EPA/600/R-13/112
ARS/295385
July 2013
www.epa.gov/research

United States Environmental Protection Agency

Investigating Historic Parcel Changes to Understand Land Use Trends

A Methodology and Application for the San Pedro River Watershed

RESEARCH AND DEVELOPMENT

Investigating Historic Parcel Changes to Understand Land Use Trends

Methodology and Application for the San Pedro River Watershed

Charlotte C. Ely[1], William G. Kepner[2], Dave C. Goodrich[3], and Maliha S. Nash[2]

[1]Corresponding Author, U.S. EPA Region 9, Water Division

[2]U.S. Environmental Protection Agency, Office of Research and Development, Landscape Ecology Branch

[3]USDA-Agricultural Research Service, Southwest Watershed Research Center

U.S. Environmental Protection Agency
Office of Research and Development
Washington, DC 20460

Acknowledgements

This research was made possible by the U.S. Environmental Protection Agency's (EPA) Regional Research Partnership Program (RRPP), which provides training opportunities for regional technical staff to work directly with Office of Research and Development (ORD) scientists in the ORD laboratories and centers. I'm very grateful for the opportunity, and to the EPA Region 9 and ORD management and staff who supported the project.

I also owe a considerable debt of gratitude to the ORD Las Vegas Laboratory's Landscape Ecology Branch and to the United States Department of Agriculture (USDA) Agricultural Research Service's (ARS) Southwest Watershed Research Center. Both agencies provided generous logistical support and their staff generously contributed their time and expertise.

I'm very thankful to the Cochise County Archives and Information Technology staff. Without their advice, generosity, and impeccable management of historic documents and geodata, this project could not have been completed.

I am also grateful to William M. Rodgers, whose 1965 research inspired this study. Upon receiving his postgraduate degree, Rodgers accepted a teaching position in UC Denver's Geography Department. In honor of the late professor, UC Denver annually awards a scholarship in his name.

Dr. Britta G. Bierwagen (Physical Scientist, EPA/ORD, Global Change Research Program, Washington, D.C), Dr. Russell L. Scott (Research Hydrologist, U.S. Department of Agriculture Agricultural Research Service, Southwest Watershed Research Center, Tucson, AZ), and Dale Turner (Conservation Planner, The Nature Conservancy, Tucson, AZ) peer-reviewed the report. Thank you, Britta, Russ, and Dale for your suggestions and corrections.

Lastly, I am most appreciative of my mentors and co-authors, for their guidance and support throughout all phases of this project.

Notice

This report has been peer reviewed by the U.S. Environmental Protection Agency Office of Research and Development and the USDA Agricultural Research Service and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation by EPA nor USDA/ARS for use.

Table of Contents

List of Figures

List of Figures (cont.)

List of Tables

List of Appendices

Acronyms and Abbreviations

AGWA	Automated Geospatial Watershed Assessment
APN	Assessor Parcel Number
BLM	U.S. Bureau of Land Management
CFR	Code of Federal Regulations
EPA	U.S. Environmental Protection Agency
GIS	Geographic Information System
HD	Housing Density
ICLUS	Integrated Climate and Land Use Scenarios
IPCC	Intergovernmental Panel on Climate Change
IT	Information Technology
MGD	Million Gallons a Day
MSS	Multi-spectral Scanner (Landsat)
NEPA	National Environmental Policy Act
NHD	National Hydrology Dataset (USGS)
PLSS	Public Land Survey System
SPRNCA	San Pedro Riparian National Conservation Area
SRES	Special Report on Emissions Scenarios
STORET	Storage and Retrieval Database
SWAT	Soil and Water Assessment Tool
TANA	TeleAtlas of North America
TM	Thematic Mapper (Landsat)
USGS	U.S. Geological Survey
USPP	Upper San Pedro Partnership
WWTF	Wastewater Treatment Facility

Abstract

Long-term land use and land cover change, and the associated impacts, 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 parcel density maps and graphs employ housing density categories developed by the Environmental Protection Agency's Integrated Climate and Land Use Scenarios project. 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 indirect effects as required by the National Environmental Policy Act.

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).

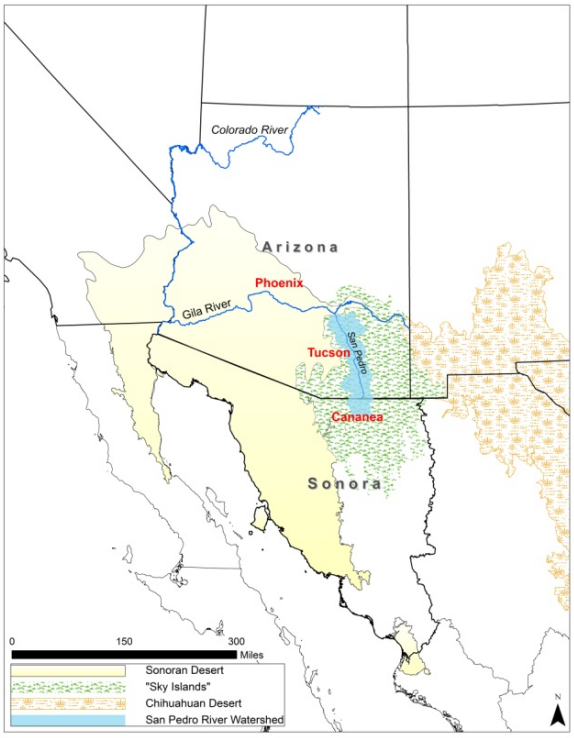


Figure 1: The San Pedro River flows 230 km (~142 mi) from its headwaters in Cananea, Sonora, Mexico to its confluence with the Gila River in Arizona. The watershed is within the Madrean Archipelago, also known as "Sky Islands." This area is one of the most biologically diverse in the world (Koprowski 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 and 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 growth-induced land use change in watersheds across the country.

Land use change can have devastating impacts on the landscape. The consequences of human modification of the Earth's surface for extraction of natural resources, agricultural production, and urbanization may even rival those that are anticipated via climate change (Vitousek 1994, Vorosmarty et al. 2000, Chapin et al. 2002, DeFries and Eshleman 2004, Brauman et al. 2007, Whitehead et al. 2009).

Understanding and mitigating the consequences of future land use change require knowledge of past trends and impacts. Historic reference conditions can provide resource-managers with baseline "snap shots" capable of informing and directing the management and implementation of present day projects and planning. Evaluating management decisions using only current conditions belies potential impacts (Covington and Moore 1992). Without knowledge of past projects and their consequences, how can we evaluate whether present management will lead to significant environmental impacts in the future?

Preferably, reference 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.

Comparing conditions across large landscapes and assessing cumulative environmental impacts over time has been challenging. Before the launch of remote sensing satellites in the early 1970s, past and present conditions could be compared using archival literature and photography. Since then, remote imagery has increasingly been used to chronicle change. Despite certain limitations, both datasets have been used to produce compelling analyses of landscape change in the arid Southwest.

Vegetation change in the American West has been a subject of concern throughout the twentieth century (Humphrey 1958, Hastings and Turner 1965, Branson 1985, Grover and Musick 1990, Bahre 1991, Bahre and Shelton 1993, and Turner et al. 2003). Most of the evidence for vegetation change is provided from a series of matched photographs - a method called repeat photography - beginning in the late 1800s and early 1900s (Figure 2). However, there are serious drawbacks in using this technique to assign change over this period of history.

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)

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 in plant occurrence over large regional areas. Secondly, the historic photographic series are usually separated by large periods of time, often captured more than a decade after the sites were first disturbed by human activity. Lastly, repeat photography has largely been used for qualitative comparisons and little progress has been made in quantifying and characterizing change using this dataset. Although several studies have addressed specific aspects of vegetation change in the Southwest, few have attempted to synthesize the cumulative impacts over large regional or watershed areas.

Important advances in the integration of remote imagery, computer processing, and spatial analysis technologies have been coupled to landscape ecology theory to study the distribution patterns of communities and ecosystems (Kepner et al. 2000 and 2002). Landsat imagery, for example, has been used to evaluate the human and environmental processes affecting distribution patterns over time (Figure 3). The combination of these technologies contributes to our ability to characterize large areas; it also provides predictive models for alternative future scenarios, which can lead to a more robust comparative analysis of impacts relative to alternative courses of management action (Kepner et al. 2004).

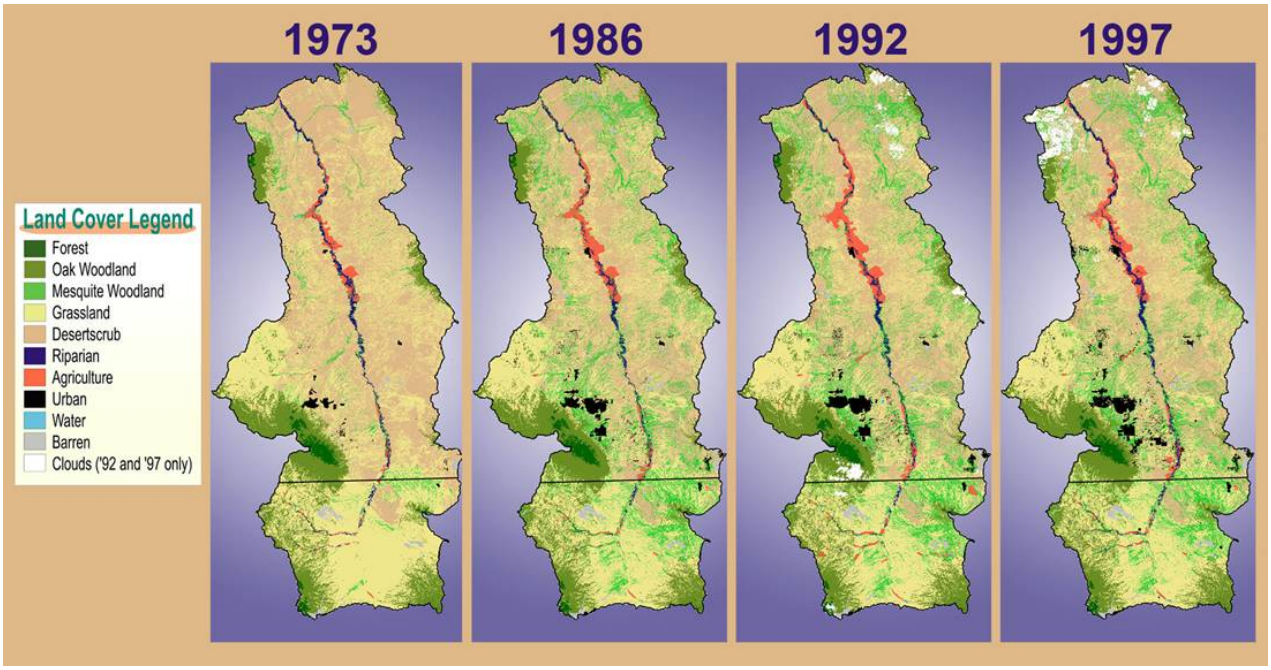


Figure 3: Land cover in the Upper San Pedro Watershed using Landsat MSS and TM (Kepner et al. 2002)

There are limits, however, to how much change can be detected employing remote imagery and spatial analysis technologies. For example, satellite images 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. For instance, the earliest Landsat imagery dates back only to 1972.

Archival ownership records also provide information for understanding reference conditions, and may help facilitate the analysis of photographs and satellite images. While such records - notably county Treasurer and Assessor documents - may be limited as well, our research suggests property records (i.e., parcel data) may nonetheless provide important insight into historic land use trends, fill data gaps, and corroborate the findings of other change-detection methodologies.

For the purpose of this report, the results are restricted to a portion of the Upper San Pedro River Watershed that was studied by William R. Rodgers, a University of Arizona graduate student in the mid-1960s. Our study area encompasses the same rectangular section of the watershed Rodgers defined as the Upper San Pedro River Valley and mapped using the Public Land Survey System (PLSS) (Figure 4).

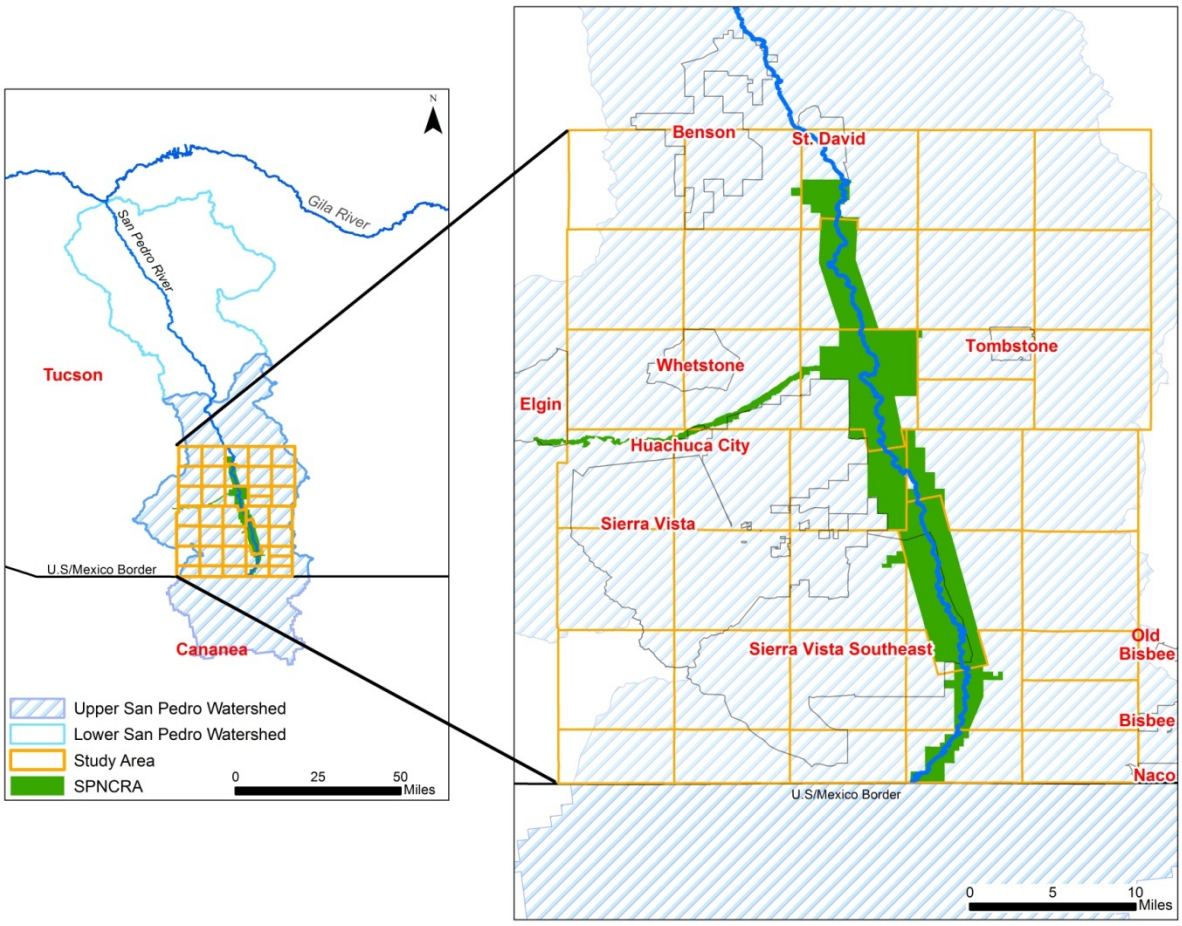


Figure 4: Location Map of the Study Area. The study area was defined using the Public Land Survey System (PLSS); the grid shows historic township boundaries. Also shown is the San Pedro Riparian National Conservation Area (SPRNCA). Administered by the U.S. Bureau of Land Management (BLM), SPRNCA protects 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 5 shows the 1900 and the 1964 landholding maps from Rodgers’ study. In Figure 5, 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.

