 98.74%; parcels with an area between 160 and 319 acres dropped from 71.70% to 0.47%.

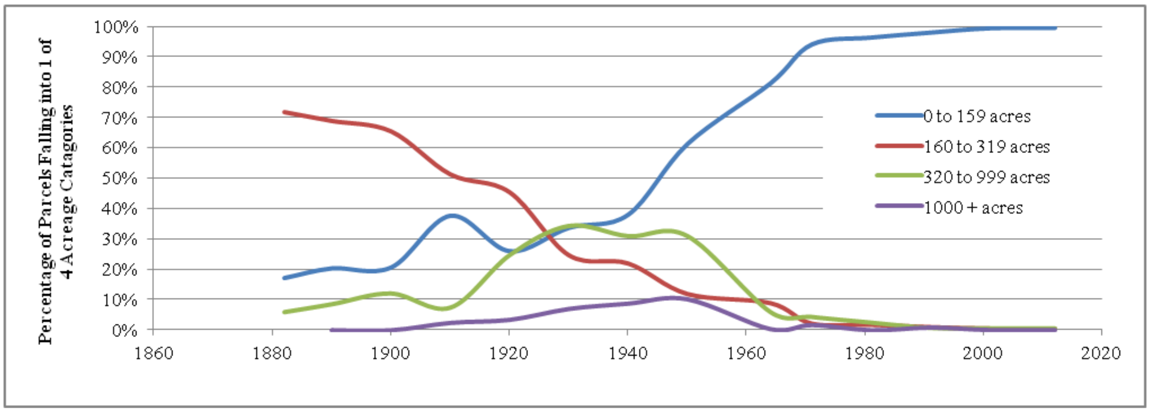


Figure 19: Decadal Trends Using Rodgers Acreage Categories: 1882 to 2012.

Using the ICLUS housing unit sizes to analyze parcel data between 1971 and 2012 provides greater insight into land-use changes. Over the course of 41 years, the number of "urban" parcels increased by over 36%, while parcels in all other acreage categories decreased: "suburban" parcels by ~15%, "exurban" by ~8%, and "rural" parcels by ~10%. Figure 20 shows these acreage trends graphically. Table 6 details the percentage of parcels falling into the ICLUS housing unit categories for each decade.

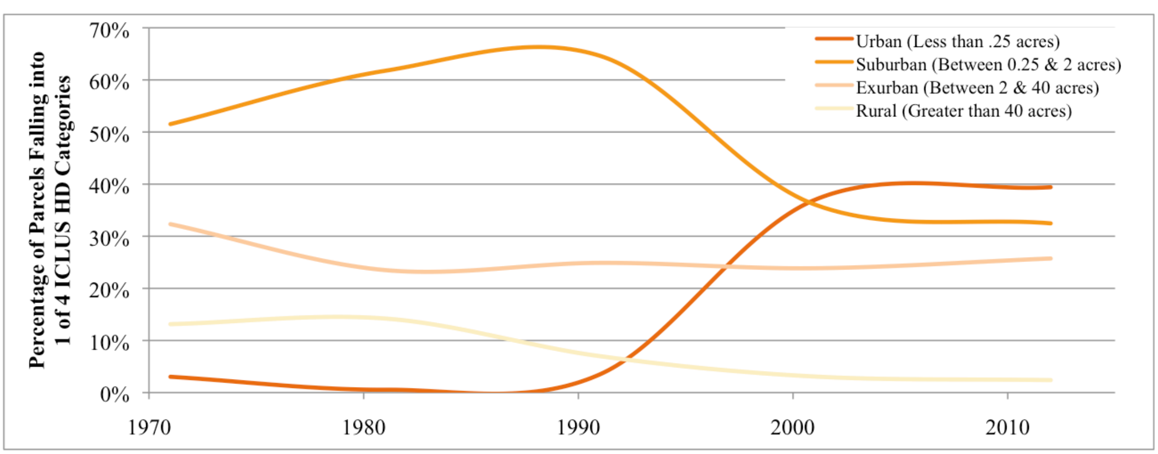


Figure 20: Decadal Acreage Trends Using ICLUS Housing Density Categories, 1971 to 2012.

Year	Urban (Less than 0.25 acres)	Suburban (Between 0.25 & 2 acres)	Exurban (Between 2 & 40 acres)	Rural (Greater than 40 acres)	Parcel Sample Size	Total Number of Parcels
1971	3.03%	51.52%	32.32%	13.13%	99	9,035
1981	0.55%	61.75%	23.50%	14.21%	183	18,016
1991	3.49%	64.63%	24.89%	6.99%	229	22,786
2001	36.96%	36.10%	23.86%	3.08%	28,200	29,319
2012	39.41%	32.47%	25.73%	2.39%	36,511	36,511*

Table 6: Decadal Acreage Trends Using ICLUS HD Categories, 1971 to 2012. (*Note: Of the 37,360 parcels within the study area (Figure 11), 849 were mining parcels and therefore excluded from the ICLUS analysis).

As explained in the methods section, only the 2012 dataset included geographic information for each parcel. Mapping changes over time required tracking the changing number of parcels within individual book-maps. Figures 21 and 22 show decadal book-maps trends between 1971 and 2012. Table 7 details the number and percentage of book-maps falling into the ICLUS HD categories for each decade. Over the course of 41 years, the area of land classified as "urban" increased by 2.82%, the area classified as "suburban" by 8.35%, and the area classified as "exurban" by 11.95%. The area of land classified as "rural" decreased by 23.13%.

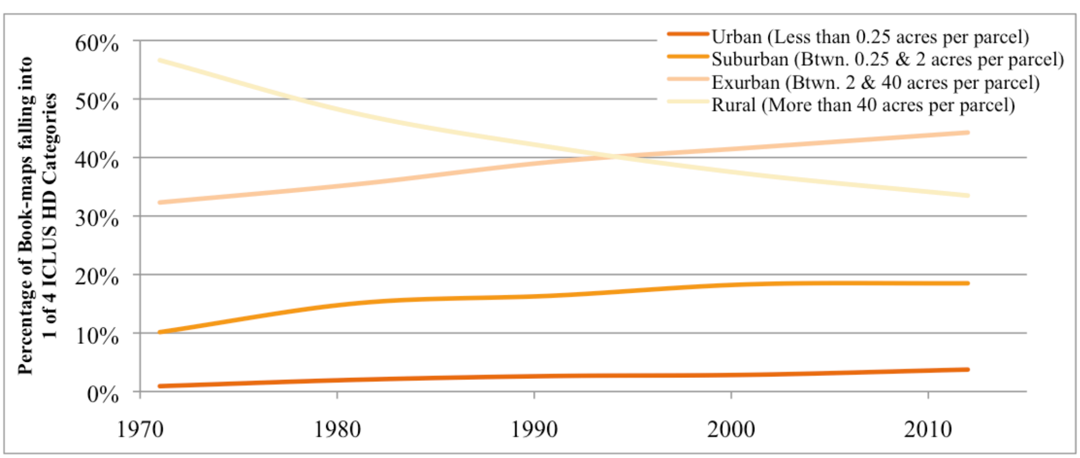


Figure 21: Decadal Book-map Trends, 1971 to 2012 (Changing Percentage).

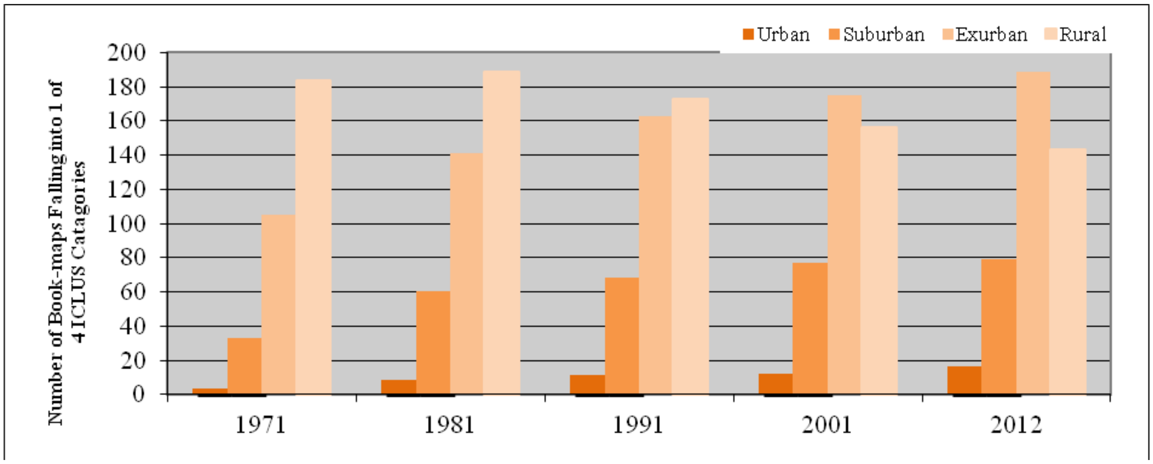


Figure 22: Decadal Book-map Trends, 1971 to 2012 (Changing Number).

	Urban		Suburban		Exurban		Rural		Book-maps, total number
	Number of Book-maps	Percentage of Total	Number of Book-maps	Percentage of Total	Number of Book-maps	Percentage of Total	Number of Book-maps	Percentage of Total	
1971	3	0.92%	33	10.15%	105	32.31%	184	56.62%	325
1981	8	2.01%	60	15.08%	141	35.43%	189	47.49%	398
1991	11	2.65%	68	16.39%	163	39.28%	173	41.69%	415
2001	12	2.86%	77	18.33%	175	41.67%	156	37.14%	420
2012	16	3.75%	79	18.50%	189	44.26%	143	33.49%	427

Table 7: Number & Percentage of Book-maps Falling into ICLUS HD Categories, 1971-2012.

Figures 23 through 27 show land use in the study area for the years 1971, 1981, 1991, 2001, and 2012. The most significant changes occurred in and around established communities. The land use in and around the communities of Tombstone, Bisbee, and Huachuca City changed at a notable pace. For example, the number of parcels within the City of Tombstone's boundaries increased by 194% while the land designated as rural decreased by 100%. Change was most pronounced in the central southwestern portion of the study area, near Fort Huachuca and Sierra Vista. For example, the number of parcels in Sierra Vista's unincorporated counterpart, Sierra Vista Southeast, increased by 550% while the area classified as rural decreased by 70.84%. Figure 28 shows detailed maps of Sierra Vista Southeast and Tombstone in 1971 and 2012.

Esparza and Carruthers (2000) have also noted the growth and changing land use in and around Sierra Vista. This pattern of growth, particularly in regard to its accompanying increase in water consumption, agitates many. The concern that a rapidly increasing population could destructively deplete water resources has been repeatedly expressed (American Rivers 1999, Arias 2000, Browning-Aiken et al 2004, Bredehoeft et al. 1999, Pool and Coes 1999, West and Vásquez-León 2008, USPP 2010, and many others), and periodically litigated – e.g., a 1990s suit against a U.S. Fish and Wildlife Service non-jeopardy decision, a 2002 suit against Fort Huachuca's planned expansion (CBD 2013), and a recently filed Superior Court suit seeking to overturn a state ruling that permitted a new 6,900-home development in Sierra Vista. There is particular concern over how the new development could affect water rights the BLM holds to maintain flows through SPRNCA (Davis 2013).

