6-7-2013

Assessing change and resilience in a northern New Mexico acequia irrigation community

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ASSESSING CHANGE AND RESILIENCE IN A NORTHERN NEW MEXICO ACEQUIA IRRIGATION COMMUNITY

by

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A Professional Project Report Submitted in Partial Fulfillment of the Requirements for the Dual Degree of:

Master of Water Resources
Master of Community & Regional Planning

The University of New Mexico
Albuquerque, New Mexico

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COMMITTEE APPROVAL

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ABSTRACT

Acequias in New Mexico are the oldest water management institutions of European origin in the United States. Remarkably, the acequias studied in this project have been continuously maintained for over 200 years. These communal water management systems have survived through major droughts and persisted through time, but are now vulnerable to new disturbances that threaten their livelihood. Research on these disturbances helps us protect acequias, not only for their inherent cultural and historic values, but also for the example they provide as an effective way to manage water in times of scarcity. This should be particularly important in an era and region of current and projected water shortages. Three major disturbances affecting the Rio Hondo acequias were studied in this project: land use change, climate change, and demographic change. Land use change was quantified over time by examining historic and contemporary aerial photos of the region in a Geographic Information Systems program and by utilizing a historic crop report. Climate data were collected from a number of sources and evaluated using a statistical trend test. Demographic data were collected mainly from the U.S. Census and the American Community Survey and analyzed through time. The findings suggest a loss of 25 percent of the agricultural lands in the Rio Hondo between 1969 and 2010, a shift towards less crop diversification, and displacement of agricultural land by development. The climate change research findings indicate that the region has experienced increased temperatures and drier conditions over time. Substantial shifts in demographics took place, including a decline in Hispanics and increase in Anglos, an aging of the population, and large overall population growth rates. Even with these major changes, the acequias in the Rio Hondo are found to be resilient, although there is some evidence of weakening of the acequia institution. Recommendations for future resilience are provided based on the report findings.

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ACKNOWLEDGEMENTS

First and foremost, I want to thank my committee members Bill Fleming, José Rivera, and Bruce Thomson for their patience, flexibility, and support throughout the long life of this project. Each of you brought a unique viewpoint and critique style that greatly improved my research. I would also like to thank David Gutzler for his review of the climate change chapter and the valuable advice that he provided in developing that chapter. Numerous folks in various organizations throughout Taos County and New Mexico helped me and I am deeply grateful for their assistance, because many of them provided access to the data that I needed to complete this project. They are: Darlene Vigil and Anthony Martinez of the Taos County Assessor's Office, Judy Torres of the Taos Valley Acequia Association, Floyd Archuleta of the Des Montes Folk Art Gallery, Tanya Duncan of the Taos Land Trust, and Quita Ortiz of the New Mexico Acequia Association. I would also like to thank fellow EPSCoR graduate researchers Sandeep Sabu and Marcos Roybal who were always there to help, not only with technical issues and data requests, but also with much needed moral support. Thanks are also in order for other fellow researchers who provided valuable resources including Michael Cox of Dartmouth College and Bobbi Jo Fossberg, Caiti Steele, Carlos Ochoa, and Sam Fernald – all of New Mexico State University. I would like to thank my husband, Nate Miller, for his help with editing and unwavering support of me during this process including dealing with my long hours. I am also indebted to my immediate family who managed to show their support from 1,500 miles away. Lastly, I would like to acknowledge the support provided by New Mexico EPSCoR under NSF Grant #0814449.

I would like to dedicate this professional project to my late grandmother, Betty Ruth Stone, who helped raise me to become the woman I am today. I have no doubt that my successes are largely due to the sacrifices she and other family members made for me early on in my life.

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CHAPTER ONE: INTRODUCTION

1.1 Professional Project Introduction and Objectives

This professional project is focused on studying change in an acequia irrigation system in the Rio Hondo watershed in northern New Mexico. The Rio Hondo is an 18 mile long tributary to the Rio Grande that originates in the Sangre de Cristo Mountains. It is a perennial stream that provides water for irrigation purposes during the growing season. Agricultural lands in the lower watershed are irrigated using an extensive acequia ditch network. Physically, acequias are gravity powered water ditches that deliver water from the river to agricultural fields. Culturally, acequias are much more than just water ditches – they are historic and complex social institutions that have provided a local form of government that would otherwise not exist and that allows for the communal management of water (Rivera, 1998).

The project first quantifies recent disturbances of land use, climate, and demographic change that threaten the Rio Hondo acequia system. The research then shifts to how well the acequia institution has adapted and responded to these disturbances to make a determination of resiliency. Land use change is considered to be the main indicator of resiliency, although other measures of resilience and functionality are utilized. Climate change and demographic change are studied because they are considered to be the causal forces of land use change and it is important to quantify these changes to determine the main causes of land use change in the region. Then, with the causes of land use change in mind, strategies are suggested that the acequias can adopt to ensure their future resiliency.

The primary feature of the study is the evaluation of land use change through the interpretation of aerial photography using Geographic Information Systems (GIS). Land use change was calculated by tracking the acreage of building development, crops grown, and riparian area at three points in time between 1935 and 2010 to facilitate the analysis of change over time. Climate change data and demographic data are also analyzed over time, but utilizing already existing sources of data. Resiliency is determined not only using the land use, climate, and demographic change data, but also using other sources such as local interviews and focus groups, an acequia functionality assessment, and an analysis of crop yields and income generation.

The overarching objectives identified for the project are outlined below; these objectives guided the entire research process:

1. Estimate how land use (building development and riparian area) has changed using photographic data from the years 1935, 1969, and 2010;
2. Determine the current mix of crops and establish how it has evolved since 1935;
3. Compare the results of land use/cropping pattern changes with another recent study to ascertain if there is a regional trend in this indicator (Ortiz, 2007);
4. Understand the impacts of climate change on the region and, to the greatest extent possible, the local Rio Hondo watershed;
5. Quantify any demographic changes that have occurred in the region;
6. Assess how well the acequia institution in the Rio Hondo is functioning and responding to the above changes;
7. Develop policy recommendations and provide ideas on how the community can ensure future cultural resiliency.

1.2 Experimental Program to Stimulate Competitive Research (EPSCoR)

This project was conducted through the New Mexico Experimental Program to Stimulate Competitive Research (NM EPSCoR) Research Infrastructure and Improvement Phase 3 (RII 3) titled “Climate Change Impacts on New Mexico’s Mountain Sources of Water.” In terms of the acequia sociocultural component of the research, the study addressed the following objectives:

- To document the ancient customs and traditions of acequia systems during times of climate variability and effects on human adaptation
- To characterize acequia socio-cultural institutions and robustness of acequia systems in the face of climatic variation
- To organize acequia focus groups and facilitate discussion of possible climate change impacts on traditional irrigation practices, cropping patterns and land use, water sharing agreements, storage facilities, and water conservation practices
- To monitor riparian health and develop student and stakeholder-driven partnerships in a long term environmental monitoring program.

This professional project was aimed at understanding land use change and its connection to climate change (as described in the objectives above) as well as demographic change. A main feature of this study was to characterize the robustness, or resilience, of the Rio Hondo acequia system. Care was also taken to document the customs and traditions of acequias in the Rio Hondo watershed, keeping in line with objectives of the larger research study.

1.3 Client

Although this research was undertaken as part of a larger research project through NM EPSCoR and serves to fulfill the requirements of a Master’s degree, it has always been intended that the principal client for this project be the acequias in the Rio Hondo watershed. The data generated by this project is intended to help these acequias in their endeavor towards continuing their unique way of life. Findings from this study may also be useful to other acequias in the region that are also grappling with land use, demographic, and climate change pressures.

1.4 Organization of Report

Chapter two will introduce the watershed, provide background information on acequias, and present a literature review of the pertinent topics studied in this project. Chapter three will cover land use and describe the methods used to assess land use change. Chapter four is focused on climate change and chapter five covers demographic change. The last chapter looks at additional measures to assess the resilience of the acequia system, provides a synthesis of results, gives conclusions on the resilience and functionality of the Rio Hondo acequia system, and, finally, offers recommendations for the future resilience of the acequia system.

CHAPTER TWO: BACKGROUND AND LITERATURE REVIEW

2.1 Introduction

This Professional Project was focused on studying change as it relates to land use, climate and demographics in the acequia irrigation community in the Rio Hondo watershed in northern New Mexico. Before analyzing these topics, it is important to describe the Rio Hondo watershed and the acequia institution itself. These introductions are followed by a literature review that summarizes relevant research that has been completed on the Rio Hondo watershed and reviews studies related to the research topics described above.

2.1.1 The Rio Hondo Watershed

The Rio Hondo watershed is located in northern New Mexico in the Sangre de Cristo Mountains and is just north of Taos, New Mexico. It includes the communities of Valdez, Des Montes, Arroyo Seco, Cañoncito, Arroyo Hondo, Kiowa Village, Twining, and the Taos Ski Valley. The elevation ranges from 5,500 feet in the lower watershed to 13,161 feet at Wheeler Peak (the highest point in New Mexico). The watershed drains about 72 square miles.

A general area map showing the study area is presented in Figure 1. In addition to showing the location of various towns that will be referenced in this report, the map illustrates the general vegetation density pattern with less dense vegetation existing in the lower watershed and more dense vegetation starting in the middle watershed. The upper watershed is also densely vegetated, though there is a clearly identifiable ski area and areas of bare rock at the highest elevations. The vegetation map (Figure 2) shows that there are agricultural fields in the lower, western part of the watershed, most of which are on the southern side of the Rio Hondo, and that there are a variety of different vegetation types at different elevations (elevation increasing to the east). Figure 3 shows the irrigated area of the lower watershed, which is the primary area of study for this report. The irrigated area is about 3,482 acres, or 5.5 square miles, and comprises about 8% of the total watershed area. Lastly, Figure 4 shows the land ownership in the Rio Hondo region. Most of the upper watershed is owned by the US Forest Service and most of the lower watershed is private land, though some is owned by the Bureau of Land Management (BLM) and some is owned by the Taos Pueblo.

The average calendar year water yield for the period of record at the USGS gaging station near Valdez is 25,072 acre-feet (Daniel B. Stephens, 2008). As is typical for watersheds in this region, the flow in the Rio Hondo is comprised primarily of snowmelt during the growing season since precipitation is meager at this time (Cox, 2010). Calculations have shown that the flow of water available on the Rio Hondo during the growing season is about 75 percent of the annual supply, meaning that the other 25 percent flows through the river outside of the irrigation season (Daniel B. Stephens, 2008). This statistic shows just how important the timing of the flow in the river is for the intended irrigation use and how it is possible for so many acres to be irrigated in the summer in this watershed.

2.1.2 Acequia Community Irrigation Systems

Acequias are community irrigation ditches that deliver water from a river to agricultural fields using only gravity to move the water. Traditionally, the ditches are earthen ditches, as is the case in most of the Rio Hondo (Rivera, 1998). Also, in most cases in New Mexico, acequias have been around for a long time – the acequias in the Rio Hondo have been consistently maintained for over 200 years (OSE Hydrographic Survey Bureau, 1969). Irrigation is typically done by flooding fields or orchards, but other methods such as drip irrigation have been used.

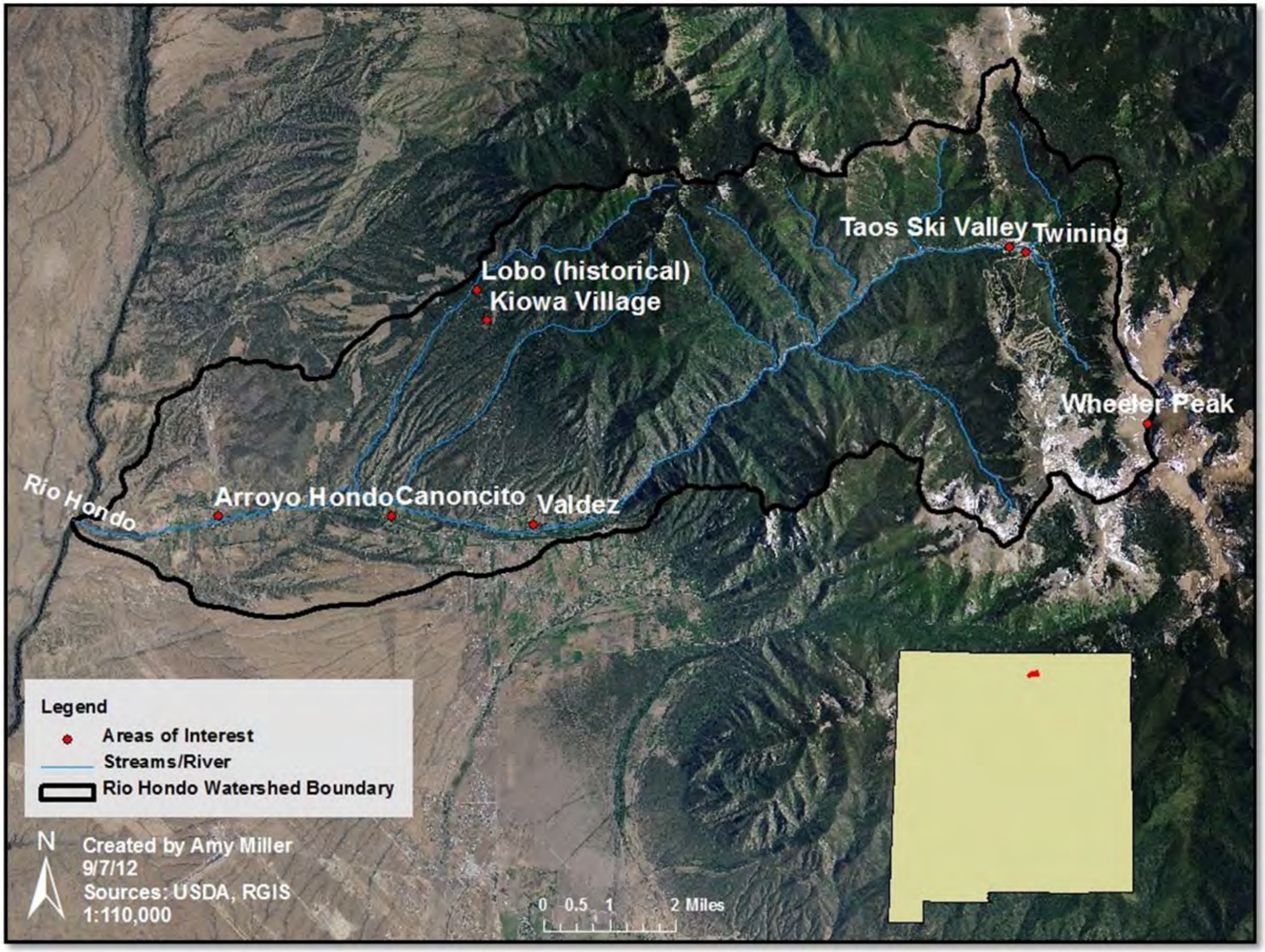

Figure 1: General Map of the Rio Hondo Watershed

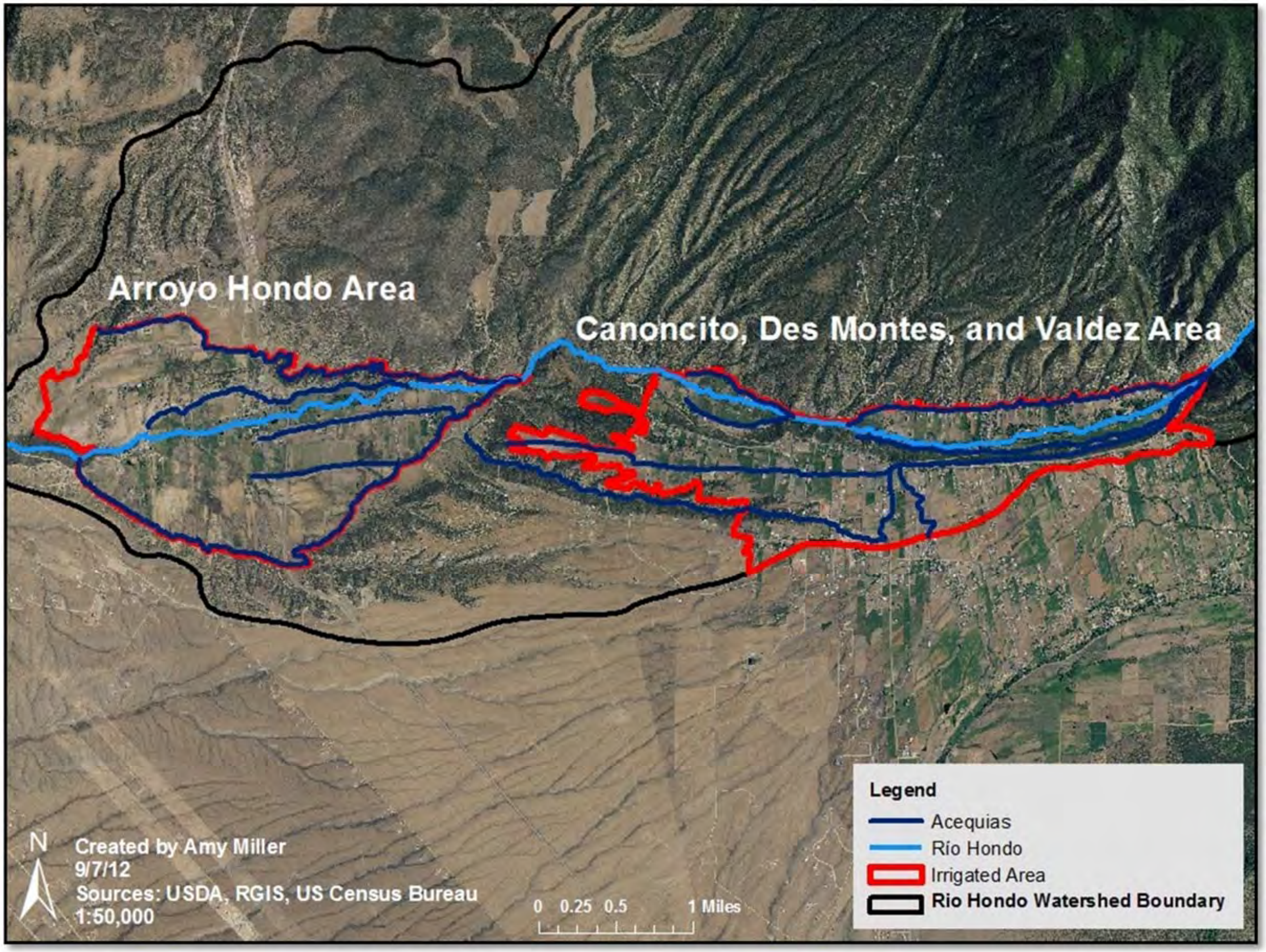

Figure 2: Irrigated Area in the Lower Rio Hondo Watershed

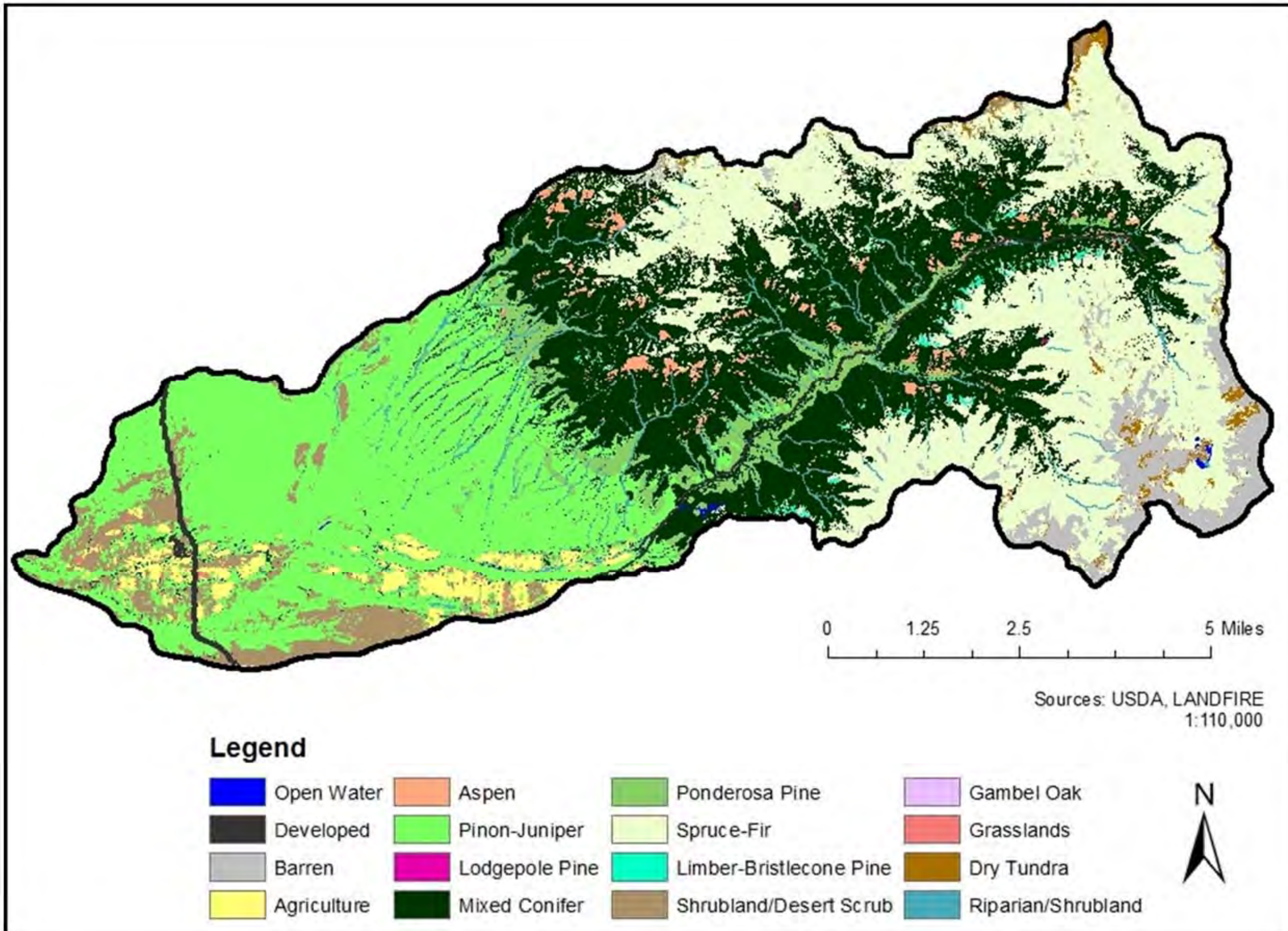

Figure 3: Vegetation Types in the Rio Hondo Watershed

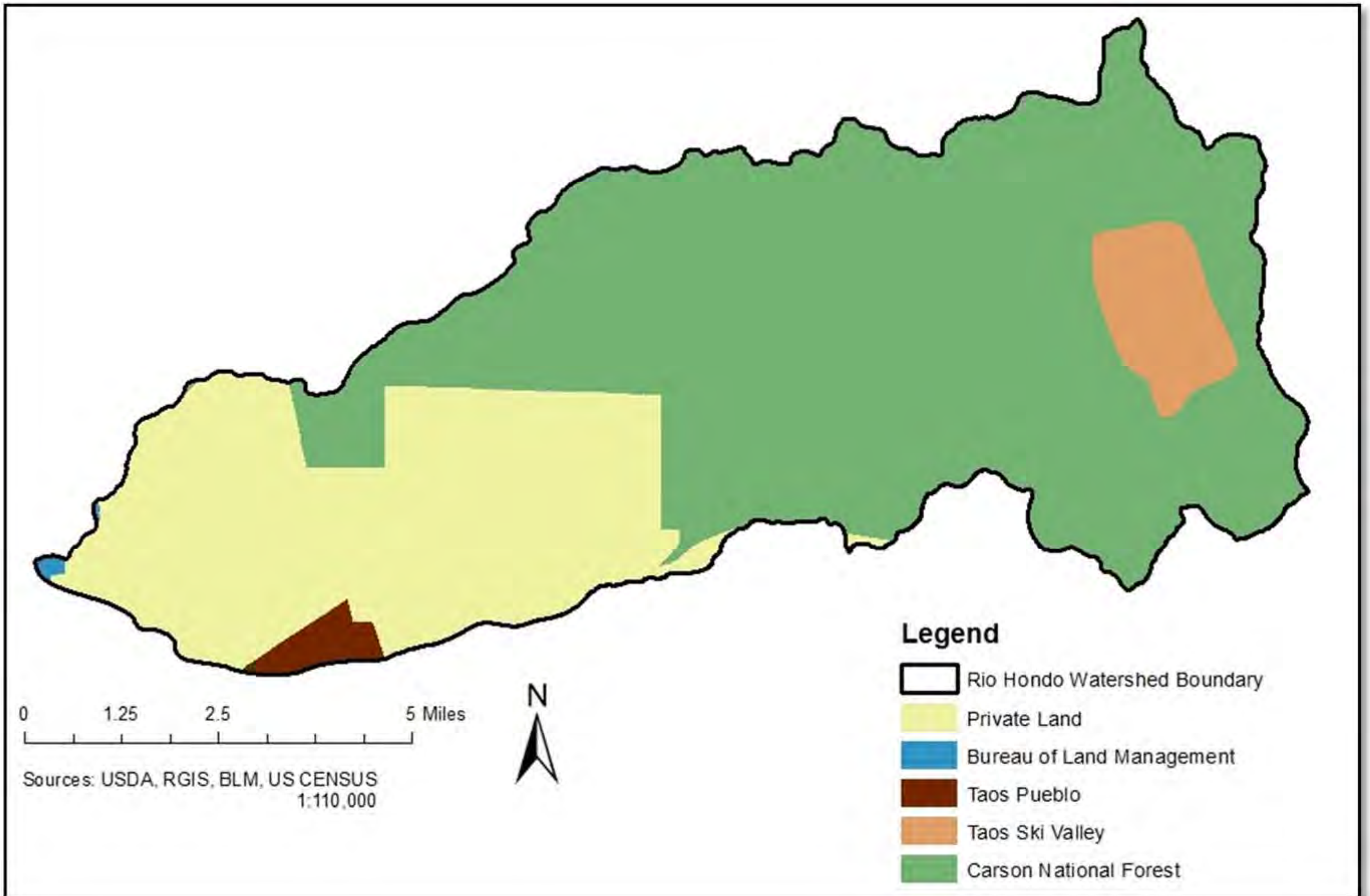

Figure 4: Land Ownership in the Rio Hondo Watershed

The first acequia in northern New Mexico was built by Spanish settlers at the Oñate colony in 1598 (Rivera, 1998). Outside of the Middle Rio Grande Valley, self-governed acequias continue to function much like they did when the Hispanos first introduced the practice centuries ago (Rivera and Martinez, 2009). Traditional acequias are still characterized by several features. The first is a main water ditch called the *acequia madre* that carries water from the stream to smaller lateral ditches (*sangrias*) that ultimately deliver water to fields. The *presa* is a dam that backs water up so that it may enter the *acequia madre*. The *compuerta*, or headgate, must be lifted to release water from the stream into the *acequia madre* (Rivera, 1998). In addition, traditional acequia systems are still communal systems that rely on local users to participate in maintenance and upkeep of the local ditch. All *parciantes* (irrigating landowners) follow the rule in which each *parciante* must contribute to maintenance in direct proportion to the benefits they receive (Rivera and Martinez, 2009; Rodriguez, 2006). Of course, the benefits they receive refers to the amount of water they are entitled to, which is related to the size of the property to be irrigated. The Spanish names for these waterworks are still used today, signifying the fact that this is still a strong Hispanic tradition.

Parciantes come together to form an acequia association. The members of the acequia association create their own rules and regulations for the management of water in the system, and they elect their own officers (Rivera and Martinez, 2009). The day-to-day management of the acequia is overseen by the mayordomo (ditch boss) whose responsibility lies in coordinating the *limpia* (spring cleaning) and making sure water is allocated according to the established set of rules (Rivera, 1998; Rodriguez, 2006). The ditch commission consists of three elected officials – a president, secretary, and treasurer. These ditch commissioners hold meetings, establish rules and policies, determine fees and fines, resolve disputes, and conduct the business affairs of the acequia (Rivera, 1998).

As noted in the introduction, the term acequia refers to the physical water ditches described above, but also to the complex social institution that is characterized by communal participation and local self-governance. The acequia as a social institution serves purposes other than just providing water to support local agricultural in an otherwise semi-arid landscape. According to Rivera (1998), these other purposes are social, political, and ecological. Socially, they have maintained local cultures and historic settlements through time. Politically, acequia associations have served as the only form of local government below the county level and are considered political subdivisions of the state. Ecologically speaking, acequias provide a number of additional services that extend from the lush landscape that is created as a result of acequia irrigation. This landscape has been called the *paisaje de la acequia* or *paisaje del agua*. These terms describe the "constructed artifact where water is the principle tool of landscape modification for human use and benefit….this modification produces a greenbelt extending the riparian zone of the river, creating an oasis that sustains habitats for plant biodiversity and wildlife native to the region, while recharging the aquifer and returning surplus water to a *desagüe* (drain) channel for reutilization by other stakeholders downstream (Rivera and Martínez, 2009, p. 2)."