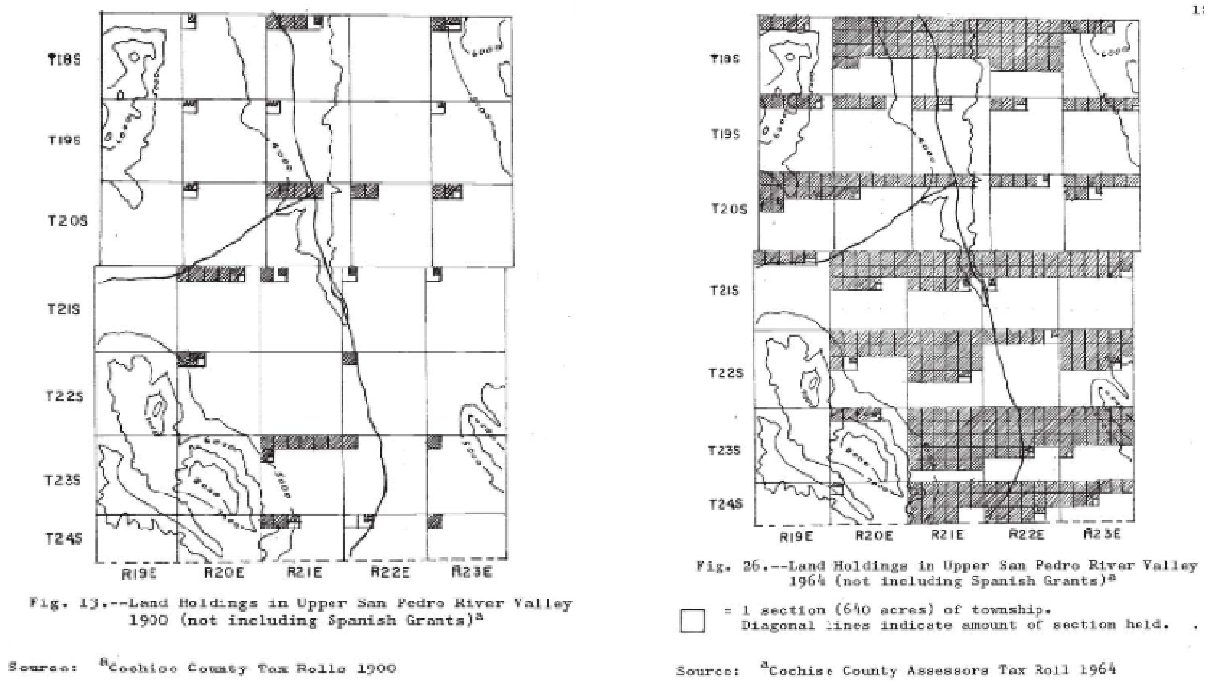


Figure 5: Landholdings in Upper San Pedro River Valley, 1900 and 1964 (Rodgers 1965)

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 - 35441” contains all tax records with assessment numbers ranging from 35015 through 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 6).

Figure 6: 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 7).

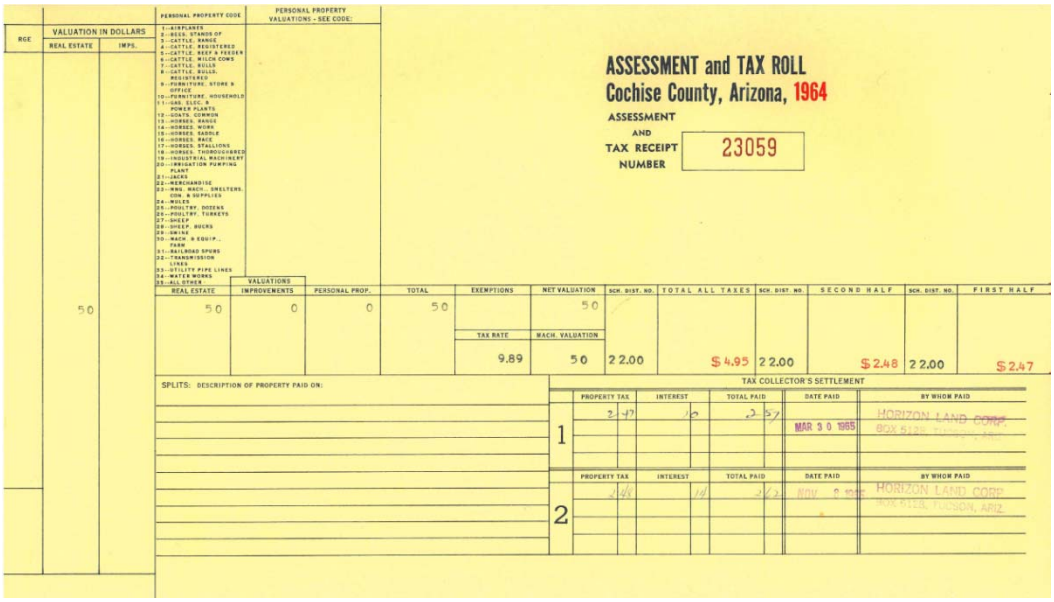
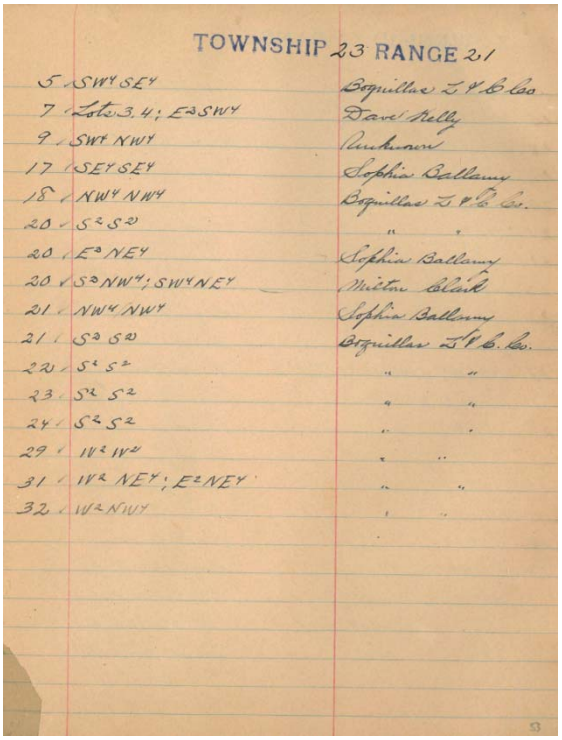


Figure 7: Scanned Image of 1964 County Assessor Tax Roll Record (Courtesy of Cochise County Archives, 2012)

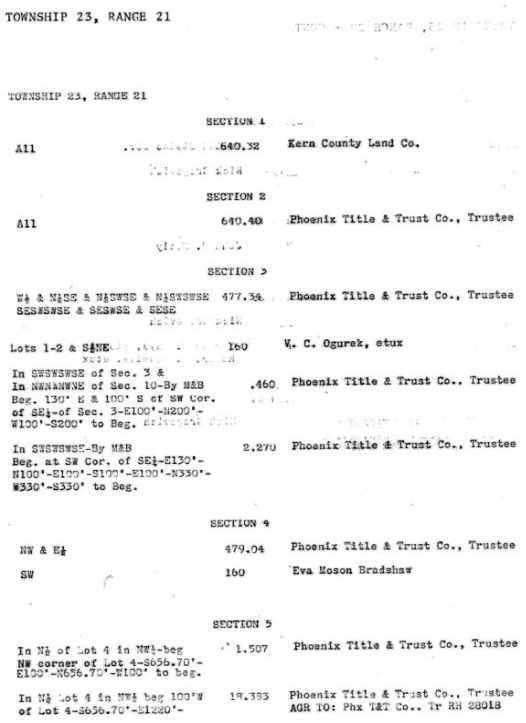
If a property spanned multiple sections in multiple townships and/or ranges, the Tax Roll record - if complete - would list the acreage owned within each area (e.g. Township 21, Range 22, southeast corner of section 32, 160 acres; Township 22, Range 22, northern half of the northwest quarter of section 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 4 and 5). 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 8). 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	Unknown
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	Mister 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 & N½SESWSE 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 NWNANWNE 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'-E150'-N656.70'-W100' to beg.	1.507	Phoenix Title & Trust Co., Trustee
In N½ Lot 4 in NW¼ beg 100'N of Lot 4-S656.70'-E1220'-	18.385	Phoenix Title & Trust Co., Trustee AGR TO: Phx T&T Co.. Tr RH 28018

Figure 8: 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 9). 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).

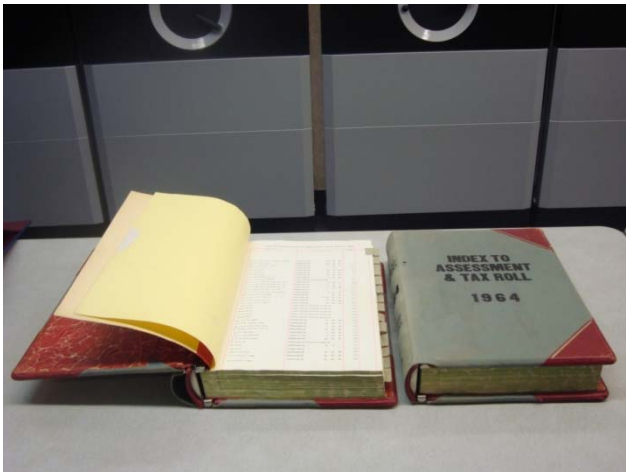


Figure 9: 1964 Alpha Index to Assessment and Tax Roll

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 - 159 acres, 160 - 319 acres, 320 - 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 10 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

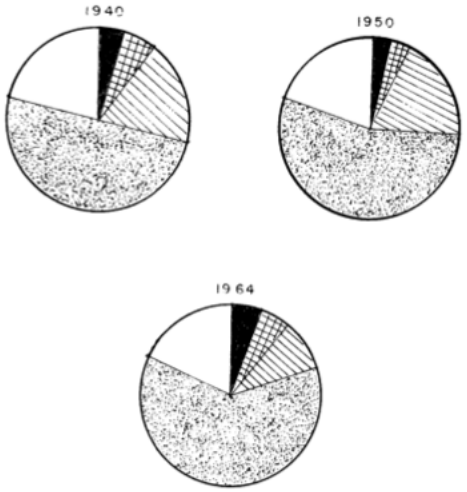


Fig. 28.--Privately Owned Land in Upper San Pedro River Valley by Size of Holdings 1940-1964[a]

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

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

Figure 10: 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 10) 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 the authors with 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 11 shows the landholdings within the study area for the year 2012. Including public and mining land, there are 37,360 individual parcels.

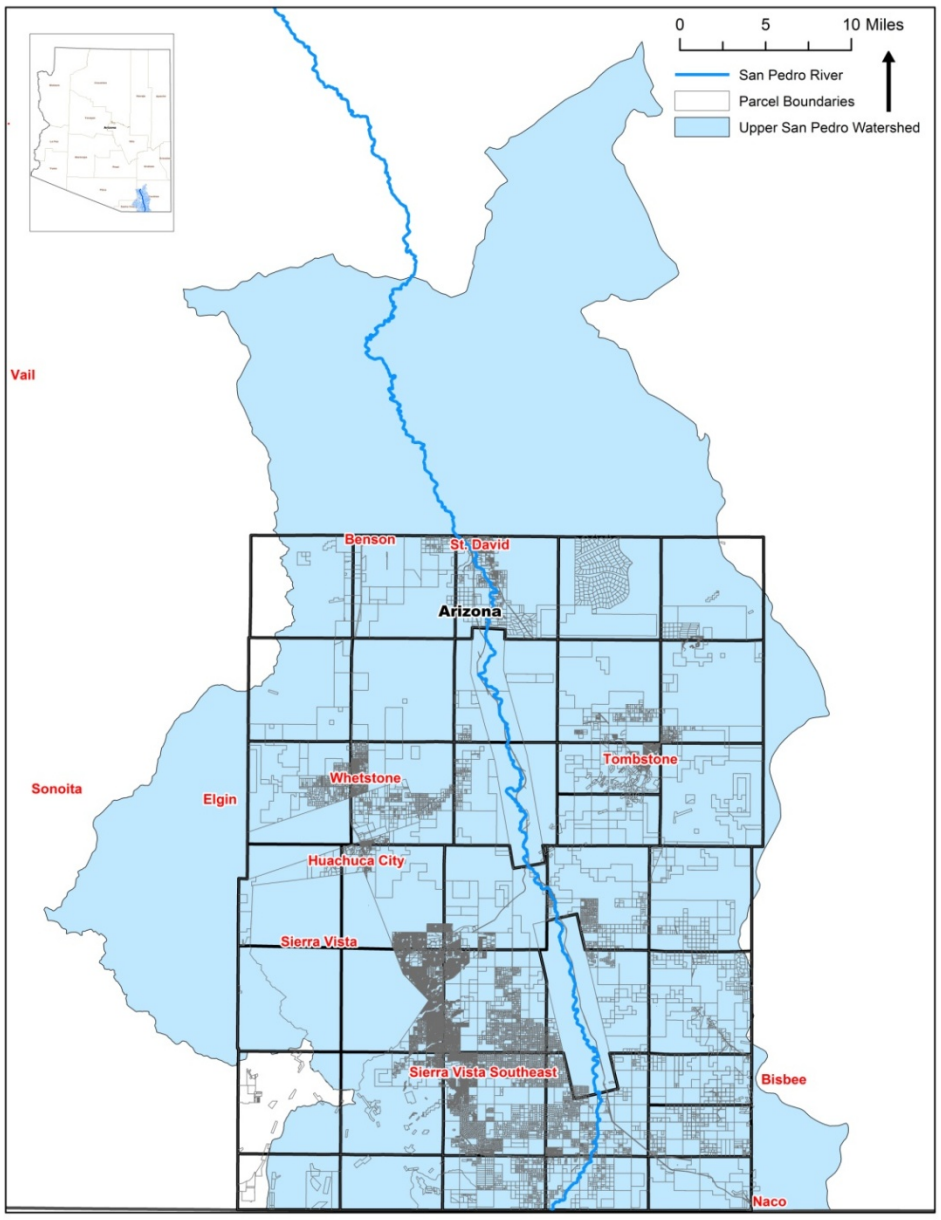


Figure 11: Parcels within the Study Area, 2012. Parcel data provided by Cochise County IT department; Hydrology data from USGS NHD