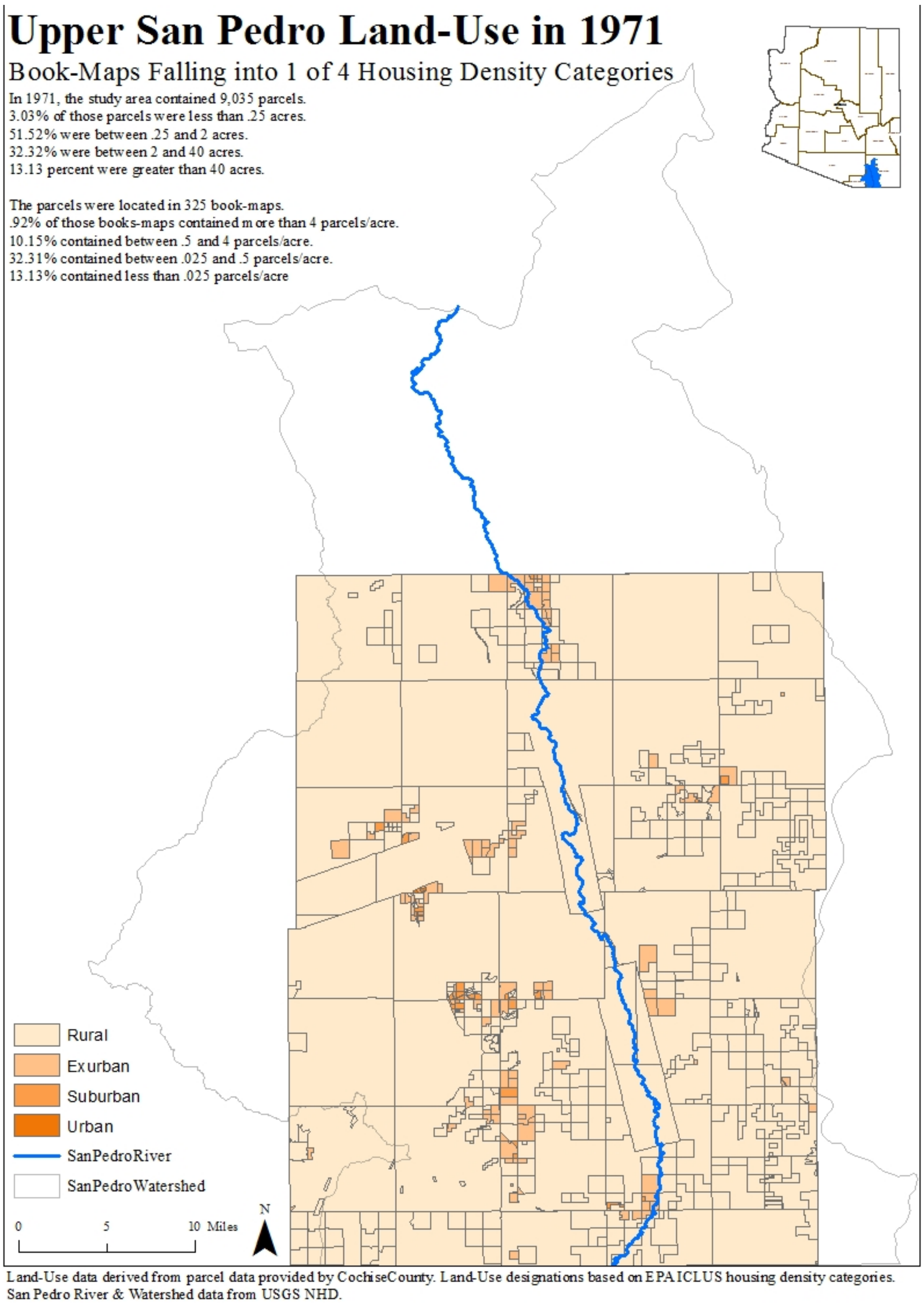


Figure 23: Upper San Pedro Land Use, 1971

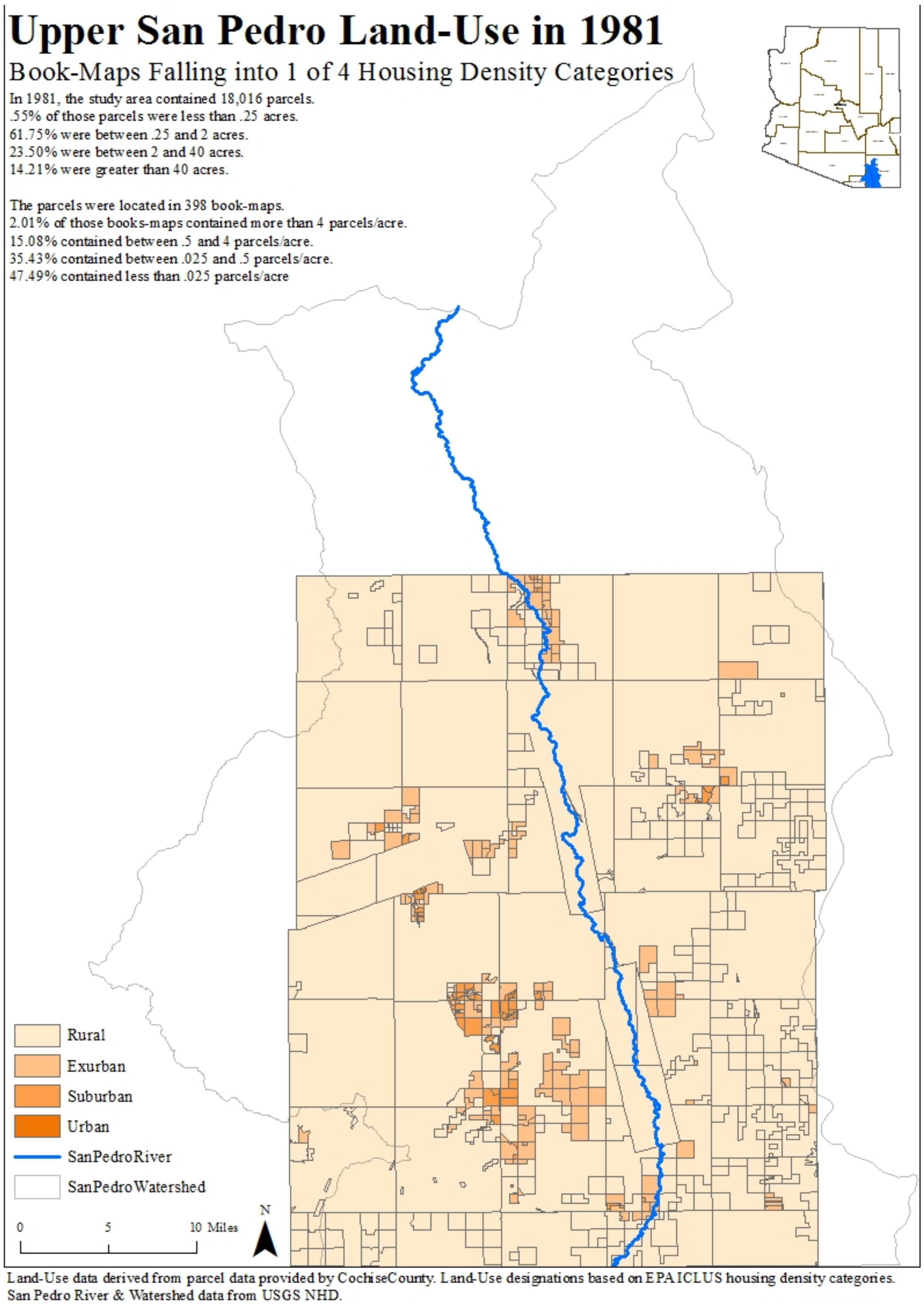


Figure 24: Upper San Pedro Land Use, 1981

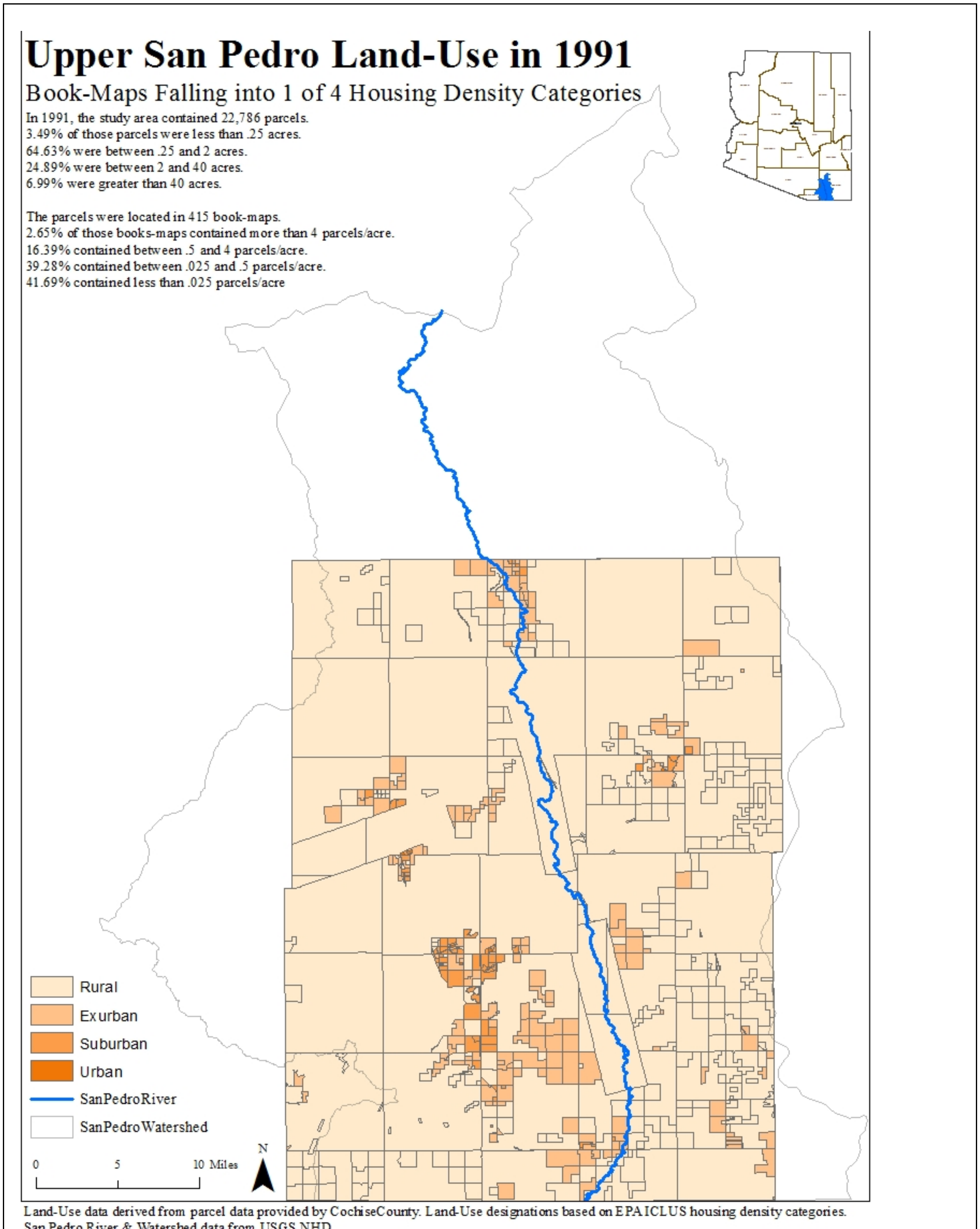


Figure 25: Upper San Pedro Land Use, 1991

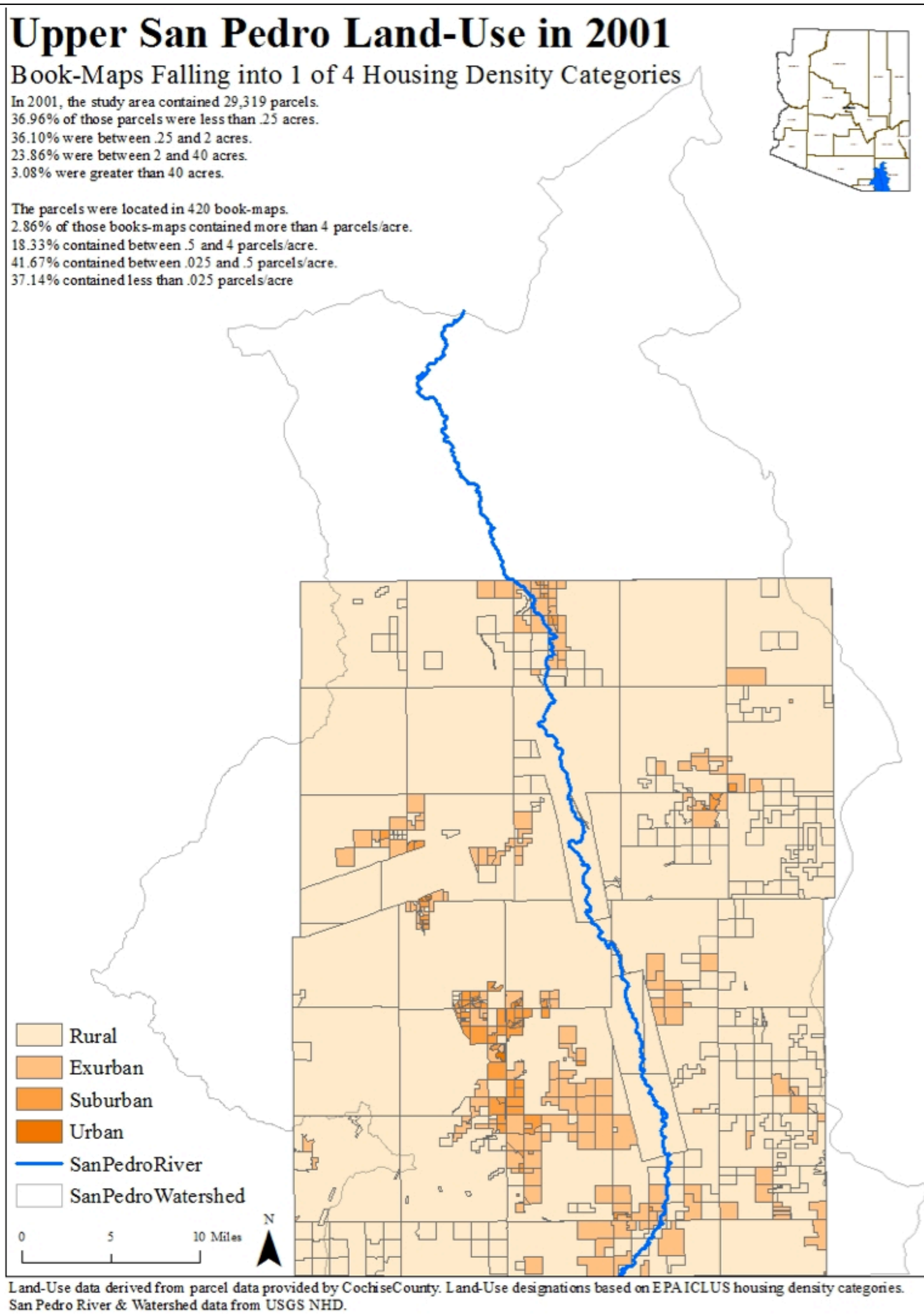


Figure 26: Upper San Pedro Land Use, 2001

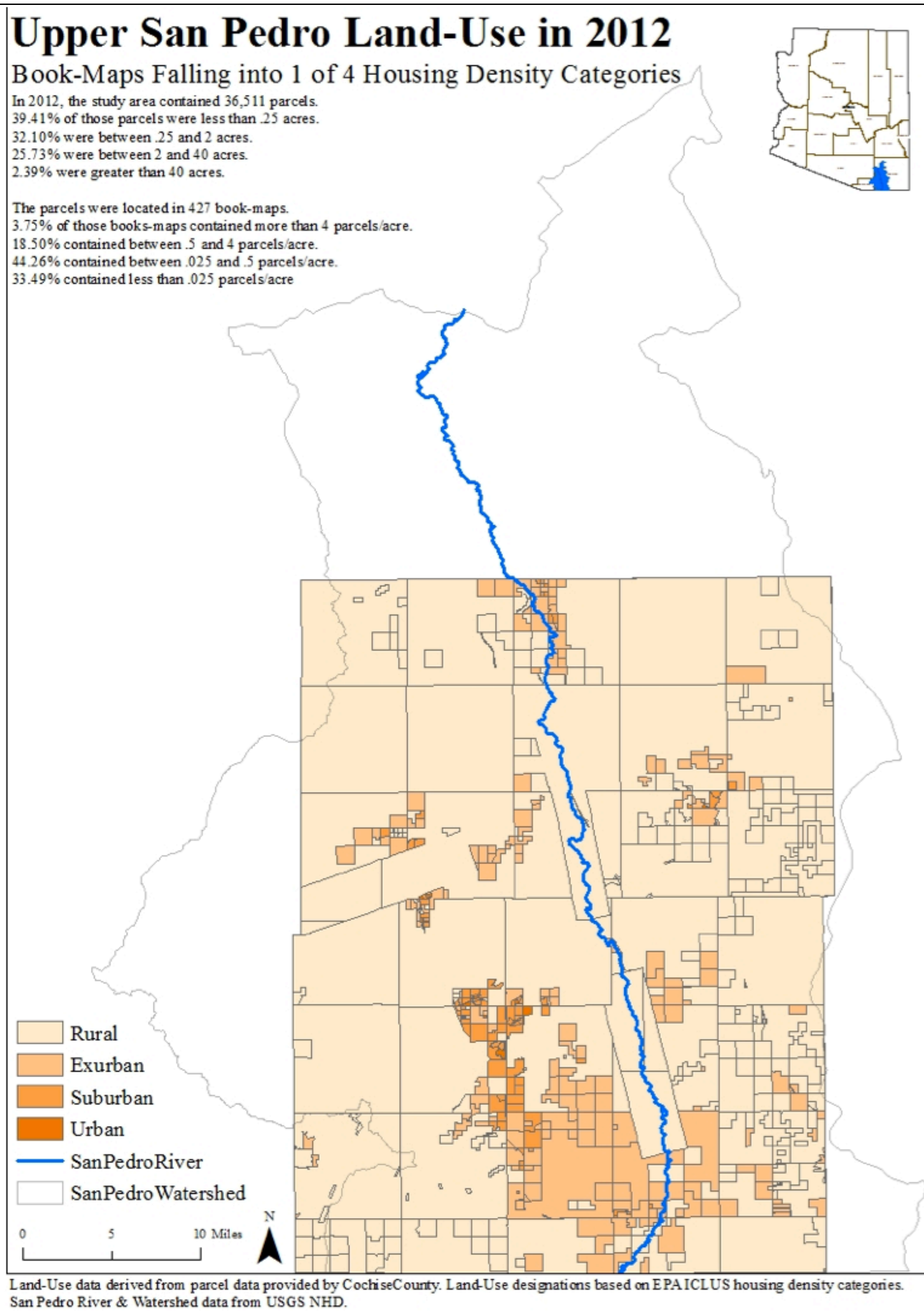
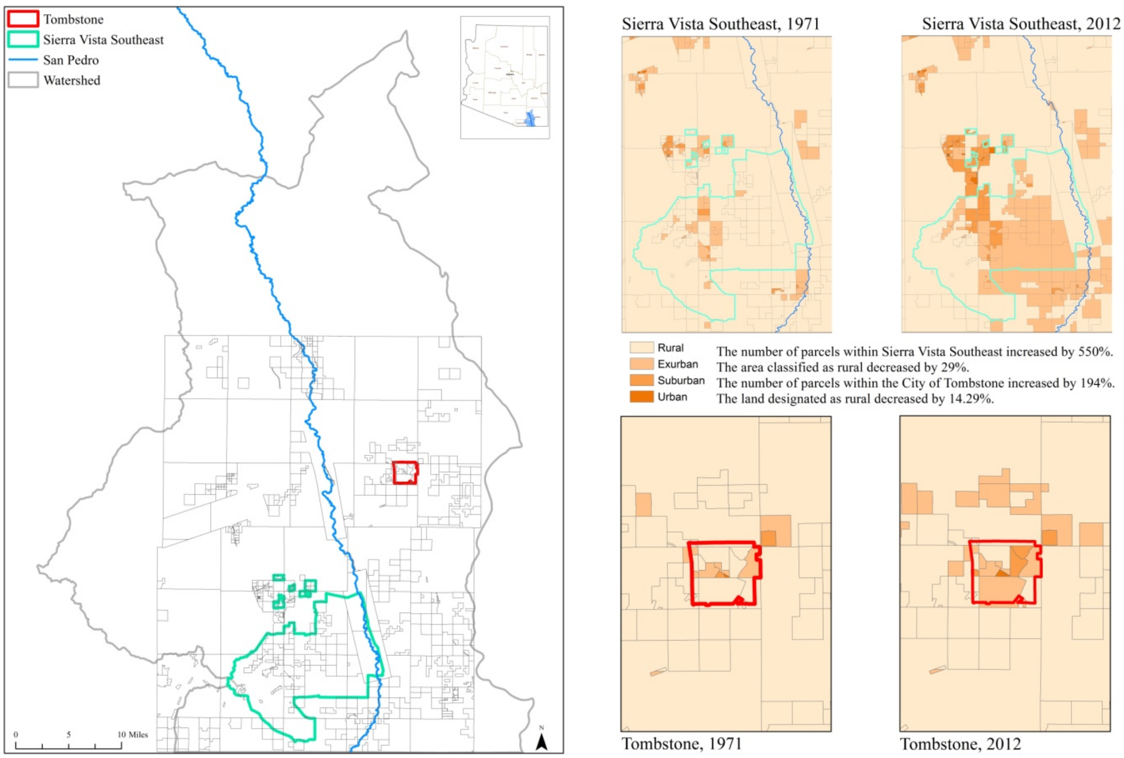


Figure 27: Upper San Pedro Land Use, 2012

Land Use Change in Two Upper San Pedro Communities:
Sierra Vista Southeast and Tombstone, 1971 and 2012



Land Use data delivered from parcel data provided by Cochise County. Land use designations based on EPA ICLUS housing density categories. San Pedro River and Watershed data from USGS NHD. Arizona administrative boundaries from TANA

Figure 28: Land Use Changes in Sierra Vista Southeast and Tombstone, 1971 and 2012

Discussion

Historic parcel data have been used to show land use trends in a portion of the Upper San Pedro River Watershed, and the methodology described. As a methodology for evaluating land use change, analyzing parcel data is promising but has serious limitations. Some challenges include:

- The difficulty in amassing representative historical data, especially exact parcel sizes;
- The discrepancy between what exists on paper versus reality, e.g., parcels that have been subdivided may not have been developed (Figure 29);
- The substantial amount of time needed to collect the data.

Incorporating findings from other change detection methodologies (such as those used to interpret archival photographs and remote imagery) could make historic parcel data analysis more accurate. Differences and similarities in findings could offer important insight into the efficacy of each approach, and provide more reliable reference conditions to use in environmental decision-making.