Rural communities in New Mexico consider water to be the lifeblood of their communities. Their culture and way of life is threatened by climate change, urbanization of acequia landscapes, pressure on the scarce water resources brought to bear by other interests (urban growth, industry, tourism, recreation, the protection of endangered species), and the fact that current laws consider only the commodity value of water and do not recognize the community value of water (Rivera and Martínez, 2009). Another disturbance is the demographic shifts in which residents are increasingly new to the area and, unlike Hispanos in the region, do not carry with them the traditions and customs of the acequia way of life (Ortiz, 2012b). This research project seeks to explore many of these threats to the acequias in the Rio Hondo.

Figure 5 displays the extensive acequia network of the lower Rio Hondo watershed (Hawk and Mariposa ditch not pictured). There are 15 main acequias. Their lengths are presented in Table 1. Collectively they add up to over 30 miles in total length.

Table 1: Acequias and Their Length in the Rio Hondo, Adapted from Sabu (2012)

Acequia	**Total Length (miles)**
Acequia de Atalaya	5.2
Acequia de la Plaza	2.0
Acequia de San Antonio	2.7
Acequia del Cordillera Lateral	1.3
Acequia del Medio Lateral	1.6
Acequia Madre del Llano	3.8
Acequia del Llano	2.0
Canoncito North	0.8
Canoncito South	0.8
Cuchilla	2.1
Des Montes	2.5
Hawk	0.9
Mariposa	0.7
Prando	1.6
Rebalse	2.1
Total	**30.1**

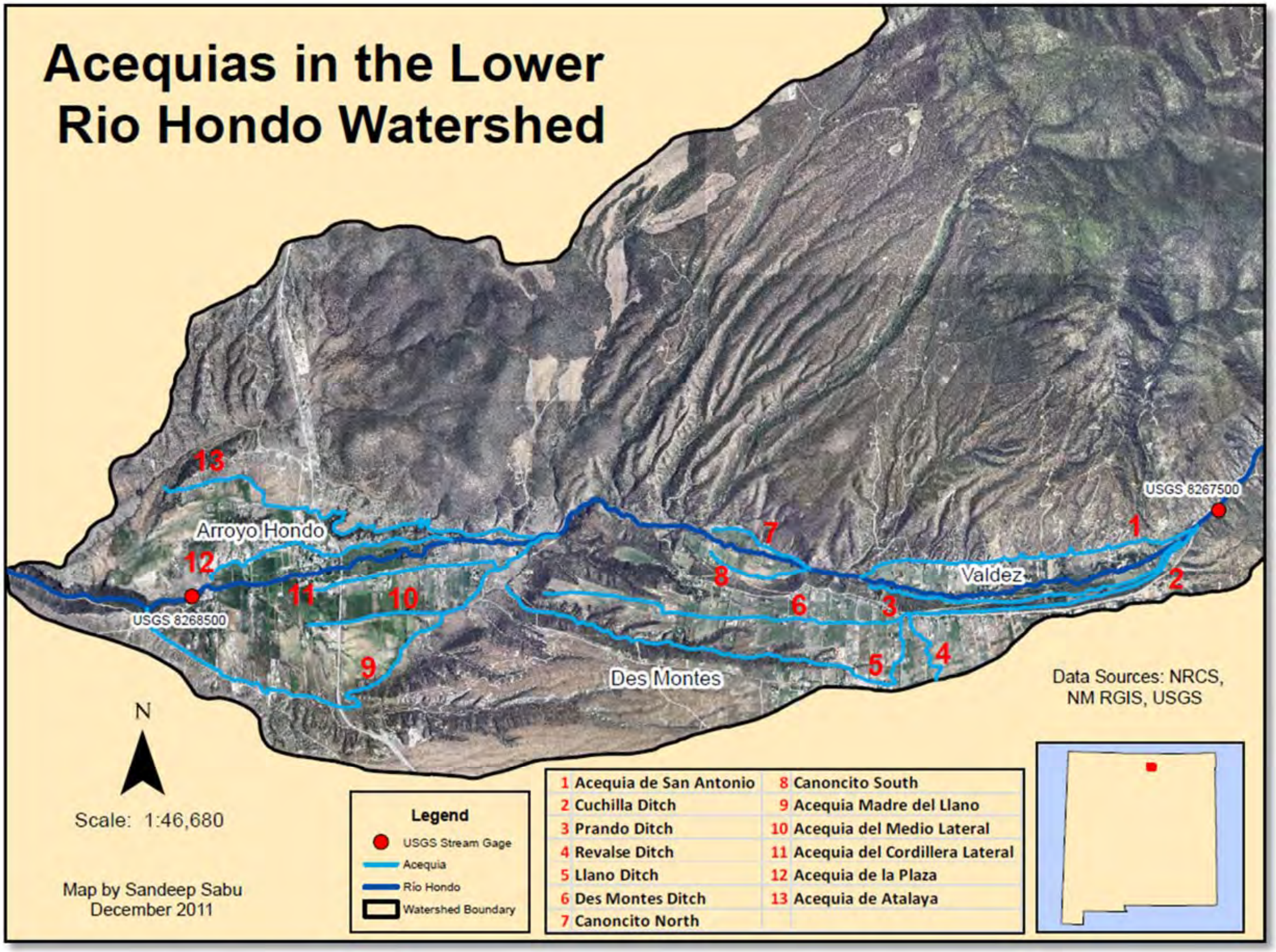

Figure 5: Acequias in the Lower Rio Hondo Watershed, Sabu (2012). Used with permission.

2.2 Literature Review

Although the watershed is small, a large amount of research and historical documentation has been completed on the area. The literature review below will start with a summary of relevant research that has been completed on the Rio Hondo watershed and then focus on other studies that are generally related to the research topics of this project.

2.2.1 Water Sharing on the Rio Hondo

In 1990, John Baxter prepared a study for the New Mexico State Engineer's Office, which administers the water resources in the state of New Mexico. The purpose of the study was to document settlement of the area and irrigation use in the Taos Valley. The Rio Hondo is featured in chapter one of Baxter's book. The most relevant information for this publication was the documentation of the historic tension between towns in the Rio Hondo area over the water rights of each community. A hearing was held in 1852 to determine the water rights of communities on the Rio Hondo. The judge ruled that Arroyo Hondo had first priority and was entitled to two-thirds of the flow of the river. However, this two-thirds had to be split between Arroyo Hondo, Valdez, and Canoncito. Des Montes was held to have rights to the remaining one-third of the flow of the river (Baxter, 1990).

The current flow sharing agreement, dated January 9, 2006, states that the water supply will be shared in the following proportions: 41% of the flow to Des Montes, 22% of the flow to Valdez, and 37% of the flow to Arroyo Hondo (Rio Hondo Acequias, 2006). Other terms are also described in the agreement including an operations manual that defines how water will be administered and the duties of commissioners and mayordomos. An allocation table also shows how much water each ditch will receive in cubic feet per second based on different flow rates of the Rio Hondo. The peak demand for irrigation for the Rio Hondo acequias during the months of July and August is estimated to be around 40 cfs and may be less during other months of the year (Rio Hondo Acequias, 2006). Tension arises from the fact that although Arroyo Hondo ditches have an earlier priority (1815) than the Des Montes ditches (1816), the Des Montes ditches always get water first, since they are upstream of Arroyo Hondo (Baxter, 1990). Its downstream location makes it harder for Arroyo Hondo to get their water. Further, since Arroyo Hondo has an earlier priority, its residents feel that they technically should get water first under the prior appropriation system (Ortiz, 2012a).

2.2.2 Historic Land Use Change Impacts

In 1987, local Taos area ethnographer Sylvia Rodriguez examined the ecological impact of the Taos Ski Valley on the Rio Hondo watershed (Rodriguez, 1987a). Rodriguez took an in-depth look at the sewage pollution caused by an inadequate sewage treatment plant in the 1970's and 80's. She also outlined other threats such as the potential expansion of the ski resort and secondary real estate development, and other pollution sources such as un-sewered homes, runoff from large parking lots, and runoff from fertilized ski trails. The major conclusions were: the ski industry has polluted, but not irreversibly damaged the Rio Hondo, the ski industry has removed a significant quantity of water from the acequia system, and the impacts on water quantity and quality have been intensified by changing economic and climate conditions, state water policy, and real estate development pressure (Rodriguez, 1987a).

Rodriguez also wrote in detail about an event in the Rio Hondo watershed popularly referred to as the Valdez Condo Wars (Rodriguez, 1987b). This took place in the 1980's when a developer proposed a transfer of water from land irrigated by an acequia in Valdez to an underground well for the purpose of supplying water to a new condominium project. The state engineer approved the transfer in 1982, but residents were not aware of the approval and began protesting the construction of the condos. According to Rodriguez, the protest was in reaction to a series of accelerated developments around the area caused by resort expansion that involved either water rights transfers or sewage discharge permits. In this particular case, administrative means of protesting the water transfer did not pan out, so residents turned to public event protesting. One powerful message from an anti-condo sign sums up the fears of the residents on new tourism development: "Commandments Against Condos: Thou shall not build condos…pollute our water…disrespect our way of life….pollute our land…covet our land and water…steal what belongs to our children. Thou shall not kill our valley (Rodriguez, 1987b, p.371)." In this case, the businessman who was trying to build the condos lost support of his financial venture, filed for bankruptcy, and left town. A few condos were built, but the full plan for the development was never realized.

2.2.3 Rio Hondo Resilience and Community Preparedness for Climate Change

In 2010, a dissertation titled "Exploring the dynamics of Social-ecological Systems: the Case of the Taos Valley Acequias" was published by Michael Cox. The basic research questions addressed by this dissertation include: (1) What properties enable community-based natural resource systems to persist in the face of various historic disturbances? and (2) Are community-based natural resource systems vulnerable to disturbances that are more recent and novel, and if so, what is the nature of these disturbances (Cox, 2010)? Major findings were that individual acequias are robust to drought and vulnerable to novel disturbances of urbanization and land fragmentation. The acequia system as a whole is robust/resilient to the state water rights adjudication and vulnerable to novel disturbances of lower resource dependence, economic development, and water transfers (Cox, 2010). The findings of this dissertation highlight the fact that changing land use has the potential to severely disrupt acequia systems, giving importance to research on land use change in acequia communities.

A 2011 study by Mayagoitia utilized a survey to collect data on the factors and community characteristics that contribute to community adaptation and community preparedness to climate change and population growth. This survey is very important to this research and will be summarized in detail in Chapter six. It is therefore omitted from the literature review.

2.2.4 GIS and Aerial Photography as a Tool for Land Use Research

The most relevant research to this project is a similar study which utilized GIS, remote sensing, and aerial photography interpretation to analyze land use along the Alcalde Reach of the Upper Rio Grande Basin for the years 1962, 1997, and 2003 (Ortiz, 2007). Major findings of the Ortiz study were that land devoted to orchards and row crops have decreased, pasture land has increased, and residentially used land has significantly increased in recent years. This research confirmed that the Alcalde area, which has historically been focused on agricultural activities, saw a conversion to residential/urban land use. Interestingly, it was revealed that residential land conversion largely occurred on the floodplain terrace above the irrigated lands (Ortiz, 2007).

Ortiz further asserted that additional research is needed to understand why orchards never recovered in the area and also stressed the need for comparative analyses between different acequia communities. The analysis on impacts of land use on the traditional culture relied on a literature review, oral histories, and formal interviews. Some of the impacts identified were: a shift from barter economy to capitalist economy, a less equitable political structure, a decrease in participation in use and maintenance of acequias, decreased participation in acequia activities by youth, lack of passing on acequia knowledge and history by elders, increasing numbers of newcomers in the acequia system, and new agricultural techniques that don't always improve existing practices (Ortiz, 2007). The results of Ortiz will be compared to the results from this study in Chapter three.

2.3 Conclusion

The topics examined in this literature review provide good insights into how water is currently managed and used in the Rio Hondo watershed. This must be understood for this research to be useful. It was imperative to understand historic land use changes that have impacted the region as well. This informs the analysis of land use change over time and gives the data a grounded context. Lastly, GIS and aerial/satellite photography technology were both shown to be powerful tools - determining land use classifications is one of the classic applications of these types of technologies.

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CHAPTER THREE: LAND USE CHANGE IN THE RIO HONDO

3.1 Introduction

This section of the report will focus on how land use has changed over time in the irrigated region of the Rio Hondo watershed using the years 1935, 1969, and 2010. First, the crop mix for each of these years will be explored. This will provide information on how the crop diversity has changed over time, but it will also show how much land was in agriculture in each year. Given the recent increasing pressures of development, demographic change, and water scarcity on the region, it is important to understand how much land has been moved out of acequia agriculture. This will ultimately help determine the resiliency of the acequia system. Second, the building footprints will be counted for each of these years to determine how much development has taken place over the years. This is a key factor to consider given the tourism, recreation, and second home development draws to the area. Riparian area acreage will also be tracked and analyzed. The results of the land use analysis will be compared to the results from another similar recent study that was performed on the Alcalde, NM acequia system to determine if there are any regional trends in the data. Third, land fragmentation will be evaluated to understand how land property rights have changed over time. Land fragmentation is not only an indication of urbanization, but also just makes it harder to share and distribute water (Ortiz, 2012b). Lastly, Taos Land Trust lands will be explored to identify what parts of this region are protected from development in perpetuity.

This chapter will begin by explaining the methods used to collect and analyze data and then the results of the analyses described above will be provided. A discussion of the results will follow, leading into the final conclusions.

3.2 Data Sources, Data Collection, and Research Methods

Data on land use were collected from a variety of sources. Methods of analyses vary as well and will be described in detail below, but in general the data were analyzed as time series data sets, with a focus on quantifying changes across time periods. It should be mentioned that all of land use data that were collected and analyzed come only from the irrigated area of the watershed (see Figure 2). Though land development has happened in other parts of the watershed, the main interest is in understanding shifts of land use from agriculture to residential, commercial, or other uses. The waters of the Rio Hondo are also used to irrigate lands outside of the boundaries of the Rio Hondo watershed, but ultimately it was decided that the watershed as an analysis unit was most appropriate.

3.2.1 Land Use

There are three categories of land use that were quantified in this project. The first is agricultural use by crop, the second is the building footprints, which indicate how much development has taken place over time, and the third is riparian land. These data were collected for the entire irrigated area in the Rio Hondo watershed for the years 1935 (to the extent possible), 1969, and 2010.

Land use data for 1935 were collected by the author by interpreting a historic black and white aerial image (time of year unknown). This aerial image, which was acquired without spatial references for GIS, is the oldest aerial image of the region available and was acquired from the Earth Data Analysis Center (EDAC) at UNM. The low resolution of this aerial photo made it difficult to really discern crop types with the only exception that orchards are easily discernible due to their distinct pattern on the landscape. For this reason, only the acreage of orchards was quantified for 1935. Buildings were not easily identified either; so the building footprint data is not available for 1935. Figure 6 illustrates the low resolution of the image, the washed out image quality of developed areas, and the distinct pattern of an orchard.

Figure 6: Snapshot of 1935 Imagery Showing Developed Area and Orchard

The aerial image was first georeferenced by the author (its location was established; it was given a spatial reference) in ArcMap 10.1, a Geographic Information Systems (GIS) program. This was complicated because of the lack of tick marks in the image that indicate coordinates and because the image was broken up into three panels. The images were placed in the correct location by creating control points that connect the aerial photo to a “control map” via easily identifiable landscape features (Cote, 2012). The landscape features used might be the intersection of a road, or the edge of a mesa, to name a few examples. The detailed process of georeferencing that was completed by the author is described in detail in Cote (2012). Once the image was georeferenced, ArcMap was then used to calculate acreages by drawing polygons around the boundaries of the orchards. The process of drawing polygons onto an image is referred to as “heads-up digitizing.” The acreage of orchards (found by using the “Calculate Geometry” function) was exported to Microsoft Excel to facilitate the data analysis process.

The georeferencing process used for the 1935 image is subject to a few different types of error. The first is that the control points might not be in the exact same spot. Using the examples above, the edge of the mesa may have eroded a bit or the intersection of roads might have changed slightly over time. This would be a small source of error. The 1935 aerial image was not orthorectified, as information about the camera and lens used were not available. This makes the calculations of polygon areas less accurate. Lastly, the image panels overlapped themselves so the images had to be placed in the correct alignment. This alignment was not always straightforward as the image panels were very distorted around the edges.

For 1969, data on building footprints and riparian areas were collected by interpreting a black and white aerial image, with a date of September 23, 1965. An aerial image for 1969 was not available, so the next closest year (1965) was used to approximate these land uses in 1969. Like the 1935 image, it was also acquired from EDAC and was not georeferenced or orthorectified. The same georeferencing process that was used for the 1935 image was also used for the 1965 image and the same types of errors described above would also apply to the 1965 image. However, the 1965 image has a much higher resolution than the 1935 image (less error) and uses five image panels to cover the entire irrigated area instead of three (more error). Heads-up digitization was used to draw polygons around buildings and the riparian zones. These polygons were ultimately used to calculate the square footage of buildings and the acreage of riparian canopy.

Detailed information on crops grown for 1969 was taken from the Office of the State Engineer (OSE) Rio Hondo Hydrographic Survey. The purpose of the survey was to quantify and document water usage and crops grown in order to inform water rights adjudications. The information in the report is mostly displayed in the form of maps, which show all the parcels in the Rio Hondo region, how much land was being irrigated in each parcel, and what crop was being grown. GIS versions of these maps were acquired from the Taos Valley Acequia Association. The GIS layer of crops grown was clipped to the boundaries of the irrigated area. Any parcel that fell partially into the irrigated area boundaries was included, but only the part of the parcel that fell within the boundaries was included. Because some parcels were cut down, the acreages given by the hydrographic survey were no longer reliable. For this reason, acreages of each polygon were computed using ArcMap's Calculate Geometry function. The acreages that were calculated by ArcMap were very close to the acreages found in the hydrographic survey, so this method is acceptable in terms of accuracy.

For 2010, a combination of site visits and interpretation of a contemporary 2010 satellite image were used to determine the area of building footprints, crops grown, and riparian canopy. Site visits were done in May, September, and November 2012. Site visits in September and November, although not during the active growing season, were actually very useful because many fields had been mowed and were clearly being used as hay fields. Site visits were done to ground-truth the land uses that were found to be uncertain or undistinguishable using the satellite imagery. Overall, about 10% of the parcels from the 2010 analysis were checked on site and any corrections were made to the land use classifications in GIS. It should be noted that there was some difficulty in ground-truthing an image that was two years old, however a more recent image was not available for this region.

The 2010 image used was a high resolution, four-band multi-spectral, pan-sharpened, natural color, orthorectified, Geo-eye 1 satellite image with 50 cm resolution. This is very similar to the quality of image used in Ortiz (2007), though slightly higher resolution. The date of this image was August 14th, 2010 and it was purchased through the vendor MapMart. This type of satellite image provides a very accurate estimate of the square footage of building footprints, the acreage of crops grown, and the acreage of the riparian zones. It is important to mention that differences across years in image resolution would certainly influence the mapping results.

Data on acreages/square footage in 2010 were calculated the same way as for the 1935 and 1969 images - using heads-up digitizing to draw boundaries and classify land uses and using the Calculate Geometry tool to calculate areas. However, the multi-band imagery provided the capability of looking at the image in actual color as well as in false color composite, both of which were very helpful in the land use interpretation process.

3.2.2 Aerial Photo Interpretation Techniques

At the outset of this part of the project, it was determined that aerial photo interpretation cannot be reliably used to determine crop types beyond distinguishing between pasture/hay (a combined category), row crops, fallow land, and orchards because these fields have distinct patterns and colors on the landscape (M. Ortiz, personal communication, September 10, 2012). For example, distinguishing between an alfalfa field and a pasture field is very hard to do with confidence using an aerial image (M. Ortiz, personal communication, September 10, 2012). Because of the size of the irrigated area (~3,500 acres) and the lack of public access, it is also difficult to collect this information through site visits. The result is a slightly less detailed analysis of crop types than originally desired, though much insight can still be gained by using more general crop categories.

In addition to the methods described by Ortiz (2007), guidance was provided by the following: *Remote Sensing and Image Interpretation* by Lillesand and Kiefer (2004), *Manual of Photographic Interpretation* by the American Society of Photogrammetry (1960), and lastly *Aerial Photography and Image Interpretation* by Paine and Kiser (2012). The aerial photo interpretation techniques garnered from these sources are summarized below.

Patterns, or the spatial arrangement of features, are particularly useful in identifying crops (Ortiz, 2007). Earlier in this chapter of the report, the unique spatial arrangement of orchards was explored – these crops generally have linear rows with spaces around the tree canopy on all sides (see Figure 6). Older orchards look less linear because of tree die off. Other patterns that were easily distinguishable are marks of harvesting machines (see Figure 8) and row crops, which also have a distinct linear pattern, with only space between rows (Ortiz, 2007). Figure 7 shows row crops late in the season (so space between crops is hard to see) that were verified in a site visit. The building is a greenhouse.

Figure 7: Row Crops and Greenhouse in the Rio Hondo Watershed

Shapes of features were of great use in identifying buildings since most buildings have rectangular shapes. Many of the agricultural fields had distinct rectangular shapes as well - this is noticeable in Figure 8, which also shows the harvesting marks inside rectangular shaped fields. Color and tone are also valuable in interpreting imagery (Ortiz, 2007). The 2010 color image was much easier to interpret than the black and white images of the earlier years. The use of false color composite helped in determining the edges of vegetation, as vegetation is colored red (since it has a high reflectance in the near infrared band) and other surfaces are not. The red color helps eliminate errors that might arise from having shadows from trees or other vegetation nearby (signified by a different shade of red). An example of a false color composite image is shown in Figure 8. The false color composite also helped in diagnosing non-agriculture land and fallow land. On the far right hand side of Figure 8, the land has a greyish color, signifying vegetation that is non-existent (bare land) or vegetation that is thin, dry, or dying. This also illustrates how texture can be used to determine crop type because it is obvious that this grey mottled texture is scrub/shrubland. Tree canopies also have an obvious texture (Ortiz, 2007).

Figure 8: Snapshot of a False Color Composite Display

Temporal conditions play an important role in interpreting aerial imagery and can either be an impediment or an aid to the process (Ortiz, 2007). The 2010 image was taken in August and the 1965 image was taken in September. Although these months are later in the growing season, vegetation was still clearly alive and identifiable. Knowing the date the image was taken along with the growing stages of the crops at that time is invaluable information. The row crops image that was provided earlier (Figure 7) is an example of how knowing the stage of growth of the crop during that time of year helped in determining the crop type.

Lastly, a dichotomous key from the book *Aerial Photography and Image Interpretation* proved to be another good resource for identifying crop types. Of particular use from this key was the suggestion to look for signs of pasture including watering holes and livestock trails. In fact, in one part of the aerial image, livestock were identifiable on the landscape, making the classification of pasture easy. An adaptation of this dichotomous key is provided in Table 2.

Table 2: Dichotomous Interpretation Key for Major Crops and Land Cover Types, adapted from Paine and Kiser (2012)

1. Vegetation or soil clearly discernible on photographs	See 2
1. Vegetation or soil either absent or largely obscured by man-made structures, bare rock, or water	**Non-agriculture Lands**
2. Cultivation pattern absent; field boundaries irregularly shaped	See 3
2. Cultivation pattern present; field boundaries regularly shaped	See 5
3. Trees present, covering most of ground surface	**Timberland**
3. Trees absent or widely scattered; ground surface covered by low-lying vegetation	See 4
4. Crowns of individual plants discernible; texture coarse and mottled	**Brushland**
4. Crown of individual plants not discernible; texture fine	**Grassland**
5. Crop vegetation absent	**Fallow**
5. Crop vegetation present	See 6
6. Crowns of individual plants clearly discernible	See 7
6. Crowns of individual plants not clearly discernible	See 8
7. Alignment and spacing of individual trees at intervals of 10 ft or less	**Vine and Bush Crops**
8. Rows of vegetation clearly discernible, usually at intervals of 2–5 feet	**Row Crops**

8. Rows of vegetation not clearly discernible; crops forming a continuous cover before reaching maturity	See 9
9. Evidence of use by livestock present (watering holes, livestock trails); evidence of irrigation from sprinklers or ditches usually conspicuous	**Irrigated Pasture Crops**
9. Evidence of use by livestock absent; evidence of irrigation from sprinklers or ditches usually inconspicuous or absent; bundles of straw or hay and harvesting marks	**Continuous Cover Crops** (small grains, hay, etc)

3.2.3 Land Fragmentation

Cox (2010) found that individual acequias are vulnerable to novel disturbances of urbanization and land fragmentation. Cox's method of calculating land fragmentation is a valuable research tool that can be applied in land use change studies like this one. He estimated land fragmentation in an area by dividing the number of parcels of land recorded by the Taos County Assessor in their current GIS database by the number of parcels established by the older hydrographic survey in that area (Cox, 2010). A high value of this variable would indicate a greater degree of land fragmentation (Cox, 2010). The exact same method will be used to calculate land fragmentation in this report. The land fragmentation calculation will only focus on the irrigated portion of the watershed. It should also be noted that the parcels layer that was provided by the Taos County Assessor is a draft GIS layer and because of this some of the parcels are not in an accurate position. However, the inaccuracies of this data are not big enough to cause major error in the land fragmentation calculation.

3.2.4 Summary of Methods

For the year 1935, aerial images georeferenced by the author in GIS, were interpreted using the techniques described above, to determine the acreage of orchards and riparian area. Other crops and buildings were not interpreted in 1935 due to the low resolution of the image. In 1969, crops were quantified using the Rio Hondo Hydrographic Survey GIS layers created by

TVAA because these map layers are much more accurate than aerial photo interpretation. However, aerial photo interpretation was used for an image acquired in 1965 to determine the area of building footprints and riparian land for this time period. Lastly, a high resolution georeferenced aerial image was acquired from a vendor and used to interpret crop types, building area, and riparian area for the year 2010. The author performed all the aerial photo interpretation using the guidance described above and utilizing GIS as a tool to calculate areas on a digital map. These calculated areas were exported to Excel and analyzed to provide the results in the next section. The maps themselves, which cover the entire irrigated area of the watershed (3,482 acres), are available in Appendix 1.

3.3 Results

Results from the cropping pattern analysis will be reviewed first, followed by the results from the development footprint data, and an analysis of riparian area acreage. The land fragmentation calculation will then be reviewed, followed by a look at the trust lands.

3.3.1 Cropping Pattern Changes

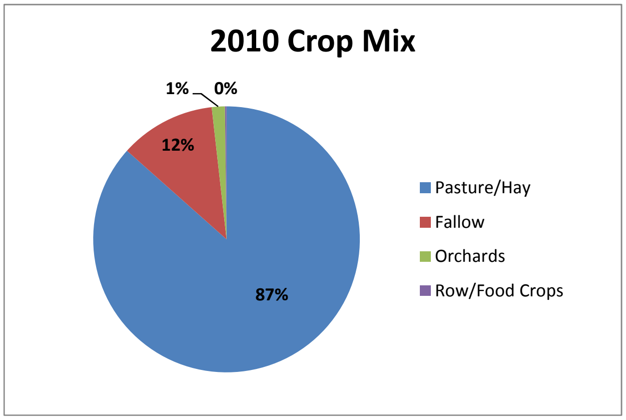
The crops that were quantified were: orchards, row/food crops, pasture/hay (a combined category), and fallow land. There was more detail in crop types in the Rio Hondo hydrographic survey; so some re-categorization needed to be done for comparison across years. First, row crops were changed to row/food crops because the hydrographic survey included acreage in wheat, which didn’t fit well into any of the other categories. Therefore, the row/food crops category in 1969 included acreage in corn, gardens, and wheat. Second, land that was plowed ground was assumed to be fallow for the 1969 data. Lastly, there is a category in the 1969 data set that is called "Unknown." Unfortunately, some of the parcels in the hydrographic survey maps were not labeled and details on crops grown were not available. They were still included because they are irrigated lands and should be counted in the total irrigated land acreage calculation. Table 3 displays the results of the cropping patterns data from 1935, 1969, and 2010.