In order to complete the survey that Rodgers began, the same analysis was performed for the 2012 data. The 37,360 parcels were grouped into the four size categories. The number of parcels within each category were counted, the sum acreage calculated, the percentage of all holdings determined, and the average property size established (Table 1). Rather than, as Rodgers did, calculate "percentage of all holdings" using "Total Acreage," "Number of Holdings" was used instead. Figure 12 displays the results of those calculations for 1940, 1950, 1964 and 2012. With the goal of continuing Rodgers' decade-by-decade analysis, the authors sought to additionally obtain parcel data 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%	5,158.65
Total	37,360		100%	

Table 1: 2012 Land Holdings Analysis (Data Courtesy of Cochise County IT Department, 2012)

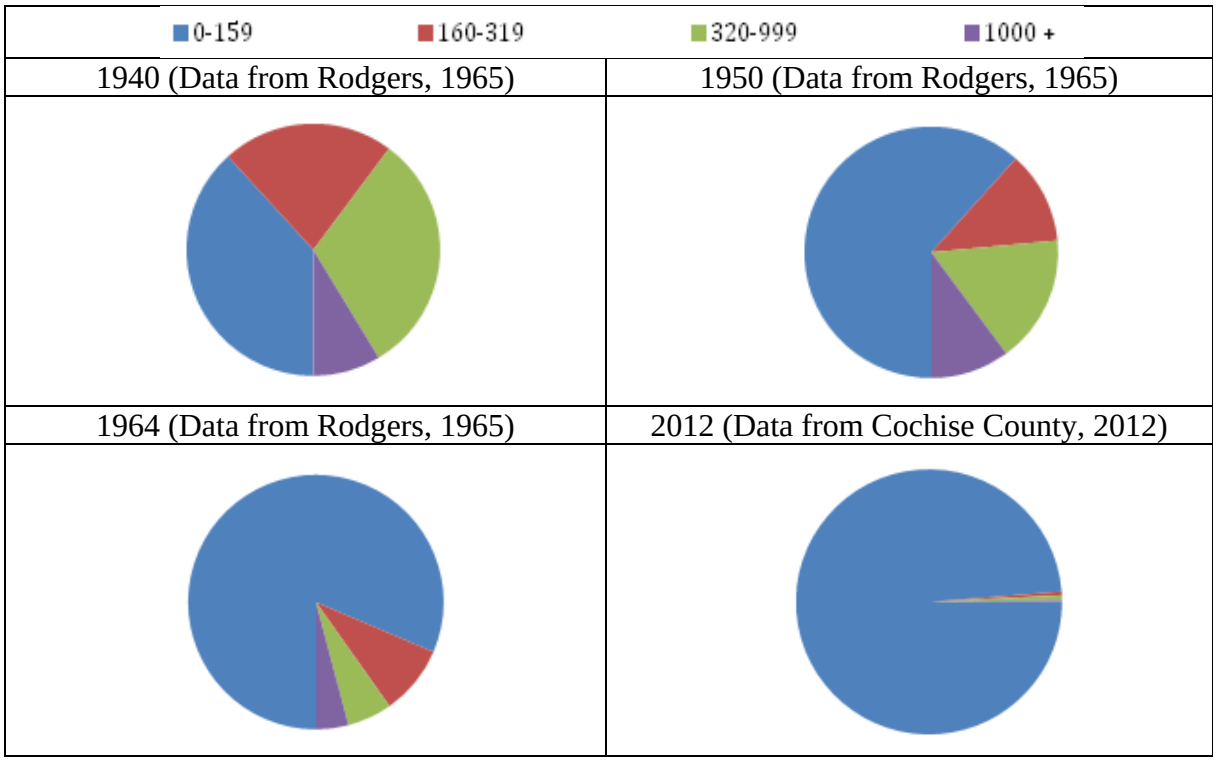


Figure 12: Percentage of all holdings using "Total Acreage" for 1940, 1950, 1964 and 2012. For example, in 2012, there were 90 properties as large as 1,000 acres or more, and a total of 37,360 properties: (90 /37,360)*100 = 0.24%.

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 private, non-mining 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 private, non-mining parcels (Appendix B).

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 refer to a specific area (Figure 13). Some books are not shown in Figure 13 because the study area contains relatively small portions of their area not visible at the map's resolution.

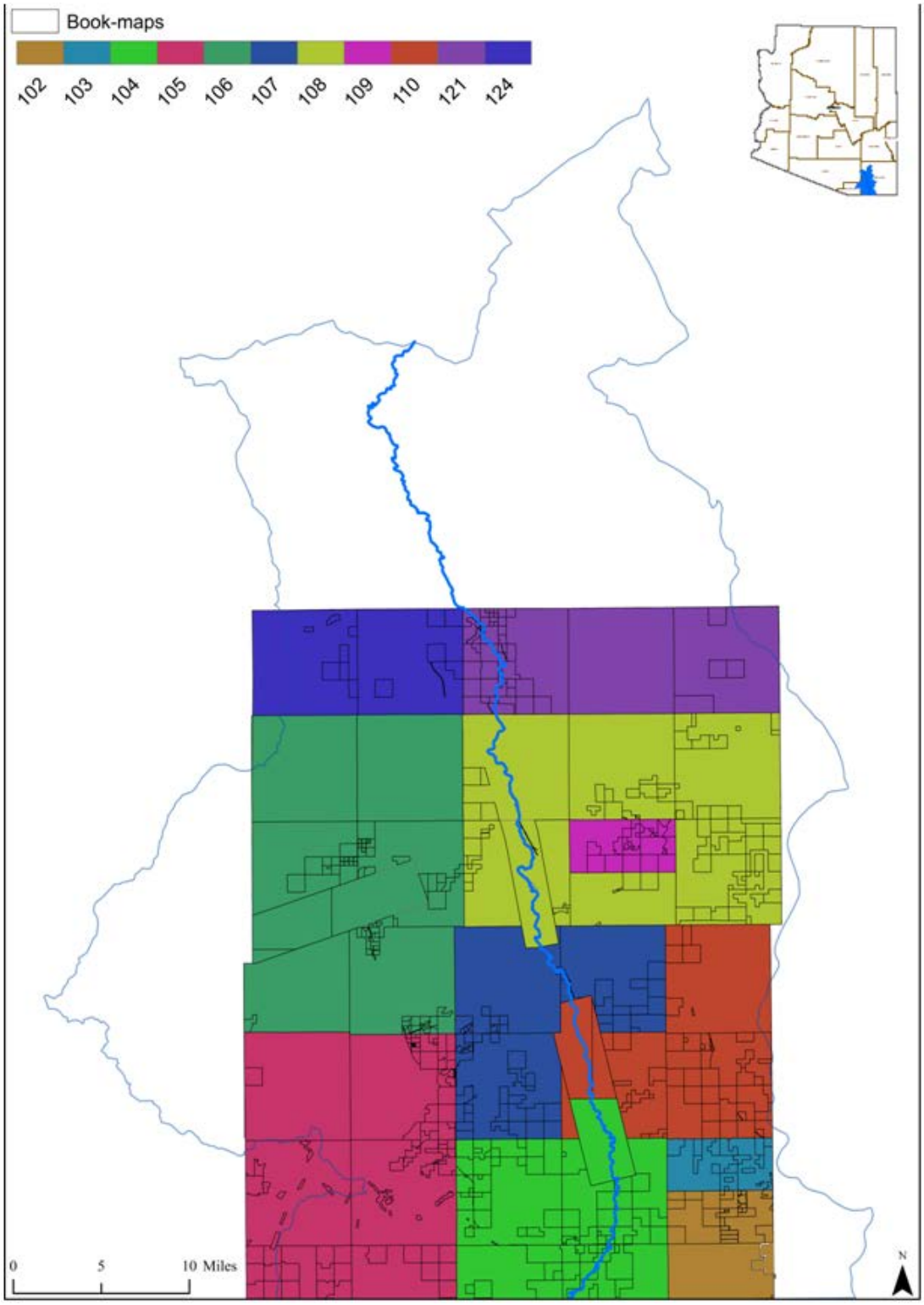


Figure 13: Books and Book-Maps in the Study Area (Book-Map data provided by Cochise County IT department; Hydrology data from USGS NHD)

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 private, non-mining 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 14 shows a segment of the first page of the 1971 Tax Roll record. Appendix D provides examples of multiple records for 1971, 1981, and 1991.

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).

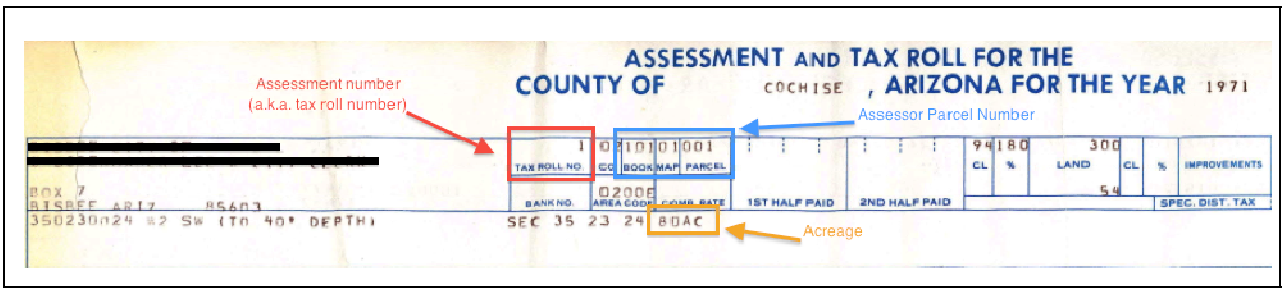


Figure 14: Segment of scanned 1971 Tax Roll Record (Courtesy of Cochise County Archives, 2012). Identifying annotations added.

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 private, non-mining 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) greenhouse gas emissions storylines. 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 2: 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 private, non-mining 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 private, non-mining parcels within the study area increased from 9,035 to 36,511. The overall change increased consistently from 1971 to 2012, with a rate of 657 parcels per year (dashed line in Figure 15). However, the decadal change had a different trend. The rate of increase was the highest between 1971 and 1981 (898 parcels/year), lower but still high between from 1981to1991 and from 1991to 2001 (477 and 653 parcels/year, respectively), and an increasing but smaller rate from 2001 to 2012 (654 parcels/year). Between 1971 and 2012, the average parcel size dropped from 37.98 to 8.01 acres.

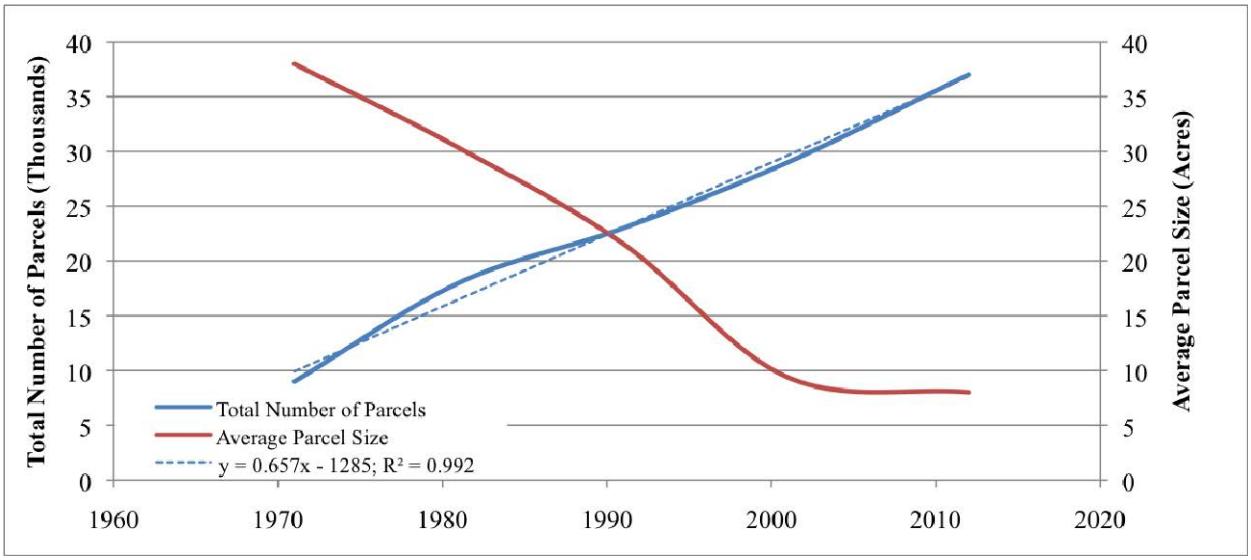


Figure 15: Decadal Changes in Total Number of Parcels and Average Parcel Size for 1971-2012

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 12; Figure 16). Figure 16 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%.