Establishing environmental baselines can help environmental decision-makers identify and assess trends that can be used to develop future scenarios. Whether used to explore the consequences of nuclear proliferation (Kahn and Wiener 1967), to alert Shell managers of global development possibilities relevant to the company's future (Wack 1985), or to warn that human consumption patterns may overwhelm the planet's carrying capacity (Meadowset al. 1972), future scenarios have been and increasing are being (e.g. the aforementioned IPCC emission scenarios) used to help envision and plan for the future.

"Coherent and plausible stories told in words and numbers," future scenario analyses strive to represent the interactions, behaviors and emergent properties of natural and social systems; by doing so, they provide decision makers with better tools and frameworks to consider the consequences of various decisions. Neither predictions nor forecasts, they represent a spectrum of possibilities. Future analyses help organize disparate data into integrated frameworks, gauge emerging risks, and bring together stakeholders. "Though their subject is the future, scenarios can catalyze and guide appropriate action today" (Swart, Raskin and Robinson 2004).

Using historic parcel data to develop future land use scenarios could be quite useful. Pairing historic parcel data with other historic and localized parameters could allow environmental managers to consider changing land use alongside other environmental and cultural trends at the community scale. For example, if paired with demographic and water quality data, unique and scaled historic baselines could enable environmental managers to explore the plausible future impacts of different scenarios to a specific watershed, or specific areas within a watershed.

The Automated Geospatial Watershed Assessment (AGWA) tool has recently been used to characterize the hydrologic impacts of growth in the San Pedro River Watershed (Burns et al. 2013). However, rather than rely on historic population data unique to the watershed, the analysis drew from nation-wide population projections. Instead of using historic water quality data unique to the watershed, the analysis predicted water quality impacts by integrating the Soil Water Assessment Tool (SWAT) with national scenarios provided from ICLUS. As with many scenario models, ICLUS projections are based on change observed over a limited time period; specifically, ICLUS modeling is based on 1990–2000 growth patterns (Bierwagen et al. 2010).

As they are available, incorporating historic data into AGWA could potentially provide more accurate and relevant projections for smaller scale analyses, such as the community scale. For example, between 1971 and 2012, the number of parcels in Tombstone increased 194%. The number of “urban” and “suburban” book-maps increased by 40% and 110%, respectively; and the number of “exurban” and “rural” book-maps decreased by 12.5% and 100%, respectively. In the same period, population increased by 11% (U.S. Census Decennial, 1970 & 2010). Models used to forecast probable landscape and population changes could incorporate such trends.

Historic water quality data are available through EPA's STOrage and RETrieval (STORET) data "warehouse," a repository for water quality data, including biological, chemical, and physical parameters. Within two miles of Tombstone, there are ten monitoring stations with a combined 1,023 water quality records, the earliest dating from 1952 (EPA STORET 2012). These records might also reveal useful trends that could be incorporated into models such as the AGWA watershed modeling system.

Environmental managers could also use historic baselines, including the data generated from this study, to assess the impacts of specific projects. NEPA requires that the indirect effects of federally funded projects be analyzed and described in environmental documents, such as Environmental Assessments and Environmental Impact Statements. Federal regulations state that, "indirect effects may include growth inducing effects and other effects related to induced changes in the pattern of land use, population density or growth rate, and related effects on air and water and other natural systems, including ecosystems" (40 CFR § 1508.8(b)).

The lack of historic data often requires decision makers to assess a project's indirect effects without sufficient context or background. How well can a NEPA reviewer assess the growth-inducing impacts of, for example, a wastewater infrastructure expansion project without knowing the historic relationship between wastewater treatment capacity, population, land use, and other environmental parameters? Pairing historic parcel data and the resulting land use trends analysis with historic population and wastewater treatment capacity data could help evaluate "reasonably foreseeable consequences that occur later in time or farther in distance" (Sec. 1508.8).

The City of Sierra Vista provides an example. Between 1971 and 2012, the number of parcels in Sierra Vista (including Sierra Vista Southeast) increased ~549%, from 1,591 parcels to 10,327 parcels; the percentage of "urban" and "suburban" book-maps increased by ~800% and ~112%, respectively. The number of "exurban" and "rural" book-maps decreased by ~8% and ~75%, respectively. In that same period, the population increased by ~780% (U.S. Census Decennial, 1970 & 2010), and wastewater treatment capacity increased ~566%, from 0.6 million gallons a day (MGD) to 4 MGD (SEAGO 1978, 2012). Table 8 lists the decadal changes. Figures 30, 31, and 32 display the historic relationships graphically.

Decade	Population of Sierra Vista	Number of parcels	Book-maps % Urban	Book-maps % Suburban	Book-maps % Exurban	Book-maps % Rural	Wastewater capacity (MGD)
1970	6,689	1,591	0.00%	19.23%	46.15%	34.62%	.6
1980	24,937	3,909	3.36%	30.25%	48.74%	17.65%	.6
1990	42,220	5,548	5.65%	33.06%	48.39%	12.90%	2.9
2000	52,123	8,406	6.40%	38.40%	45.60%	9.60%	4
2010	58,685	10,327	8.00%	40.80%	42.40%	8.80%	4

Table 8: Decadal Trends in Population, Parcels, Book-maps, and WWTF capacity in Sierra Vista, AZ.

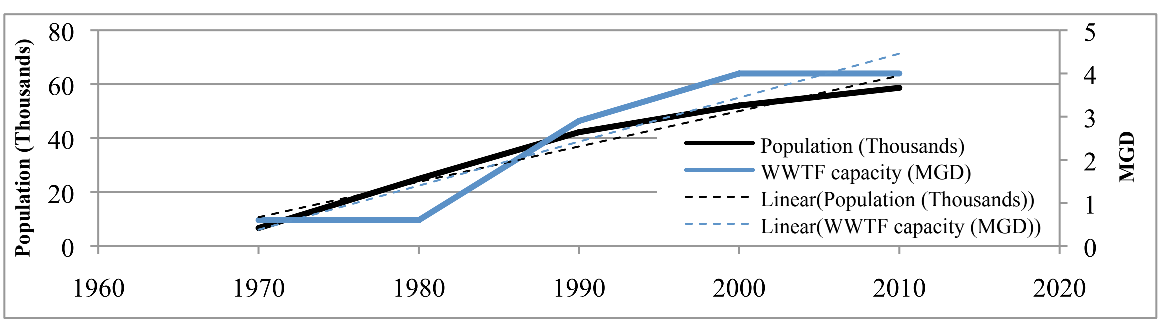


Figure 30: Population & Wastewater Treatment Facility (WWTF) Capacity in Sierra Vista, AZ: 1971-2010

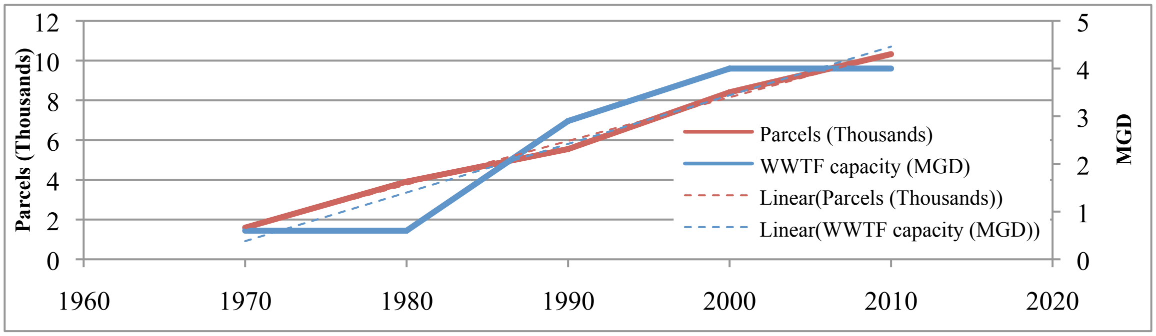


Figure 31: Number of Parcels & WWTF Capacity in Sierra Vista, AZ: 1971-2012

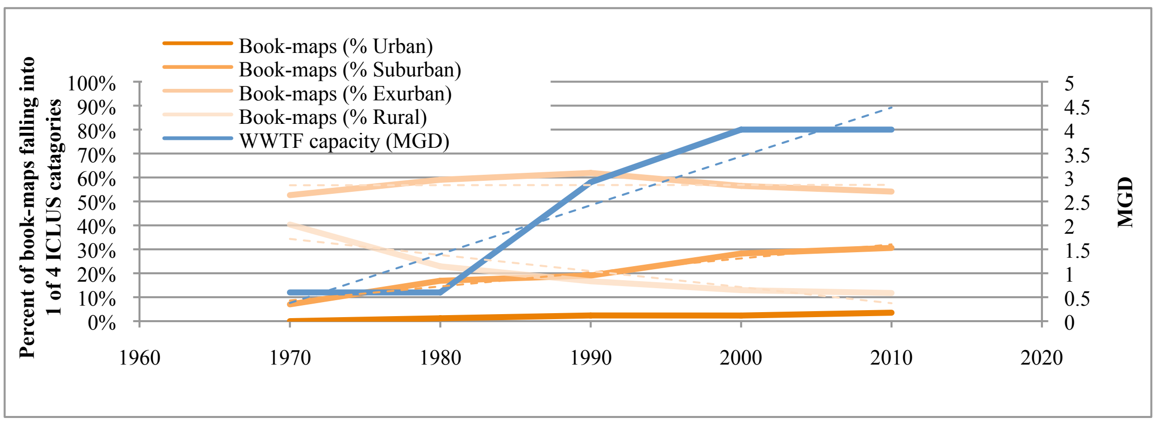


Figure 32: WWTF Capacity & Book-maps in Sierra Vista, AZ: 1971-2012

While Sisyphean to incorporate each and every factor that affected everything from wastewater flow to subdivision development between 1971 through 2012, the trends derived from Figures 30, 31, and 32 can nonetheless be used to develop scenarios that sufficiently examine how expanding Sierra Vista's WWTF could affect the area's pattern of land use[3]. For example, Excel's FORCAST formula predicts one scenario in which the capacity of the Sierra Vista WWTF will increase to 7.5 MGD by 2040. In that scenario, a NEPA reviewer would consider a future in which 37,555 more people and

[3] Many of the properties in Sierra Vista Southeast rely on private wells and septic systems. While the expansion of the Sierra Vista WWTF would not necessarily directly serve its unincorporated counterpart, the expanded capacity would accommodate a greater number of individuals and businesses within the facility's core service area. Growth in central Sierra Vista would very likely catalyze growth in Sierra Vista Southeast, the historical development of which has been tied to its incorporated neighbor.

5,207 more parcels produce a landscape that's 5% more urban and 13.5% more suburban with no more exurban and rural areas.

Comparing this scenario to others and determining whether or not any of the projected changes "significantly affect the pattern and type of land use…including altering the character of existing residential areas" (40 CFR § 6.207 (a)(3)(xi)) is, of course, a more complicated endeavor that would require additional information. Furthermore, as recommended previously, any parcel data analysis should be evaluated against the analysis of coarser, but nonetheless more accurate data sets (e.g. satellite imagery). As Tombstone demonstrates, a large increase in number of parcels does not always correlate to a large increase in population, exemplifying why relying on parcel data to determine land uses could be problematic and inapt for areas where land-speculation is common – and commonly idle.