Table 3: Crop Mix Data and Percent Change Over Time

	1935 (acres)	1969 (acres)	2010 (acres)	% Change 1935 to 1969	% Change 1969 to 2010
Pasture/Hay	-	1,311	1,207	-	-8%
Fallow	-	258	162	-	-37%
Orchards	23	51	22	117%	-56%
Row/Food Crops	-	206	3	-	-99%
Unknown	-	26	-	-	-
Total Irrigated Lands	**N/A**	**1,852**	**1,394**	**-**	**-25%**

Overall, there is a 25 percent decline in irrigated acreage in the Rio Hondo watershed between the years 1969 and 2010. This was a decrease of 458 acres of irrigated land. All of the individual crop types have decreased their acreage over time. Pasture/hay saw the smallest decrease in acreage of 104 acres or 8 percent from 1969 to 2010. Fallow land decreased 96 acres or 37 percent from 1969 to 2010. Orchards increased 117 percent between 1935 and 1969, but became less popular recently, decreasing 56 percent between 1969 and 2010. In 1969, there were 128 total orchards with an average size of 0.4 acres and in 2010 there were 37 orchards with an average size of 0.6 acres. Row/food crops saw the largest decline in acreage as well as decline in percentage between 1969 and 2010 - these crops decreased by 204 acres or 99 percent.

Figure 9 shows the crop mixes for each year in a pie chart format. Fallow lands are around the same percentage for both years. Pasture and hay are a larger percentage of the total irrigated land in 2010 (87 percent) than in 1969 (71 percent). Orchards are a smaller percentage of the total crop mix in 2010 compared to 1969. And in 2010, row/food crops are less than 1 percent of the total crop mix, whereas they were 11 percent of the total crop mix in 1969.



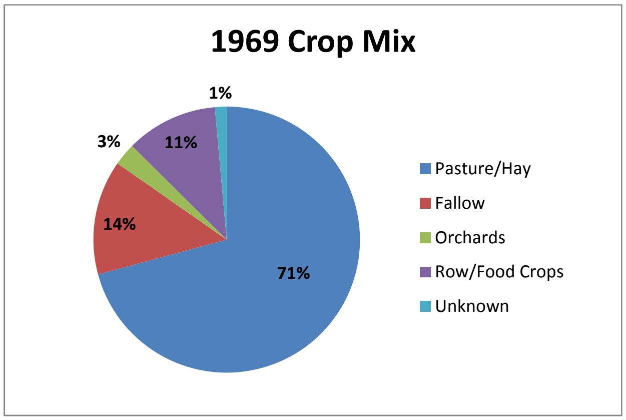


Figure 9: Crop Mixes in the Rio Hondo Watershed

The last thing with regards to the cropping patterns is the distribution of row/food crops between each type of crop. In 1969, 12 acres of corn were grown (6 percent of total food crops), 47 acres of gardens (23 percent of total food crops) were grown, and 147 acres of wheat (71 percent of total food crops) were grown. Only three acres of row/food crops were grown in 2010. The exact breakdown of these row/food crops is not available, but most of these food crops were small gardens and some were small corn fields. No wheat fields were found in the irrigated area of the Rio Hondo watershed for the year 2010. One other point of comparison is the number of gardens in each year. In 1969, there were 103 garden parcels with an average size of 0.5 acres and in 2010 there were 25 garden parcels (row crop parcels) with an average size of 0.1 acres, a decrease of 76 percent in total garden parcels. This decrease may be exaggerated a bit because small gardens are difficult to spot on an aerial image and they are also hard to spot on site due to size and often cannot be accessed on private land without trespassing. The last thing to note in this section is that full maps, created by the author, that display the crops grown in the Rio

Hondo for each year are available in Appendix 1. Crop maps for the Valdez area in 1969 and 2010 are shown in Figure 10 and Figure 11 as an example.

3.3.2 Building Footprint Changes

Table 4 shows the square footage of building footprints and the number of buildings that were found for the years 1965 and 2010. It is necessary to note that any building on the landscape was included in this analysis. This means that even a small barn would be included. There was no easy way to set a lower limit on size, so everything was included for both years. The differences between 1965 and 2010 are remarkable. There are 1,203 more buildings in the irrigated area of the watershed than in 1965 - that's more than a threefold increase in the number of buildings in an area that is only 5.5 square miles. The square footage went from around 560,000 square feet to around 2,200,000 square feet, an almost fourfold increase in square footage. Average square footage has increased 24 percent (from 1,017 sq. ft. to 1,261 sq. ft.) from 1965 to 2010. Median square footage has increased 13 percent (from 801 sq. ft. to 902 sq. ft.) from 1965 to 2010. Not only was there a big increase in development in this region, but the buildings themselves got bigger over time. Figure 12 and Figure 13 show building footprints in the Valdez area for 1965 and 2010 respectively. Additional maps are included in Appendix 1.

Table 4: Building Footprints in the Irrigated Area of the Rio Hondo Watershed

	1965	**2010**	**Percent Increase**
Building Footprint (sq. ft.)	559,076	2,208,892	295%
No. of Buildings	549	1,752	219%
Average Square Footage	1,017	1,261	24%
Median Square Footage	801	902	13%

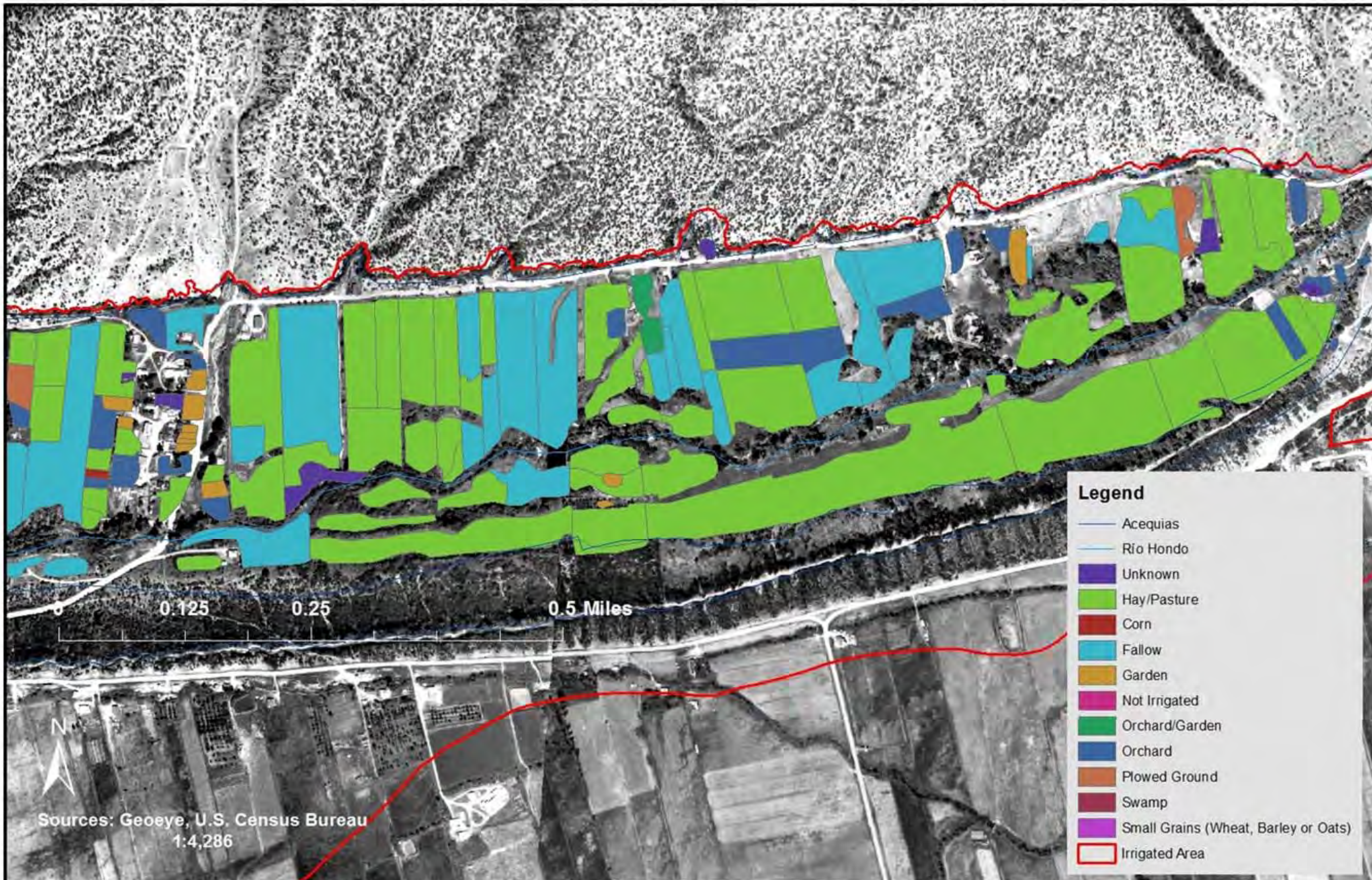


Figure 10: Crop Type Map, Valdez Area, Aerial Image from 1965, Crop Types from 1969 Hydrographic Survey

Figure 11: Crop Type Map, Valdez Area, 2010

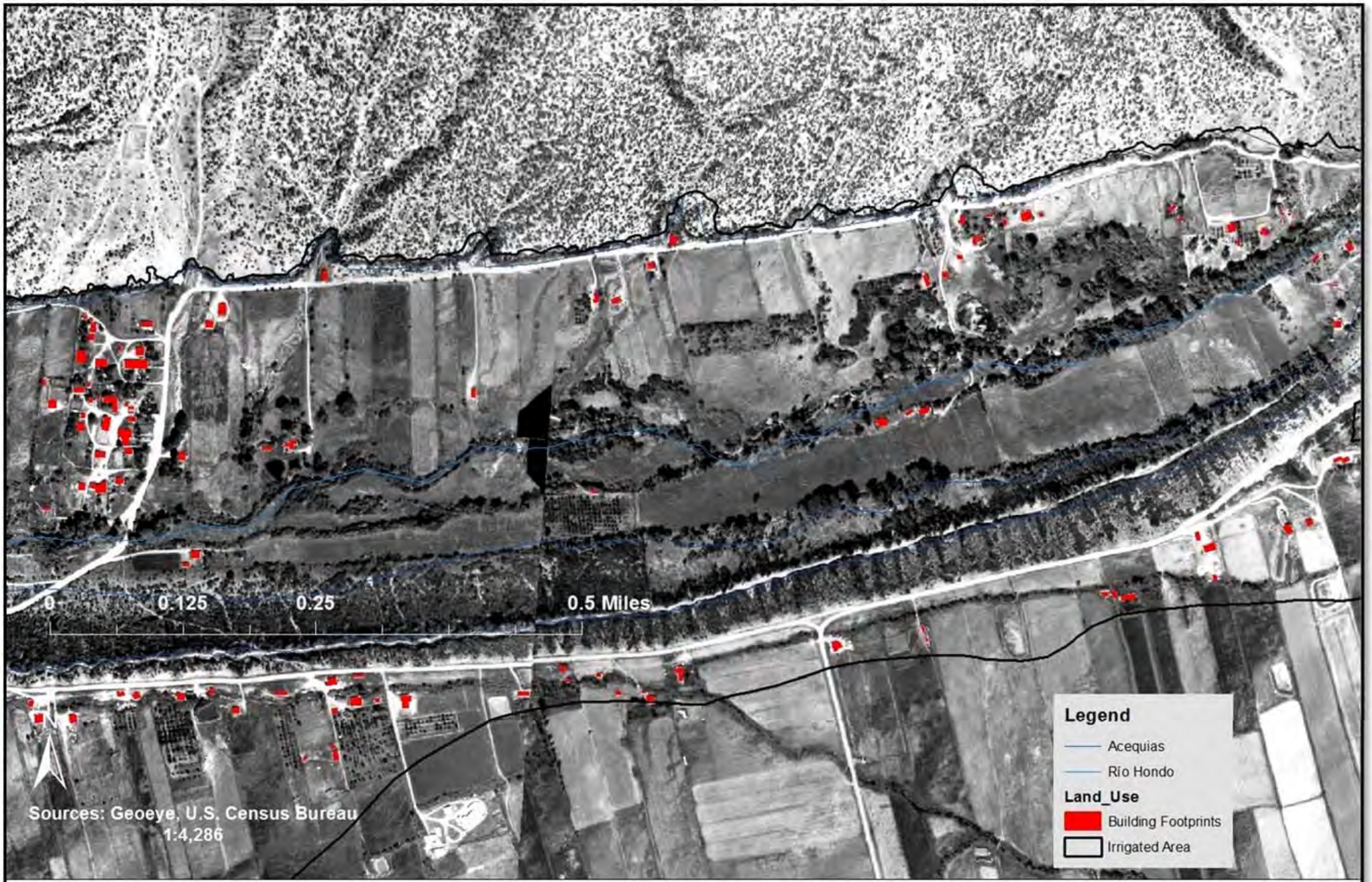


Figure 12: Building Footprints, Valdez Area, 1965

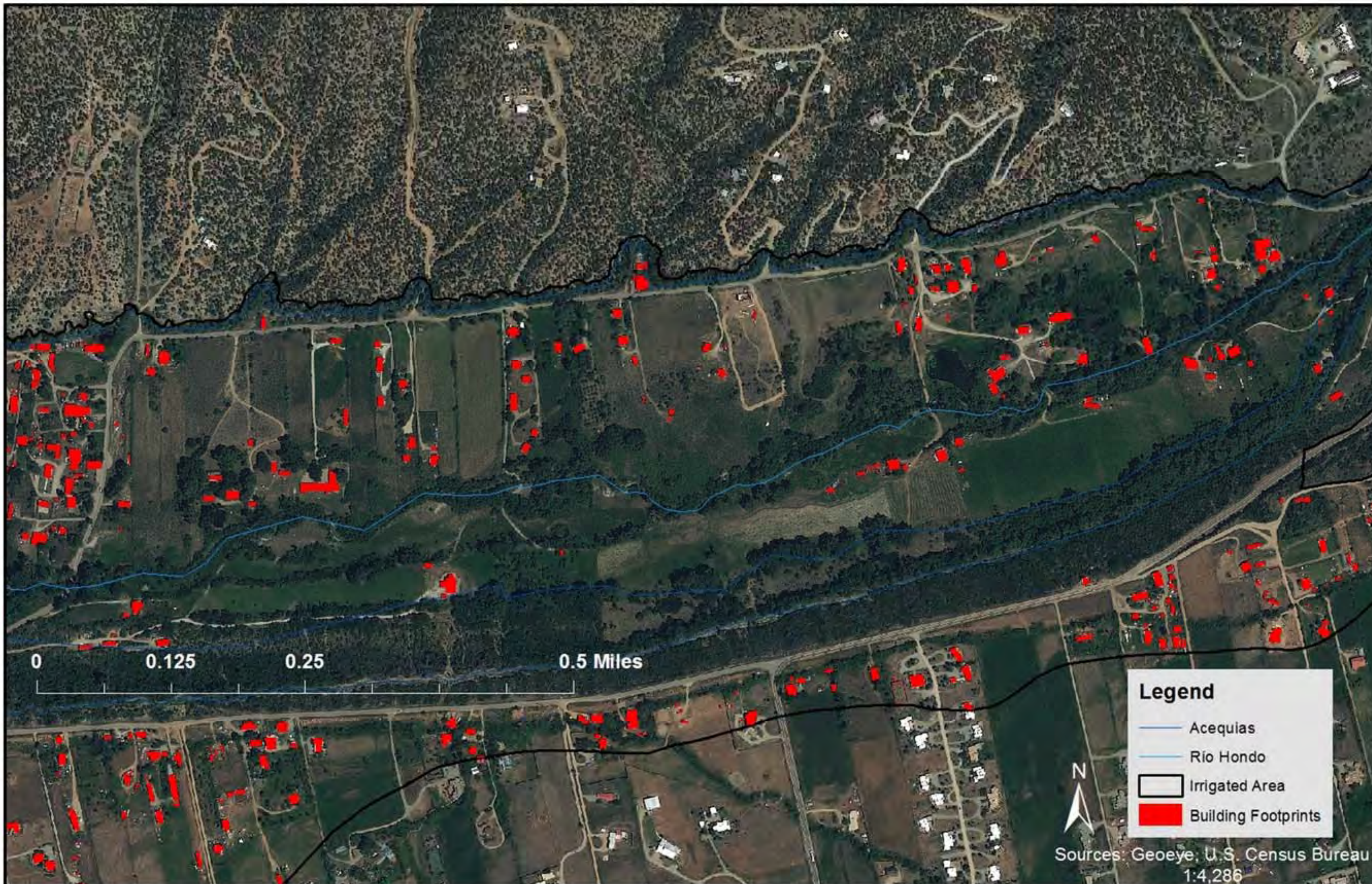


Figure 13: Building Footprints, Valdez Area, 2010

3.3.3 Riparian Area Acreages

The total area of the riparian zones along the river and the acequias was 202 acres in 1965 for the entire irrigated area. The riparian area increased 31 percent to 264 acres in 2010. In 2010, 100 acres of the riparian area were along the river and 164 acres were along the acequias. The data for 1965 were not tracked by river or acequia, but from the image, the river riparian zones appear similar to those in 2010 and the riparian zones around the acequias seem much thinner. Part of the overall increase in riparian area can be attributed to the seasonal difference between the two images. The 2010 image was taken in mid-August, whereas the 1965 image was taken much later in the season in late September when the vegetation is going dormant. The discrepancies in resolution of the data may have also played a part in this difference. Interestingly, looking at PRISM (Parameter-elevation Regressions on Independent Slopes Model) data for this area, the temperature and precipitation amounts are much higher in 1965 than in 2010 signifying that this difference is not driven by temperature or precipitation amounts in those years.

3.3.4 Land Fragmentation Results

The number of parcels in the Rio Hondo irrigated area in 1969 was 924 parcels and 1,054 parcels in 2010, an increase of 14 percent. Using the Cox method, the land fragmentation value is 1.14. The mean land fragmentation value found in Cox’ 2010 study of all Taos valley acequias was 1.185. So, here in the Rio Hondo, the land fragmentation is just slightly lower than the average land fragmentation value of all acequia systems in the Taos area.

3.3.5 Taos Land Trust Conservation Easements

There are five Taos Land Trust (TLT) conservation easements that fall into the boundaries of the irrigated area in the Rio Hondo watershed (see Figure 14). The Rio Hondo Park easement is about 23 acres, the Casa Caballos easement is about 13 acres, the Frank easement is about 101 acres, the New Buffalo easement is about 13 acres, and the Sofia Lucinda easement is about 36 acres. Landowners have decided how their land will be used in the future and have retired some or all of the development rights on these properties. No conservation easements through the New Mexico Land Conservancy or The Nature Conservancy were found.

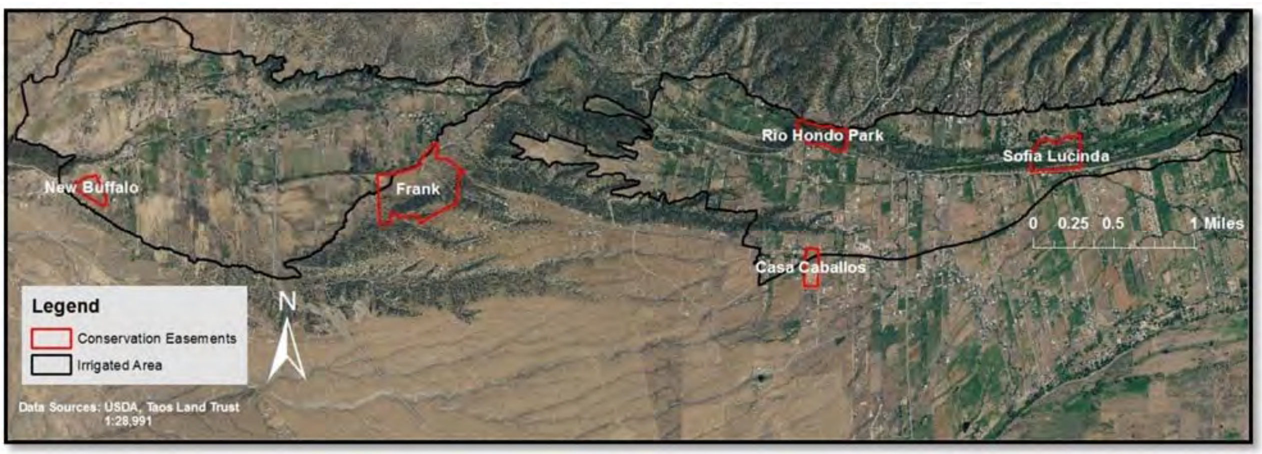


Figure 14: Conservation Easements in the Irrigated Area of the Rio Hondo Watershed

Part of the reason why there are so few easements in the area may be that setting up the easements is too expensive. The average conservation easement fee charged by the TLT is $8,600 (TLT, 2011). Landowners also have to pay a one-time stewardship fee that is a $5,000 minimum that increases $50 per acre for each acre above 25 acres (TLT, 2012). Of course these costs would need to be weighed against any tax benefits gained from setting up the easement. The tax benefits of conservation easements created in New Mexico include the following: the New Mexico State Land Conservation Tax Credit, the Federal Income Tax Deduction, the

Federal Estate Tax Benefit, and the reduction of Property Tax. When land is donated to a conservation easement, it loses value (a fact that also likely deters landowners from using easements). The difference between the market value before and after the easement is considered the appraised value of the conservation easement and represents a charitable contribution that can be used towards the tax benefits listed above. The New Mexico State Land Conservation Tax Credit is a transferable tax credit (meaning it can be sold to a third party) worth 50 percent of the appraised value of the easement, up to $250,000. With regard to the Federal Income Tax Deduction, landowners who set up a conservation easement can deduct up to 30 percent of their Adjusted Gross Income (AGI) each year from federal income tax for up to six years in a row, or until they use up the appraised value of the land. The Federal Estate Tax Benefit allows landowners to pay less estate tax since the property's market value has been lowered and, currently, the IRS allows the taxable value of property with a conservation easement to be reduced up to 40 percent more for estate tax purposes. Lastly, some counties and municipalities allow for the reduction of property taxes based on the reduced value of the land (TLT, n.d.).

3.4 Discussion

This section will start by comparing the results of this study to the 2007 Ortiz study to understand if there are any regional trends in land use or cropping patterns. A thorough discussion of all the results will be provided, followed by a conclusion.

3.4.1 Comparison to the 2007 Ortiz Study

In her 2007 study, Ortiz studied land use change in the Alcalde, NM acequia system for the years 1962, 1997, and 2003. Table 5 shows a comparison of the percent changes over time found in the Ortiz study versus the changes found in this study. Some similarities between the two papers are that orchards decreased significantly and by a similar amount. The percentage of land acreage in row crops also decreased significantly in Alcalde, although this decrease was about half the rate found in the Rio Hondo area. The other similarity is the overall decrease in agricultural lands. This study found a 25 percent decrease in agricultural land and the Ortiz study found a 19 percent decrease in agricultural land. Fallow land is not really comparable because Ortiz did not have these data for 1962.

The biggest differences between the findings of the two studies are in the pasture/hay, residential/building footprint, and riparian acreage figures. Although this study found a slight decrease in pasture/hay acreage, the Ortiz study found a 47 percent increase in this land use. Residential land acreage increased 553 percent in the Ortiz study. The statistic used to describe development impacts in the Rio Hondo was building footprints and the square footage of building footprints increased 295 percent. Both regions appear to be experiencing substantial development impacts, though it seems to be worse in the Alcalde region, based on the large increase in residential land acreage. However, development in the Alcalde region is largely taking place in areas above the floodplain terrace and out of the irrigated area, while in the Rio Hondo region there is significant development in the irrigated area. Lastly, there is a big difference in the riparian acreages – this study found 31 percent increase in riparian area and the Ortiz study found a 3 percent reduction in riparian area from 1962 to 2003. It is unclear why these two numbers are so different, although it should be noted that the increase of 62 acres in the Rio Hondo area between the years 1965 and 2010 is the same order of magnitude as the increase in riparian area that Ortiz found between 1997 and 2003 - an increase of 38 acres.

Table 5: Percentage Changes in Acreages for Ortiz and Miller Studies

	Ortiz Study ('62 to '03)	Miller Study ('69 to '10)
Orchard	-69%	-56%
Row Crop	-53%	-99%
Fallow	0%	-37%
Pasture/Hay	47%	-8%
Riparian	-3%	31%
Residential/Building Footprint	553%	295%
Total Agricultural Land	**-19%**	**-25%**

The data found in this study also support Ortiz's finding that a severe frost in 1971 destroyed many trees in orchards that were never replanted. This frost likely also affected the Rio Hondo region because it is at an even higher elevation than Alcalde and only about 50 driving miles away. Orchards were likely never replanted due to the fact that the following years had bad frosts which discouraged farmers from planting fruit trees and increased the desire to grow alfalfa (a more certain crop) and because the replacement of dead trees would require lots of capital and labor (Ortiz, 2007). Unlike the Ortiz study, it was not found that the decrease in orchard acreage resulted in an increase in pasture acreage.

3.4.2 Error Estimate for the 1965 Area Calculations

In order to estimate the amount of error in the 1965 area calculations, the square footage calculation of a building that appears to have not changed since 1965 was compared to the square footage calculation of the same building in 2010. The square footage calculated in 1965 was 1,195 square feet and the calculation of the square footage in 2010 was 1,173 square feet for this building. Since 2010 estimates are very accurate due to the high resolution of the data, it is assumed that the error is in the 1965 estimate. This error estimate shows that calculated areas in 1965 may be *exaggerated* by as much as 2 percent. This means that the scale of the 1965 maps is about 2 percent bigger than it should be. This finding does not support the notion that there is large error in the riparian area calculations due to the resolution of the 1965 image.

3.4.3 Synthesis of Results

In terms of the change in agricultural land, there has been loss of 25 percent (458 acres) of the agricultural lands in the Rio Hondo in the 41 year period between 1969 and 2010. This is very similar to the loss of agricultural land (19% or 208 acres) found in Alcalde for a similar 41 year time period. All crops in the Rio Hondo saw declines in this 41 year period, but the biggest declines were seen in the acreage of row/food crops and the acreage of orchards. Orchards are now less popular, but the average size of orchards has increased. Gardens are less plentiful and smaller in size than they were in the past. Wheat used to be a crop that held 9 percent of the total crop mix in 1969, but now appears to be gone from the crop mix completely. It is clear that the area is becoming less agriculturally diverse with an increasing focus on growing hay or pasture, something that has been repeated over and over again by local farmers.

Building development in the Rio Hondo area has been significant. There was a threefold increase in buildings and a fourfold increase in square footage of building footprints in the 41 year period between 1969 and 2010. Building sizes have increased as well. But, the more significant finding is that, unlike the 2007 Ortiz study, this development is happening within the boundaries of the irrigated area. Development is clearly displacing agricultural land in this area. Other impacts of development, such as increased pollution from runoff or septic systems and increased demand for groundwater were not studied here, but should be mentioned. The land fragmentation calculation showed that there are now 130 new parcels in the Rio Hondo region, a 14 percent increase over 41 years. These additional parcels break up the traditional long lots and make it harder for acequias to administer water. Lastly, the examination of the Taos Land Trust showed that not very much land is currently being protected from development through conservation easements.

The area of the riparian zones has increased significantly over the 41 year period studied, suggesting that development in this region has not encroached upon these areas – in fact, they seem to be flourishing compared to the past. The acequias themselves are responsible for providing a larger percentage of the riparian zone acreage than the actual river provides, most likely due to the extensive system and length of acequias in this region. This increase in riparian canopy suggests that the Rio Hondo valley is actually providing more ecosystem services than it did in the past. These additional ecosystem services would be lost if the acequia system becomes defunct in the future. This finding also supports the idea proposed by Ortiz that the "persistence of riparian vegetation may also reflect a widely held value for riparian area as buffer and aesthetic landscape features that provide valuable wildlife habitat (Ortiz, 2007, p.65)."

A summary of the known limitations of this analysis should be provided. First, it was mentioned that small gardens are hard to spot on aerial and even in person during field visits. For this reason, gardens are likely underestimated in this analysis. Details on garden crops grown were not able to be collected in this analysis for the same reasons. Anecdotal evidence from EPSCoR interviews (2009-2011) shows that garden crops grown include the following: corn, potatoes, squash, peas, fava beans, green beans, horse beans, tomatoes, eggplant, cucumbers, raspberries, carrots, beets, and garlic. This is mentioned to show that there is a diverse mix of garden crops being grown, though they are mostly used for household consumption. Interviews with residents have also revealed that some people are growing wheat, winter wheat, and oats. This was not captured in this study and therefore those crops are also underestimated. Winter wheat is planted in September and so would have slipped through the analysis since the aerial photo in 2010 was dated to mid-August. Lastly, this study looked at three different snapshots in time. Crops grown in these years are subject to the conditions of those years. More years of data would strengthen the analysis by allowing for more inferences about the consistency of changes over time.

3.5 Conclusion

Air photo interpretation has shown that significant land use changes have occurred over time in the Rio Hondo watershed. Agricultural land irrigated by acequias has decreased, while residential land has increased and property rights have become more fragmented. Riparian zones are very healthy even though the influence of development on the region has been great. Despite all these changes, the area is agriculturally centered, with almost 1,400 acres of land still irrigated in the traditional way. The fields are lush and beautiful in the summertime and the valleys still echo with the culture of the acequias.