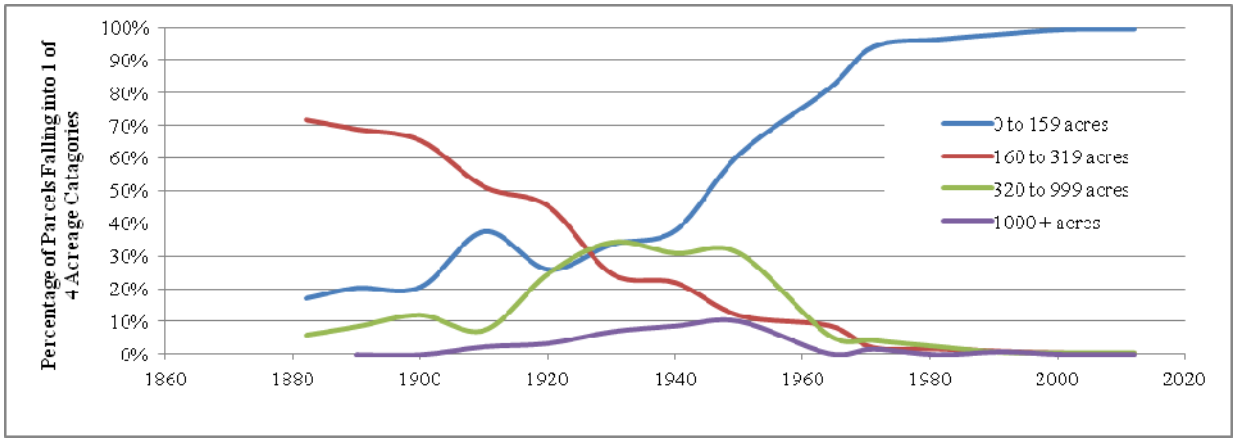


Figure 16: Decadal Trends Using Rodgers Acreage Categories: 1882 - 2012.

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 17 shows these acreage trends graphically. Table 3 details the percentage of parcels falling into the ICLUS housing unit categories for each decade.

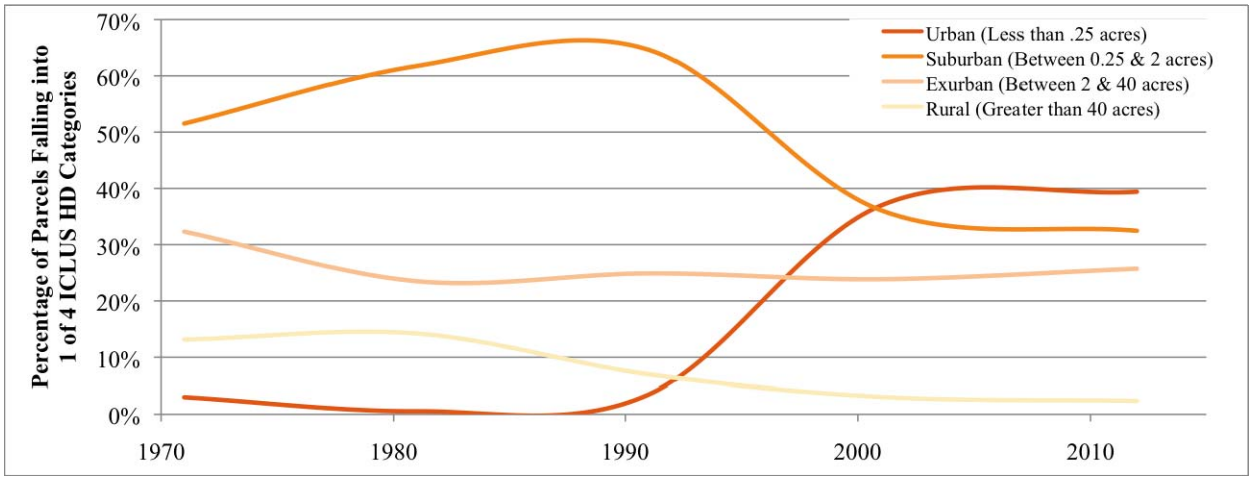


Figure 17: Decadal Acreage Trends Using ICLUS Housing Density Categories, 1971 - 2012.

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 3: Decadal Acreage Trends Using ICLUS HD Categories, 1971 - 2012. (*Note: Of the 37,360 parcels within the study area (Figure 11), 849 were public and/or 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 18 and 19 show decadal book-maps trends between 1971 and 2012. Table 4 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%.

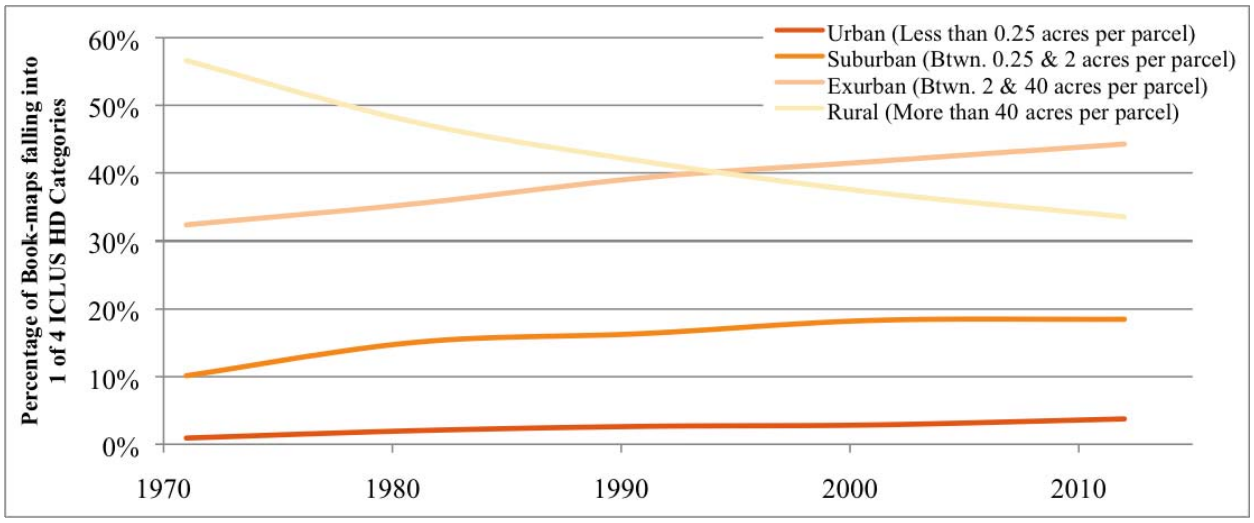


Figure 18: Decadal Book-Map Trends, 1971 - 2012 (Changing Percentage).

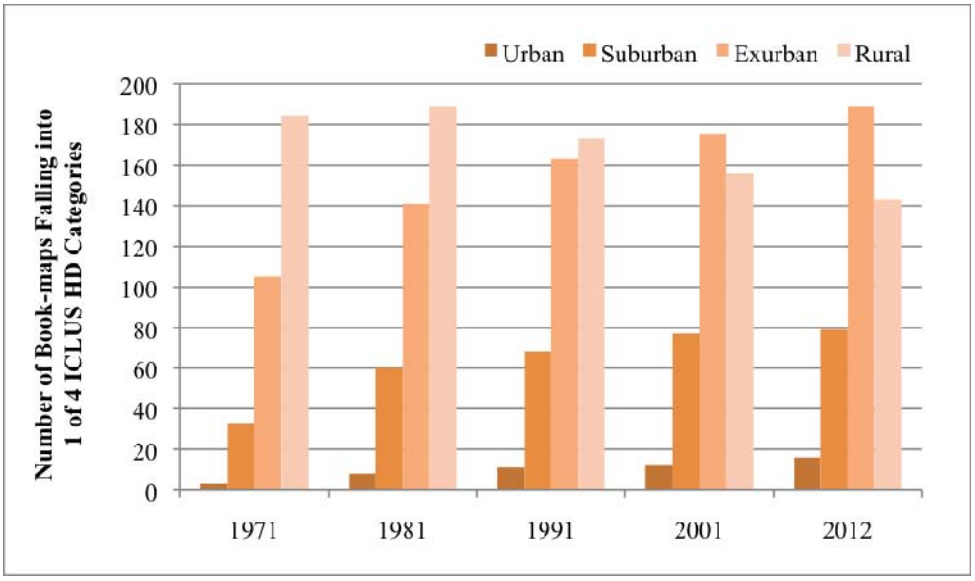


Figure 19: Decadal Book-Map Trends, 1971 - 2012 (Changing Number).

	Urban		Suburban		Exurban		Rural		Total Number of Book-Maps
	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 4: Number and Percentage of Book-Maps Falling into ICLUS HD Categories, 1971 - 2012.

Figures 20 through 24 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 25 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 (Davis 2013).