NEPA also requires that the cumulative effects of federally funded projects be analyzed and described in environmental documents. Described by Odum (1982) as the "tyranny of small decisions," cumulative effects are "the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions…" (40 CFR Sec. 1508.7). A NEPA analyst evaluating a potentially growth-inducing project such as the expansion of a WWTF would also consider the synergistic or cumulative effects of "connected actions." One likely connected action would be the expansion of a community's drinking water supply.

In the case of the San Pedro watershed, increasing the drinking water supply would require expanding the capacity and/or number of wells. Analyzing the potential consequences of such an action could be completed with a historical analysis of well and stream flow data. The following builds upon the hypothetical expansion of Sierra Vista's WWTF to 7.5 MGD to consider how the addition of 37,555 people could cumulatively affect the river. Table 6 summarizes trends in population, well activity and stream flow; figures 33 through 37 display the trends graphically.

Year	**1970**	**1980**	**1990**	**2000**	**2010**
Population	61,910	85,686	97,624	117,755	131,346
Number of Wells	1,180	1,978	3,229	4,725	6,325
Pumping Volume (AF)	82,555	115,101	143,348	158,318	167,015
Depth to Water Level (ft)	106	122	143	159	169
Average Flow (cf/s)	24	46	34	18	9

Table 9: Decadal Trends in Population, Well Activity, and Stream Flow, 1970-2010. "Population" refers (crudely) to the total population for Cochise County, and was obtained from the U.S. Census. The "number of wells" refers to the cumulative number of wells in the Upper San Pedro watershed, the "pumping volume" to the combined pumping volume of those wells (measured in acre feet, AF), and "depth to water level" to the averaged depth-to-water level of all those wells (measured in feet, ft)—this information was obtained from the Arizona Department of Water Resources' (ADWR) Wells55 database. "Decadal flow" refers to the averaged decadal winter flow (in cubic feet per second- cf/s) recorded at 3 gauging stations: Charleston, Tombstone, and Palominas—this information was obtained from the USGS National Water Information System.

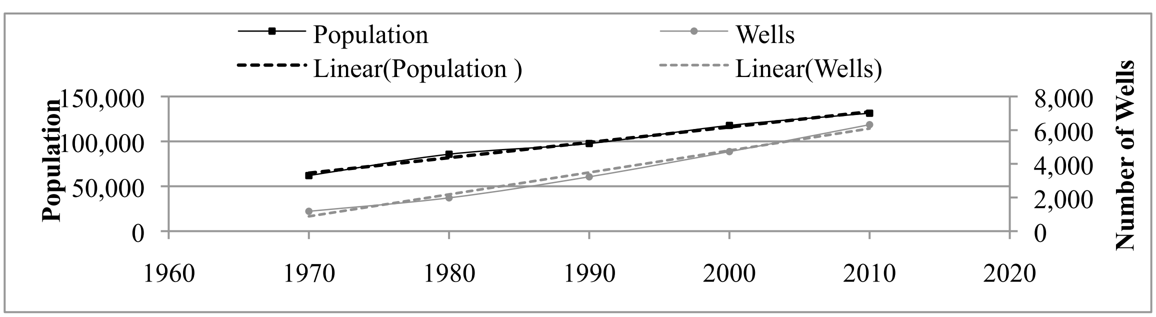


Figure 33: Increasing Population and Increasing Number of Wells in the Upper San Pedro Watershed, 1970-2010

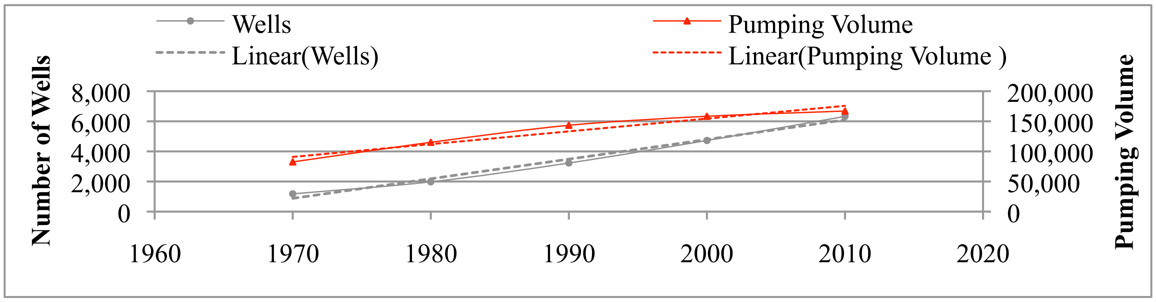


Figure 34: Increasing Number of Wells and Increasing Pumping Volume in the Upper San Pedro Watershed, 1970-2010

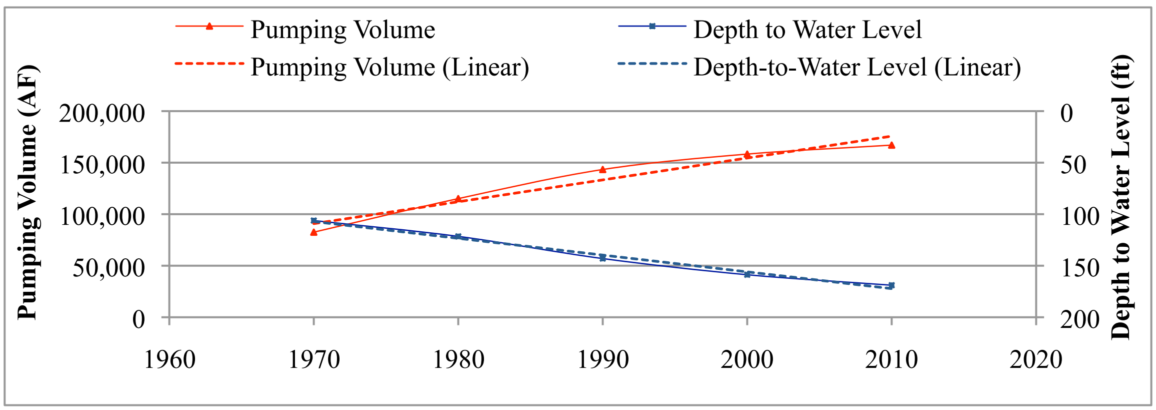


Figure 35: Increasing Pumping Volume and Dropping Depth to Water in the Upper San Pedro Watershed, 1970-2010

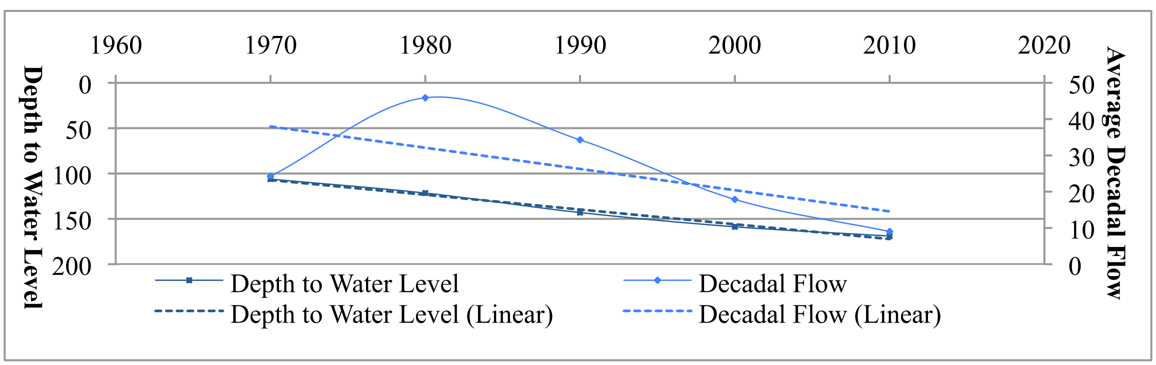


Figure 36: Dropping Depth to Water Level and Decreasing Steam Flow in the Upper San Pedro Watershed, 1970-2010

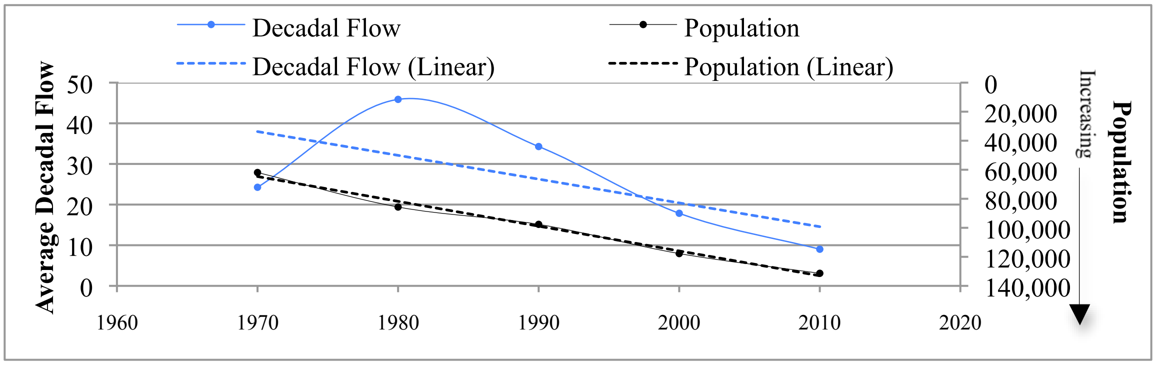


Figure 37: Decreasing Steam Flow and Increasing Population in the Upper San Pedro Watershed, 1970-2010

Using the trends displayed in Figures 33 through 37, Excel's FORCAST formula predicts a future scenario in which a population increase of 37,555 people would lead to 2,405 more wells, the pumping of an additional 53,310 acre-feet, a depth to water level that drops 37 more feet, and an average winter flow that declines another 4 cf/s. Census, flow, and well data are rich datasets. Particularly cooperative are well data, as even their rudimentary analyses follow linear trends. Future scenarios drawing from robust historic data and resulting trends analyses can be used to produce indirect effect and cumulative impact assessments, assessments one might as easily describe as "coherent and plausible stories..." Informed by the past, such stories can provide a more reliable basis from which to make predictions and consider alternatives than the present approach, which has been criticized as inconsistent and imprecise (Mandelker 2010).

Conclusion

"Upper San Pedro River Valley" parcel size and location trends between 1882 and 2012 were evaluated using 1) assessor records, and 2) the 1965 research completed by William M. Rodgers. Land use trends between 1971 and 2012 were produced using

1) assessor records, 2) the book-map geodatabase provided by Cochise County IT staff, and 3) EPA's ICLUS HD categories. The analysis shows substantial land use change, particularly in and around Sierra Vista. However, the changes seem relatively minor compared to the linear increase in the total number of parcels and people. Perhaps this is because the watershed includes large amounts of land where development is either restricted or limited (Appendix C). The analysis, in other words, shows increased density. While typically indicative of a more sustainable community (Burchell and Mukherji 2003), population-driven urbanization could exhaust the one source of drinking water (the local aquifer) and the aquifer-dependent San Pedro River.

The methodology described provides a comprehensive and straightforward approach to analyze historical parcel data. Because of its relative simplicity, the proposed methodology could be particularly useful in NEPA analyses. As has been demonstrated, trends derived from parcel data could be used to assess indirect effects such as induced changes in land use patterns. Of course, induced change in land use patterns is just one of many unintended consequences that could result from a project; and historical parcel data is just one of many historic datasets that can help untangle the web of indirect and cumulative effects. Building a historical GIS that incorporates parcel data with 1) satellite imagery to ensure its accuracy and 2) other robust and scalable historical datasets such as census, water quality, stream flow and well data would certainly be "slow, expensive, and…tedious" (Gregory and Ell 2007). But the resulting analyses would no doubt assist the many communities in arid and semi-arid geographies whose rising populations place considerable pressure on finite water resources.