Now that land use change and development in the region has been quantified, the next two chapters will examine the forces that are often cited as having led to the decrease of agricultural land acreage in New Mexico – demographic change and climate change. The last chapter will focus on other factors beyond amount of irrigated land that can help in the final diagnosis of how resilient the acequia system is to demographic change, climate change, and development.

CHAPTER FOUR: CLIMATE CHANGE IN THE RIO HONDO

4.1 Introduction to Climate in the Rio Hondo Watershed

The Rio Hondo acequia system is located in high desert, piñon-juniper/shrub land country. The climate type is semi-arid continental, with the warm summer subtype (Wilkerson, 2010). Winters are usually mild, with snow generally arriving by late October. The growing season in the Taos region is May to September, although irrigation can start in April and continue into October (Daniel B. Stephens, 2008). The closest Western Regional Climate Center (WRCC) cooperative observer station is in Cerro, NM which is located about 15 miles northeast of Arroyo Hondo, NM and is about the same elevation (see Figure 15). At Cerro, the mean winter temperature (monthly average from 1910 to 2012 for December, January, and February) is 24°F and the mean summer temperature is 64°F (monthly average from 1910 to 2012 for June, July, and August). The annual average precipitation at Cerro is 12.68 inches (WRCC, 2012). The New Mexico Water Resources Institute's (WRRI) precipitation contour maps show that average annual precipitation is around 30 inches at top of the watershed at Wheeler Peak (13,161 feet) and decreases to about 12 inches at Arroyo Hondo (Daniel B. Stephens, 2008).

4.2 Observed Climate Change in the Literature

According to the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report, the global average surface temperature has increased by about 0.74°C (1.33°F) during the 100 year period of 1906 to 2005 (IPCC, 2007a). Much more rapid warming occurred in recent years; the warmest years were 1998 and 2005 and 11 of the 12 warmest years occurred between 1995 and 2006 (IPCC, 2007a). New Mexico has seen even higher warming rates than the global average, which is to be expected of a continental site. Since the 1960's, the cold

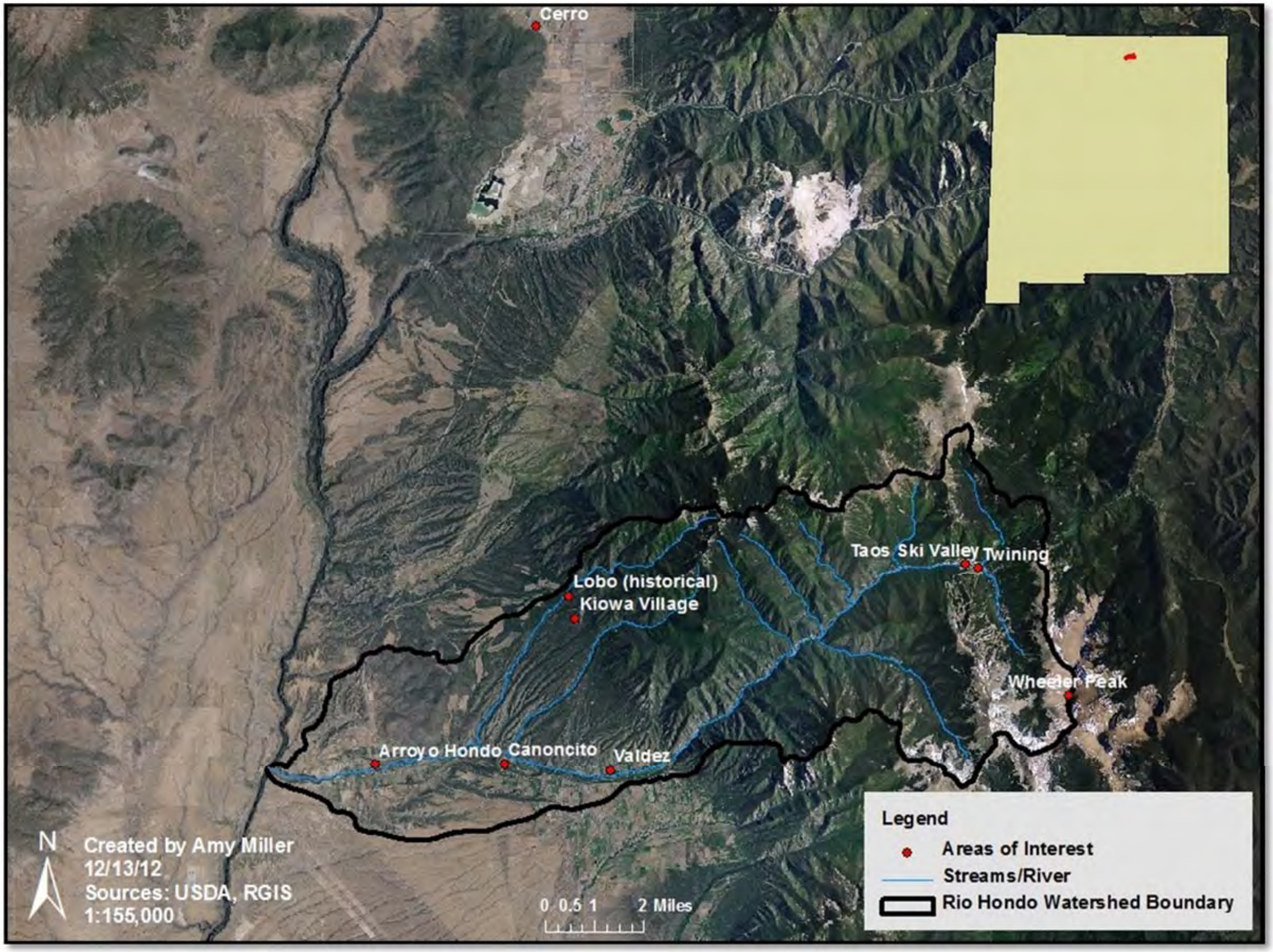


Figure 15: Locator Map Showing the Location of Cerro, NM in Relation to the Rio Hondo Watershed

season in New Mexico has warmed by roughly 2°F and the warm season has warmed by almost 3°F (Gutzler, 2007).

With regard to the hydrologic cycle, precipitation patterns in New Mexico show no clear trend over the past 100 years - instead we see recurring decade – scale droughts and wet spells (Gutzler, 2007). Tree-ring analyses also show a very long history of around 500 years of variable precipitation and streamflow in the Rio Grande (of which the Rio Hondo is a tributary), marked by periods of high precipitation and runoff and periods of drought (Hurd and Coonrod, 2008). The magnitude of droughts in the last 100 years does not exceed the natural extremes that were detected in the tree-ring reconstructed streamflow of the Rio Grande.

Many studies have been undertaken of actual weather measurements at sites throughout the West to understand if there are local climate trends. Fortunately, New Mexico was included in many of them. Since the Rio Hondo is located in central northern New Mexico, findings for stations in these regions are included in this section. One study found the following climatological trends for the years 1950-1999 for central northern New Mexico: later timing of snowmelt streamflows in general (by >= 15 days, statistically significant at only one site), an increase of accumulated snowpack (>= 15cm, statistically significant at many sites), earlier timing of the spring warm spell (by 5-15 days, statistically significant at many sites), an increase in winter precipitation (5-15cm, statistically significant at many sites), and increases in annual and March, May, and June streamflows (statistically significant at many sites) (Regonda et al., 2004). Observed increases in winter precipitation and snowpack in central northern New Mexico were also confirmed in other studies (Mote et al., 2005; Knowles et al., 2006). Central northern New Mexico sites had earlier spring pulse onsets and earlier dates of center of mass of annual flow (CT), although many sites were not considered as having statistically significant trends

(Stewart et al., 2005). Knowles et al. (2006) found only one site in central Northern New Mexico that shows with significance that more winter precipitation is falling as rain than snow, despite the fact that, in general, winter mean daily minimum wet day air temperatures (1949-2004) have increased in this area.

Examination of all of these studies shows the complexity of the observed climatological trends in central Northern New Mexico and how some of the expected responses to warming (i.e. less snowpack) may actually be reversed in this region. The goal now is to look at trends in climatological data that were measured either in the Rio Hondo watershed or in areas close to the watershed to understand how climate may have changed in this local region.

4.3 Rio Hondo Climate Data Analysis

The Mann-Kendall trend test was used to test the magnitude and significance of trends in the climate data in this section. This particular trend test is often used in hydrological data analysis, because it is a non-parametric test. This means that data do not have to be normally distributed for the test to work properly and thus outliers and skewed data that are common in hydrological time series are not a problem. This is in contrast to using standard linear regression in which case the data have to be normally distributed (Helsel and Hirsch, 2002). The statistical Mann-Kendall test was calculated by using Addinsoft's XLSTAT 2012. Detailed results of the Mann-Kendall trend test for each data set are provided in Appendix 2.

4.3.1 Rio Hondo Streamflow

Data on the Rio Hondo streamflow have been gathered at a USGS gage located in Valdez, NM since 1935. These data were downloaded from the USGS Water Information

System Web Interface (USGS, 2012). Figure 16 displays the Average Annual Flow (cfs), the Ten Year Running Average of Annual Flow (this smooths the data to emphasize long-term variability), and the linear trend line generated by Microsoft Excel for each water year. This chart reveals a remarkable range of annual flow, the lowest being around 10 cfs in 2002 and the highest around 70 cfs in 1942. The annual average flow across all years is 34.6 cfs. The linear trend line shows a moderately decreasing trend in annual average flow. However, the Mann-Kendall trend test showed that this trend is not significant at the 95% confidence level.

Plots were also created for flows during the growing season from May through September (see Figure 17). Linear trend lines in these plots indicate slight decreases in June, July, and August flows. More moderate decreases in flow were seen in the month of May. September shows an almost straight trend line indicating no trend at all in the data. None of these trends are statistically significant at the 95% confidence level.

Seasonal timing of Rio Hondo flow is described by the center of mass of the annual flow center timing (CT), calculated using the following formula:

$$CT = \sum_i (t_i q_i) / \sum_i q_i$$

where t_i is the time in days from the beginning of the water year (October 1), and q_i is the corresponding streamflow for water yearday i. The CT provides a time-integrated perspective of the timing of the spring pulse and the overall distribution of flow for each year (Stewart, 2004, p. 1139). This is a good approach to use to examine the timing of flow in snow-melt dominated basins like the Rio Hondo because the spring pulse onset date is hard to determine and the data are very noisy (Stewart, 2004).

Figure 18 displays the results of the CT calculation for flow in the Rio Hondo. This measurement shows that the CT in days from October 1st ranges from 168 days in water year

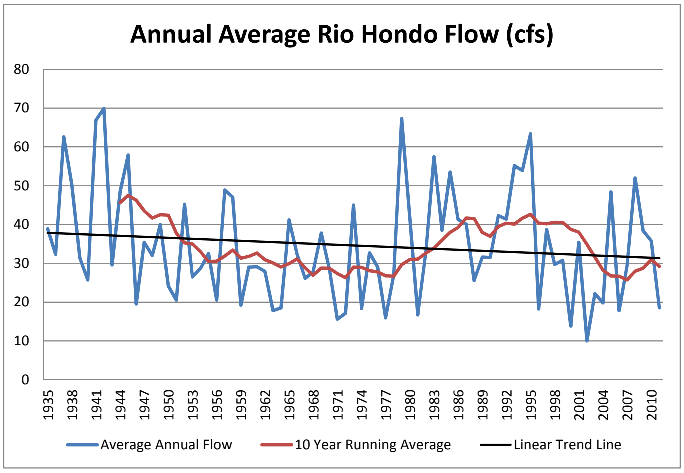


Figure 16: Annual Rio Hondo Flows for Each Water Year (1935 to 2011)

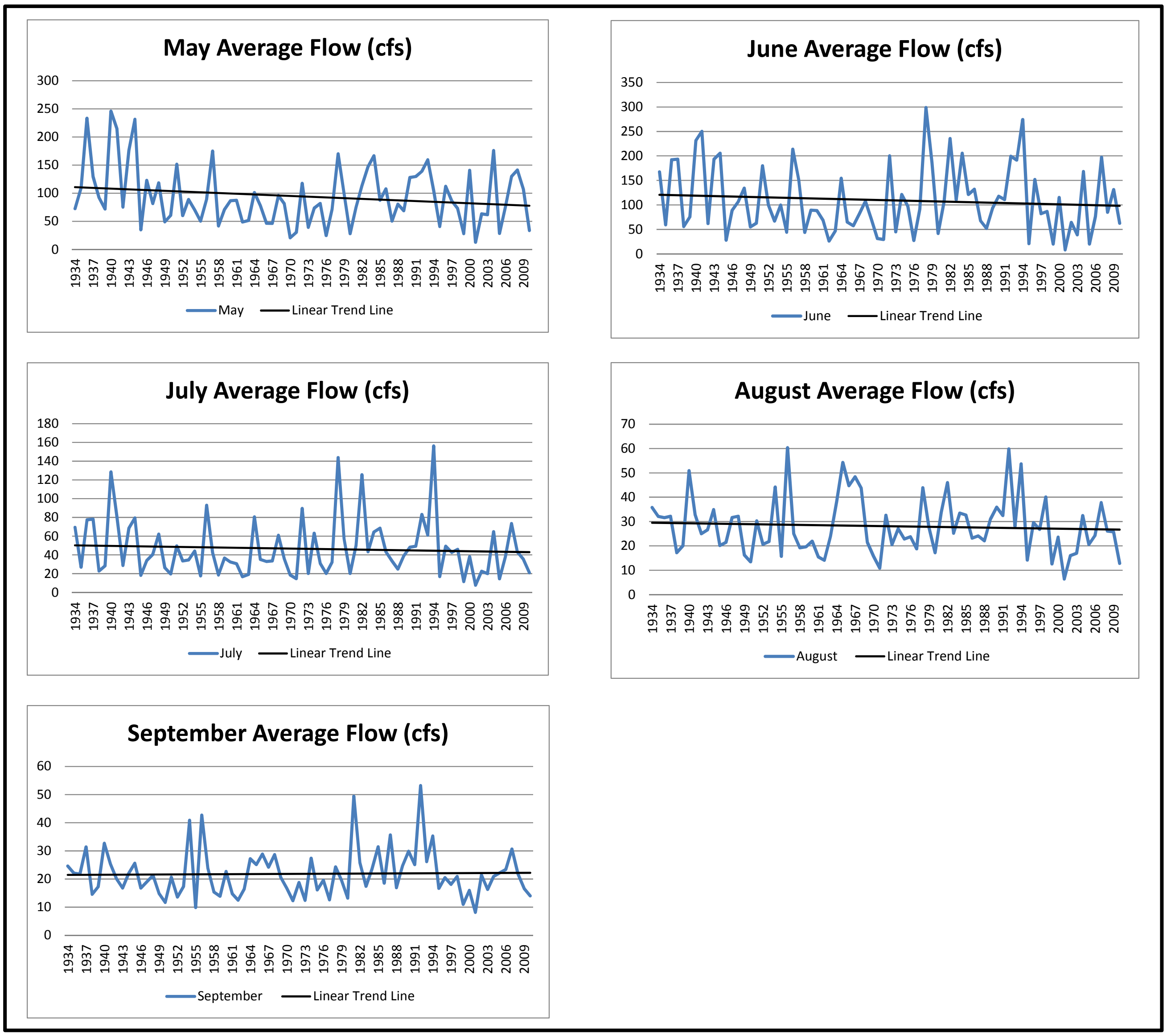


Figure 17: Monthly Rio Hondo Flows (1935 to 2011)

2001 (March 17th, a very early runoff) to 251 days (June 8th) in water year 1956. It's not hard to imagine that the water year in 2001 (from Oct 1, 2000 to Sept 30, 2001) was a very hard year for farmers in the region. The average CT of all years is 221 days, or around May 9th. The trend line in Figure 18 shows that there is a slight downward trend in the CT measurement indicating that flows in general may be coming earlier than in previous decades. However, the Mann-Kendall trend test did not find that this trend is statistically significant.

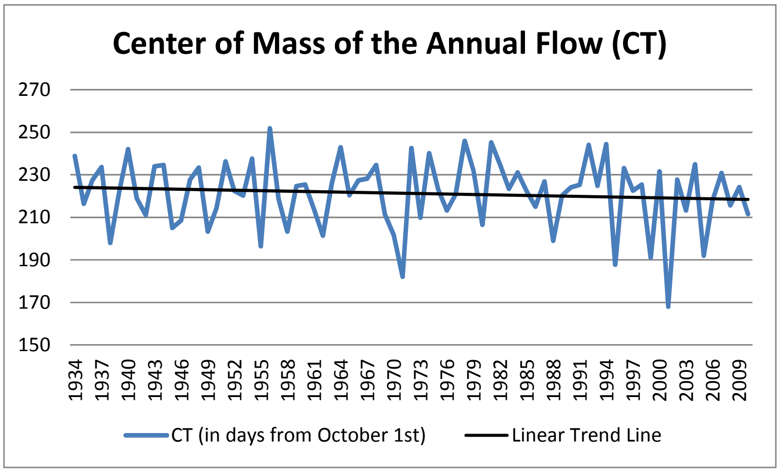


Figure 18: CT Calculation for Rio Hondo (Water Years 1934-2010)

4.3.2 Temperature

There are no WRCC cooperative observer stations in the Rio Hondo watershed to use for temperature trends. The WRCC station in Cerro, NM is the closest to the watershed, however, its historical data sets were very sparse so it was not used as a proxy for temperature trends in the Rio Hondo. Instead, data were downloaded from the PRISM climate mapping system, which uses actual point measurements of precipitation and temperature, a digital elevation model, and expert knowledge to create a continuous grid of monthly and yearly climate parameters (PRISM, 2012). PRISM data were downloaded for maximum and minimum temperature on a monthly basis for the years 1895 to 2011 for the grid cell that incorporates the latitude and longitude of

Valdez, NM. It is important to keep in mind that the temperature data used do not represent actual measured temperatures in Valdez.

Figure 19 shows the maximum monthly temperatures averaged over the warm season (April-September) and the cold season (October-March) and Figure 20 shows the corresponding minimum monthly temperatures for each season. All the trends appear to be positive, meaning that Valdez, NM is experiencing warmer temperatures than in previous decades. The warmest years appear to be happening in the early part of the 21st century, with another noteworthy peak in temperatures in the 1950's. Both trends for maximum temperature pass the Mann-Kendall trend test for statistical significance at the 95% confidence level and the strength of the trends (measured by the Kendall's tau which is unit less and has a value of up to 1) are 0.178 for the cold season and 0.213 for the warm season. The warm season trend is therefore stronger than the cold season trend in maximum temperature. The minimum temperature trend for the warm season is significant at the 90% confidence level with a Kendall's tau of 0.116. The minimum temperature trend for the cold season is not statistically significant.

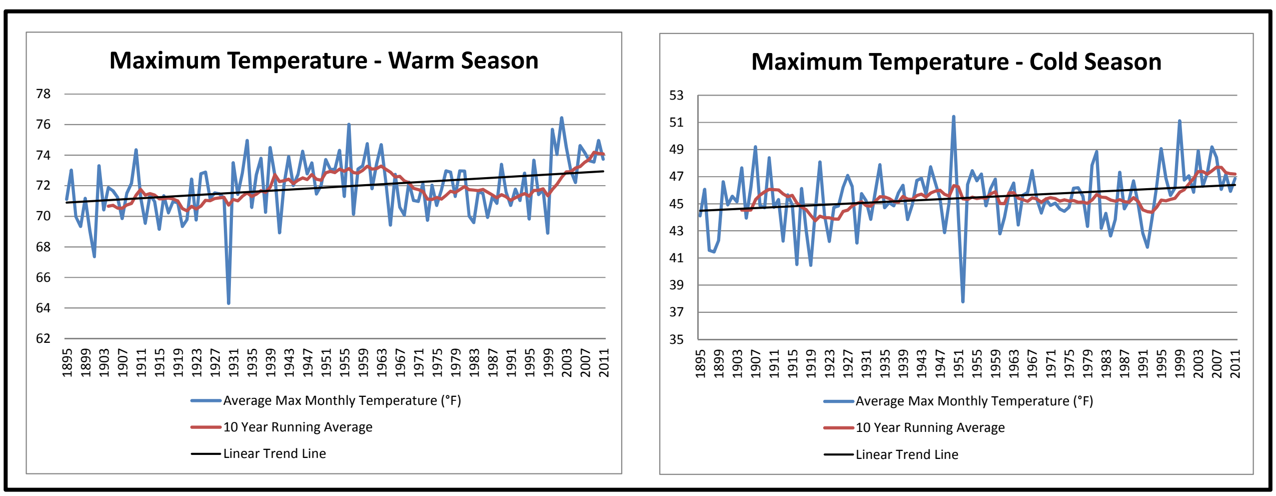


Figure 19: Maximum Temperatures at Valdez, NM (1895-2011)

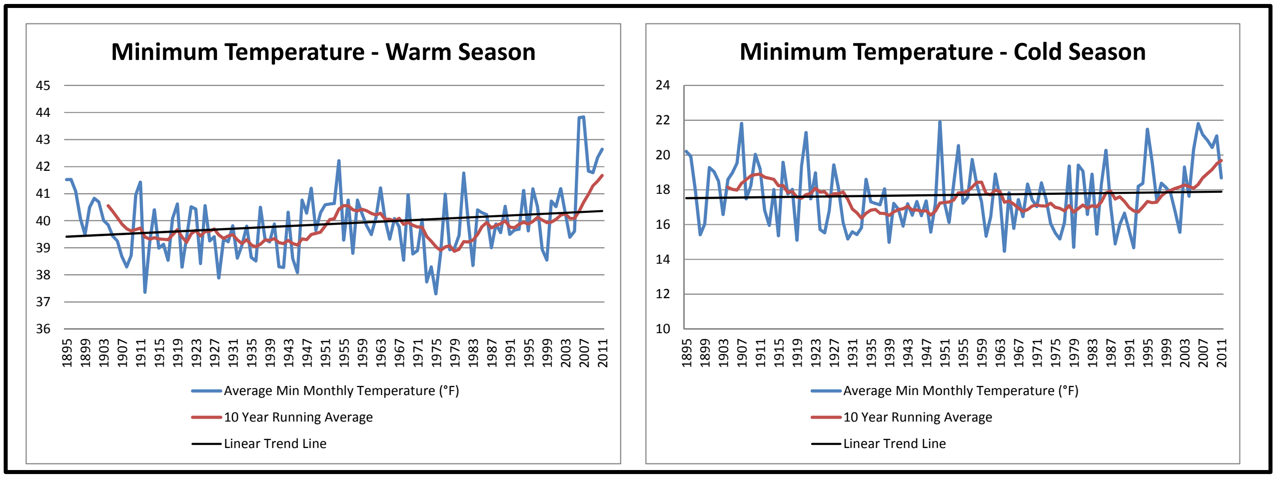


Figure 20: Minimum Temperatures at Valdez, NM (1985-2011)

4.3.3 Precipitation

Precipitation data were also collected at Valdez, NM through PRISM because of the lack of complete historical data at the WRCC Cerro, NM site. Figure 21 illustrates the variability of annual precipitation over the entire period of record, much like the precipitation variation across the entire state that was mentioned earlier. The lowest year for precipitation was 1956, with only 7.07 inches and the highest year was 1986 with 20.25 inches. The linear trend line indicates a slight increase in annual precipitation and the annual (calendar year) average precipitation across all years is 13.4 inches. The Mann-Kendall trend test found no statistically significant trend.

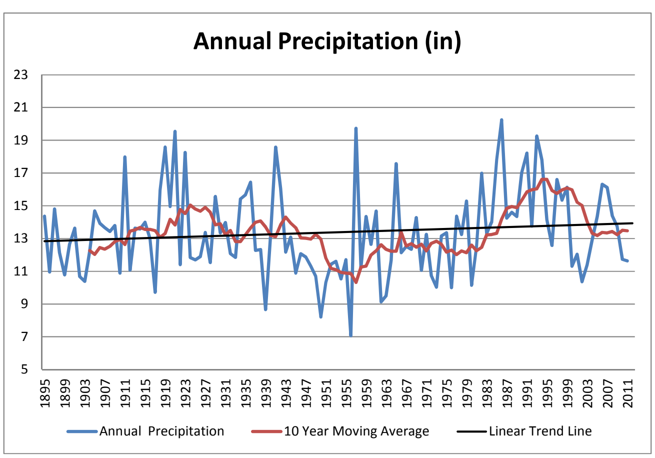


Figure 21: Annual Calendar Year Precipitation at Valdez, NM (1895-2011)

4.3.4 Snowpack

There is one SNOTEL (for SNOwpack TELemetry) site in the Rio Hondo called the Taos Powderhorn site. It is managed by the Natural Resources Conservation Service (NRCS) and as such, the data were downloaded from the NRCS' National Water and Climate Center website (NRCS, 2012). The elevation at this site is 11,507 feet and it is located in the northern part of the watershed, close to the Taos Ski Valley and Wheeler Peak. First of the month snow water equivalent (SWE) measurements are available for January through May. Snow water equivalent refers to the amount of water contained in snowpack and is the depth of liquid water that would result from melting the snow. January and May data were not analyzed due to the fact that data only extend back to 1989 for these months. At least 30 years of data are needed to assess a change in climate statistics. February, March and April SWE measurements were available back to 1974 (although data are missing from 1984 to 1988 for these months).

February, March, and April SWE measurements are shown in Figure 22. Consistently low snowpacks were observed from 2000-2005. Highest snowpacks were measured in 1979 and lowest snowpacks were measured in 2006. February and March show slight downward linear trends in SWE, whereas April shows a stronger downward linear trend. None of these trends were found to be statistically significant using the Mann-Kendall method (with missing values replaced with the average of the previous and next values). However, the p-value for the April SWE trend was 0.134, which is just above 0.100 - the level that would indicate significance at a 90% confidence level.

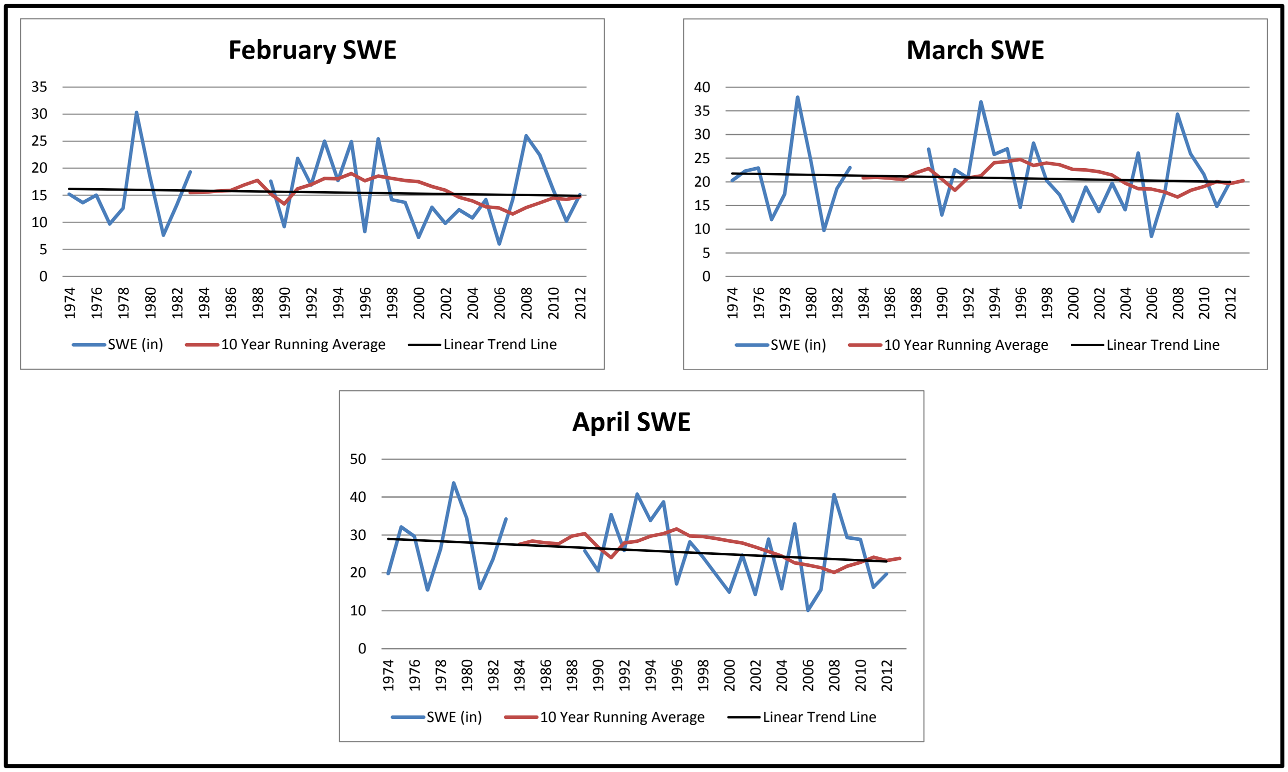


Figure 22: Taos Powderhorn SWE Measurements (1974-2012)

4.3.5 Drought Severity

Palmer Drought Severity Index (PDSI) data were downloaded from the National Climatic Data Center for the Northern Mountains Climate Division in New Mexico for the years 1895 to 2011. The PDSI is a semi quantitative index of the drought severity in a region on a scale of 1 to 10 and is calculated monthly. The index is calculated using a formula with current and historical temperatures to determine dryness. Values generally range between six (extreme wet conditions) and negative six (extreme drought). A limitation of this statistic is that it treats all precipitation as rain, so the index does not perform as well at high elevations where there is a lot of snowpack (NOAA, 2003). The index also measures long term meteorological drought, rather than hydrological drought. Meteorological drought is determined based on the degree of dryness compared to the 'normal' or average and the duration of the dry period. Hydrological drought occurs following extended periods of precipitation shortfalls that impact water supply and has the potential to cause societal impacts. Figure 23 shows the monthly PDSI values from 1895 to 2011 for the NM Northern Mountains Climate Division. The trend over time is significantly negative at the 95% confidence level and the Kendall's tau is -0.114. This means that we can confidently reject a null hypothesis that the PDSI has no trend and conclude that the area is becoming more dry over time as measured by PDSI.