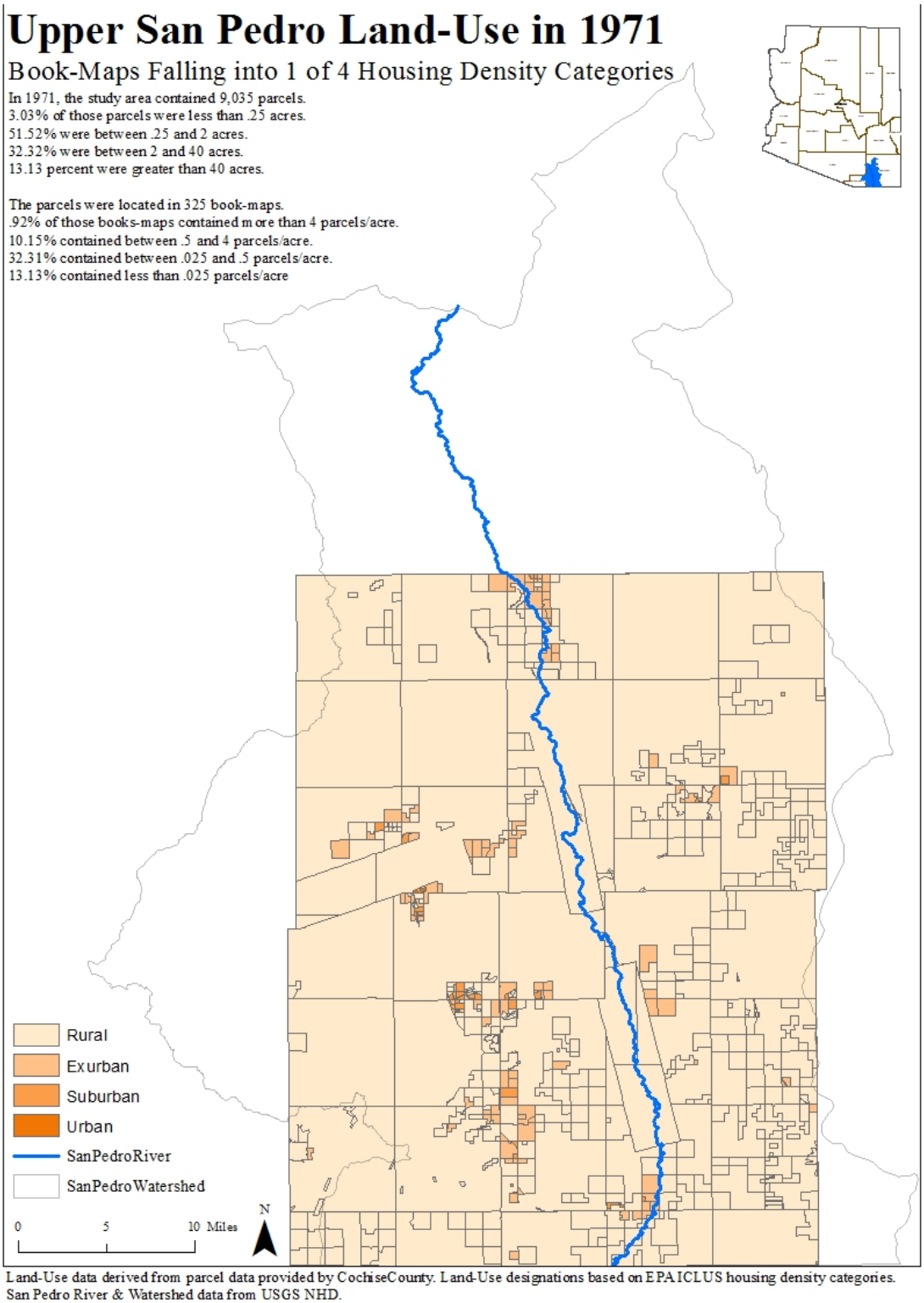


Figure 20: Upper San Pedro Land Use, 1971

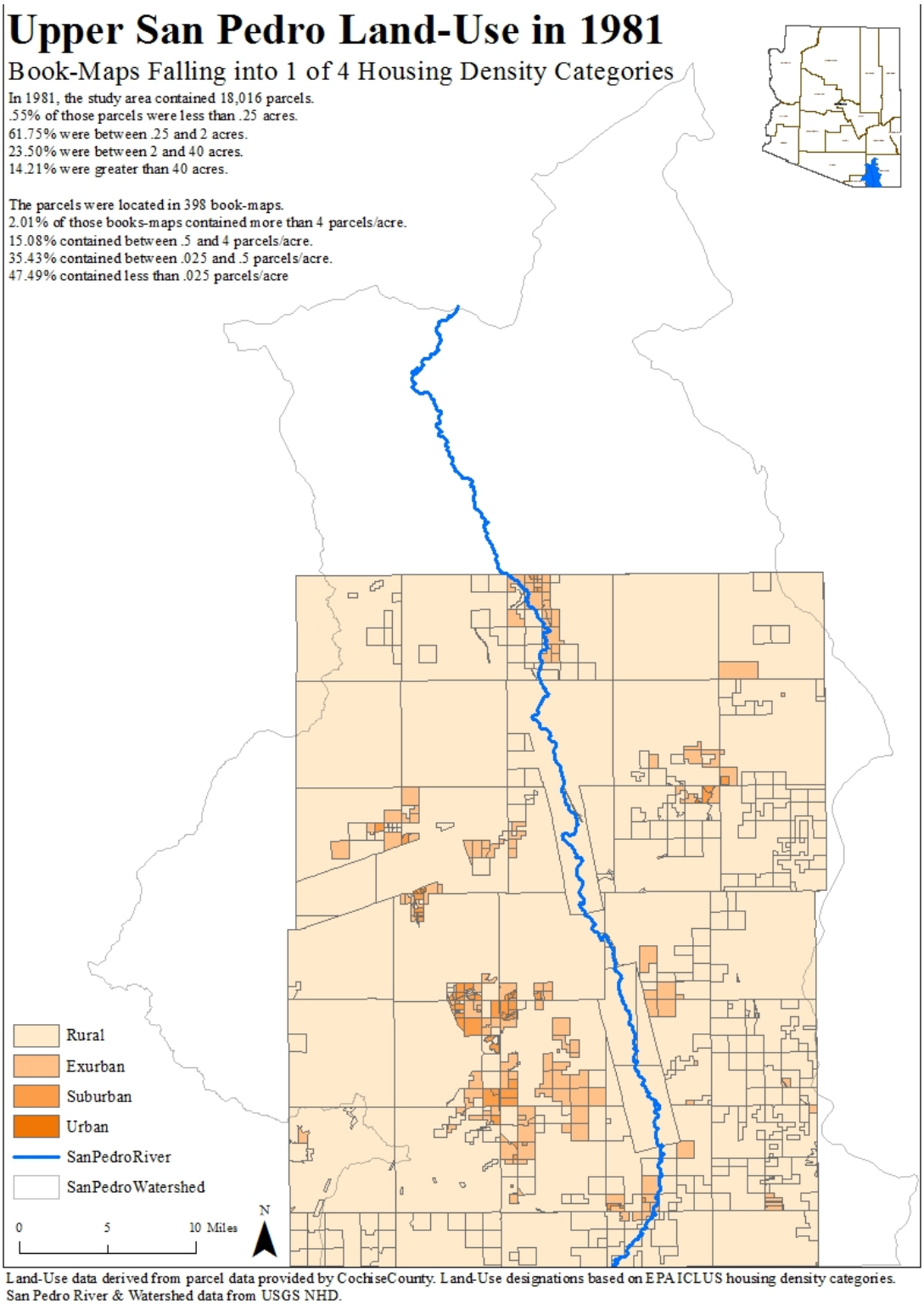


Figure 21: Upper San Pedro Land Use, 1981

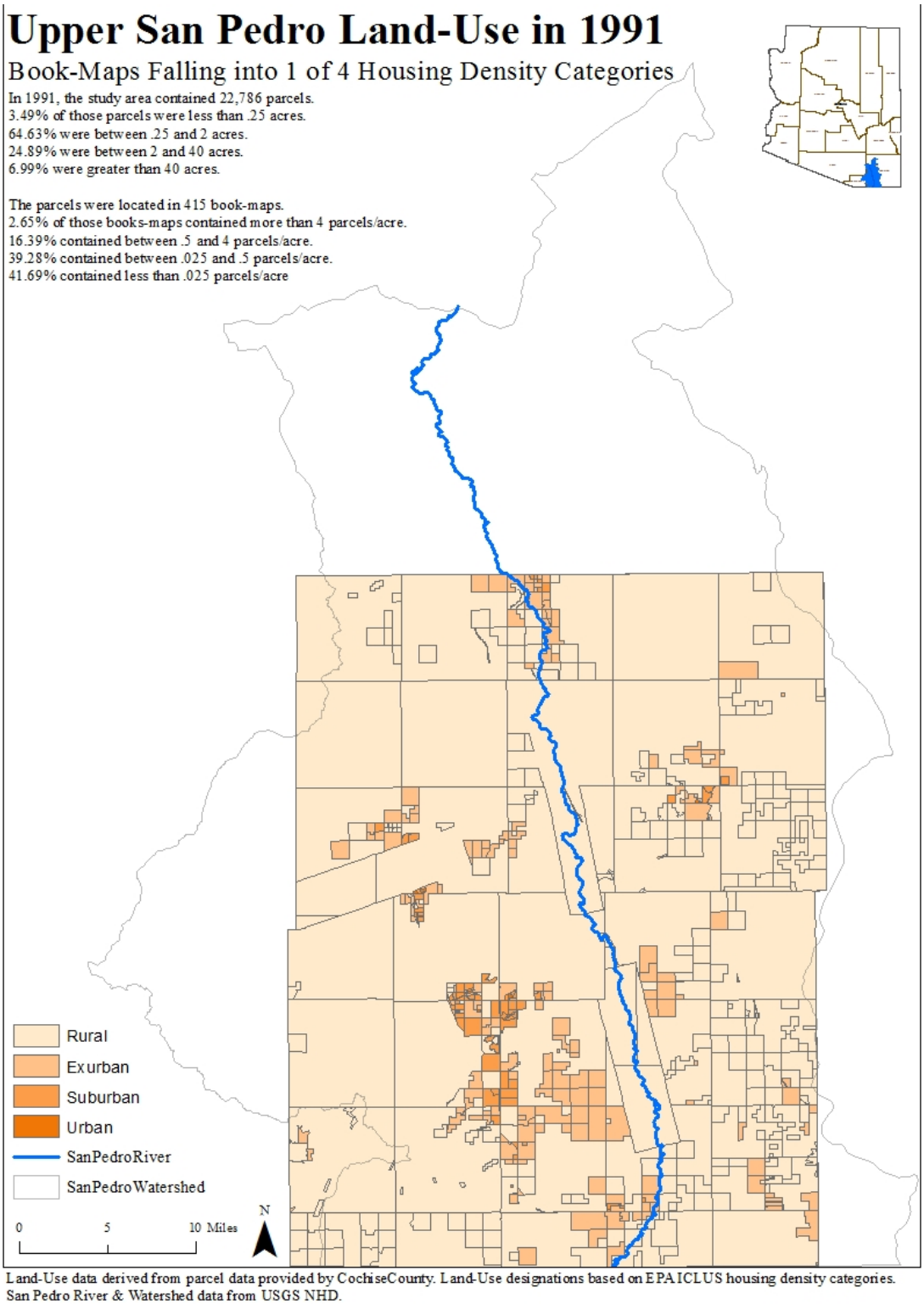


Figure 22: Upper San Pedro Land Use, 1991

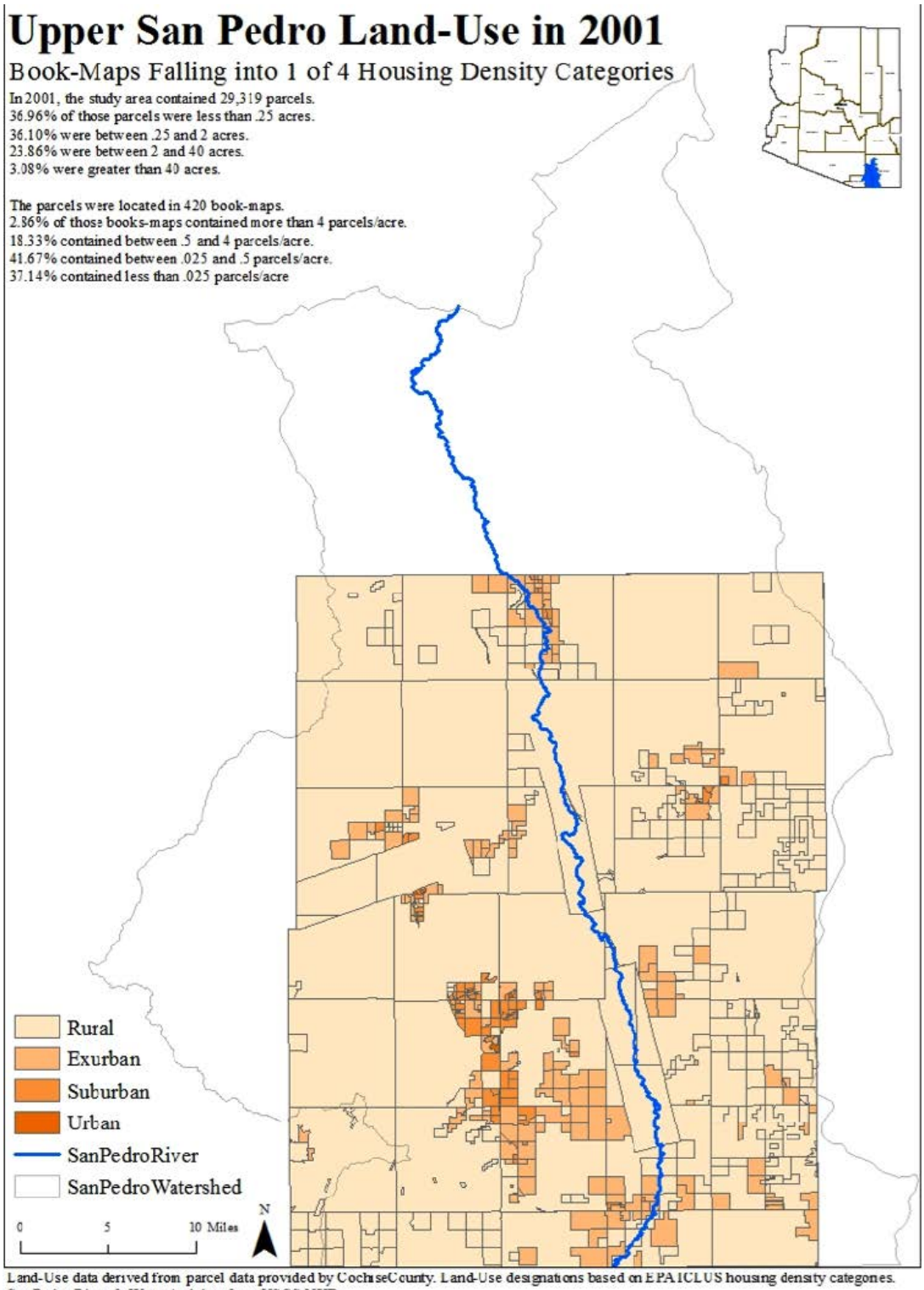


Figure 23: Upper San Pedro Land Use, 2001

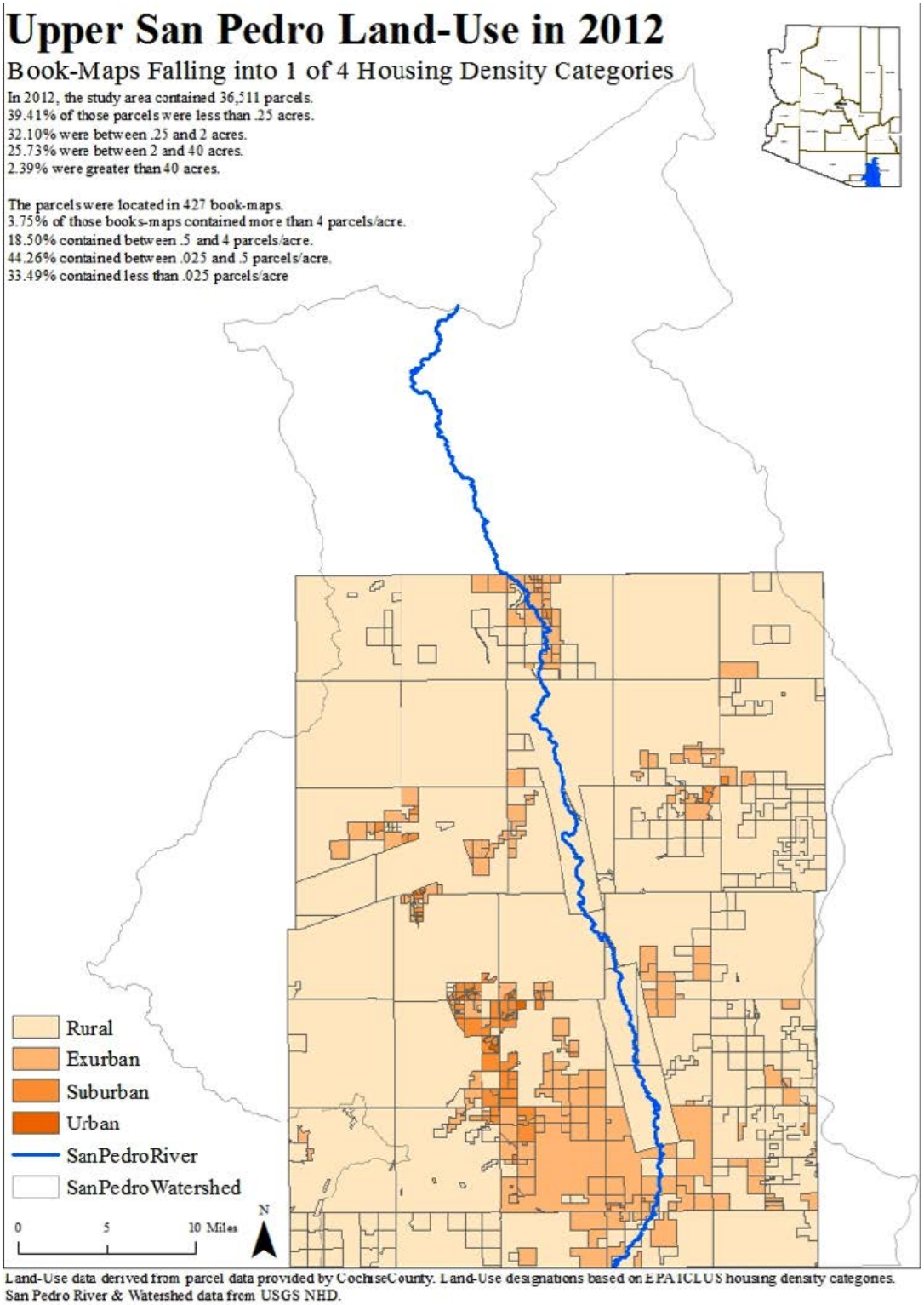
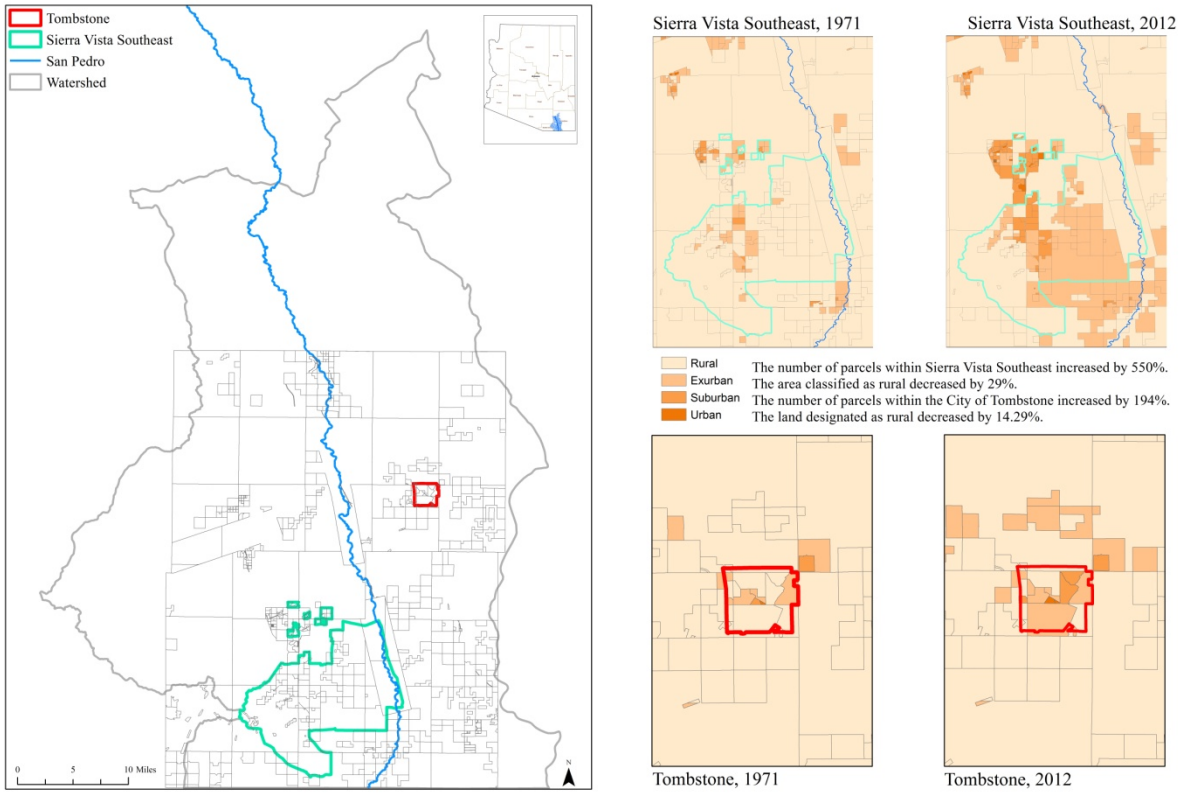