Investigating parcel changes to understand historic land use trends is a methodology that could be applied well beyond the San Pedro. Communities across the Country - including the vast majority of municipalities within California, Arizona, New Jersey, New York, Virginia, and Nevada, as well as an unknown percentage of municipalities within Georgia, Kentucky, Maryland, and Vermont - have used the assessor map-based system (USDA 1979). While many of these communities have likely incorporated GIS technologies to more reliably track parcels, it is also likely that today's parcel identification numbers reflect yesterday's map-based system and that the approach defined here could be widely replicated.

Alternative futures analyses allow us to consider various scenarios, and to develop strategies that better prepare society to confront the challenges ahead. In the face of climate change, economic instability, and resource scarcity, futures analyses can help protect our most vulnerable people and places. When possible, such analyses should be based on local historic trends. At the very least, the usefulness of present models should be judged by their ability to generate simulations that describe known historic conditions. As Richard Powers wrote, "the simplest possible test for any futures game consisted in finding out whether it could predict the past."

Appendix A: Books and Book-maps within the Study Area

102	104		105		106		107		108	109	110	121	
10201	10401	10450	10502	10549	10601	10651	10701	10761	12031	10901	11001	12101	12147
10202	10402	10451	10503	10550	10602	10652	10713	10762		10902	11003	12102	12149
10203	10403	10452	10504	10551	10603	10653	10715	10763		10903	11004	12103	12150
10204	10404	10453	10505	10552	10604	10654	10716	10764		10904	11005	12104	12151
10206	10405	10454	10506	10553	10605	10655	10717	10765		10905	11006	12105	**120**
10207	10406	10455	10507	10554	10606	10656	10718	10766		10906	11009	12106	12031
10208	10407	10456	10508	10556	10608	10657	10719	10767		10907	11012	12107	
10209	10408	10457	10509	10558	10609	10658	10720	10768		10908	11013	12108	
10210	10409	10458	10510	10559	10610	10659	10721	10769		10909	11014	12109	
10211	10410	10460	10511	10560	10611	10661	10722	10770		10910	11016	12110	
10218	10411	10461	10512	10564	10612	10662	10723	10771		10911	11017	12111	
10221	10412	10462	10513	10565	10615	10663	10724	10772		10912	11018	12112	
10234	10413	10463	10514	10566	10616	10664	10727	10773		10913	11019	12113	
10235	10414	10464	10515	10567	10617	10665	10728	10774		10914	11020	12114	
10236	10415	10465	10516	10568	10618	10666	10729	10775		10915	11022	12115	
10259	10416	10466	10517	10569	10619	10667	10730	10776		10917	11023	12116	
	10417	10467	10518	10570	10620	10668	10731	10777		10918	11024	12117	
103	10418	10468	10519	10571	10621	10669	10733	10778		10919	11025	12118	
10337	10419	10469	10520	10573	10622	10670	10734	10779		10921	11026	12119	
10338	10420	10470	10521	10574	10623	10671	10736	10780		10924	11027	12120	
10339	10421	10473	10524	10575	10624	10672	10737	10781		10925	11028	12121	
10340	10422	10474	10525	10576	10625	10673	10738	10782		10928	11029	12122	
10341	10423	10475	10527	10577	10626	10674	10739	10783		10930	11030	12123	
10342	10424	10476	10528	10578	10627	10675	10740	10784		10932	11031	12125	
10343	10425	10477	10529	10583	10628	10677	10741			10933	11032	12126	
10344	10426	10478	10530	10588	10629	10678	10742				11033	12127	
10346	10427	10479	10531	10589	10631		10743				11034	12128	
10347	10431	10480	10533	10590	10632		10744				11035	12129	
10348	10434	10481	10534	10591	10634		10745				11040	12130	
10350	10437	10482	10535	10592	10635		10746				11041	12131	
10351	10438	10483	10536	10593	10636		10747				11042	12133	
	10439	10484	10537	10594	10639		10748				11043	12134	
	10440	10485	10538	10595	10640		10749				11044	12135	
	10441		10539	10596	10641		10750				11045	12136	
	10442		10540	10597	10642		10751				11050	12137	
	10443		10541	10598	10643		10752				11051	12139	
	10444		10542	10599	10645		10754				11054	12140	
	10445		10543		10646		10755				11055	12141	
	10446		10544		10647		10756				11056	12142	
	10447		10546		10648		10758				11057	12143	
	10448		10547		10649		10759				11059	12144	
	10449		10548		10650		10760				11060	12146	

Appendix B: Changing Number of Parcels within Book-maps

Book-Map	**1971** (# of parcels)	**1981** (# of parcels)	**1991** (# of parcels)	**2001** (# of parcels)	**2012** (# of parcels)
10201	8	17	22	25	26
10202	1	5	5	5	7
10203	1	7	7	7	10
10204	0	6	10	11	14
10206	1	1	1	1	1
10207	0	0	5	5	3
10208	0	3	4	5	6
10209	0	3	5	5	9
10210	0	16	26	34	31
10211	1	11	14	19	48
10218	0	8	19	21	24
10221	0	13	18	23	23
10234	11	14	19	20	45
10235	3	4	6	7	1
10236	14	21	24	29	2
10259	0	0	13	15	28
10337	3	8	18	19	21
10338	1	3	3	3	3
10339	4	5	6	9	11
10340	1	1	1	1	1
10341	1	1	1	1	1
10342	0	2	2	2	2
10343	1	12	13	13	13
10344	0	4	6	6	6
10346	0	1	1	1	1
10347	0	2	4	5	5
10348	0	1	6	6	6
10350	1	1	1	1	4
10351	2	8	10	10	15
10401	0	18	15	289	395
10402	14	21	29	285	373
10403	46	52	52	66	72
10404	6	6	12	222	227
10405	1	10	12	95	106
10406	3	14	25	34	35
10407	102	110	162	298	402
10408	5	34	150	222	247

BookMap	1971 (# of parcels)	1981 (# of parcels)	1991 (# of parcels)	2001 (# of parcels)	2012 (# of parcels)
10409	21	49	58	115	126
10410	104	105	109	109	107
10411	0	16	26	50	85
10412	17	18	21	23	27
10413	18	23	23	35	18
10414	21	28	31	33	36
10415	27	43	76	74	75
10416	10	10	16	24	27
10417	1	2	2	65	137
10418	1	2	2	81	149
10419	6	7	7	7	8
10420	17	25	31	29	30
10421	17	25	26	27	27
10422	8	10	11	16	16
10423	29	47	47	43	42
10424	0	0	0	16	259
10427	5	15	25	224	473
10431	0	17	76	220	271
10434	2	7	8	8	13
10437	3	3	5	7	8
10438	2	6	5	7	11
10439	2	2	2	2	11
10440	1	1	8	15	14
10441	9	9	14	15	18
10442	33	61	67	81	99
10443	1	8	9	72	94
10444	3	17	37	80	106
10445	6	8	10	15	25
10446	366	359	357	343	336
10447	6	9	9	29	43
10448	9	10	19	24	27
10449	124	122	121	90	82
10450	9	12	11	11	29
10451	7	6	7	7	13
10452	3	4	5	5	6
10453	1	1	1	24	42
10454	8	10	85	122	138
10455	7	7	47	79	137
10456	3	15	14	14	15
10457	0	0	0	5	5

BookMap	1971 (# of parcels)	1981 (# of parcels)	1991 (# of parcels)	2001 (# of parcels)	2012 (# of parcels)
10458	0	80	82	82	83
10460	2	14	18	20	20
10461	6	2	2	2	2
10462	3	5	7	12	15
10463	1	3	4	5	5
10464	13	17	17	18	20
10465	3	3	3	4	6
10466	12	14	14	14	13
10467	5	6	6	7	10
10468	4	10	22	23	26
10469	3	3	3	3	3
10470	2	3	3	3	3
10473	1	1	1	1	1
10474	2	3	22	33	38
10475	0	46	66	77	83
10476	0	24	183	236	217
10477	0	64	76	106	87
10478	0	24	31	34	34
10479	0	0	18	45	67
10480	0	0	28	42	83
10481	0	0	5	7	7
10482	0	16	179	187	258
10483	0	16	12	12	15
10484	0	0	36	67	95
10485	0	0	33	35	36
10502	1	1	1	1	1
10503	4	7	5	45	646
10504	422	481	501	500	502
10505	81	414	555	562	578
10506	2	22	32	46	53
10507	15	25	43	51	57
10508	3	2	6	6	7
10509	9	51	57	57	58
10510	37	39	43	42	43
10511	15	15	16	16	16
10512	23	24	26	26	28
10513	110	110	111	111	111
10514	100	202	259	205	207
10515	2	140	143	143	329
10516	5	48	51	339	967

BookMap	**1971** (# of parcels)	**1981** (# of parcels)	**1991** (# of parcels)	**2001** (# of parcels)	**2012** (# of parcels)
10517	0	66	102	102	100
10518	0	47	96	160	168
10519	1	1	1	1	1
10520	1	34	111	159	170
10521	1	3	3	3	4
10524	1	1	1	1	1
10525	4	11	12	13	13
10527	1	1	1	1	1
10528	4	3	6	6	6
10529	131	130	130	111	104
10530	5	7	7	8	10
10531	1	1	1	1	1
10533	1	1	1	1	1
10534	1	1	1	1	1
10535	1	2	2	2	2
10536	1	4	4	4	4
10537	9	14	20	29	37
10538	7	9	10	20	67
10539	56	69	78	87	105
10540	24	31	62	81	96
10541	1	5	15	38	50
10542	5	5	7	17	27
10543	3	5	5	6	6
10544	1	1	1	1	1
10546	6	10	12	17	22
10547	1	1	1	1	1
10548	3	7	9	9	10
10549	2	1	1	1	1
10550	1	1	1	8	8
10551	8	10	12	12	13
10552	4	14	13	13	14
10553	2	2	2	2	2
10554	1	1	1	1	6
10556	0	161	160	160	160
10558	4	4	4	4	12
10559	0	1	1	1	1
10560	1	0	0	0	1
10564	1	1	1	1	1
10565	0	0	0	0	1
10566	0	0	0	0	1

BookMap	1971 (# of parcels)	1981 (# of parcels)	1991 (# of parcels)	2001 (# of parcels)	2012 (# of parcels)
10567	1	1	1	1	1
10568	3	3	3	3	3
10569	2	2	2	2	2
10570	2	2	2	2	2
10571	1	1	1	1	1
10572	0	0	0	1	1
10573	1	1	1	1	1
10574	1	1	1	1	1
10575	1	1	1	1	1
10576	1	1	1	1	1
10577	1	1	1	1	1
10578	1	1	1	1	1
10583	1	1	1	1	1
10588	0	272	272	272	263
10589	59	58	56	54	58
10590	24	35	34	35	35
10591	41	159	157	155	155
10592	3	516	861	896	882
10593	0	74	72	72	68
10594	0	277	277	273	275
10595	0	0	390	875	989
10596	0	1	3	105	659
10597	0	278	352	798	819
10598	0	265	321	390	395
10599	0	209	290	473	473
10601	6	6	6	6	7
10602	3	3	3	3	6
10603	6	10	11	30	117
10604	156	151	149	148	157
10605	36	47	51	62	63
10606	94	31	47	58	75
10608	4	15	24	36	37
10609	3	38	38	65	66
10610	4	3	4	3	2
10611	2	3	5	7	8
10612	2	3	10	19	25
10615	7	11	9	15	293
10616	2	50	64	122	130
10617	3	21	23	28	56
10618	12	22	24	65	84