Figure 24 displays the Palmer Hydrological Drought Index (PHDI), an index that measures long-term hydrologic drought, for the same area and time period. This PHDI is also decreasing over time. The Mann-Kendall trend test also found this trend to be significant at the 95% confidence level and the Kendall's tau is -0.148, a slightly stronger decreasing trend than the PDSI. A test of sensitivity of the trend in PDSI and PHDI was also performed that just looked at data from January 1901 to December 2000. This removed the sharp drought early in the 21st century. Both trends were still found to be statistically significant though the strength of the trends was smaller – the Kendall's tau for PDSI was -0.068 and the Kendall's tau for PHDI was -0.087.

Climatologists are not in agreement over whether or not it is appropriate to use PDSI/PHDI as an indicator of climate change, because the index itself was designed to describe climate variability (changes in climate statistics over a time period of less than 30 years) about a defined mean climate (D. Gutzler, personal communication, December 2, 2012). Using an index that has a shifting defined mean climate means that the index is biased over time with regard to actual climate change (changes in climate statistics over a time period of more than 30 years). In other words, if it is getting warmer, the climate mean shifts and therefore the value of the PDSI/PHDI shifts reflecting the climate variability. So the magnitude of the change in

PDSI/PHDI over time is constrained by this shifting climate mean. In this case, the bias likely under predicts how much drier it has become in New Mexico. It should be noted that a recent study concluded that global drought has been overestimated by the PDSI because of its simplified model of evapotranspiration, though climate scientists are also not in agreement over this conclusion (Sheffield et al., 2012; D. Gutzler, personal communication, January 17, 2013).

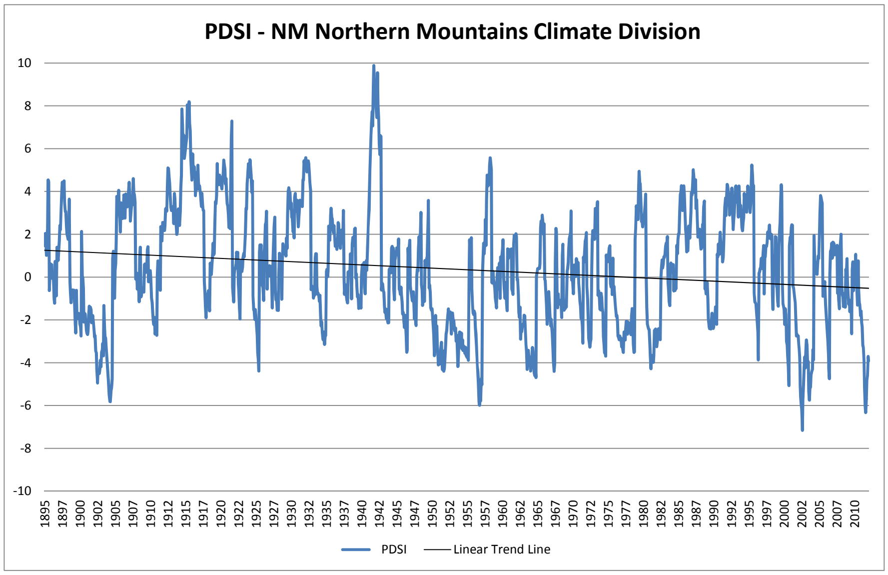


Figure 23: PDSI Values for NM Northern Mountains Climate Division

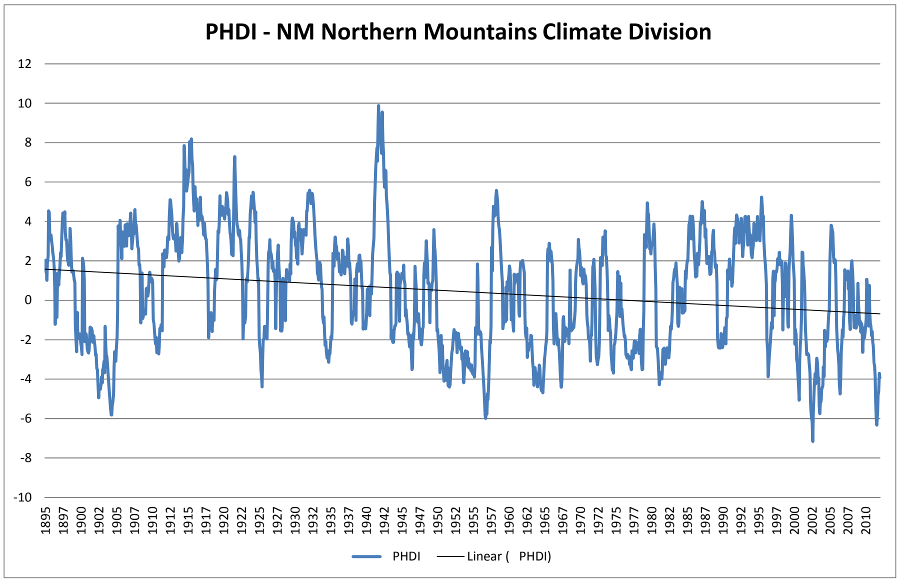


Figure 24: PHDI Values for NM Northern Mountains Climate Division

4.3.6 Conclusions on Rio Hondo Climate Change Data Analysis

Data analysis in previous studies found sometimes differing trends in climatological data records as well as trends that would not be expected in an area of the country that has experienced warming temperatures significantly higher than the global average (i.e. increased snowpack). For this reason it was important to look at local Rio Hondo data measurements to gain a better understanding of climate change that might have impacted acequia farmers.

There are a few things that can be said with certainty about the climate in the Rio Hondo. One is that temperatures in this region are increasing both in the warm and cold season. The temperature trends are one of only two statistically significant trends found in this analysis and are considered to be a change in climate. Farmers are likely dealing with more surface water evaporation than in previous decades, though temperature is only one component of evaporation.

The second certain conclusion is that this region has experienced periods of wet spells and dry spells, just like the rest of the state and the rest of the Southwest. Farmers have dealt with drought repeatedly and are no strangers to water scarcity. However, the drought indices examined are decreasing with time, meaning that the area is experiencing more dry conditions than in the past. These two statistically significant findings are consistent with each other as increased temperatures can serve to drive droughts in arid regions and future increases in temperature are expected to exacerbate evaporative losses (Gutzler and Robbins, 2010).

The data showed that there are no statistically significant trends in precipitation, river flows, CT timing, and snowpack in the Rio Hondo. The impacts of increased temperatures, considered in isolation, would be to decrease river flows (due to increased evapotranspiration associated with a longer growing season), to shift spring snowmelt to earlier in the year, and to decrease the amount of snowpack (due to the shift of rain to snow). However, these impacts are not reflected in the data up to this point. Increased temperatures are also thought to cause more variable and extreme precipitation events, but this impact was not captured in this analysis. The complexity of the climate and its interaction with hydrological parameters is very apparent.

Significant variability was shown in all of the climate measures looked at in this report. The fact that acequias have thrived through this variability is a testament to their resilience. The 2010 Cox study found the same result through looking at climate change from the perspective of how robust or resilient the social-ecological systems are to disturbances. In this study individual acequias and acequia systems in Taos were found to be robust to drought. Robustness is defined as the maintenance of some desired system characteristics despite fluctuations in the behavior of its component parts or its environment (Cox, 2010, p. 21). This robustness was attributed to the high level of social capital and collective action in the acequia system. Maintaining the social capital and collective action inherent in traditional acequia systems is key to their continued resilience against climate change, like the increased temperatures described in this chapter. The IPCC also concluded in 2007 that rural or small communities that are historically familiar with change have developed more effective strategies and adaptation practices than centralized government institutions (IPCC, 2007b). Acequias certainly seem to have proven this point.

As a last note, trend analysis was used to analyze time series climate data. More could be inferred in the future with the use of other time series data analysis techniques, such as deviation from the long-term average or deviation from the long term trend. Other factors that could have been included to strengthen the analysis include the date of the spring onset of flow, an analysis of summer versus winter precipitation, an analysis of the length of the growing season, and the list goes on. However, the goal of this section of the report was to cover the basic hydrological and weather measures that indicate changes in climate.

4.4 A Final Word on Projected Climate Change

This project is focused on understanding observed change over time and its impacts on acequia farmers. However, it is also important to understand where the climate is headed, given what we know from the past. Although acequias seem robust to climate change and drought, if significant changes are projected for the future, acequias may need to consider additional measures to ensure their continued existence.

The 2005 report *The Impact of Climate Change on New Mexico's Water Supply and Ability to Manage Water Resources* assessed climate model simulations to project major seasonally varying consequences of climate change in New Mexico. The report suggests that snowpack could be reduced drastically due to temperature changes and that there is a possibility of a reduction in winter precipitation. Warmer temperatures and drier land surface conditions could also raise evaporation rates and increase vulnerability to drought cycles in the warm season (NM Office of the State Engineer, 2006, p.14-15). A recent study by Gutzler and Robbins (2010) projected temperature and precipitation trends for the last 93 years of the twenty-first century. This study came to conclusions similar to those stated above for the northern mountains region of New Mexico: (1) that temperature changes will be larger than precipitation changes, (2) that late twenty-first century summer temperatures will exceed any monthly temperature ever recorded in parts of the Southwest, (3) that there will be sharp increases in the severity and duration of droughts and that these droughts will be spread across the west, and lastly, (4) that future droughts will be driven to a greater degree by temperature than precipitation, meaning that precipitation-driven droughts will be harder to recover from because of increased evaporation from higher temperatures (Gutzler and Robbins, 2010, p.13).

What this means for New Mexico was summarized powerfully in the report *Potential Effects of Climate Change on New Mexico:* "Warmer temperatures will reduce mountain snowpacks, and peak spring runoff from snowmelt will shift to earlier in the season. A longer and hotter warm season will likely result in longer periods of extremely low flow and lower minimum flows in late summer. Water supply systems which have no storage (e.g., many acequia systems) or limited storage may suffer seasonal shortages in summer" (NM Office of the State Engineer, 2006, p.2). There has already been a report that shows a projected decrease in mean winter snowpack in central northern New Mexico (Brown and Mote, 2009). Additionally, a 2004 study projected that central northern New Mexico will experience earlier peak runoffs, especially during the latter years of the 21st century (Stewart et al., 2004). Middle Rio Grande streamflows have also been projected to decrease total volume between four and 14 percent by 2030 and between eight to 29 percent by 2080 (Hurd and Coonrod, 2008).

These climate projections highlight one of the major threats to the acequia way of life in New Mexico. Since acequia farmers rely heavily on snowmelt for flows in the river during the growing season, they will be impacted by projected climate change. Although they have been shown to be robust to drought and climate change in the past, these new projections suggest that droughts may be more severe in the 21st century than they were in the 20th century and that additional safe guards need to be put into place to protect acequia systems. Projected climate change along with projected population growth (described in the next chapter) will strain acequia systems even more than in the past, making adaptation and adaptive capacity important for the future of acequias. Fortunately, work has recently been done to try to quantify rural community preparedness and adaptation to climate change (and demographic pressures), but results show divided opinions of the level of preparedness and vulnerability (Mayagoitia, 2011).

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CHAPTER FIVE: DEMOGRAPHIC CHANGE IN THE RIO HONDO

5.1 Introduction

Acequias in New Mexico were built by early *hispano mexicano* settlers in order to divert stream waters and regulate water resources between users (Rivera, 1998). The importance of human interaction in the acequia institution is apparent. Not only is community cooperation required for communal upkeep and operation of acequias, but historically the acequia institution has bonded the community through self-help mutualism, shared values, and traditions that formed a regional culture (Rivera, 1998). Demographic changes can have a large impact on the acequia institution's ability to continue this communal approach to water resources management in the ways outlined below.

Rivera (1998) asserts that the demographic forces of in-migration, population growth, and land development pressures place fragile acequia communities at great risk. In-migrating newcomers frequently do not understand the established rules and social norms of the acequia culture, do not share the native residents' attachment to land and water, sometimes do not participate in communal activities like the *limpia,* and there are even some easement issues with newcomers (Ortiz, 2012a&b; Mayagoitia et al, 2012). Newcomers in developments above the irrigated valley can also have impacts on the acequia in the form of damage from additional runoff and water pollution (Ortiz, 2012b, Rodriguez, 1987a). Out-migration of *parciantes* weakens the acequia institution, because traditional knowledge on how the acequia best operates can be lost. This mainly happens because individuals move to larger towns/cities for economic opportunities. Young people also move for economic and cultural reasons and often elders are not able to pass on the acequia way of life. All of these issues have impacts on the effectiveness and strength of the acequia institution.

Population growth is a demographic change that is an enormous threat to acequia communities. Population growth within the local acequia community associated with in-migration of newcomers can have the impacts described above. However, population growth downstream of the acequia system is also problematic. The threat of population growth is outlined very well in the "El Agua es la Vida" declaration from the 2006 Congreso de las Acequias. The first four threats outlined in this declaration are paraphrased here:

> Unprecedented growth and development in New Mexico are driving demands to move water rights out of agriculture to urban, resort, and commercial development. Acequia communities are projected to lose 30% to 60% of their water rights base and farmland to development in the next 40 years. Acequias may be driven to extinction by water transfers because of reduced pressure head at the point of diversion and fewer families to contribute to the maintenance and governance of the acequia. Wealthier individuals, entities, and regions acquire water rights because of their position of greater economic power (NMAA, 2006).

Population growth in urban centers provides economic incentive for the transfer of water rights from agriculture to urban and commercial uses, especially as farmers struggle economically and often have to turn to selling their land or water rights or both in order to make ends meet. As stated above, the impact of these water rights transfers are to weaken the acequia literally – through reduced pressure head, but also through loss of communal labor and participation. As more people move to cities for economic opportunities the tension on water resources and appropriate uses becomes greater.

Many of the points made above hit on the last issue brought up by Rivera (1998) – land development pressure. In the Rio Hondo valley this is of particular importance due to the construction of the Taos Ski Valley in 1954, as well as its vicinity to the Taos, NM "art colony" as dubbed by Rodriguez (1987a). Land development pressure has increasingly been felt in this region through the construction of vacation homes or commercial development. A good example of this is the Valdez Condo wars which were mentioned earlier (Rodriguez, 1987b). Land development can not only lead to the conversion of agricultural land to non-agricultural land, but can also result in water rights transfers out of agricultural uses.

This section of the paper will focus on understanding how demographics have changed in the State of New Mexico, Taos County, and the local Rio Hondo watershed. From this data analysis, it will be possible to infer how much pressure the Rio Hondo acequia systems have had to deal with in regards to demographic changes. Documentation of demographic change in the literature will be reviewed first, followed by a supplemental analysis of current and historical census data. The demographic change findings will then be discussed, followed by a conclusion.

5.2 Demographic Change Documented in the Literature

In the Rio Hondo watershed, land values were $1,000 per acre in 1965, were $25,000 or higher by 1986, and were $40,000 or higher in 1997 (Rodriguez, 1986). One acre in Twining, which is a town right next to the ski basin, went for between $45,000 and $75,000 in 1981 (Rodriguez, 1987a). All of these increased land values can be attributed to the demand for second homes, condos, lodges, and recreational facilities. It should be noted that people in a recent focus group were concerned that these increased property values due to tourism were causing property taxes to increase accordingly leading to gentrification in this area (Ortiz, 2012b). Though some might think that tourism development implied by this data would translate into economic prosperity in the region, it is actually true that unemployment has remained consistently high in the region since 1970 (Rodriguez, 2009).

Since 1960, tax rolls indicate a decrease in acreage owned by Hispanics and an increase in acreage owned by Anglos (Rodriguez, 1987a). In the 1960's more than 50 percent of the land in the Valdez-Twining tax district belonged to Anglos. In 1987 in Arroyo Hondo, about 65 percent of land was still owned by Hispanics, although the number of Anglo landowners increased fivefold between the years 1970 and 1980. Also in 1987, the town of Des Montes was characterized by 75 percent Hispanic landowners (with about half the land acreage), but the number of Anglo residents outnumbered Hispanic residents when renters were included (Rodriguez, 1987a).

A 2000 study by the Bureau of Business and Economic Research (BBER) examined Taos County migration for the period of 1970 to 1999. The 1970's were characterized by a negative net migration, the 1980's saw a positive net migration of about a thousand people, and the 1990's saw net migration increase of almost two thousand people. Migration has had a dramatic impact on some of the demographic characteristics of Taos County. The first is the age structure – the median age for the county increased from 24 to 34 from 1970 to 1990. This is because out-migrants were generally younger (median age a young 28) whereas the in-migrants were generally older. The second demographic impact of migration is racial and ethnic composition. From 1980 to 1990 the percentage of Hispanics decreased from 69 to 64 percent at a time when the percentage of Hispanics in the State and Nation were increasing. What this means is that more Hispanics left Taos County than migrated in. In-migrants were more likely to be highly educated, higher income earning, Anglo, and single. In-migrants to Taos County originating from out of the state of New Mexico out-numbered in-state migrants by two to one. Lastly, migration contributed to a decline in married couple families and increases in non-family households and single-female headed households in Taos County (BBER, 2000).

The BBER study also analyzed migration at the census tract level. Tract 9522 includes Arroyo Hondo, Valdez, and Arroyo Seco. This tract had the second highest percentage of out-of-state in-migrants of all tracts in Taos County at 14 percent. This tract also had the highest percentage of Anglo in-migrants of any tract in Taos County with 80 percent of all in-migrants being Anglo. The overall Anglo population in this tract was 43 percent in 1990. Tract 9522 also had the highest median house value and rent and residents had the second highest median income of all Taos County tracts (BBER, 2000). In her survey of three acequia irrigation communities, Mayagoitia (2011) found that the Rio Hondo had the highest number of newcomers integrating in the acequia system, a similar, but more recent finding to the BBER study.

Mayagoitia et al (2012) found that the population in Taos County has increased 92 percent over the last six decades, with the most significant increases happening in the decades 1990 and 2000. These increases in population/newcomers have also altered the economic profile of the region – in 2006 zero percent of Taos County's employed population were employed in the agriculture/forestry/fishing sector. Not surprisingly, 66 percent of the county's employed population worked in the service sector in leisure, hospitality, education, health, trade, transportation, and utilities (Mayagoitia et al, 2012). Cox (2010) cited 2000 US Census data which showed only 4.4 percent employment in the agriculture/fishing/hunting/mining sector and also showed increases in employment associated with tourism, real estate, and entertainment. This data shows that acequia *parciantes* are earning a living through full or part-time employment rather than by being farmers or ranchers (Cox, 2010).

5.3 Supplemental Census Data

The research cited above sheds some light on the demographic changes that have occurred in Taos County and the Rio Hondo region. This next section serves to supplement the findings from above and to collect demographic data at the most local level available. Data from the 2000 Census and the 2010 Census are readily available via the Census' American Fact Finder website. Older Census data are harder to track down; in many instances the data used for these years comes from BBER sources. In order to analyze 2000 and 2010 Census data at the most local level possible, the Arroyo Hondo Census County Division (CCD) was utilized. The town of Arroyo Hondo is a census designated place, but unfortunately it did not become a census designated place until 2010. For this reason data are not available for the town of Arroyo Hondo before 2010 and even in 2010, data are only available for a few basic parameters that will be cited in this text where possible. In some instances 2010 American Community Survey (ACS) 5-year estimates are used and it is noted in the text where ACS data are utilized.

The boundaries of the Arroyo Hondo CCD are displayed in Figure 25. The Arroyo Hondo CCD, although much bigger than the boundaries of the irrigated area, is a good proxy for what is happening in the Rio Hondo acequia community because there aren't many other populated towns outside of the irrigated area, except Arroyo Seco, which is also a rural area with an extensive acequia irrigation network that generally pulls water from Arroyo Seco Creek and the Rio Lucero.

5.3.1 General Population Data

The Census shows that in 2010, 449 people lived in Valdez and 474 people lived in Arroyo Hondo (Mayagoitia, 2011). Additionally, 1,785 people lived in Arroyo Seco in 2010.

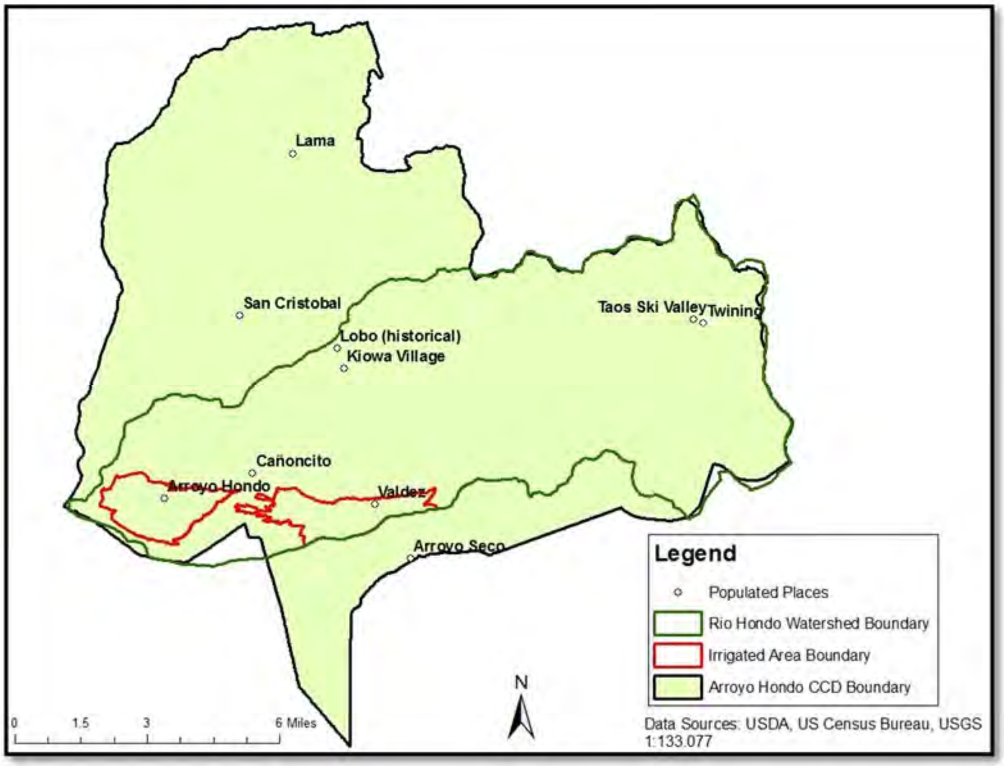

Figure 25: Map Showing Boundaries of Watershed, Irrigated Area, and Arroyo Hondo CCD

Figure 26 shows the population of Taos County and the Arroyo Hondo CCD and how these populations have grown over time. The population in Taos County has been consistently increasing since the 60's, growing significantly faster than the rest of the State in the 1990's and 2000's. The largest increase in the Taos County population happened between 1990 and 2000, with 30 percent increase in population during that decade. Growth slowed in the 2000's, but still there was an increase of about 3,000 people. The Arroyo Hondo CCD added 455 people between 2000 and 2010, an increase of 12 percent, which was about 2 percent more growth than the county and one percent less growth than the State during the same period. Significant population growth is seen in both Taos County and the Arroyo Hondo CCD in recent years with the Arroyo Hondo CCD experiencing even more growth than the County, but less growth than the State.

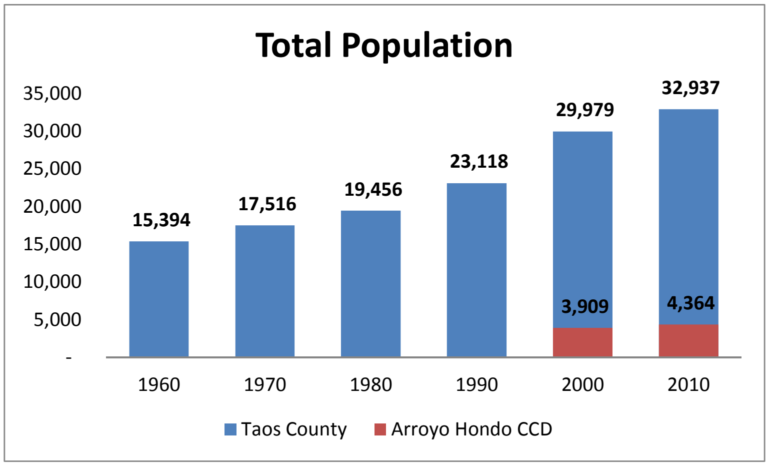

Figure 26: Populations of Taos County and Arroyo Hondo CCD, Sources: BBER, 2012; US Census Bureau

5.3.2 Age Data

A good measure of how the population is aging is how the median age changes over time. As described in the review of literature above, Taos County aged significantly between 1970 and 1999, which is also shown in the Census data in Figure 27. The median age in 1960 for Taos County was 19.6 years and in 2010 the median age has increased to 45.2 years of age. In Taos County, the 1970's, 1980's, 1990's all saw an over 20 percent increase in median age over the previous decade. The more remarkable data comes from the Arroyo Hondo CCD. Here the median age is even higher than the county in both 2000 (41.3 years) and 2010 (47.8 years) and there was a 16 percent increase in median age between 2000 and 2010, compared to a 14 percent increase in median age for the same time period for Taos County. As a further comparison, the median age in the State of New Mexico was 36.7 in 2010 and the median age for the town of Arroyo Hondo was 43.3 in 2010. It is very clear that both Taos County and the Arroyo Hondo CCD have both experienced an aging of their population in recent years, with a higher rate of aging in the Arroyo Hondo CCD than the County.

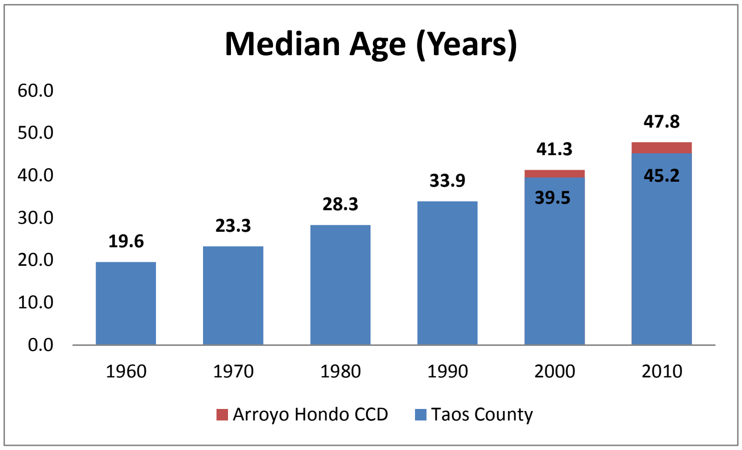

Figure 27: Median Age for Taos County and Arroyo Hondo CCD. Sources: BBER, 2012; US Census Bureau

5.3.3 Ethnicity Data

Taos County has much higher percentages of Hispanics or Latinos than the State of New Mexico (see Figure 28). However, while the percentages of Hispanics and Latinos have been decreasing over time in the County, the state of New Mexico has seen increasing percentages of Hispanics or Latinos over time. The Arroyo Hondo CCD has much lower percentages of Hispanics or Latinos than Taos County. Between 2000 and 2010 there was a decrease of about 3 percent in the percentage of Hispanics and Latinos living in the Arroyo Hondo CCD. About 66 percent of people living in the town of Arroyo Hondo were Hispanic in 2010, whereas only 44 percent of people living in the Arroyo Hondo CCD were Hispanic in 2010.