Figure 24: Upper San Pedro Land Use, 2012

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 25: 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 has been 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 acreage data;
- The discrepancy between what exists on paper versus reality, i.e., parcels that have been subdivided may not have been developed;
- The substantial amount of time needed to collect the data.

Incorporating findings from other change detection methodologies (such as 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.

Despite its limitations, using historic parcel data to examine land use change can be quite useful. Pairing historic parcel data with other historic and localized parameters could allow environmental managers to qualify the relationship between changing land use and other environmental and cultural trends at the community scale. For example, if paired with demographic and water quality data, environmental managers could use unique and scaled historic baselines to calibrate planning tools designed to explore plausible future impacts of different scenarios to a specific watershed, or even 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 integrated the Soil Water Assessment Tool (SWAT) component of AGWA with national scenarios provided from ICLUS.

As they are available, incorporating historic data into AGWA could potentially provide more accurate and relevant projections for smaller scale analyses versus the basin scale as was reported by Nie et al. (2011). 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 that same period, the population increased by 11% (U.S. Census Decennial, 1970 & 2010). Models used to forecast probable landscape 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 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 an expansion project's potential impact on land use patterns.

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 5 lists the decadal changes. Figures 26, 27, and 28 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 5: Decadal Trends in Population, Parcels, Book-Maps, and WWTF capacity in Sierra Vista, AZ.

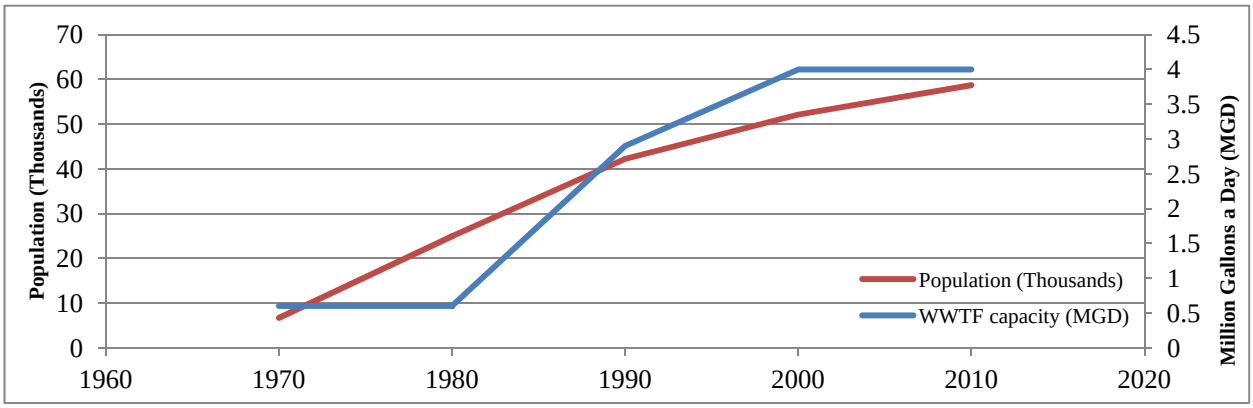


Figure 26: Population and Wastewater Treatment Facility (WWTF) Capacity in Sierra Vista, AZ: 1971 - 2012

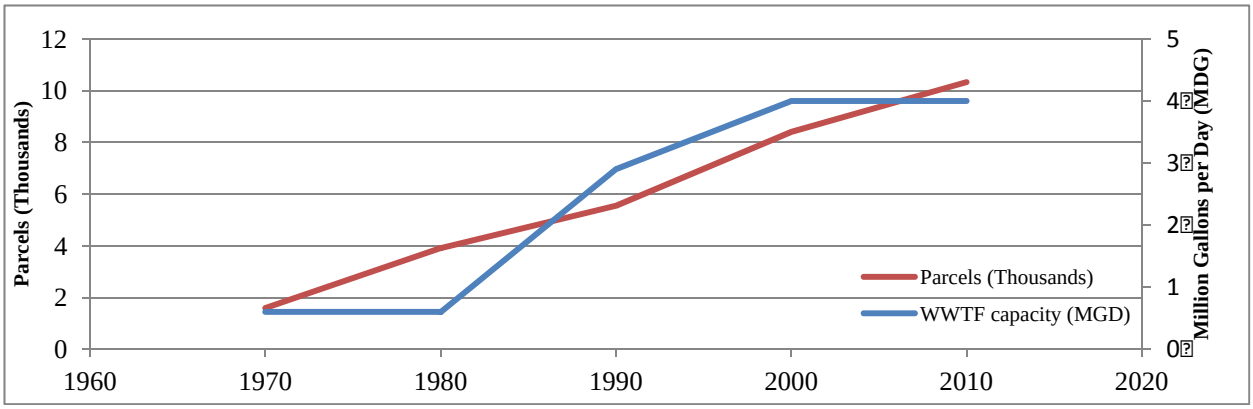


Figure 27: Number of Parcels and WWTF Capacity in Sierra Vista, AZ: 1971-2012

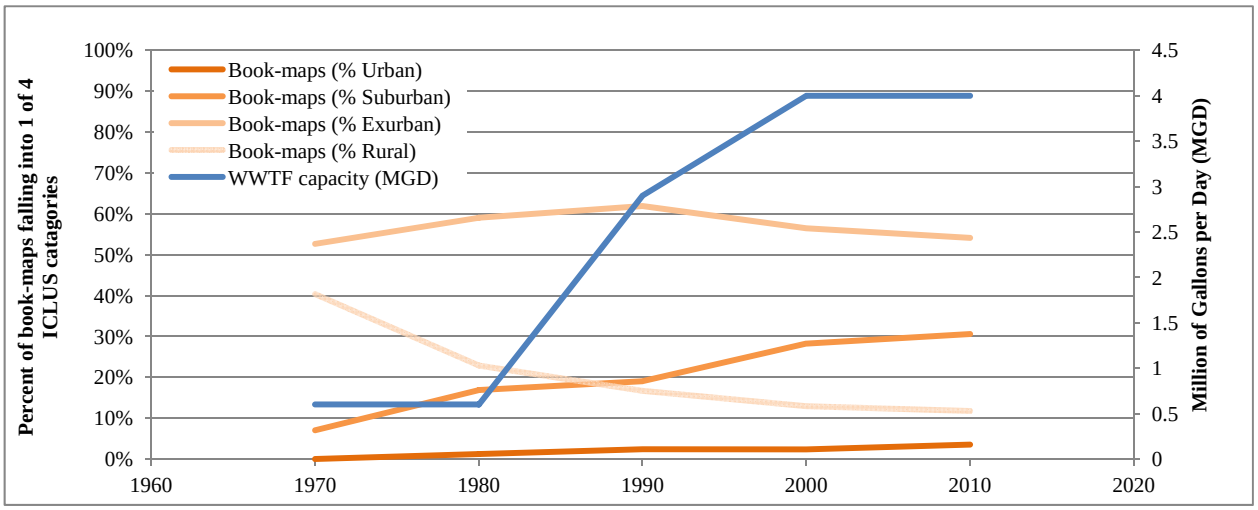


Figure 28: WWTF Capacity and Book-Maps in Sierra Vista, AZ: 1971-2012

Assuming the complex factors that affect everything from wastewater flow to subdivision development continue at the same rate as they did between 1971 through 2012, the trends displayed in Figures 26, 27, and 28 could be used to develop a scenario that projects how expanding Sierra Vista's WWTF would affect the area's pattern of land use[1].

The analysis suggests that for every increase of 1 MGD in Sierra Vista's wastewater treatment capacity, 1) the population would increase by nearly 13,000 people; 2) the number of parcels would increase by roughly 2,150 units; and 3) the land use would become roughly 1% more urban, 6% more suburban, and nearly 7% less rural. Using these assumptions, a NEPA reviewer analyzing the indirect effects of expanding Sierra Vista's WWTF from the current 4 MGD to a hypothetical 6 MGD could consider the addition of 26,000 more people, 4,300 more parcels, and a landscape that would become 2% more urban, 12% more suburban, and 14% less rural.

Determining whether or not these 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. But incorporating a future scenarios analysis into an indirect effects assessment could provide a more reliable basis from which to make predictions than the present approach, which has been criticized as inconsistent and imprecise (Mandelker 2010).

[1] *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.*

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. ICLUS HD categories were used for a number of reasons, including their use in a similar EPA research effort (Burns et al. 2013), the relative simplicity of their reclassification to a product supported by modeling tools (e.g. AGWA), and the significant science behind the product (IPCC and SRES consistent storylines).

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. There is particular concern over how new development could affect water rights the BLM holds to maintain flows through SPRNCA. This concern again emerged in the courts in May 2013 when the BLM filed suit to prevent the proposed 6,900-unit development in Sierra Vista (Davis 2013).

Evaluating the relationship between land use trends and water consumption patterns (i.e. changing number and capacity of wells, depth to aquifer levels, and river flow) could also help calibrate forecasting tools, inform indirect effect analyses, and generally help communities within the Upper San Pedro Watershed navigate contentious projects and environmental management quandaries. Such an analysis would benefit many communities in arid and semi-arid geographies. Rapidly rising populations place considerable pressure on finite water resources throughout the Southwest. Southwestern communities could greatly benefit from looking to their past to understand future impacts to water and other vital resources.

The methodology described 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 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. As 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 observed, "the simplest possible test for any futures game consist(s) in finding out whether it (can) predict the past."

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

102	103	104		105		106		107		108	109	110	120	121
10201	10337	10401	10454	10502	10553	10601	10655	10701	10765	10801	10901	11001	12031	12101
10202	10338	10402	10455	10503	10554	10602	10656	10713	10766	10806	10902	11003		12102
10203	10339	10403	10456	10504	10556	10603	10657	10715	10767	10807	10903	11004		12103
10204	10340	10404	10457	10505	10558	10604	10658	10716	10768	10808	10904	11005		12104
10206	10341	10405	10458	10506	10559	10605	10659	10717	10769	10811	10905	11006		12105
10207	10342	10406	10460	10507	10560	10606	10661	10718	10770	10812	10906	11009		12106
10208	10343	10407	10461	10508	10564	10608	10662	10719	10771	10813	10907	11012		12107
10209	10344	10408	10462	10509	10565	10609	10663	10720	10772	10814	10908	11013		12108
10210	10346	10409	10463	10510	10566	10610	10664	10721	10773	10815	10909	11014		12109
10211	10347	10410	10464	10511	10567	10611	10665	10722	10774	10816	10910	11016		12110
10218	10348	10411	10465	10512	10568	10612	10666	10723	10775	10817	10911	11017		12111
10221	10350	10412	10466	10513	10569	10615	10667	10724	10776	10818	10912	11018		12112
10234	10351	10413	10467	10514	10570	10616	10668	10727	10777	10819	10913	11019		12113
10235		10414	10468	10515	10571	10617	10669	10728	10778	10820	10914	11020		12114
10236		10415	10469	10516	10573	10618	10670	10729	10779	10821	10915	11022		12115
10259		10416	10470	10517	10574	10619	10671	10730	10780	10822	10917	11023		12116
		10417	10473	10518	10575	10620	10672	10731	10781	10829	10918	11024		12117
		10418	10474	10519	10576	10621	10673	10733	10782	10830	10919	11025		12118
		10419	10475	10520	10577	10622	10674	10734	10783	10831	10921	11026		12119
		10420	10476	10521	10578	10623	10675	10736	10784	10832	10924	11027		12120
		10421	10477	10524	10583	10624	10677	10737		10833	10925	11028		12121
		10422	10478	10525	10588	10625	10678	10738		10836	10928	11029		12122
		10423	10479	10527	10589	10626		10739		10837	10930	11030		12123
		10424	10480	10528	10590	10627		10740		10838	10932	11031		12125
		10425	10481	10529	10591	10628		10741		10839	10933	11032		12126
		10426	10482	10530	10592	10629		10742		10840		11033		12127
		10427	10483	10531	10593	10631		10743		10841		11034		12128
		10431	10484	10533	10594	10632		10744		10844		11035		12129
		10434	10485	10534	10595	10634		10745		10850		11040		12130
		10437		10535	10596	10635		10746		10853		11041		12131
		10438		10536	10597	10636		10747		10869		11042		12133
		10439		10537	10598	10639		10748		10876		11043		12134
		10440		10538	10599	10640		10749		10881		11044		12135
		10441		10539		10641		10750		10882		11045		12136
		10442		10540		10642		10751		10883		11050		12137
		10443		10541		10643		10752				11051		12139
		10444		10542		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
		10450		10549		10651		10761						12147
		10451		10550		10652		10762						12149
		10452		10551		10653		10763						12150
		10453		10552		10654		10764						12151