BookMap	1971 (# of parcels)	1981 (# of parcels)	1991 (# of parcels)	2001 (# of parcels)	2012 (# of parcels)
10619	24	29	35	39	42
10620	48	48	46	44	44
10621	196	198	195	185	184
10622	96	96	96	95	95
10623	0	0	12	17	19
10624	157	177	182	183	192
10625	65	75	84	116	134
10626	36	38	41	40	41
10627	51	50	54	57	59
10628	9	10	11	11	14
10629	0	129	122	103	97
10631	10	10	13	15	16
10632	0	51	4	4	4
10634	32	34	41	43	47
10635	9	9	13	14	21
10636	3	3	3	3	4
10639	210	208	193	178	170
10640	0	60	61	58	58
10641	4	4	5	9	24
10642	2	2	3	7	7
10643	0	0	0	18	31
10645	2	2	2	3	2
10646	5	8	11	34	41
10647	44	59	132	77	96
10648	154	158	159	161	164
10649	62	70	69	76	78
10650	0	41	104	159	159
10651	81	115	117	118	127
10652	1	1	1	2	4
10653	4	5	3	4	4
10654	4	4	6	17	28
10655	2	3	3	3	2
10656	133	191	192	196	202
10657	18	23	24	18	16
10658	34	35	36	132	132
10659	0	108	108	108	108
10661	21	24	25	27	28
10662	81	71	81	82	85
10663	0	361	360	408	410
10664	108	108	108	108	108

BookMap	1971 (# of parcels)	1981 (# of parcels)	1991 (# of parcels)	2001 (# of parcels)	2012 (# of parcels)
10665	27	30	40	40	41
10666	0	123	122	122	123
10667	11	13	23	24	24
10668	295	297	296	298	295
10669	342	391	450	527	527
10670	137	138	138	138	221
10671	238	246	247	249	250
10672	2	9	11	72	595
10673	12	25	33	35	38
10674	181	178	178	178	180
10675	113	115	124	125	172
10677	0	80	80	80	80
10678	0	0	148	152	152
10701	7	13	8	15	226
10713	0	0	2	68	8
10715	0	37	104	119	126
10716	12	23	46	76	107
10717	110	110	111	110	111
10718	0	1	49	49	49
10719	12	23	29	34	35
10720	8	18	23	38	43
10721	12	18	19	22	24
10722	127	155	152	162	164
10723	28	29	39	39	49
10724	33	8	10	10	12
10727	2	2	2	2	11
10728	0	0	2	2	6
10729	10	13	14	15	16
10730	0	0	0	0	2
10731	13	27	27	27	27
10733	176	176	176	176	176
10734	0	0	1	8	14
10736	0	162	240	243	245
10737	69	72	76	136	139
10738	7	7	7	7	7
10739	9	12	13	20	24
10740	5	8	9	16	27
10741	0	7	7	7	7
10742	7	7	16	20	21
10743	2	2	36	68	85

BookMap	1971 (# of parcels)	1981 (# of parcels)	1991 (# of parcels)	2001 (# of parcels)	2012 (# of parcels)
10744	8	12	16	21	28
10745	0	23	24	18	18
10746	0	8	8	9	10
10747	42	29	28	27	53
10748	4	7	14	378	190
10749	0	0	174	290	951
10750	173	205	208	208	215
10751	69	329	345	414	421
10752	11	24	43	90	114
10754	0	17	27	36	42
10755	0	9	20	46	63
10756	3	15	33	57	352
10758	1	8	14	17	29
10759	13	42	47	55	65
10760	0	14	15	60	78
10761	2	12	58	83	99
10762	0	48	63	86	99
10763	0	46	50	63	99
10764	0	22	30	41	46
10765	0	0	0	0	119
10766	99	144	177	222	226
10767	140	183	204	214	222
10768	245	291	292	298	299
10769	53	84	93	103	124
10770	0	9	22	29	40
10771	0	153	146	145	145
10772	1	64	107	116	119
10773	0	107	163	161	163
10774	0	145	145	144	144
10775	0	44	59	83	89
10776	0	133	124	124	124
10777	0	173	155	155	156
10778	0	51	423	819	876
10779	0	219	219	219	220
10780	0	1	1	1	1
10781	0	2	0	0	1
10782	0	117	117	117	117
10783	0	124	124	124	124
10784	0	178	178	178	178
10801	3	4	4	4	12

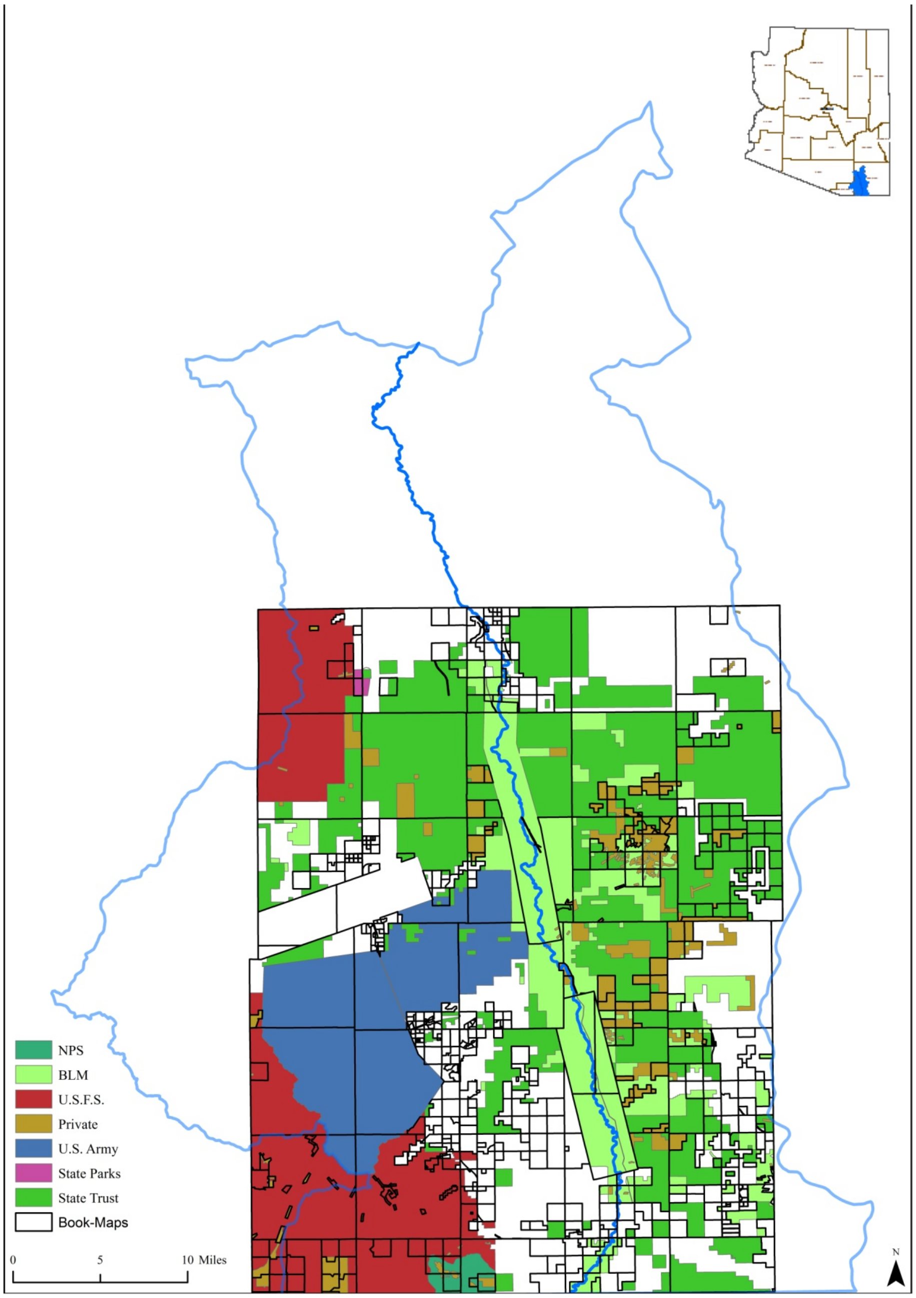
BookMap	1971 (# of parcels)	1981 (# of parcels)	1991 (# of parcels)	2001 (# of parcels)	2012 (# of parcels)
10806	4	3	3	3	3
10807	1	2	2	2	1
10808	10	10	10	11	48
10811	0	12	14	19	19
10812	0	30	36	37	40
10813	0	17	17	35	37
10814	0	1	4	23	31
10815	65	66	65	73	76
10816	4	5	6	6	9
10817	1	1	1	1	28
10818	5	4	4	6	8
10819	2	2	2	2	4
10820	2	7	11	10	75
10821	2	2	2	2	2
10822	1	1	1	1	1
10829	1	1	1	1	1
10830	1	3	3	3	3
10831	27	67	76	99	112
10832	91	89	86	83	85
10833	0	0	0	10	17
10836	3	3	3	3	6
10837	2	2	3	3	5
10838	8	11	11	31	60
10839	13	21	22	23	27
10840	6	13	13	15	15
10841	11	13	13	18	18
10844	1	1	1	1	1
10850	1	1	1	1	1
10853	9	11	13	14	19
10869	2	2	2	2	2
10876	0	1	1	1	1
10881	42	42	42	42	42
10882	0	0	0	0	1
10883	0	0	0	0	4
10901	7	4	4	4	11
10902	0	2	2	3	5
10903	4	5	10	12	25
10904	28	32	38	39	39
10905	31	38	38	40	43
10906	21	23	23	16	20

BookMap	1971 (# of parcels)	1981 (# of parcels)	1991 (# of parcels)	2001 (# of parcels)	2012 (# of parcels)
10907	55	60	64	64	73
10908	36	41	40	41	43
10909	45	55	60	58	58
10910	154	174	179	179	192
10911	111	133	143	140	141
10912	91	96	98	93	118
10913	96	98	98	100	105
10914	43	46	43	41	42
10915	94	94	92	90	86
10917	8	9	10	9	11
10918	3	3	93	3	6
10919	5	10	10	10	21
10921	0	398	400	392	378
10924	0	0	0	0	3
10925	7	13	24	25	36
10928	0	1	1	1	1
10930	0	1	1	10	10
10932	0	160	159	160	158
10933	0	263	258	258	221
11001	5	11	15	14	15
11003	2	2	2	2	2
11004	7	7	7	9	18
11005	2	2	93	2	6
11006	2	2	2	2	2
11009	0	0	2	2	2
11012	0	0	7	9	9
11013	0	0	10	10	11
11014	0	0	7	9	11
11016	0	0	8	8	8
11017	0	0	24	25	29
11018	4	6	7	18	146
11019	31	31	31	31	31
11020	36	36	36	34	31
11022	1	3	5	5	5
11023	1	1	1	7	8
11024	1	1	1	1	1
11025	1	2	2	2	2
11026	1	1	1	1	1
11027	1	2	2	2	2
11028	1	3	3	3	3