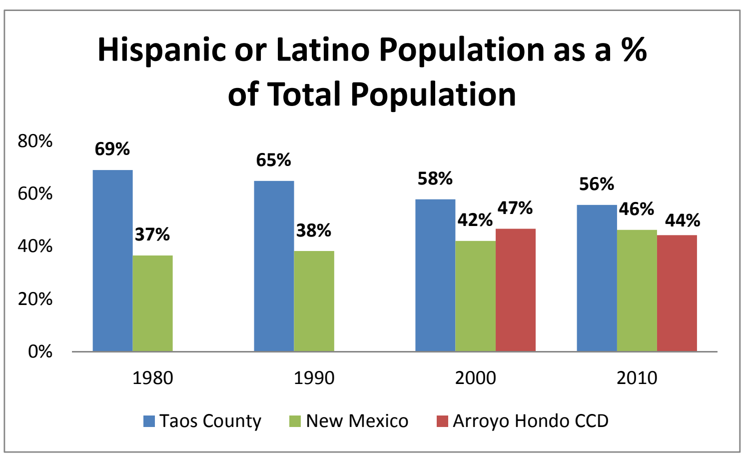

Figure 28: Hispanic or Latino Percentage, Sources: BBER, 2003; US Census Bureau

5.3.4 Income and Poverty Data

Median household incomes in Taos County are consistently lower than the median household incomes in the State of New Mexico for the past 5 decades (see Figure 29). Over time, the median household income has gone up and down in Taos County, with the median household income down to $32,940 in 2009. In the Arroyo Hondo CCD we see higher median household incomes than in Taos County, and in 2009, the Arroyo Hondo CCD had an even higher median household income than the State of New Mexico at $45,123. It should be noted that the 2009 estimate is taken from the 2010 ACS 5 year estimates and has a large error estimate of +/- $20,291. Overall, it looks like residents in the Arroyo Hondo CCD are better off in terms of income than the rest of their counterparts in Taos County.

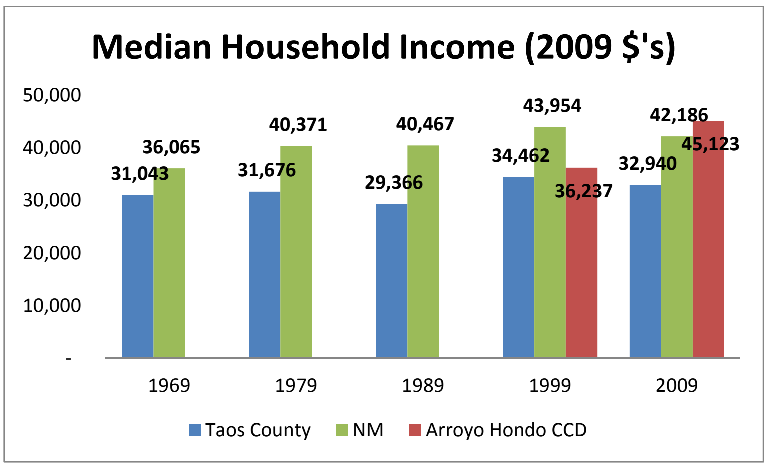

Figure 29: Median Household Income in 2009 Dollars, Sources: BBER, 2003; US Census Bureau

In four of the five last decades, Taos County has had higher percentages of individuals below the poverty level than the State of New Mexico (see Figure 30). There was a sharp decrease of 10 percent between 1969 and 1979 and another sharp decrease of 7 percent from 1989 to 1999 in Taos County. Finally, in 2009, Taos County's percentage of individuals below the poverty level is below the State's poverty level in 2009. It is clear that Taos County is doing much better on the poverty issue than in the past. With regard to the Arroyo Hondo CCD, it appears that even smaller percentages of people are below the poverty level than found in Taos County. It should again be noted that the 2009 estimate is taken from the 2010 ACS 5 year estimates and has a large error estimate of +/- 7.6 percent. Again, the Arroyo Hondo CCD seems to be slightly better off than the county in its percentage of people below the poverty level.

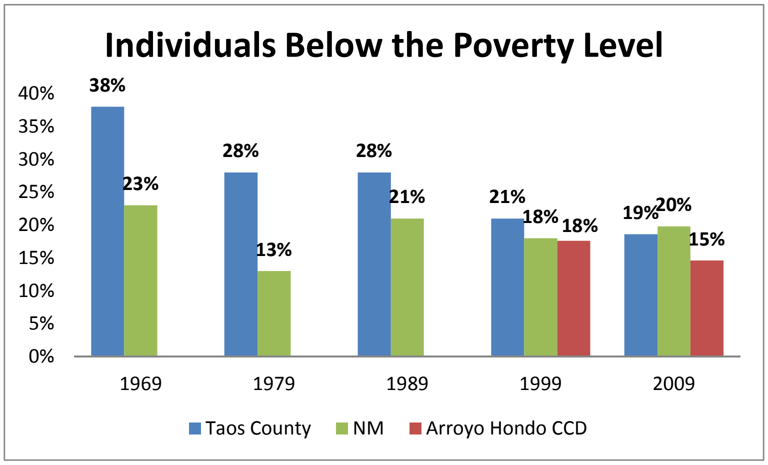

Figure 30: Individuals Below the Poverty Level, Sources: BBER, 2003; US Census Bureau

5.3.5. Employment Data

Figure 31 displays the annual average unemployment rate from 2000 to 2011 for Taos County, New Mexico and the US (data is not generally available for areas smaller than counties, except for major cities). The data is from the Bureau of Labor Statistics (BLS) website. Over time, the unemployment rate has seen ups and downs, with unemployment rates in the last few years being the highest of the last decade. The 2011 Taos County unemployment rate (9.4 percent) was slightly higher than the US unemployment rate (9.0) and much higher than the New Mexico unemployment rate (7.4 percent). New Mexico’s unemployment rate has been consistently lower than the US unemployment rate since 2006. During the entire period from 2000 to 2011, Taos County has had a significantly higher unemployment rate than the unemployment rate for the State. This pattern of higher unemployment rates in Taos County than the rest of the State has persisted since at least 1970 (BBER, 2003). So although Taos County is doing better than the State on poverty levels, it is doing worse than the State on unemployment.

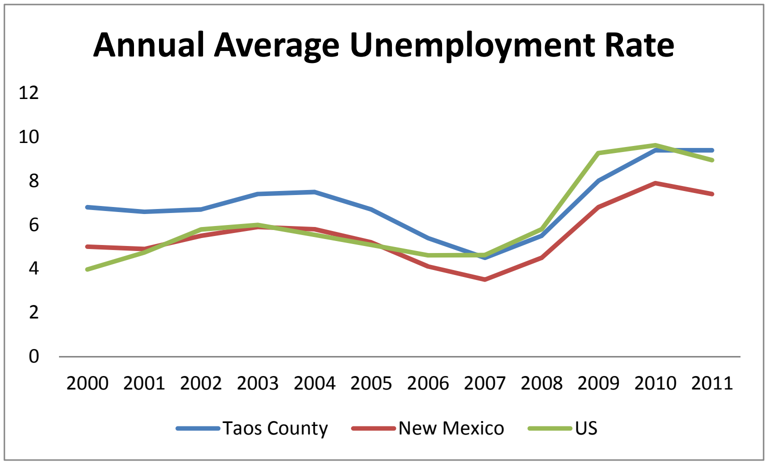

Figure 31: Annual Average Unemployment Rate, Source: Bureau of Labor Statistics

Data on percentage of people in each occupation group is shown in Table 6 – red indicates a decrease in that sector from 2000 to 2010 and green indicates an increase in that sector from 2000 to 2010. The 2000 data are from the 2000 Census and the 2010 data are from the 2010 ACS 5 year estimates. As such, data in 2010 have margins of error that make the data points less accurate. Of interest is that in both the Arroyo Hondo CCD and Taos County there are observed decreases in the number of people occupied in the agriculture, forestry, fishing and hunting, and mining sector. In fact, the total number of people working in this sector in the Arroyo Hondo CCD was 96 people in 2000 and 24 people (+/-39 people) in 2010. The data seem to agree with the finding in the literature review above that less and less people are able to work solely in agriculture and must turn to other full or part-time work to subsist. This decline in agricultural workers appears to be worse in the Arroyo Hondo region than it is in Taos County. Similar patterns are shown for increases/decreases by sector from 2000 to 2010 for both regions.

The biggest occupation was educational services, health care, and social assistance for both study areas in 2010. Arts, entertainment, recreation, and accommodation occupations were the highest percentage in 2000 for the Arroyo Hondo CCD, but that percentage has since decreased in 2010.

Table 6: Percentage of People in each Occupation Group, Source: US Census Bureau

	Arroyo Hondo CCD		Taos County	
	2000	2010	2000	2010
Agriculture, forestry, fishing and hunting, and mining	4.8%	1.3%	4.4%	2.9%
Construction	11.6%	7.4%	10.1%	10.2%
Manufacturing	2.0%	5.1%	3.2%	2.9%
Wholesale trade	1.2%	0.0%	1.6%	1.2%
Retail trade	9.4%	17.0%	12.8%	13.8%
Transportation and warehousing, and utilities	3.1%	3.9%	3.0%	6.4%
Information	0.8%	9.5%	1.5%	2.2%
Finance and insurance, and real estate and rental and leasing	6.6%	5.6%	5.4%	3.5%
Professional, scientific, and management, and administrative and waste management services	6.6%	12.1%	6.9%	9.2%
Educational services, and health care and social assistance	18.1%	22.2%	20.3%	19.4%
Arts, entertainment, and recreation, and accommodation and food services	27.3%	10.8%	19.1%	18.3%
Other services, except public administration	3.9%	2.8%	5.2%	4.2%
Public administration	4.5%	2.3%	6.5%	5.6%

5.3.6 Education Data

Taos County has had equal or higher percentages of population 25 years and older with at least a high school education compared to the State since 1990. See Figure 32 for this metric given for the years 1980, 1990, 2000, and 2010. All of the 2010 data are from 2010 ACS 5-year estimates and have a certain degree of error that is associated with this particular survey. Interestingly, the Arroyo Hondo CCD has had greater rates of high school graduates or higher than both the State and Taos County in both 2000 and 2010. In fact, this percentage has increased significantly – from 85 percent in 2000 to 94 percent in 2010 for the Arroyo Hondo

CCD. It is clear that the residents in the Arroyo Hondo CCD have higher educational attainments than their counterparts in Taos County and the State of New Mexico.

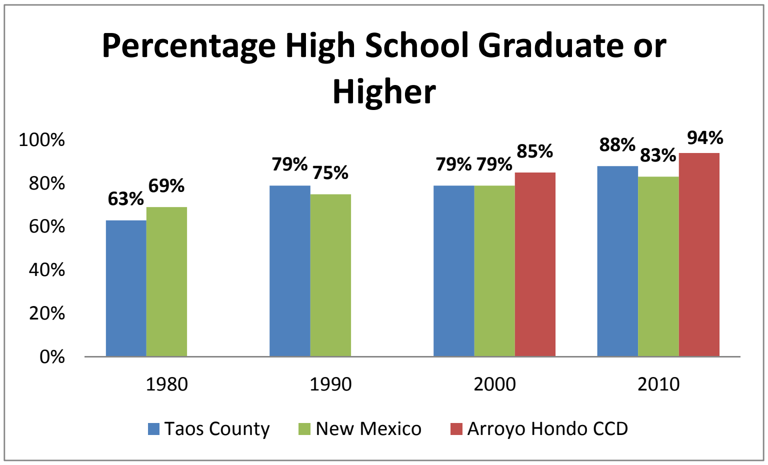

Figure 32: Educational Attainment - High School and Above, Sources: BBER, 2003; US Census Bureau

5.3.7 Housing Data

Figure 33 shows the percentage of all housing units that are vacant because they are for seasonal, recreation, or occasional use. This is an important measure to look at since tourism impacts (such as vacation homes) are of particular concern to acequia communities. There wasn't much change between 2000 and 2010 for any of the study areas. There were 697 total houses for recreational use in the Arroyo Hondo CCD in 2010 and in 2000 this number was 623 – a growth of 12 percent in that ten year period. What is apparent is that the Arroyo Hondo CCD has a much higher percentage of housing units for recreational use than both the State and Taos County. It is imperative to mention that the town of Arroyo Hondo itself only has 4.8 percent of the total housing units as housing units for recreational use in 2010. The data suggest that there is a large population of people in the Rio Hondo region that live in their houses for only a portion of the year, but that many of these houses may exist outside the boundaries of the towns in the irrigated area.

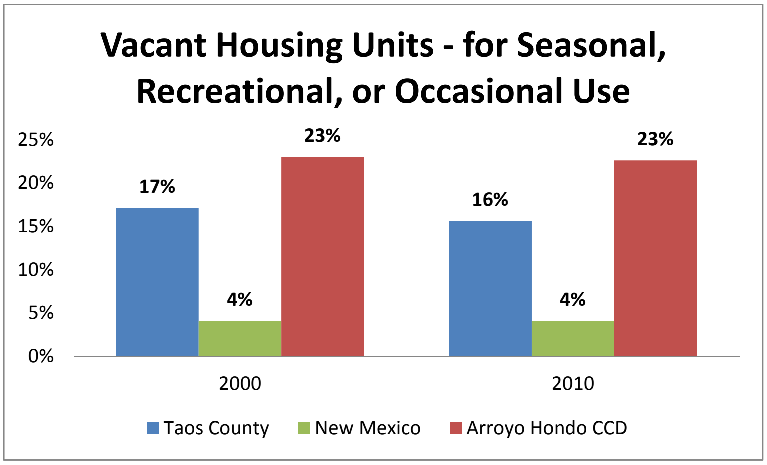

Figure 33: Vacant Housing Units - For Seasonal, Recreational, or Occasional Use, Source: US Census Bureau

The median value of owner-occupied housing units is shown in Figure 34 for the years 2000 and 2010 for Taos County, New Mexico, and the Arroyo Hondo CCD. Data could not be found for earlier years. Taos County has much higher median housing values than the State. More remarkable is that housing unit values are even higher for the Arroyo Hondo CCD - in 2010 the median owner-occupied housing unit value was $326,300 for the Arroyo Hondo CCD and $212,400 for Taos County. However, the 2010 housing unit values were taken from the 2010 ACS five year estimates and as such have associated errors (Taos County = +/-$20,424, NM = +/-$1,029, CCD = +/-$51,331). Also very noteworthy is the increase in housing values between 2000 and 2010 for the Arroyo Hondo CCD. There was an increase of 51 percent in the median housing unit value for this region. This percentage would still be significant (27 percent) even if one took the low end of the error estimate and assumed the median housing unit value was $51,331 less ($274,969). Houses are clearly more valuable in the Arroyo Hondo CCD than the surrounding area.

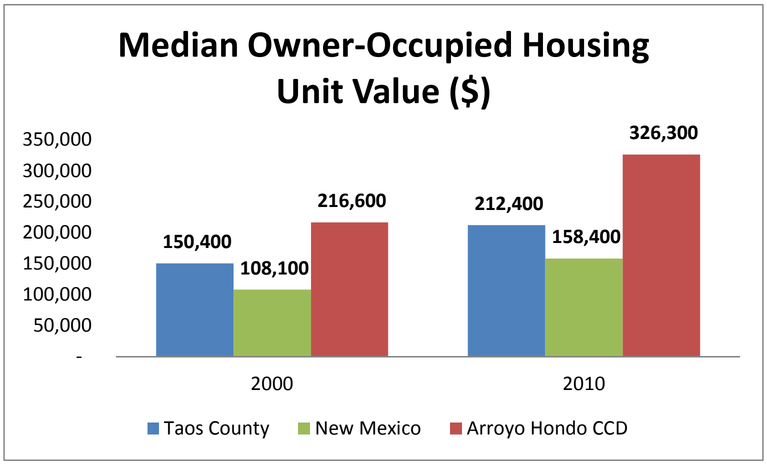

Figure 34: Median Owner-Occupied Housing Unit Value, Source: US Census Bureau

5.4 Conclusion on Demographic Change Findings for the Rio Hondo Region

From the literature review it is apparent that land values have skyrocketed in the Rio Hondo along with high median house values and rent. It was also found that although there has been tourism development in the region that this has not necessarily translated into more jobs for area residents. Hispanics were found to own decreasing amounts of land in the region over time and, in general, there have been increases in total Anglos and decreases in total Hispanics living in the area. The population in the region is also aging due to in-migration of older individuals and out-migration of younger individuals. The median income of those in the Rio Hondo area census tract was found to be higher than that of most of the other census tracts in Taos County. Lastly, it was observed that less people were working in agriculture in the region than in the past.

The supplemental research showed that the percentage of Hispanics in the Rio Hondo area continues to decline, while overall population continues to increase. Census data on median income supported the finding that there are generally higher median incomes in the Rio Hondo area, likely due to in-migration of wealthier individuals as described in the 2000 BBER report. This probably also impacted the poverty and education data and is part of the reason why the Rio

Hondo region does much better than the County and State on poverty and educational attainment. The data also showed that there is high unemployment in Taos County, supporting the notion that tourism does not itself provide enough economic opportunity for area residents. With regard to housing, there is a very large percentage of recreational/seasonal homes in the region suggesting that the ski valley and Taos itself has drawn many people to the area as a vacation destination. The housing values data on the Arroyo Hondo region provides some support for the claim that property values have increased, which may have resulted in increased property taxes and ultimately, gentrification. Property values generally also include land values, which were not examined in this report beyond what was found in the literature review.

It is clear that population growth, in-migration, and land development has considerably changed the demographics of the Rio Hondo over time. The most significant shifts are the decrease in Hispanics, the aging of the population, the increase in housing values, and the overwhelming number of seasonal or vacation homes in the region. This analysis provides proof for the demographic changes that long term residents have long said existed.

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CHAPTER SIX: THE ACEQUIA'S RESILIENCE AND FUNCTIONALITY

6.1 Introduction

As has been shown in the previous chapters, there has been significant change in the Rio Hondo acequia community. The detailed analysis of land use was performed to understand how land use has changed over time in response to development pressures, demographic change pressures, and climate change pressures. Land use change is an inherent measure of how resilient the acequia system is to these pressures. Although there was a 25 percent decrease in the amount of irrigated land, the Rio Hondo is still functioning as a traditional acequia community. This chapter will focus on identifying and summarizing other sources of information that reveal how well the acequias in the Rio Hondo are functioning in the face of all these changes. After summarizing these sources, the focus will shift to providing a summary of all findings from this report, followed by conclusions on the resilience and functionality of the Rio Hondo acequia system, and, finally, recommendations for the future resilience of the acequia system.

6.2 Other Sources of Information on Resilience and Functionality

In order to further understand how well the acequia system is functioning, the following will be utilized: results from a recent completed survey about the Rio Hondo's community adaptation and community preparedness (Mayagoitia, 2011), interviews and focus groups that were completed in the Rio Hondo by the EPSCoR team and other research groups, results from an acequia functionality assessment performed in the Rio Hondo, and lastly statistics such as crop yields and income generation.

6.2.1 Summary of the Community Adaptation and Community Preparedness Survey

A 2011 study by Mayagoitia utilized a survey to collect data on the factors and community characteristics that contribute to community adaptation and community preparedness to climate change and population growth. The survey was done in three acequia communities, one of which was the Rio Hondo. There were only nine surveys completed for this region. The Rio Hondo had the highest number of newcomers integrating into the system and the highest number of individuals with no family history in the region. This area also had the highest number of participants indicating that the acequia provides a low economic contribution to their family income (less than 5 percent of income) and participants from the Rio Hondo displayed a strong preference for growing hay or pasture. All the respondents in the Rio Hondo agreed that spirit of community and cooperation, connection to land, water and community, and equity in water sharing are the characteristics that have helped to adapt to economic downturns, population growth, increased development, and drought. Only 67 percent of the respondents in the Rio Hondo indicated that they felt somewhat prepared or prepared for significant droughts. With regards to population changes and growth, 56 percent of respondents felt somewhat prepared or prepared. And lastly, with respect to development, 49 percent of respondents felt somewhat prepared or prepared. When asked about activities that may help them cope with challenges, the respondents in the Rio Hondo felt strongly about maintaining traditional knowledge and increasing public awareness (Mayagoitia, 2011).

Mayagoitia’s overall conclusions across all the acequia regions studied include the following: that longevity and family connectivity to the area remains strong despite demographic changes, that land ownership was a principal factor that influenced the acequia’s capacity to adapt, that there is a balance between people who feel prepared versus those that feel vulnerable to the external stresses studied, and the most commonly chosen activity to strengthen the acequia's capacity to withstand challenges was increasing public awareness about the importance of acequia knowledge and traditions (Mayagoitia, 2012).

6.2.2 Summary of Interviews and Focus Groups

Numerous interviews and focus groups have been completed in the Rio Hondo. Some of the major findings of these focus groups will be highlighted here. The focus is on documenting indicators of the resilience and functionality of the acequia system. The summary of findings below comes from Ortiz (2012a) and (2012b), as well as interviews that were completed by the EPSCoR student researchers from 2009 to 2011. The findings are categorized by major topic.

Development and Newcomers

There were multiple occasions that local residents mentioned that subdividing of lots has presented challenges, not only in terms of just dealing with lots of new people, but that also the physical process of sharing water becomes more complicated. The subdivision of land in this region has reportedly led to conflict over land and water. Newcomers are said to not understand how the acequia system works. Many locals have reported easement issues with newcomers - in fact there was even a recent account of a physical dispute in the Des Montes region over access to the acequia easement. Others have said that some newcomers are building on the acequia easements. Residents in Valdez feel that real estate, condos, and drought pulls the community apart, but that embracing newcomers is the best approach to maintaining community. Area residents feel that the Taos Ski Valley provides little long-term community benefits and has polluted the water. It has also been reported that a lot of people live in trailers and rent the land, but do not have ties to the community. Some people are concerned for what the future holds in terms of land ownership and just hope that people will hold onto their land. People feel that increases in property values and property taxes have led to gentrification.

Water Sharing

Many area residents have made remarks about the historical conflict between upstream and downstream users and that still to this day there are conflicts between these users. Unfortunately, in times of drought those who are further downstream have a harder time getting water. This is especially difficult for Arroyo Hondo farmers because they are farthest downstream, but actually have an earlier priority date than the other communities. Valdez residents report that the current water sharing agreement does not actually work that well and a new, more flexible agreement is needed. Despite all this, the general feeling is that acequia members want to continue managing water independently, without interference from the state.

Climate Change/Drought

There is, in general, great concern for water availability. With regards to climate change, residents say they have good and bad years, but that snowpack has noticeably decreased. Acequia users have commented that 2011’s lack of snow was worse than in 2001 (a notoriously bad drought year for the Rio Hondo). Even though drought is a tough time, residents feel like whatever water is available is shared equally and that all people deal with it by irrigating less of their lands in these times. In times of drought, people are not just told that they can’t have water. Everyone works together to find a way to get water to those who need it.

Crops Grown

Local residents describe the overall trend in agriculture as a decrease in the number of people farming and the number of acres irrigated. Some commented that people are building on formerly irrigated land. Arroyo Hondo residents report that many believe there is no money in livestock and grazing and that in the last 10-15 years livestock numbers have decreased due to drought, the economy, and aging farmers. It was noted by locals that some people have shown interest in purchasing drought-tolerant alfalfa. Others have switched to row crops and sell their produce to the local farmer's markets. Some people feel that row crops require more water and more work and feel that alfalfa can withstand drought better.

Demographic Change/Economics

There is a lot of concern that there are not enough youth involved to keep the acequias going into the future. Many are worried that local knowledge is being lost because old timers are passing away without imparting their knowledge on to the youth. There is also concern that those who have local knowledge have little time for farming because they have to commute to outside jobs. Many locals report that no one makes a living on the farm - that they have to supplement their income. Some feel that farming is a lifestyle choice and others describe it as a hobby rather than a job. Many people have also mentioned that there is a lack of resources for litigation – that people aren't able to defend themselves in court because they can't afford it.

Acequia Governance and Participation

With regard to participation levels, many residents report that farmers are increasingly sending *peones* (day laborers) to do the ditch cleaning rather than *parciantes* doing the work themselves. But, other people also commented that young folks are gradually becoming more involved with the *limpia*. Many acequias have noted that the same people always serve as commissioners or mayordomos because no one else wants to fill the positions. *Parciantes* in Arroyo Hondo report that they put a high value on their water rights, have good knowledge of state law, and have high attendance at meetings. In the Valdez region, some acequias have low meeting attendance and some have high attendance. According to residents the Prando ditch has high attendance and the Rebalse ditch has low attendance.

6.2.3 Acequia Functionality Assessment Findings

On November 30, 2012 an acequia functionality assessment was completed for the Rebalse ditch with a *parciante* at their farm in Des Montes. The acequia functionality assessment was developed by Marcos Roybal, also of the EPSCoR research group. The assessment is a planning tool for acequia users, researchers, and funding agencies and is used to evaluate the general functionality of the physical characteristics, ecology, and governance and community use of a particular acequia (Roybal, 2012). The results of this functionality assessment for the Rebalse ditch are provided in Table 7.

For physical characteristics, the Rebalse ditch scored 20 of 28 points and received an average functionality rating of 2.9. This was the highest rating of all three ratings and for physical characteristics this has a solid "good" rating. The points of major improvement needed for this ditch on physical characteristics would be infrastructure condition improvements and improvement in the proportion of fields being irrigated. The *parciante* estimated that about 25 percent of lands in this region were thought to be irrigated and that more than 50 percent of the ditch needs improvement, mostly in the form of fixing cracks in the concreted lining.

Table 7: Acequia Functionality Assessment for the Rebalse Ditch (Rating in Yellow)

Category 1 – Physical Characteristics

Criterion	4 Points	3 Points	2 Points	1 Point
Amount of flow during irrigation season in recent years	Meets all irrigation needs	Meets most irrigation needs	Meets less than half of irrigation needs	Little or no water
Duration of useable flow in recent years	Entire growing season or more	Majority of growing season	Approximately half of growing season	Less than half of growing season
Bank stability	No erosion evident	Erosion evident in a few places	Erosion evident in a few places and seems to be increasing	Substantial erosion, and/or amount of erosion is increasing rapidly
Access to acequia easement	Adequate for maintenance along entire ditch	Adequate for maintenance along most of ditch	Accessible along less than half of ditch	Generally not accessible
Infrastructure condition and improvements needed (presa, headgates, main ditch, etc.)	Little or no improvement needed	Less than 25% of infrastructure needs improvement	About 50% of infrastructure needs improvement	More than 50% of infrastructure needs improvement
Water quality	Water appears clean with no trash	Water appears clean; some trash	Considerable trash present	Water appears dirty and has lots of trash
In general, what proportion of fields in your area is irrigated?	More than 75%	50-75%	25-50%	Less than 25%

Category 2 – Ecology

Criterion	4 Points	3 Points	2 Points	1 Point
Vegetation structural diversity along ditch bank (4 vegetation classes = trees, shrubs, grasses, and forbs)	All 4 vegetation classes are present	3 vegetation classes are present	1-2 vegetation classes are present	Little or no vegetation is present
Vegetation species diversity along ditch bank	Many species present	Dominated by a few species	Dominated by one or two species	Little or no vegetation present
Presence of noxious weeds along the ditch	Not present	Very few present	Numerous present, but not spreading	Numerous present; appear to be spreading
Acequia bed material	Mostly earthen and natural	Less than half lined or piped	More than half lined or piped	Entirely lined or piped
Wildlife use (mammals, birds, reptiles, amphibians, insects)	Many species; seen frequently	Many species; seen occasionally	Few species; seen frequently	Few species; rarely seen
What other ecosystem services does acequia provide? (riparian area, groundwater recharge, water quality, etc.)	3 or more ecosystem services are provided	2 ecosystem services are provided	1 ecosystem service is provided	No ecosystem services are provided

Category 3 – Acequia Governance and Community Use

Criterion	4 Points	3 Points	2 Points	1 Point
Meetings of local acequia association	Regular and well attended	Irregular but well attended	Regular but poorly attended	Irregular and poorly attended
Do bylaws require proposed water rights transfers be approved by commission?	Yes	No, but bylaws are being updated	No, but bylaws are otherwise complete	No, and there are no plans to update bylaws
Water banking to protect unused water rights (Is procedure for water banking included in bylaws? Yes ____ No____)	Water banking always practiced with un-used water rights (or there are no unused water rights)	Water banking occasionally practiced with unused water rights	Water banking not practiced but is included in bylaws	Water banking never practiced and is not included in bylaws
What does acequia water irrigate? (Food crops include home gardens and orchards)	Food crops, hay fields, pasture	Hay fields and pasture	Just pasture	Untended or unused lands
Who cleans the acequia?	Mostly parciantes	Mostly labor hired by parciantes	Crew appointed by mayordomo	Acequia not regularly cleaned
Interest in acequia agriculture within the local community	Strong interest across multiple generations	Moderate interest across multiple generations	Strong interest but mostly in older generations	Little or no interest remaining
Economic viability of farming and ranching in the local community	Farming and ranching yield livable incomes	Farming and ranching often yield a portion of income	Farming and ranching yield little income but are done as hobbies	Farming and ranching are rarely practiced in the community
Land use trends in the local community	Land is generally remaining in agriculture (ag)	Minor shifts from ag land to other uses, but existing ag lands remain operational	Land is generally shifting away from ag uses, but existing ag lands remain operational	Land is rapidly shifting away from ag uses; existing ag uses appear to be negatively affected
Acequia finances	Money coll-ected covers all operation costs	Money coll-ected covers most operation costs	Money collected is often insufficient	Parciantes do not contribute funds to acequia

Functionality Ratings

Category	Score	Average functionality rating*
Physical Characteristics (out of 28)	20	Score/7 = 2.9
Ecology (out of 24)	15	Score/6 = 2.5
Acequia Governance and Community Use (out of 36)	22	Score/9 = 2.4

*3.5–4: Excellent; 2.5–3.49: Good; 1.5–2.49: Fair; <1.5: Poor

The ditch scored 15 of 24 points in the ecology category and received an average functionality rating of 2.5. This places the acequia just barely into the category of “good.” The fact that most of the ditch system here is lined restricts the score that this ditch could get for ecology. It did not receive the lowest rating for acequia bed material because the laterals were not lined. The biggest area that could be improved in ecology on the Rebalse ditch is the presence of noxious weeds that appeared to be spreading.