Appendix B: Changing Number of Parcels within Study Area 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
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

Book-Map	1971 (# of parcels)	1981 (# of parcels)	1991 (# of parcels)	2001 (# of parcels)	2012 (# of parcels)
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
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

Book-Map	1971 (# of parcels)	1981 (# of parcels)	1991 (# of parcels)	2001 (# of parcels)	2012 (# of parcels)
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
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

Book-Map	1971 (# of parcels)	1981 (# of parcels)	1991 (# of parcels)	2001 (# of parcels)	2012 (# of parcels)
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
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

Book-Map	1971 (# of parcels)	1981 (# of parcels)	1991 (# of parcels)	2001 (# of parcels)	2012 (# of parcels)
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
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

Book-Map	1971 (# of parcels)	1981 (# of parcels)	1991 (# of parcels)	2001 (# of parcels)	2012 (# of parcels)
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
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

Book-Map	1971 (# of parcels)	1981 (# of parcels)	1991 (# of parcels)	2001 (# of parcels)	2012 (# of parcels)
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
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

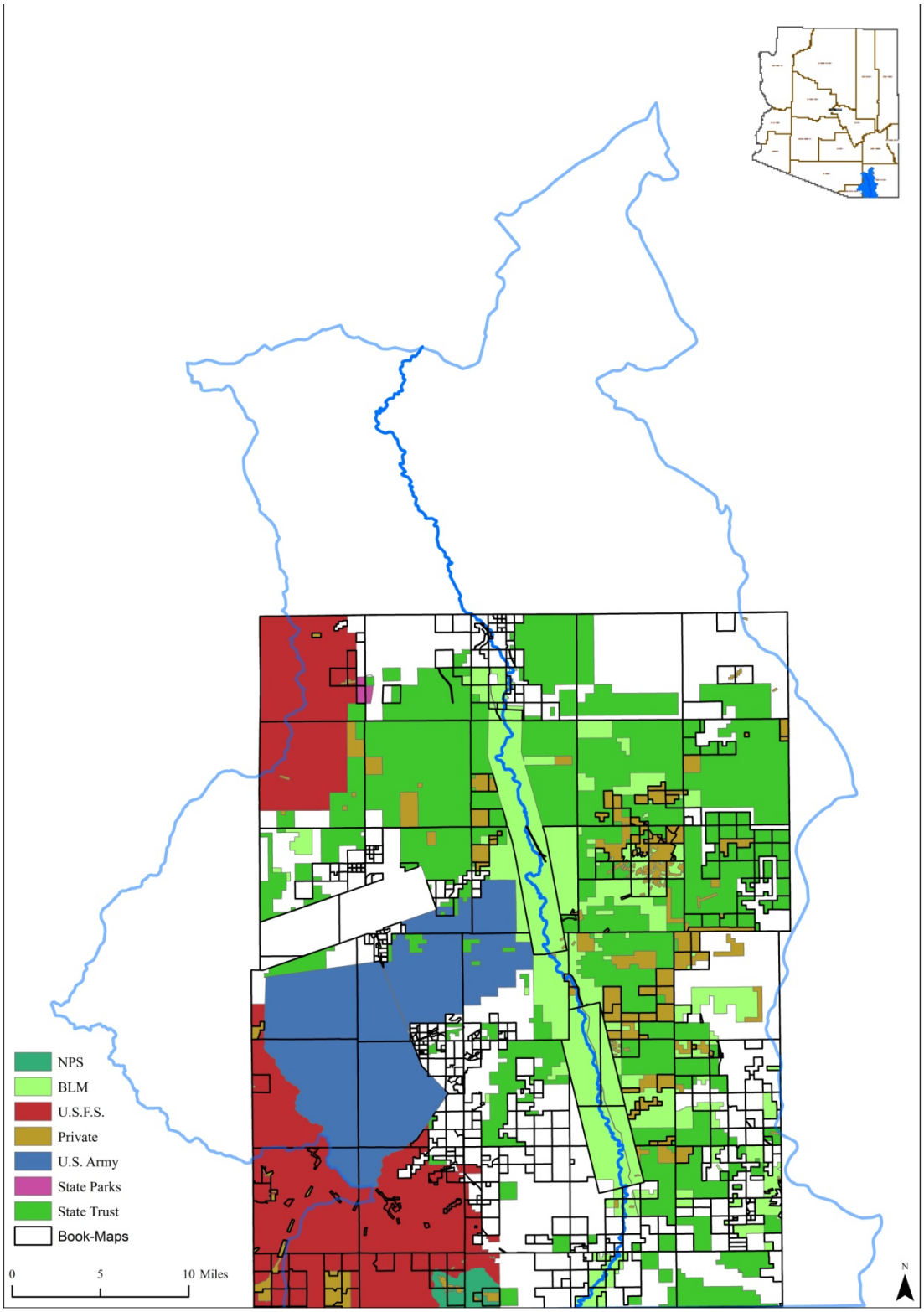
Book-Map	1971 (# of parcels)	1981 (# of parcels)	1991 (# of parcels)	2001 (# of parcels)	2012 (# of parcels)
10775	0	44	59	83	89
10776	0	133	124	124	124
10777	0	173	155	155	156
10778	0	51	423	819	876
10779	0	219	219	219	220
10780	0	1	1	1	1
10781	0	2	0	0	1
10782	0	117	117	117	117
10783	0	124	124	124	124
10784	0	178	178	178	178
10801	3	4	4	4	12
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

Book-Map	1971 (# of parcels)	1981 (# of parcels)	1991 (# of parcels)	2001 (# of parcels)	2012 (# of parcels)
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
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

Book-Map	1971 (# of parcels)	1981 (# of parcels)	1991 (# of parcels)	2001 (# of parcels)	2012 (# of parcels)
11026	1	1	1	1	1
11027	1	2	2	2	2
11028	1	3	3	3	3
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
12119	12	16	15	18	23

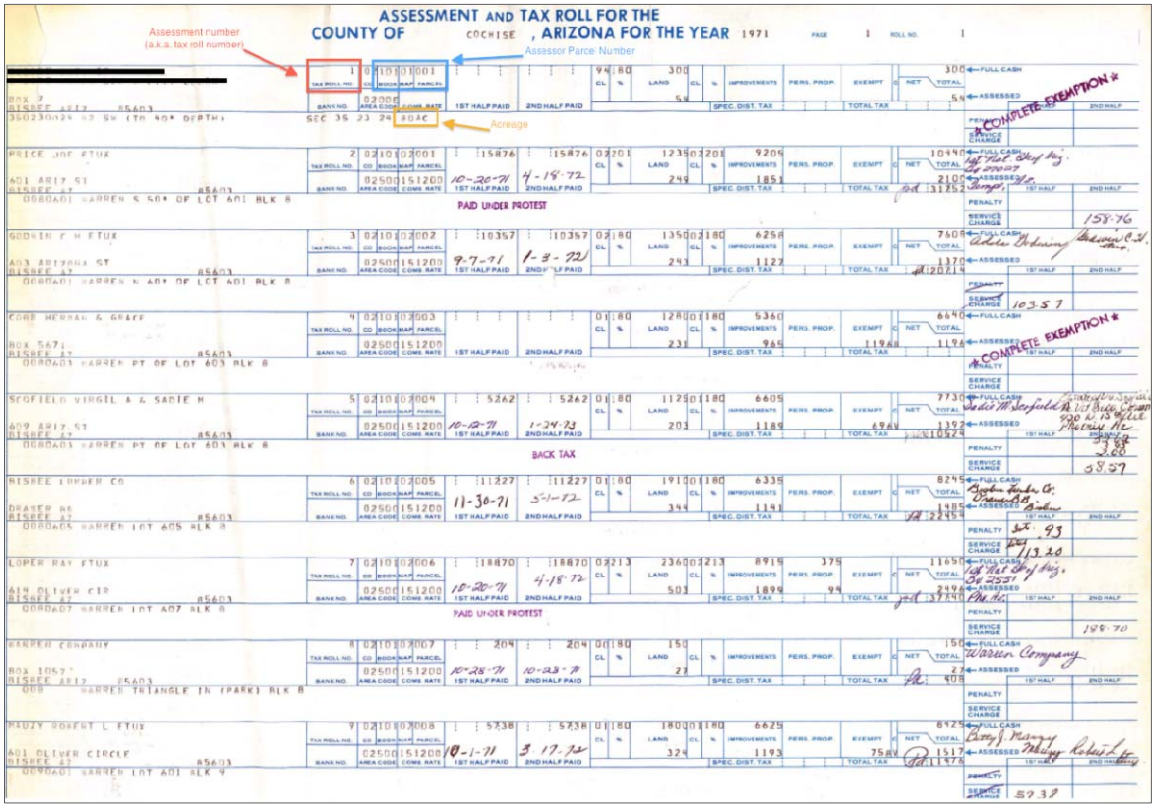
Book-Map	1971 (# of parcels)	1981 (# of parcels)	1991 (# of parcels)	2001 (# of parcels)	2012 (# of parcels)
12120	1	13	25	28	33
12121	13	44	69	91	90
12122	7	13	20	20	26
12124	4		8		
12123	2	4	4	37	47
12125	6	15	14	17	19
12126	2	2	2	2	1
12127	4	4	4	4	7
12128	11	16	23	34	40
12129	0	0	16	16	16
12130	0	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

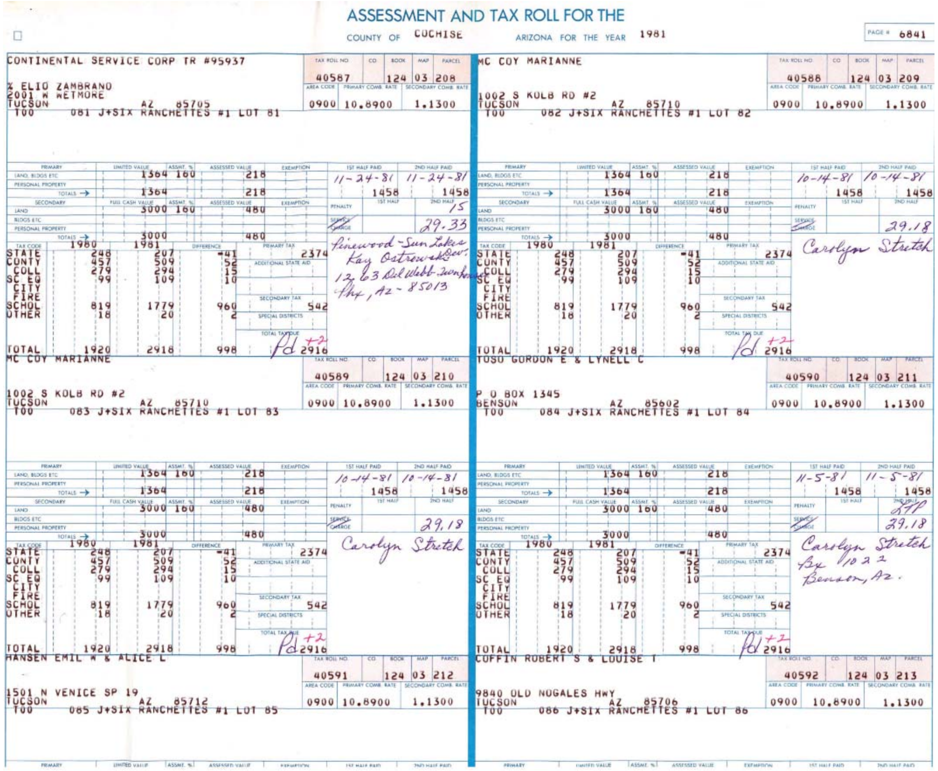


Land Jurisdiction and book-map data provided by Cochise County. San Pedro River and Watershed data from USGS NHD.