BookMap	1971 (# of parcels)	1981 (# of parcels)	1991 (# of parcels)	2001 (# of parcels)	2012 (# of parcels)
11029	2	2	4	2	4
11030	2	5	17	19	57
11031	0	0	0	8	9
11032	0	0	0	22	26
11033	1	1	2	7	7
11034	1	2	7	7	7
11035	1	1	2	3	3
11040	1	1	1	1	1
11041	2	4	4	4	5
11042	1	2	2	2	2
11043	1	1	1	1	1
11044	4	4	4	7	11
11045	4	4	4	6	7
11050	4	5	8	10	14
11051	2	3	14	18	28
11054	2	2	2	2	2
11055	1	1	1	1	1
11056	3	3	4	4	4
11057	12	13	17	19	20
11059	0	2	2	2	3
11060	0	0	0	10	6
12031	0	0	0	235	25
12101	2	3	6	43	55
12102	1	2	3	5	9
12103	4	5	8	13	12
12104	5	17	131	31	34
12105	14	14	17	18	18
12106	23	45	48	48	56
12107	3	6	6	7	6
12108	14	16	19	25	25
12109	10	12	16	16	17
12110	31	36	36	37	28
12111	9	16	18	20	18
12112	2	3	5	8	8
12113	14	21	18	23	23
12114	15	25	29	32	30
12115	18	40	45	76	89
12116	1	1	2	2	7
12117	27	34	30	40	43
12118	14	52	51	49	50

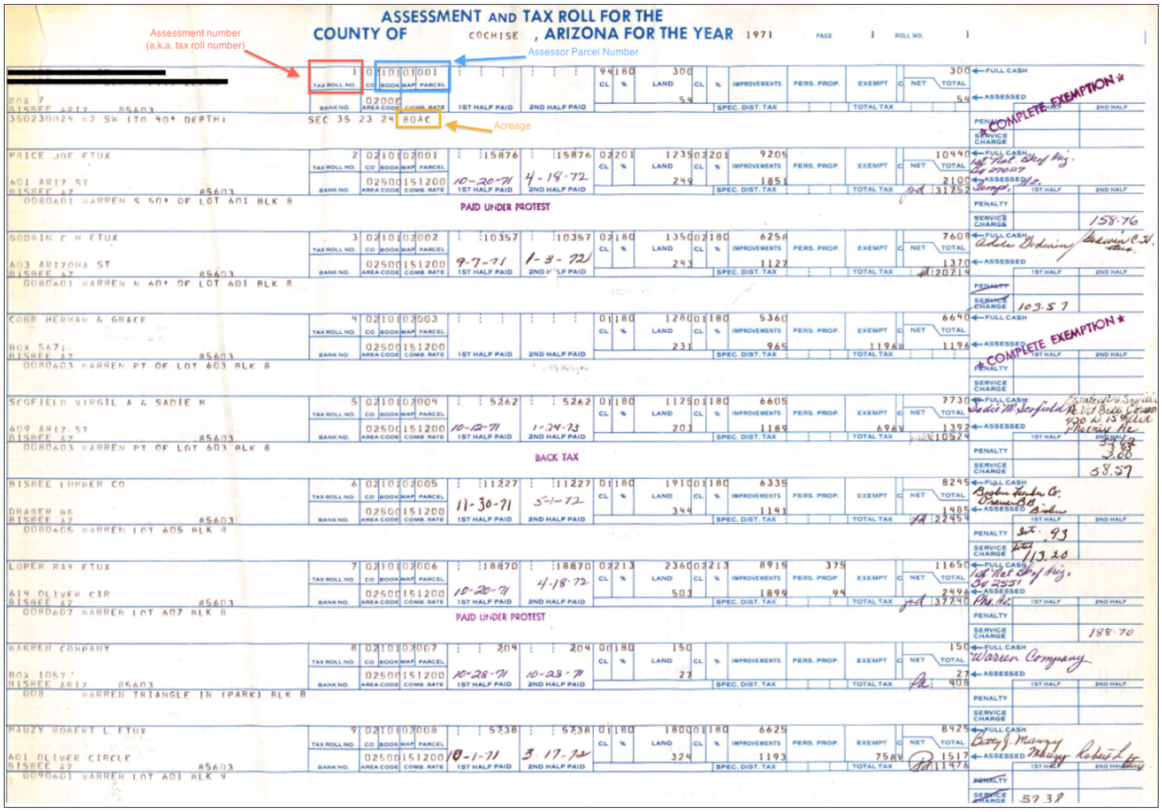
BookMap	1971 (# of parcels)	1981 (# of parcels)	1991 (# of parcels)	2001 (# of parcels)	2012 (# of parcels)
12119	12	16	15	18	23
12120	1	13	25	28	33
12121	13	44	69	91	90
12122	7	13	20	20	26
12124	4		8		
12123	2	4	4	37	47
12125	6	15	14	17	19
12126	2	2	2	2	1
12127	4	4	4	4	7
12128	11	16	23	34	40
12129	0	0	16	16	16
12130	0	0	12	12	12
12131	4	4	12	4	4
12133	5	5	4	6	7
12134	2	3	3	4	4
12135	7	8	8	10	10
12136	10	14	13	16	22
12137	2	2	4	4	6
12139	1	1	4	4	5
12140	2	2	2	2	3
12141	1	2	4	4	9
12142	1	3	3	3	3
12143	1	1	15	1	1
12144	1	2	12	1	1
12146	1	1	1	169	170
12147	2	2	2	2	76
12149	1	1	1	1	1
12150	2	2	2	2	2
12151	0	40	41	41	39
12425	0	16	18	31	44
12431	3	3	3	5	6
12432	1	1	1	1	1
12434	1	1	1	1	2
12435	2	2	2	2	2
12436	0	0	0	0	2
12439	2	2	2	2	2
12440	10	10	9	27	28
12441	29	14	24	29	33
12445	0	0	4	4	4

Appendix C: Land Jurisdiction in Study Area

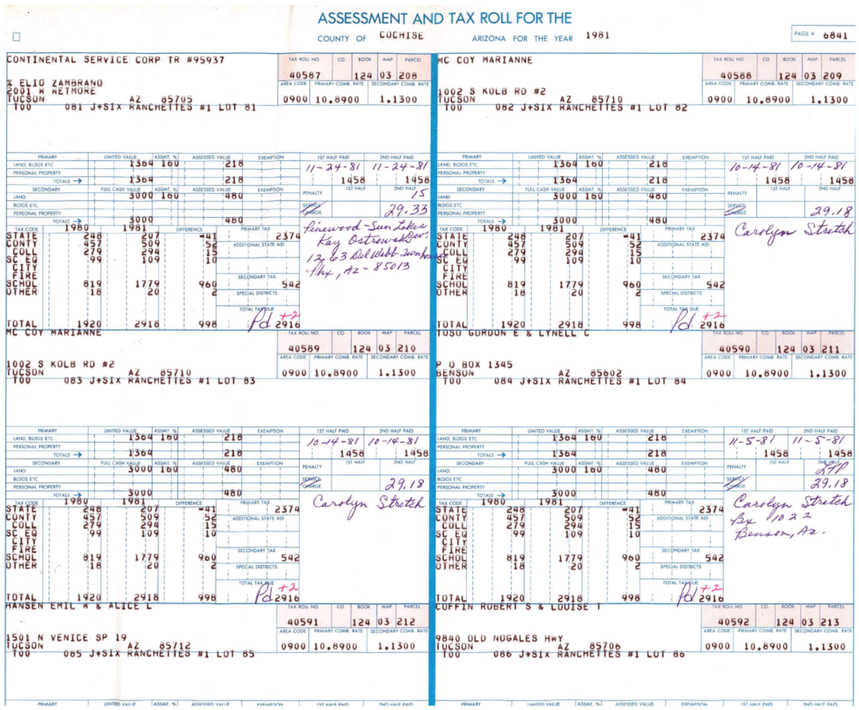


Land Jurisdiction and book-map data provided by Cochise County. San Pedro River & Watershed data from USGS NHD.

Appendix D: Example Tax Roll Records for 1971, 1981 and 1991



Scanned 1971 Tax Roll Record (Courtesy of Cochise County Archives, 2012)


ASSESSMENT AND TAX ROLL FOR THE COUNTY OF COCHISE ARIZONA FOR THE YEAR 1981 PAGE # 6841

CONTINENTAL SERVICE CORP TR #95937 % ELIO ZAMBRANO 2001 W WETMORE TUCSON AZ 85705 T00 081 J+SIX RANCHETTES #1 LOT 81 — 40587 124 03 208 0900 10.8900 1.1300

MC COY MARIANNE 1002 S KOLB RD #2 TUCSON AZ 85710 T00 082 J+SIX RANCHETTES #1 LOT 82 — 40588 124 03 209 0900 10.8900 1.1300

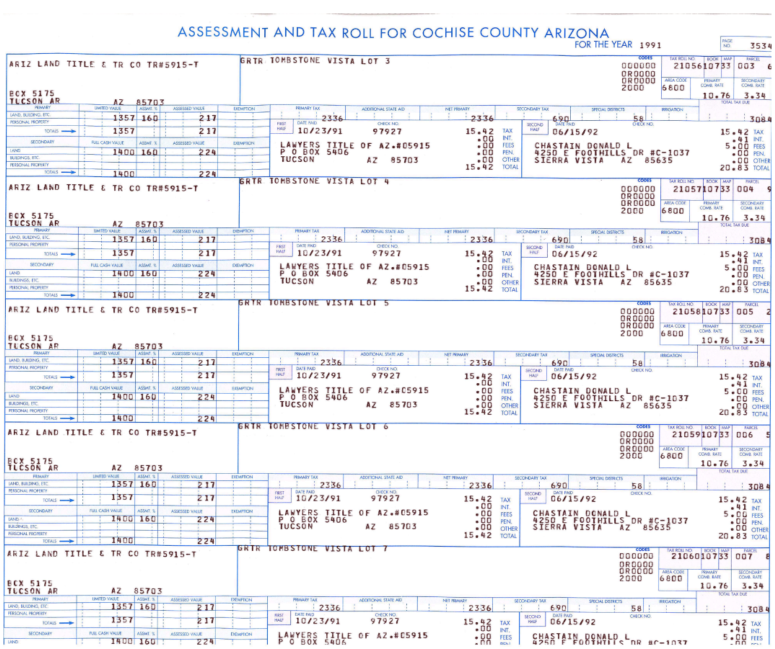
MC COY MARIANNE 1002 S KOLB RD #2 TUCSON AZ 85710 T00 083 J+SIX RANCHETTES #1 LOT 83 — 40589 124 03 210 0900 10.8900 1.1300

TOSO GORDON E & LYNELL C P O BOX 1345 BENSON AZ 85602 T00 084 J+SIX RANCHETTES #1 LOT 84 — 40590 124 03 211 0900 10.8900 1.1300

HANSEN EMIL M & ALICE L 1501 N VENICE SP 19 TUCSON AZ 85712 T00 085 J+SIX RANCHETTES #1 LOT 85 — 40591 124 03 212 0900 10.8900 1.1300

COFFIN ROBERT S & LOUISE T 9840 OLD NOGALES HWY TUCSON AZ 85706 T00 086 J+SIX RANCHETTES #1 LOT 86 — 40592 124 03 213 0900 10.8900 1.1300

Scanned 1981 Tax Roll Record (Courtesy of Cochise County Archives, 2012)


ASSESSMENT AND TAX ROLL FOR COCHISE COUNTY ARIZONA FOR THE YEAR 1991 PAGE 3534

GRTR TOMBSTONE VISTA LOT 3 / LOT 4 / LOT 5 / LOT 6 / LOT 7

LAWYERS TITLE OF AZ.#05915 P O BOX 5406 TUCSON AZ 85703

CHASTAIN DONALD L 4250 E FOOTHILLS DR #C-1037 SIERRA VISTA AZ 85635

Scanned 1991 Tax Roll Record (Courtesy of Cochise County Archives, 2012).

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