For acequia governance and community use, the Rebalse ditch scored 22 of 36 points and received an average functionality rating of 2.4. This places the ditch into the “fair” category. The biggest cause of this low score is the fact that water banking is not practiced or included in the acequia’s bylaws. This is something that they have begun to look into but have not been able to implement yet. Other areas of weakness are the poor attendance of meetings, the lack of economic viability of farming, land uses that are trending away from agricultural uses, and the fact that the money collected is insufficient for the management of the acequia.

The Rebalse ditch now has benchmark assessment that shows the weaknesses that their acequia currently faces. These are areas that the *parciantes* should focus on improving. If this assessment was performed every year, they would have a way to track their progress on improving their acequia’s functionality. This functionality assessment is included in this report because it (1) illustrates how valuable the assessment could be to acequias who are concerned about how well their acequia is functioning and (2) puts a pulse on the functionality of one of the acequias in the study region.

Of particular importance to this paper, is the fact that the Rebalse ditch assessment showed that farming and ranching are done as hobbies and yield little income and that land is generally shifting away from agricultural uses. The assessment done on this individual acequia supports some of the findings that have been established in this study for the larger acequia system as a whole – that land has shifted away from agriculture and that full time employment in agriculture is almost non-existent in this region.

6.2.4 Crop Yields and Income Generation

Here the focus is on calculating the crop yields and the economic benefits of farming in the Rio Hondo for the years 1969 and 2012. In Sabu's 2012 study he modeled different scenarios of crop mixes that generate significantly higher incomes for farmers. I will use the same crop market values from that study to calculate the annual market value of each crop for each year as well as investigate an alternative crop mix for 2010 that shifts some acreage from hay/pasture to garden/wheat crops. Crop yields are taken from a few different sources that are indicated in Table 8. A few assumptions were made in performing this economic analysis that should be mentioned here. First, garden acreage was distributed evenly between beans, chile, onions, and potatoes for the year 1969 (corn acreage was provided for this year). Garden acreage for 2010 was distributed evenly between corn, beans, chile, onions, and potatoes. Alfalfa and pasture were distributed at the same percentage in 2010 as they were in 1969 – of total hay/pasture acreage, 43 percent was assumed to be alfalfa and 57 percent was assumed to be pasture.

Most of the crop yields were taken from National Agricultural Statistics Service (NASS) data. New Mexico specific yields were used where possible and when multiple years' worth of data on yields was available, the average across these years was used. For potatoes, state yields were not available so the US yield per acre was utilized. Apple orchards were used as the representative orchard crop type. The yield here is from NASS data, but yields were not available for New Mexico, so yields for Arizona were used instead. This analysis would be stronger if the orchard acreage was distributed between all the different orchards crops grown in the Rio Hondo area including peaches, plums, apricots, cherries, walnuts, pecans, and pears. Apples are the most widely grown orchard crop in the region, based on evidence from EPSCoR interviews. Pasture yield was estimated using the 2003 study by Lauriault et al. and averaging the monthly yields provided for alfalfa pasture - the irrigated pasture of choice in New Mexico. Notice the big difference between alfalfa yields as hay and the alfalfa yields as pasture (5.5 tons per acre versus 1.7 tons per acre).

The market value of crops in both years was calculated based on the prices found in Sabu (2012) and the yields described above and sourced in Table 8. The crop mix and market value for 2010 was then altered to assume a small shift in crop mix of a 7.5 percent decrease in alfalfa and pasture acreage and a five percent increase in each category of orchard, garden and wheat crops. The market value of crops in 1969 was calculated as 1.2 million dollars. The market value of crops in 2010 was 717 thousand dollars, a decrease of almost 450 thousand dollars. This is not surprising given the fact that there is less acreage of farmland being irrigated and that a bigger percentage of the acreage was devoted to alfalfa/pasture in 2010. Alfalfa and pasture are low revenue crops compared to other crops that can be successfully grown in the region. This is proven by the fact that when altering the crop mix slightly by shifting some acreage from alfalfa/pasture to orchards/gardens/wheat, the market value of 2010 crops increased to 1.3 million dollars – an increase of over 500 thousand dollars. Although this is somewhat of a simplistic way of estimating market values, it demonstrates the point that using the land to grow alfalfa and pasture will yield lower revenues than other crops. Diversification would help increase revenues in the region, allowing for a bigger income source from the agricultural land.

Table 8: Economic Analysis of Crop Mixes in the Rio Hondo

Crop	Price Per Unit (dollars)	Unit on Price	Crop Yield per Acre	Yield unit	Crop Mix 1969 (acres)	Crop Mix 2010 (acres)	Market Value of Crops 1969 (dollars)	Market Value of Crops 2010 (dollars)	2010 Crop Mix - Decreasing Alfalfa & Pasture 7.5% and Increasing Orchards, Garden Crops, Wheat 5% (acres)	2010 Market Value - Decreasing Alfalfa & Pasture 7.5% and Increasing Orchards, Garden Crops, Wheat 5% (dollars)	Yield Source
Alfalfa	168.00	ton	5.2	ton	564	519	489,552	450,492	426	370,159	NASS, 2012a
Bean	47.50	100 lbs	291.3	100 lbs	11	1	152,222	13,838	13	184,603	NASS, 2012a
Chile	1.00	lb	5.5	ton	11	1	121,000	11,000	13	146,740	NASS, 2005
Corn	4.79	bushel	181.7	bushel	12	1	10,442	870	13	11,608	NASS, 2012a
Onions	9.00	50 lb	488.0	100 lbs	11	1	24,156	2,196	13	29,295	NASS, 2011
Apple Orchards	0.23	lb	4.7	ton	51	22	110,262	47,564	84	180,959	NASS, 2012b
Pasture	164.00	ton	1.7	ton	746	688	204,314	188,429	595	163,082	Lauriault et al.,2003
Potatoes	7.48	100 lbs	399.0	100 lbs	11	1	32,830	2,985	63	187,129	NASS, 2012a
Wheat	5.53	bushel	25.0	bushel	147	0	20,323	0	12	1,706	NASS, 2012a
					1,564	1,234	1,165,101	717,374	1,234	1,275,282	

Nothing has been said here about the costs of production, including material, labor, and opportunity costs of each of these crops. Many in the region are hesitant to switch from hay/pasture to a new crop because of these production costs. Research on production costs would also strengthen this analysis. It has also been assumed that farmers will sell the garden crops, which is something that anecdotal evidence shows is a new trend in the Rio Hondo region.

6.3 Synthesis of All Findings

This section will recap all the findings from this report in preparation for the final conclusions on the resilience and functionality of the Rio Hondo acequia system and recommendations for the future resilience of the acequia system.

There has been a loss of 25 percent of the agricultural lands in the Rio Hondo between the years 1969 and 2010. The crop mix has gone from 71 percent hay/pasture in 1969 to 87 percent hay/pasture indicating a move towards lower crop diversification. This focus on hay/pasture has been repeatedly brought up in conversations with local residents. Building development in the irrigated region has been significant and has displaced agricultural land. Land is becoming more fragmented, which presents new challenges to the acequia system. The riparian area calculations show that development has not encroached on riparian ecosystems.

In terms of climate change, the Rio Hondo area has experienced considerable warming over the past 116 years, according to the temperature data collected. This warming was significant in both the cold season and the warm season. Warmer temperatures in the summer mean that the farmers have been dealing with higher evaporation rates and drier lands. The warmer it is in the summer the more water that is needed to grow the same amount of crops. The drier conditions were confirmed in the statistically significant trends in the PDSI and PHDI drought statistics. Another point that can be made for certain is that the region has experienced wet and dry spells in terms of precipitation indicating that acequia farmers have been accustomed to dealing with droughts in the past. The additional climate measures examined in this study revealed that there are no statistically significant trends in snowpack, precipitation, flow timing, and streamflow volume. As time goes on and more data are collected, these measures may begin to more definitively reflect the impacts of increased temperatures on the region.

Substantial demographic shifts have taken place in the Rio Hondo area. The first major shift is the decline in Hispanics in the region and the increase of Anglos. The second is the aging of the population in the Rio Hondo that was caused by out-migration of youth and in-migration of older individuals. Population is overall increasing at high rates. Very few people in the region are now found to work full time in the agriculture industry. Unemployment rates are high and have been consistently high in this region over time. There is now a very large percentage of recreational/seasonal homes in the region – this reflects not only the impact of tourism, but also individuals who have had to move into the city for jobs while still maintaining property in the Rio Hondo region. Housing values have increased over time, lending support to the notion that gentrification is being driven partially by increases in property taxes.

The community adaptation and preparedness survey showed that in the Rio Hondo there are many newcomers, agriculture does not provide a significant economic contribution, and hay/pasture is strongly preferred (Mayagoitia, 2011). Interviews and focus groups findings indicate that residents are feeling the impact of newcomers and development. People in the region have reportedly noticed a trend toward a decrease in the number of people farming and the number of acres irrigated. Many commented that there is no money in livestock and grazing. Others felt there was a shift towards row crops and selling food at farmer’s markets. Concern about youth participation and loss of local knowledge is high. Participation has been low in some activities and acequias, and high in other activities and acequias. The crop yields and income generation analysis illustrated the fact that hay/pasture are low revenue crops and that to strengthen the economic input from agricultural land more crop diversification is needed.

6.4 Conclusions on the Resilience and Functionality of the Rio Hondo Acequia System

There has been major demographic change over time in the Rio Hondo area, yet it is evident that the acequia system in the region has found a way to embrace newcomers and has found ways to defend itself from land development pressures (i.e. protesting as in the Valdez Condo wars). This is evidenced by the fact that even given these considerable demographic changes and the additional pressures from increased temperatures and dryness, that only 25 percent of agricultural land has been lost. This is only 6 percent higher than the total decrease in agricultural land in Alcalde, NM – an area that has had much less tourism and development pressure (Ortiz, 2007). Just looking at the aerial images, most of the region looks very similar to what it did in 1969 and even 1935.

However, there has also been evidence of weakening of the acequia institution due to the changing demographics. First, there are just more people, which has created additional demands for surface and ground water over time. There have been lots of newcomers who have water rights who need to participate in acequia activities, but these newcomers know very little about how acequias operate. The acequia system here was built by *hispano mexicanos,* and the traditions of the acequia are deeply rooted in the Hispanic culture. The decline in Hispanic landowners and the decline in Hispanics living in the region suggests that there may have been a significant loss of local knowledge. The fact that young people are leaving and older individuals are coming questions how sustainable the acequia system can be and the question arises – who will take over these systems when the older people are no longer able to operate them? There are three other areas of substantial weakness in the acequia institution in the Rio Hondo that are complexly intertwined: the increasing trend towards a hay/pasture monoculture, the low economic contribution of farming, and the shift from agriculture as a job to agriculture as a part-time activity. When thinking about these three issues another question that arises is: can farming as a part-time activity really preserve agricultural land and the acequia tradition in the long run? The decline in the number of those working in an agricultural occupation is not surprising, but it is concerning. Acequia systems continue to operate with people participating as they can, but not participating full-time because they likely have to have another job in order to make a living. Unemployment rates are still quite high, suggesting that people are struggling in this region, even though median incomes and poverty data may not reflect this struggle.

The economic struggle described above is recent and many of the demographic changes that were examined in this report do not show signs of stopping just yet, so additional measures may need to be put in place to continue to protect the acequia way of life. In fact, Cox (2010) found that acequias are vulnerable to the novel disturbances of urbanization (essentially development and population growth), lower resource dependence (i.e. not dependent upon water/farming for major income source), economic development and market penetration (which seeks to move water to more profitable or "appropriate" uses), and water transfers. The data and findings of this report support Cox's findings described above. So even though acequias may have been resilient up to this point, there are still sources of vulnerability today that need to continue to be addressed. These vulnerabilities are not just tied to continued demographic changes, but also to the projected climate change that suggests that hydrologic conditions in this region will deteriorate in this century.

6.5 Recommendations for the Future Resilience of the Acequia System

The following recommendations are provided as ideas that the local acequias can undertake to help ensure the future resilience of the acequia system. These are suggestions that are borne out of the research at hand.

The first suggestion is that all of the acequias in the Rio Hondo region perform an acequia functionality assessment on their individual acequias. There are a few purely administrative tasks that acequias can undertake to protect themselves and the assessment helps them identify these tasks. These tasks are amending the bylaws to require proposed water rights transfers to be approved by the acequia commission and the second is to include a procedure for water banking in the acequia bylaws. The other benefit of the functionality assessment is that if it is updated once a year, the acequias can track their performance in areas that need improvement and identify areas that need more attention because they have slipped in their ratings. This is a good way for acequias who are concerned about their systems to track their functionality over time. In addition, this type of tool could provide good documentation that could potentially be used in grant applications or other official appeals.

The farmers in the region should consider switching some hay/pasture fields to crops that have higher revenue streams. This would strengthen the acequias because the farming associated with the land would be able to provide a larger portion of household income. There is some anecdotal evidence that this is already beginning to happen in the region with more people growing row crops and selling the produce at local farmers markets. Those that are successful in this endeavor should share best practices with other local farmers. An opportunity exists for local residents who are growing row crops and orchards to form a cooperative or a grower's network to pool resources and sell aggregated products to larger markets. The Cicuye del Rio Pecos Farmers' Cooperative is a recent example of a cooperative that was set up on the Rio Pecos (Ortiz, 2012c).

In the course of this project, multiple people have mentioned that farmers are unable to defend themselves in court when issues about their water rights come up simply because they cannot afford it. There are a few resources available that should be mentioned. One is New Mexico Legal Aid (NMLA), which provides free legal service in civil cases for low-income persons in New Mexico. There are NMLA offices in Taos. The second is the Acequia and Community Ditch Fund which was set up in 1998 to assist acequias in legal representation in adjudications. The last resource is the New Mexico Acequia Association's (NMAA) Acequia Legal Defense Fund which aids in acequia litigation (NMAA, 2012). Area farmers could utilize these resources when they need legal representation. The state legislature could also be approached to set up a new fund for acequia litigation for low-income farmers.

The community adaptation and preparedness survey found that people in the Rio Hondo felt that the best way to cope with challenges was to maintain traditional knowledge and increase public awareness. Conflicts over acequia easements, for example, might be more easily avoided if the acequias pool their resources and develop a public awareness program that aims to educate newcomers to the region on acequia traditions and governance. With regard to maintaining traditional knowledge and educating youth on the acequia way of life, acequias in the Rio Hondo could partner with the NMAA's *Sembrando Semillas* program to start a youth project in the Rio Hondo region.

In addition, strategies to prevent unwanted land use changes can be implemented. Conservation easements can be set up to protect agricultural land in perpetuity; however, this is likely out of the economic reach of many farmers in the region. Additionally, land use planning is of distinct importance in this region, due to the fact that development is happening in the irrigated region of the watershed. In fact, Des Montes is already active in land use planning represented by the local neighborhood association. There is currently a draft Lower Des Montes Neighborhood Land Use Plan with the Taos County Planning department that designates land in the lower Des Montes area as either: irrigated agriculture, rural residential, or sustainable community. The sustainable community land designation is a designation that allows for development, but encourages sustainable practices such as clustered housing and community infrastructure. These types of plans should be made with the involvement of all community members and acequia farmers should be particularly concerned about being involved in these processes. Valdez, Upper Des Montes, Canoncito, and Arroyo Hondo all are not recognized as neighborhoods in the Taos County land use regulations and therefore do not have a neighborhood land use plan. These towns may want to consider the benefits of becoming a neighborhood zone because the purpose of the zones is to “preserve and promote unique cultural, historical and neighborhood character of specific areas of the County, as identified by neighborhood associations, residents and property owners of those areas (Taos County Planning Department, 2011, p.15).”

These are just a few suggestions aimed at the weaknesses identified above in the Rio Hondo acequia system. For the acequias to continue to be resilient in the future, they need to organize themselves and target these weaknesses. The data and analysis provided in this report can be used as documentation of these weaknesses most of which were likely already known by long term residents. At the very least, the data in this report, like the data in the acequia functionality assessment, can be used as documentation for local residents in grant applications or other official appeals. Local farmers have shown their resilience over time and shown their willingness to defend their way of life. By teaching newcomers to the acequia institution this way of life, they become stronger and more diverse, making them even more capable of confronting the issues that face them today.

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APPENDIX 1: CROP TYPE MAPS

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2010 Crop Types
Rio Hondo Watershed
Map 1

Legend

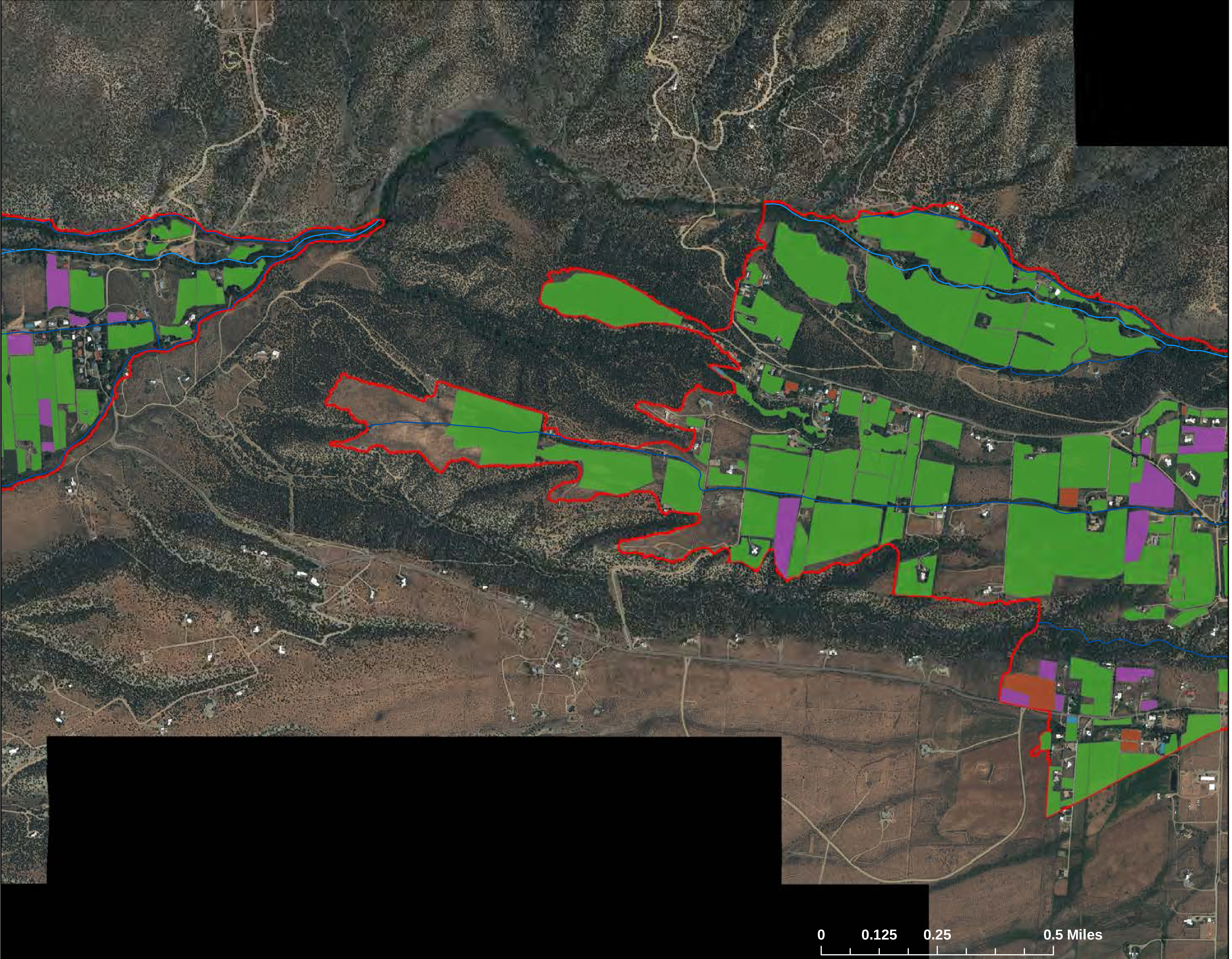
- Acequias
- Río Hondo
- Fallow
- Hay/Pasture
- Orchard
- Row Crop
- Irrigated Area

Locator Map

N

Created by Amy Miller
February 2, 2013
Data Sources: U.S. Census Bureau, GeoEye
1:12,000

2010 Crop Types
Rio Hondo Watershed
Map 2



Legend

- Acequias
- Río Hondo
- Fallow
- Hay/Pasture
- Orchard
- Row Crop
- Irrigated Area

Locator Map

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Created by Amy Miller
February 2, 2013
Data Sources: U.S. Census Bureau, GeoEye
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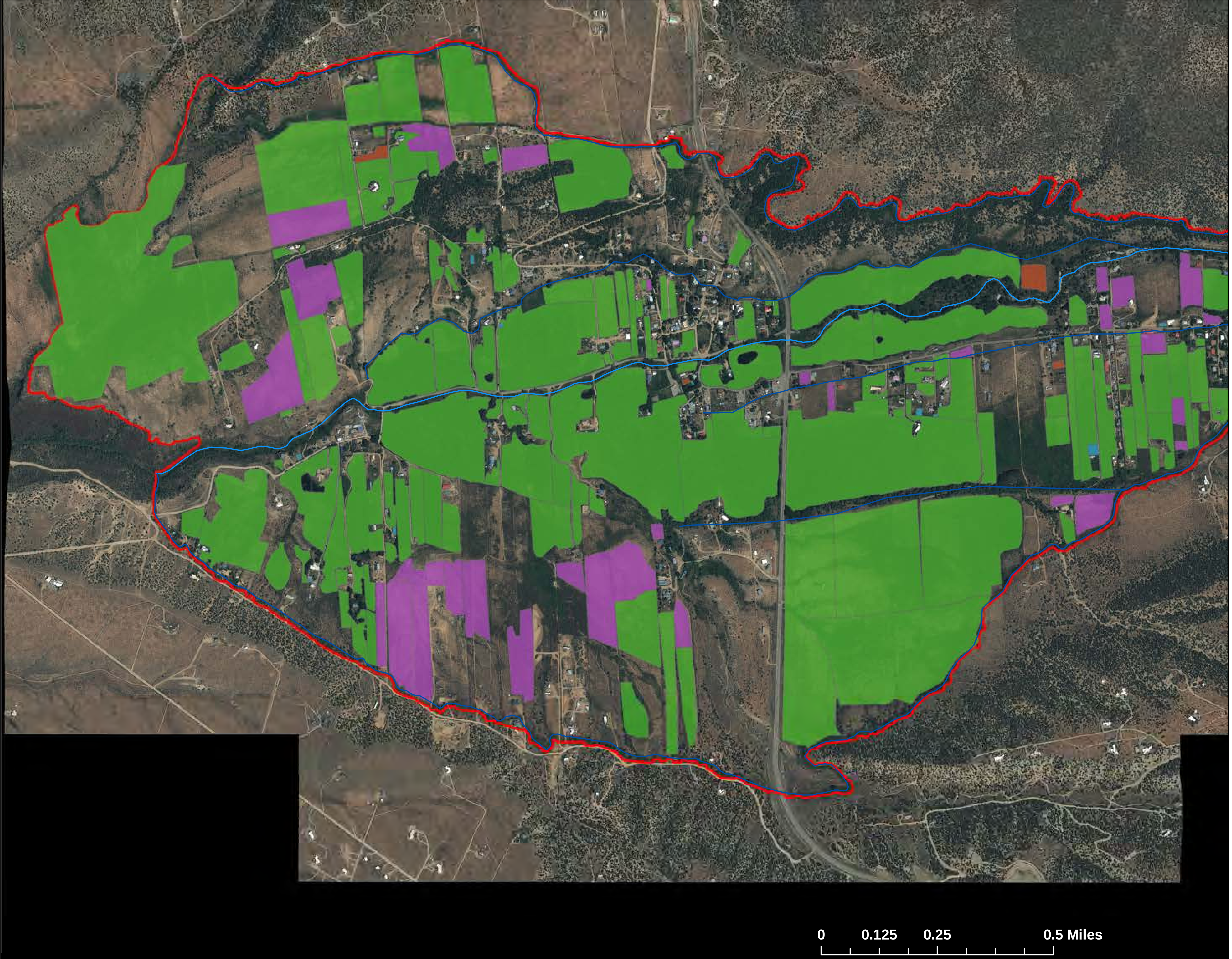

2010 Crop Types
Rio Hondo Watershed
Map 3

Legend

- Acequias
- Río Hondo
- Fallow
- Hay/Pasture
- Orchard
- Row Crop
- Irrigated Area

Locator Map

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Created by Amy Miller
February 2, 2013
Data Sources: U.S. Census Bureau, GeoEye
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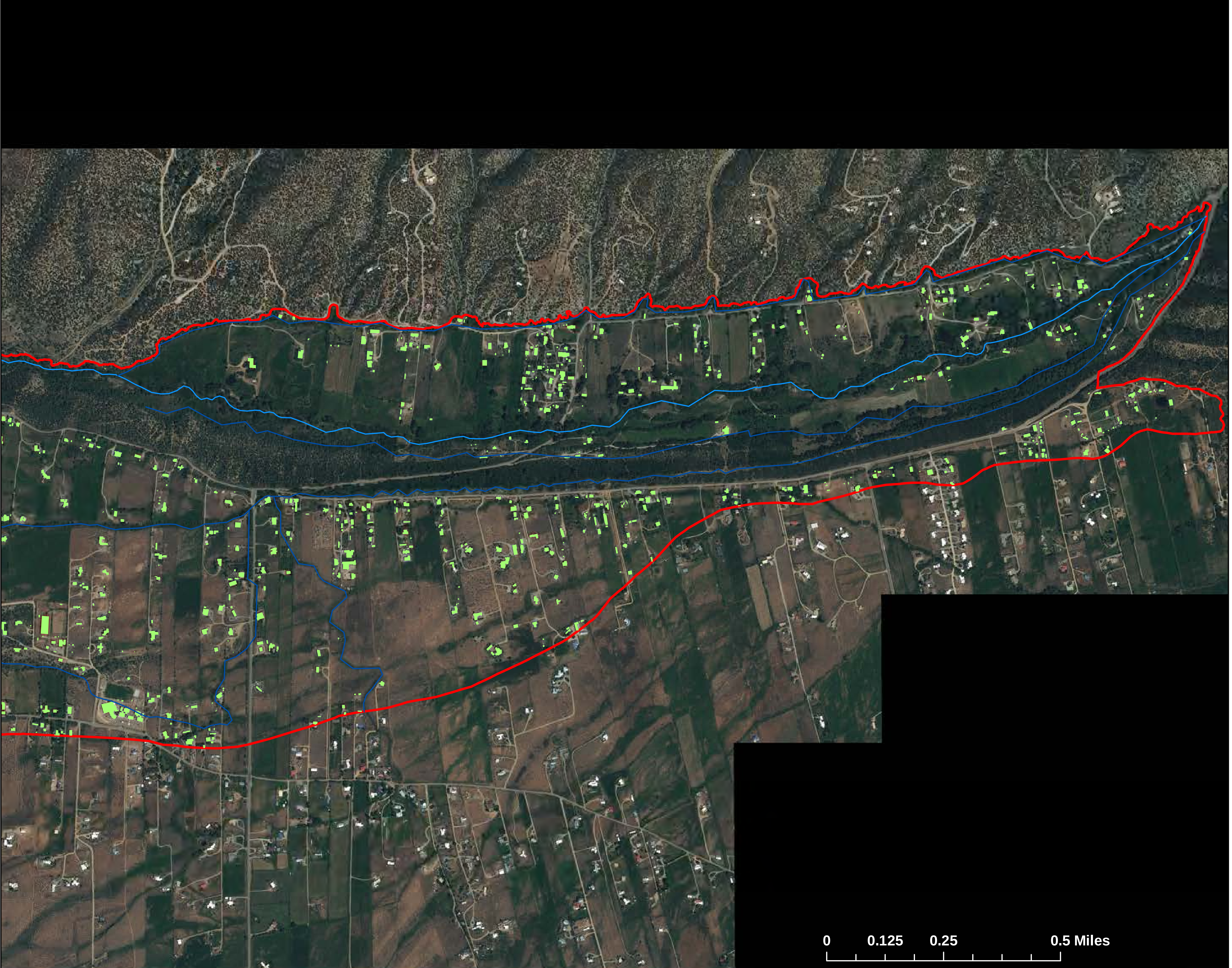