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
100 081 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
100 082 J+SIX RANCHETTES #1 LOT 82
40588 124 03 209 0900 10.8900 1.1300

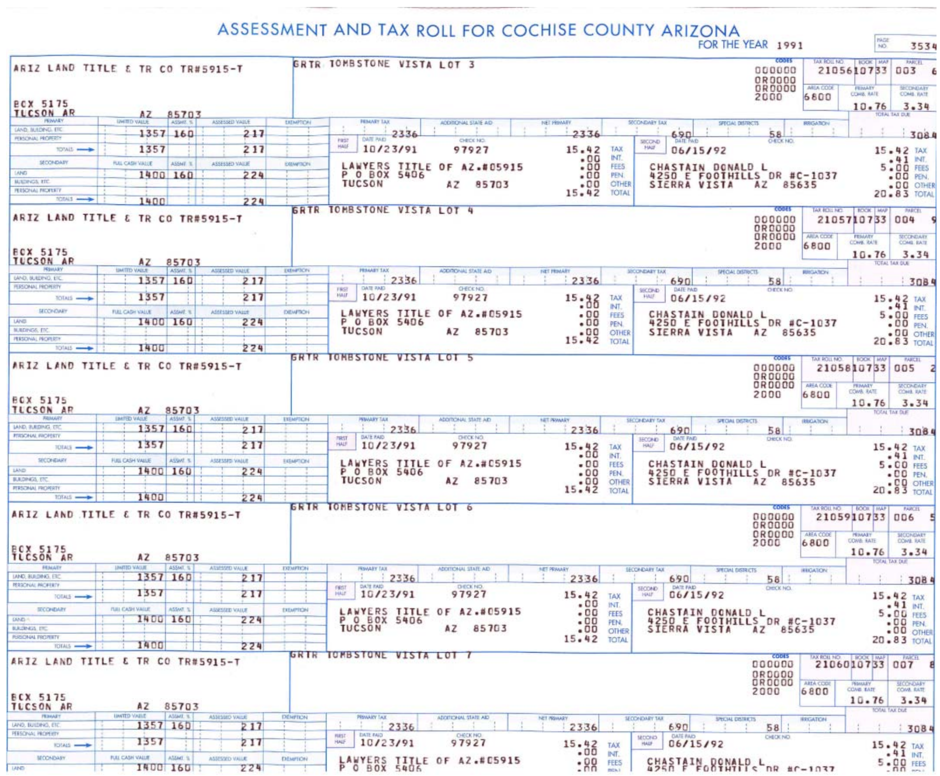
MC COY MARIANNE
1002 S KOLB RD #2
TUCSON AZ 85710
100 083 J+SIX RANCHETTES #1 LOT 83
40589 124 03 210 0900 10.8900 1.1300

TOSO GORDON E & LYNELL C
P O BOX 1345
BENSON AZ 85602
100 084 J+SIX RANCHETTES #1 LOT 84
40590 124 03 211 0900 10.8900 1.1300

HANSEN EMIL W & ALICE L
1501 N VENICE SP 19
TUCSON AZ 85712
100 085 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
100 086 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 NO. 3534

ARIZ LAND TITLE & TR CO TR#5915-T
BOX 5175
TUCSON AR AZ 85703
GRTR TOMBSTONE VISTA LOT 3
21056 10733 003 6800 10.76 3.34
1357 160 217 / 1400 160 224
2336 690 58 3084
10/23/91 97927 15.42
LAWYERS TITLE OF AZ.#05915 P O BOX 5406 TUCSON AZ 85703
06/15/92 CHASTAIN DONALD L 4250 E FOOTHILLS DR #C-1037 SIERRA VISTA AZ 85635
15.42 TAX .41 INT. 5.00 FEES .00 PEN. .00 OTHER 20.83 TOTAL

ARIZ LAND TITLE & TR CO TR#5915-T
GRTR TOMBSTONE VISTA LOT 4
21057 10733 004 6800 10.76 3.34

ARIZ LAND TITLE & TR CO TR#5915-T
GRTR TOMBSTONE VISTA LOT 5
21058 10733 005 6800 10.76 3.34

ARIZ LAND TITLE & TR CO TR#5915-T
GRTR TOMBSTONE VISTA LOT 6
21059 10733 006 6800 10.76 3.34

ARIZ LAND TITLE & TR CO TR#5915-T
GRTR TOMBSTONE VISTA LOT 7
21060 10733 007 6800 10.76 3.34

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

References

American Rivers. 1999. America's Most Endangered Rivers of 1999. http://www.americanrivers.org/our-work/protecting-rivers/endangered-rivers/background/past-reports.html (Last accessed May 16 2011).

Arias, H. M. 2000. International Groundwaters: The Upper San Pedro River Basin *Case*. *Natural Resources Journal*. 40: 199-221.

Bahre, C.J. 1991. *Legacy of Change: Historic Human Impact on Vegetation in the Arizona Borderlands*. Tucson, AZ: University of Arizona Press.

Bahre, C. J. and M. L. Shelton. 1993. Historic vegetation change, mesquite increases, and climate in southeastern Arizona. *Journal of Biogeography* 20:489-504.

Bureau of Land Management (BLM). 2013. Homesteading Timeline. www.blm.gov/pgdata/etc/medialib/blm/wo/Law_Enforcement/nlcs/education__interpretation/homestead_graphics0.Par.57736.File.dat/Expanded%20Homestead%20Timeline%20final.pdf (Last accessed May 25 2013).

Bierwagen, B. G., D. M. Theobald, C. R. Pyke, A. Choate, P. Groth, J. V. Thomas, and P. Morefield. 2010. National Housing and Impervious Surface Scenarios for Integrated Climate Impact Assessments. *Proceedings of the National Academy of Sciences of the United States of America*. Vol. 107, No. 49 20887-20892.

Branson, F. A. 1985. Vegetation changes on western rangelands. Society for Range Management.

Brauman, K. A., G. C. Daily, T. K. Duarte, and H. A. Mooney. 2007. The Nature and Value of Ecosystem Services: An Overview Highlighting Hydrologic Services. *Annual Review of Environmental Resources* 32:67–98.

Browning-Aiken, A., H. Richter, D. C. Goodrich, B. Strain, and R. Varady. 2004. Upper San Pedro Basin: Fostering Collaborative Binational Watershed Management. *International Journal of Water Resources Development* 20 (3): 353-367.

Burchell, R. W. and S. Mukherji. 2003. Conventional development versus managed growth: the costs of sprawl. *American Journal of Public Health* 93(9), 1534-1540.

Burns, I. S., W. G. Kepner, D. P. Sidman, D. C. Goodrich, L. R. Guertin, L. R. Levick, W. Yee, M. Scianni, C. S. Meek, and J. B. Vollmer. 2013. *Assessing Hydrologic Impacts of Future Land Cover Change Scenarios in the San Pedro River (U.S./Mexico).* EPA/600/R-13/074; ARS/294076. U.S. Environmental Protection Agency, Office of Research and Development, Las Vegas, NV.

Center for Biological Diversity/CBD. 2013. San Pedro River: Action Timeline. www.biologicaldiversity.org/programs/public_lands/rivers/san_pedro_river/action_timeline.html (Last Accessed July 2 2013).

Chapin, F. S., P. A. Matson, and H. A. and Mooney. 2002. *Principles of Terrestrial Ecosystem Ecology*. New York, NY: Springer Science.

Bredehoeft, J., R. Lacewell, J. Price, H. Arias, J. Stromberg, and G. Thomas. 1999. *Ribbon of Life: An Agenda for Preserving Transboundary Migratory Bird Habitat on the Upper San Pedro River*. Commission for Environmental Cooperation, Montréal, Qué.

Covington, W. W. and M. M. Moore. 1992. Postsettlement Changes in Natural Fire Regimes: Implications for Restoration of Old-growth Ponderosa Pine Forests. In *Old-growth forests in the Southwest and Rocky Mountain Regions*, eds. Kaufmann, M. R., W. H. Moir, and R. L. Bassett. United States Department of Agriculture (USDA)/ United States Forest Service (USFS), Fort Collins, CO.

Davis, Tony. 2013. Dispute looms in Sierra Vista over housing vs. water rights. *Arizona Daily Star*. http://azstarnet.com/mobi/business/article_03a3c62f-ad96-5c64-a5c0-5983e55b88ad.html (Last accessed July 2 2013).

DeFries, R. S., and K. N. Eshleman. 2004. Land-use Change and Hydrologic Processes: A Major Focus for the Future. *Hydrological Processes* 18(11): 2183-2186.

Esparza, A. X. and Carruthers, J. I. 2000. Land Use Planning the Exurbanization in the Rural Mountain West: Evidence from Arizona. *Journal of Planning Education and Research* 20: 23-36.

Grover, H. D. and H. B. Musick. 1990. Shrubland Encroachment in Southern New Mexico, U.S.A.: an Analysis of Desertification Processes in the American Southwest. *Climatic Change* 17:305-330.

Hastings, J. R., & R. M. Turner. 1965. *The Changing Mile: An Ecological Study of Vegetation Change with Time in Her Lower Mile of An Arid and Semi-arid Region*. Tucson, AZ: University of Arizona Press.

Humphrey, R. R.1958. The desert grassland a history of vegetational change and an analysis of causes. *The Botanical Review* 24(4), 193-252.

International Association of Assessing Officers/IAAO. 2012. *Standard on Digital Cadastral Maps and Parcel Identifiers*. www.iaao.org/uploads/Standard_Digital_Cadastral_Mapping.pdf (Last accessed on July 9 2013)

Kepner, W. G., D. J. Semmens, D. T. Heggem, E. J. Evanson, C. M. Edmonds, S. N. Scott, D. W. and Ebert. 2003. *The San Pedro River Geo-data Browser and Assessment Tools*. EPA/600/C-03/008; ARS/152432. U.S. Environmental Protection Agency, Office of Research and Development, Las Vegas, NV.

Kepner, W. G., C. J. Watts, C. M. Edmonds, J. K. Maingi, S. E. Marsh, and G. Luna. 2000. A Landscape Approach for Detecting and Evaluating Change in a Semi-arid Environment. *Journal of Environmental Monitoring and Assessment* 64, No. 1: 179-195.

Kepner, W.G., C. M. Edmonds, and C. J. Watts. 2002. Remote Sensing and Geographic Information Systems for Decision Analysis in Public Resource Administration: A Case Study of 25 Years of Landscape Change in a Southwestern Watershed. EPA/600/R-02/039. U.S. Environmental Protection Agency, Office of Research and Development, Las Vegas, NV.

Kepner, W. G., D. J. Semmens, S. D. Bassett, D. A. Mouat, and D. C. Goodrich. 2004. Scenario Analysis for the San Pedro River, Analyzing Hydrological Consequences of a Future Environment. *Journal of Environmental Monitoring and Assessment* 94:115–127.

Koprowski, J. L., A. J. Edelman, B. S. Pasch, and D. C. Buecher. 2005. *A dearth of data on the mammals of the Madrean Archipelago: what we think we know and what we actually do know*. USDA Forest Service proceedings RMRS-P-36, 412-415.

Mandelker, D. R. 2010. National Environmental Policy Act: A Review of Its Experience and Problems. *The Washington University Journal of Law and Policy* 32: 293-312

Nakicenovic, N., J. Alcamo, G. Davis, B. de Vries, J. Fenhann, S. Gaffin, and Z. Dadi. 2000. *Special report on emissions scenarios: a special report of Working Group III of the Intergovernmental Panel on Climate Change* (No. PNNL-SA-39650). Pacific Northwest National Laboratory, Richland, WA (US), Environmental Molecular Sciences Laboratory (US).

National Health and Environmental Effects Research Laboratory (NHEERL). 2013. *Level III Ecoregions of North America.* U.S. Environmental Protection Agency, Office of Research & Development (ORD).

Nie, W., Yuan, Y., Kepner, W., Nash, M. S., Jackson, M., & Erickson, C. 2011. Assessing impacts of Land-use and Land-cover changes on hydrology for the upper San Pedro watershed. *Journal of Hydrology* 407(1): 105-114.

40 C.F.R § 15808.8 (b). Indirect effects. 1970.

40 C.F.R § 6.207 (a)(3)(xi) Environmental Impact Statements. 1970.

Pool, D. R., & A. L. Coes. 1999. *Hydrogeologic investigations of the Sierra Vista subwatershed of the upper San Pedro basin, Cochise County, southeast Arizona*. US Geological Survey.

Powers, R. 2002. *Plowing the dark*. Random House.

Rodgers, W. M. 1965. *Historical land occupance of the upper San Pedro River Valley since 1870.* University of Arizona.

Skroch, M. 2009. Sky Islands of North America: A Globally Unique and Threatened Inland Archipelago. *Journal of Wilderness* 15(1): 9.

Swanson, F. J., J. A. Jones, D. A. Wallin, and J. H. Cissel. 1993. Natural Variability-Implications for Ecosystem Management. In *Eastside forest ecosystem health assessment, Vol. II, Ecosystem management: principles and applications*, eds. Jensen, M.E. and P.S. Bourgeron. USDA/USFS, Missoula, MT.

Smith, N. 1996. The Production of Nature. *FutureNatural: Nature, science, culture* 35-54.

Southeastern Arizona Governments Association/SEAGO. 1978. *Section 208 Water Quality Management Plan.*

SEAGO. *2012. Section 208 Water Quality Management Plan*. http://seago.org/?q=2011-wqmp-update (Last accessed July 9 2013).

Turner, R. M., R. H. Webb, J. E. Bowers, and J. R. Hastings. 2003. *The Changing Mile Revisited: An Ecological Study of Vegetation Change with Time in the Lower Mile of an Arid and Semiarid Region*. Tucson, AZ: University of Arizona Press.

U.S Census. 1970. The Decennial Censuses for Arizona. www.census.gov/prod/www/decennial.html (Last accessed June 5 2013).

U.S Census. 2010. The Decennial Censuses for Arizona. www.census.gov/prod/www/decennial.html (Last accessed June 5 2013).

U.S. Environmental Protection Agency (EPA). 2009. *Land-Use Scenarios: National-Scale Housing-Density Scenarios Consistent with Climate Change Storylines*. EPA/600/R-08/076F. U.S. Environmental Protection Agency, Global Change Research Program, National Center for Environmental Assessment, Washington, DC.

U.S. Environmental Protection Agency. 2010. *ICLUS V1.3 User's Manual: ARCGIS Tools for Modeling US Housing Density Growth*. EPA/600/R-09/143F . U.S. Environmental Protection Agency, Global Change Research Program, National Center for Environmental Assessment, Washington, DC.

U.S. Environmental Protection Agency STOrage and RETrieval (STORET). 2012. HUC 15050202. http://www.epa.gov/storet/. (Last accessed July 9 2013).

Vitousek, P. M. 1994. Beyond global warming: Ecology and global change. *Ecology* 75(7):1861–1876.

Vörösmarty, J., P. Green, J. Salisbury, and R. B. Lammers. 2000. Global water resources: vulnerability from climate change and population growth. *Science* 289, 284–288.

West, C. T. and M. Vásquez-León. 2008. Misreading the Arizona landscape: Reframing analyses of environmental degradation in southeastern Arizona. *Human Organization* 67(4), 373-383.

Whitehead, P. G., R. L.Wilby, R. W. Battarbee, M. Kernan, and A.J. Wade. 2009. A Review of the Potential Impacts of Climate Change on Surface Water Quality. *Hydrological Sciences* 54(1), 101–123.

United States Department of Agriculture/USDA. 1979. *Monitoring Foreign Ownership of U.S. Real Estate: A Report to the Congress, Vol. 2.*

Upper San Pedro River Partnership. (2011). *Water Management of the Regional Aquifer in the Sierra Vista Subwatershed, Arizona - 2011 Report to Congress.* U.S. Department of the Interior, Washington, DC.

United States
Environmental Protection
Agency

Office of Research
and Development (8101R)
Washington, DC 20460

Please make all necessary changes on the below label, detach or copy and return to the address in the upper left hand corner.

If you do not wish to receive these reports CHECK HERE ☐; detach, or copy this cover, and return to the address in the upper left hand corner.

PRESORTED STANDARD
POSTAGE & FEES PAID
EPA PERMIT No. G-35

Official Business
Penalty for Private Use
$300

EPA/600/R-13/112
USDA/ARS/295385
July 2013
www.epa.gov