2010 Building Footprints Rio Hondo Watershed Map 1

Legend

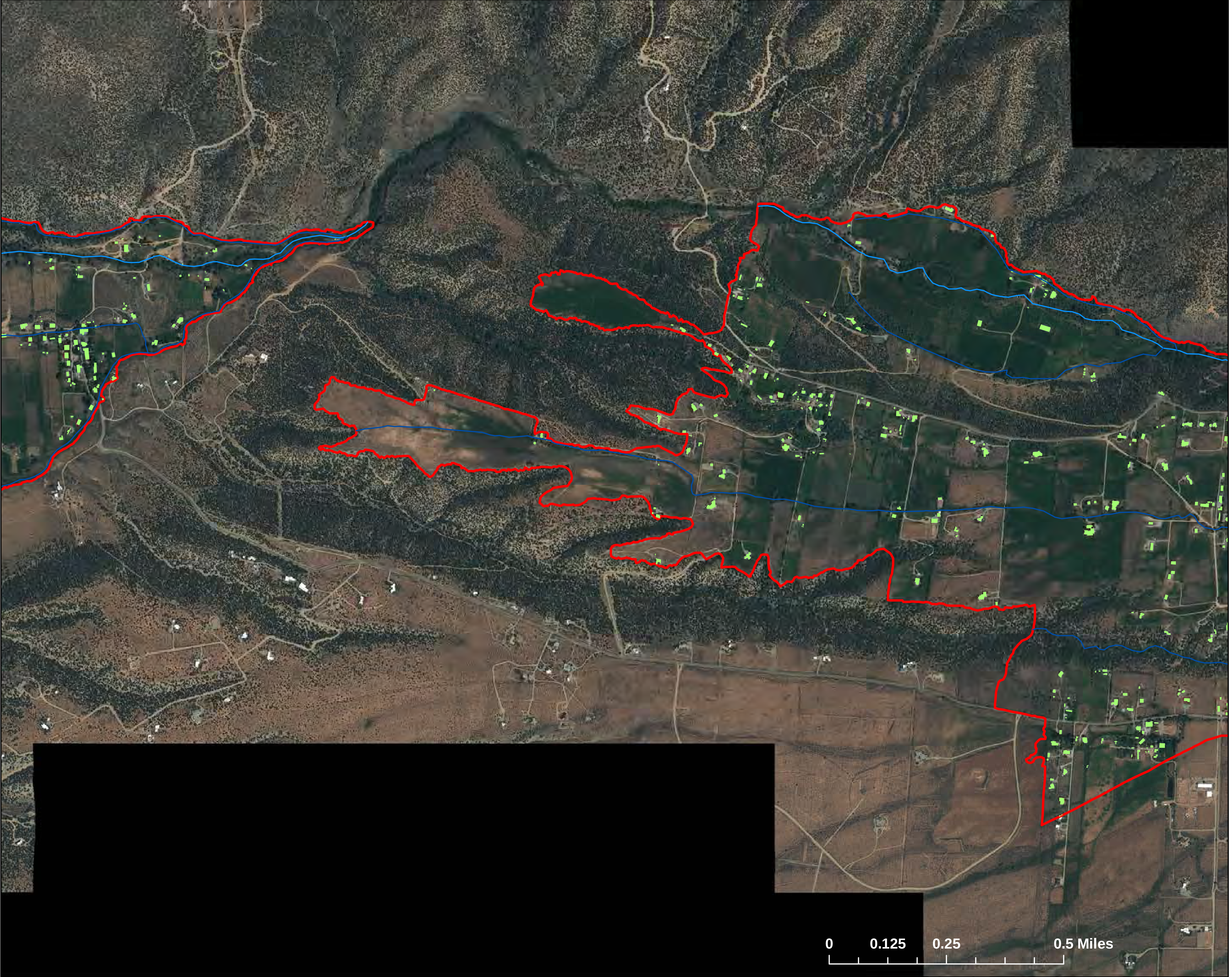
- Acequias
- Río Hondo
- Irrigated Area
- Building Footprints

Locator Map

N

Created by Amy Miller
February 2, 2013
Data Sources: U.S. Census Bureau, GeoEye
1:12,000

2010 Building Footprints
Rio Hondo Watershed
Map 2



Legend

- Acequias
- Río Hondo
- Irrigated Area
- Building Footprints

Locator Map

N

Created by Amy Miller
February 2, 2013
Data Sources: U.S. Census Bureau, GeoEye
1:12,000

2010 Building Footprints
Rio Hondo Watershed
Map 3

Legend

- Acequias
- Río Hondo
- Irrigated Area
- Building Footprints

Locator Map

N

Created by Amy Miller
February 2, 2013
Data Sources: U.S. Census Bureau, GeoEye
1:12,000

1969 Crop Types
Rio Hondo Watershed
Map 1

Legend

- Acequias
- Río Hondo
- Fallow
- Hay/Pasture
- Orchard
- Row/Food Crops
- Other/Unknown
- Irrigated Area

Locator Map

N

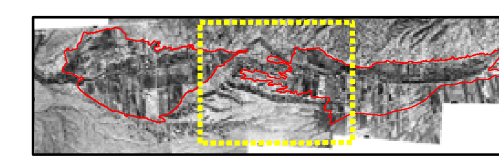
Created by Amy Miller
February 2, 2013
Data Sources: U.S. Census Bureau, EDAC
1:12,000

1969 Crop Types
Rio Hondo Watershed
Map 2

Legend

- Acequias
- Río Hondo
- Fallow
- Hay/Pasture
- Orchard
- Row/Food Crops
- Other/Unknown
- Irrigated Area

Locator Map



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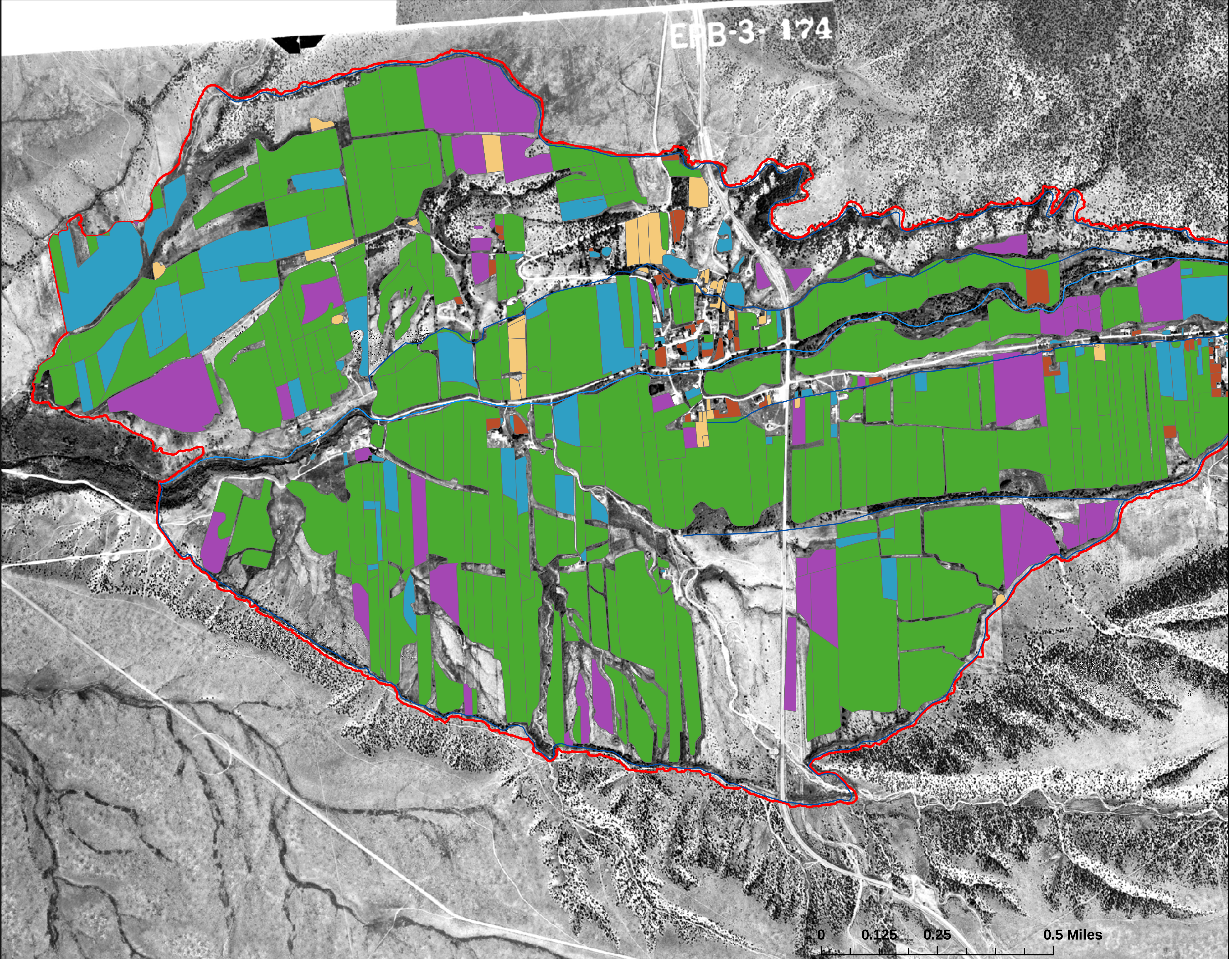
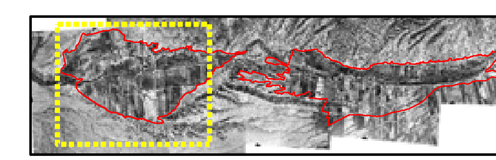


1969 Crop Types
Rio Hondo Watershed
Map 3

Legend

- Acequias
- Río Hondo
- Fallow
- Hay/Pasture
- Orchard
- Row/Food Crops
- Other/Unknown
- Irrigated Area

Locator Map



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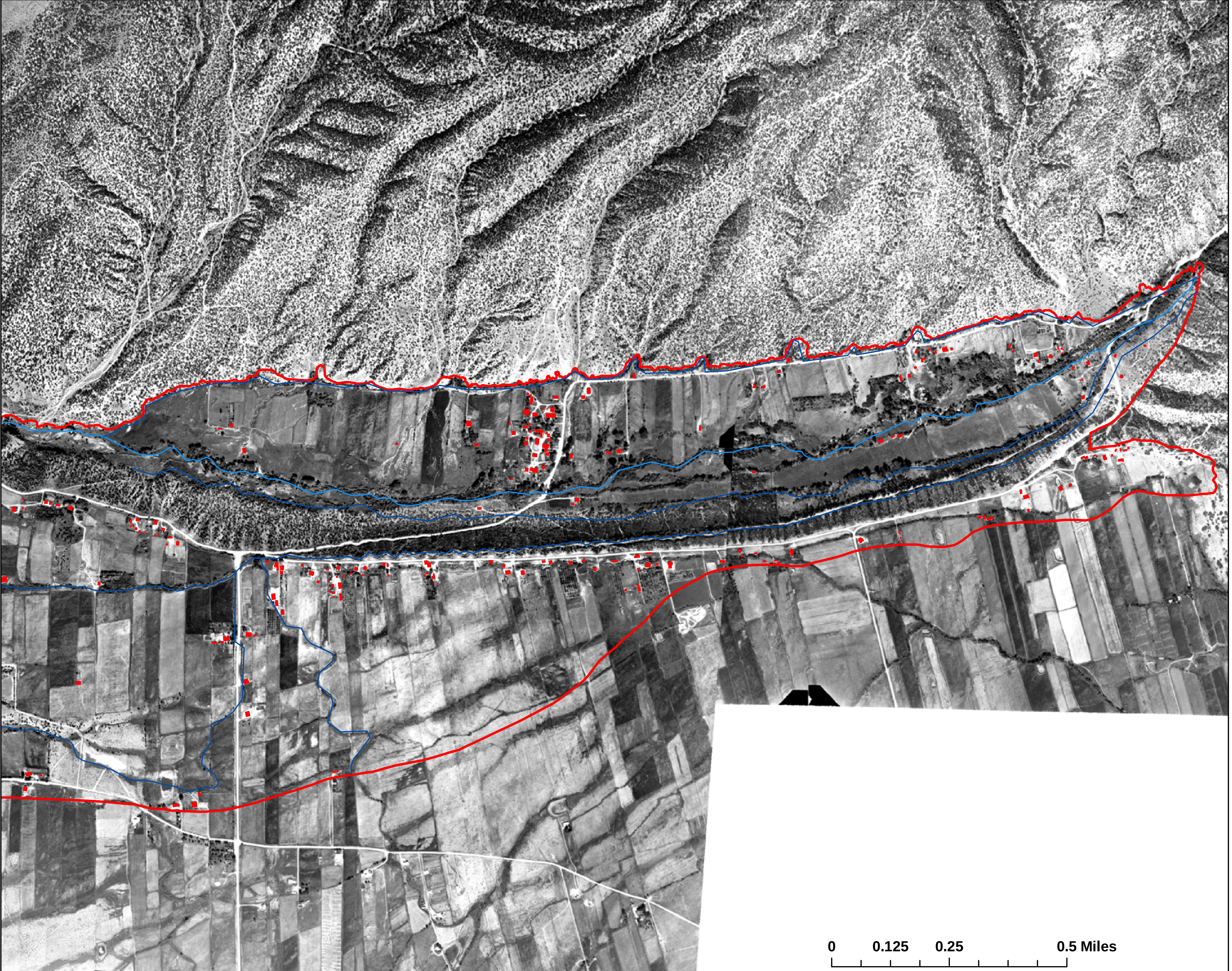
1969 Building Footprints
Rio Hondo Watershed
Map 1



Legend

- Acequias
- Río Hondo
- Building
- Irrigated Area

Locator Map

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Data Sources: U.S. Census Bureau, EDAC
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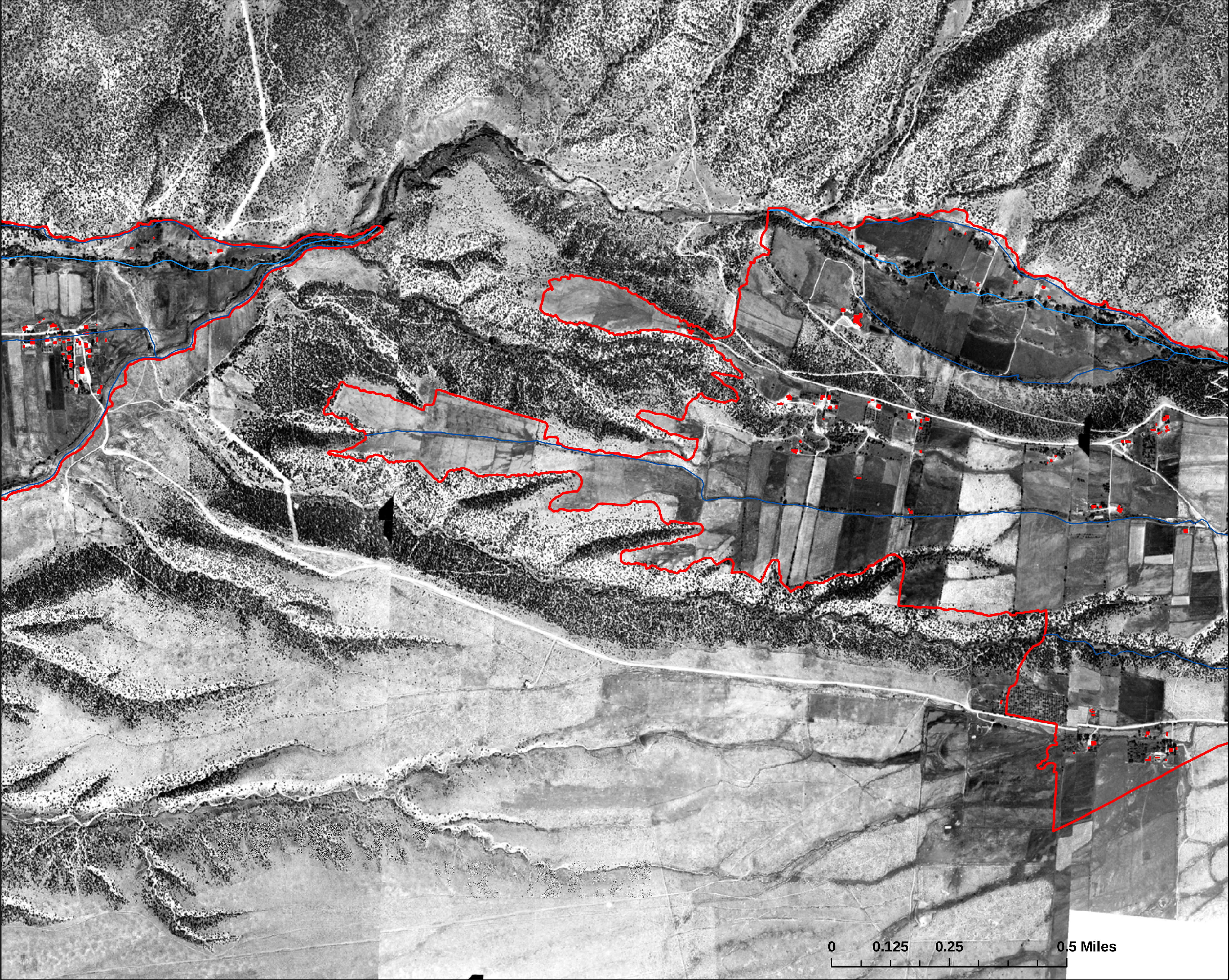
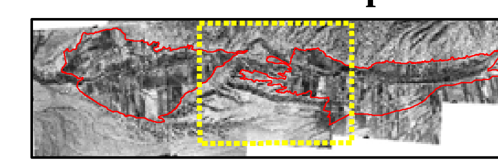


1969 Building Footprints
Rio Hondo Watershed
Map 2

Legend

- Acequias
- Río Hondo
- Building
- Irrigated Area

Locator Map



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Data Sources: U.S. Census Bureau, EDAC
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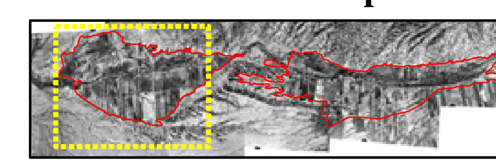
1969 Building Footprints
Rio Hondo Watershed
Map 3

Legend

Acequias
Río Hondo
Building
Irrigated Area

Locator Map



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Data Sources: U.S. Census Bureau, EDAC
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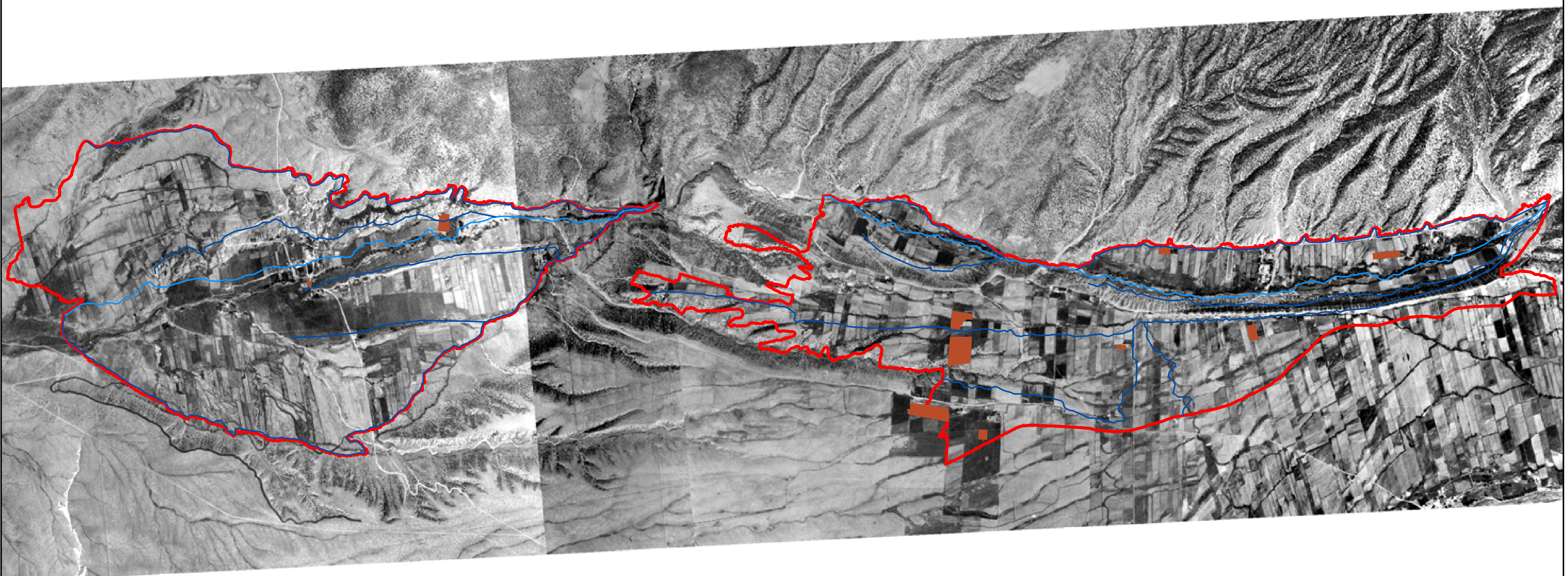
1935 Crop Types
Rio Hondo Watershed
Map 1



Legend

- Acequias
- Río Hondo
- Orchards
- Irrigated Area

N

Created by Amy Miller
February 2, 2013
Data Sources: U.S. Census Bureau, GeoEye
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APPENDIX 2: MANN-KENDALL TREND TEST FULL RESULTS

The significance level chosen is 0.05. If the p value is less than the significance level, H_0 is rejected. H_0, the null hypothesis, is that there is no trend in the series. Therefore, rejecting H_0 indicates that there is a trend in the time series. Rejecting the null hypothesis indicates that the trend is statistically significant.

Parameter	**Kendall's Tau**	**Mann-Kendall Statistic (S)**	**Var (S)**	**p-value (two tailed test)**	**alpha**	**Test Interpretation**
Annual Average Rio Hondo Flow	-0.078002	-228	51686.6667	0.318049751	0.05	Accept H_0
May Rio Hondo Flow	-0.07762	-227	51689.6667	0.320200371	0.05	Accept H_0
June Rio Hondo Flow	-0.056049	-164	51692.6667	0.473420975	0.05	Accept H_0
July Rio Hondo Flow	-0.04449	-130	51684	0.570422642	0.05	Accept H_0
August Rio Hondo Flow	-0.039001	-114	51686.6667	0.619162587	0.05	Accept H_0
September Rio Hondo Flow	0.0017115	5	51683	0.985962047	0.05	Accept H_0
Center of Mass Flow Timing	-0.03486	-102	51692.6667	0.656877028	0.05	Accept H_0
February SWE	-0.094659	-70	6830	0.403769384	0.05	Accept H_0
March SWE	-0.058108	-43	6831.66667	0.611353054	0.05	Accept H_0
April SWE	-0.168691	-125	0	0.134466741	0.05	Accept H_0
PRISM Precipitation	0.0769458	522	180202	0.219702226	0.05	Accept H_0
PRISM Max Temperature Cold Season	0.178174	1209	180205	0.004431903	0.05	Reject H_0
PRISM Max Temperature Warm Season	0.212791	1444	180206	0.000675736	0.05	Reject H_0
PRISM Min Temperature Warm Season	0.1160168	787	180201	0.064085259	0.05	Reject H_0
PRISM Min Temperature Cold Season	0.0254955	173	180205	0.685347243	0.05	Accept H_0
PDSI - Full Record	-0.114075	-112459	308494582	< 0.0001	0.05	Reject H_0
PHDI - Full Record	-0.147806	-145703	308494329	< 0.0001	0.05	Reject H_0
PDSI - 1901-2000	-0.067995	-48892	192238791	0.00042155	0.05	Reject H_0
PHDI - 1901-2000	-0.086758	-62380	192238614	< 0.0001	0.05	Reject H_0

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APPENDIX 3: HISTORIC AERIAL PHOTOS

1935 Panel 1

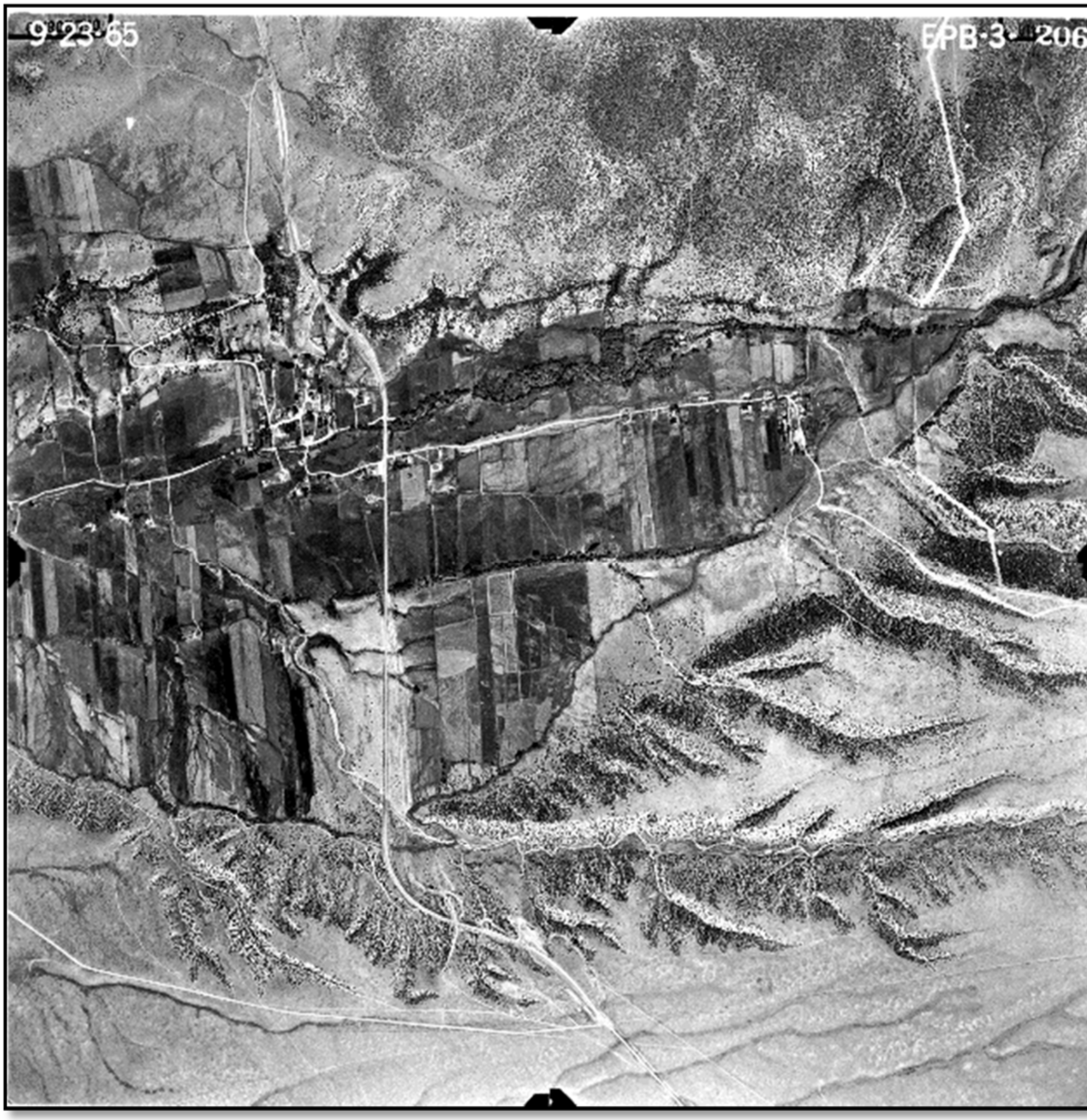
1935 Panel 2

1935 Panel 3

1965 Panel 1

1965 Panel 2

1965 Panel 3



1965 Panel 4

1965 Panel 5

1965 Panel 6