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Land Use Change Impacts on *Acequia* Water Resources in Northern New Mexico

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Rural areas throughout the western United States are undergoing rapid and far-reaching land use changes that impact water management, riparian ecosystems, and traditional cultures. Areas that have historically been focused on agricultural activities are being converted to various configurations of residential and urban land use (Anella and Wright 2004). Impacts to water resource use and management include: potential risks of ground water contamination due to increased numbers of single household septic systems, potential overdraft of ground water resources, surface water quality impacts, and changes in the distribution of water supplies from agricultural to municipal and industrial uses.

In northern New Mexico, the *acequia*[1] water use regime and attendant *acequia*-related cultural values are at particular risk due to increasing urbanization pressures and the potential impacts on actual water use, water quality, and riparian vegetation along the Rio Grande and irrigation ditches (Rivera 1998; New Mexico Acequia Association 2006). In the research we present in this paper, we employ Geographic Information Systems (GIS), remote sensing, and aerial photography interpretation techniques to create a series of land use maps to assess the impacts of land use change on critical water resources and local communities along the Alcalde Reach of the Upper Rio Grande Basin. Through discussions with acequia members and examination of related archived documents, we also began preliminary exploration into cultural values associated with the *acequia* system and the traditional way of rural life. The land use maps that we generate depict the intersection of land use changes and the attendant impacts to water resource use and management – risks to ground water, changes in *acequia* management and water use, and riparian ecosystem impacts. This project is well suited to provide local and state planning programs with constructive methods for further research, and is also applicable to other western states with similar challenges.

Research Objective and Research Questions

The objective of this research is to examine land use change across time to assess the potential impacts of these land use changes on water resource use and management, the effects on riparian vegetation communities, and the attendant changes to *acequia* cultural values and ways of life in the study area. The specific research questions we explore in this project are:

- What is the allocation of land among agricultural, riparian, housing, and other uses through time?
- What major changes in land use have occurred in the study area in the last 40 years?
- What impacts have occurred to *acequia* water use and management in the area in light of potential impacts to ground water from septic tanks and changes in the use and distribution of *acequias* as landscape and water management features?
- What impacts have occurred to riparian vegetation in the study area as a result of these land use and water resource use changes?

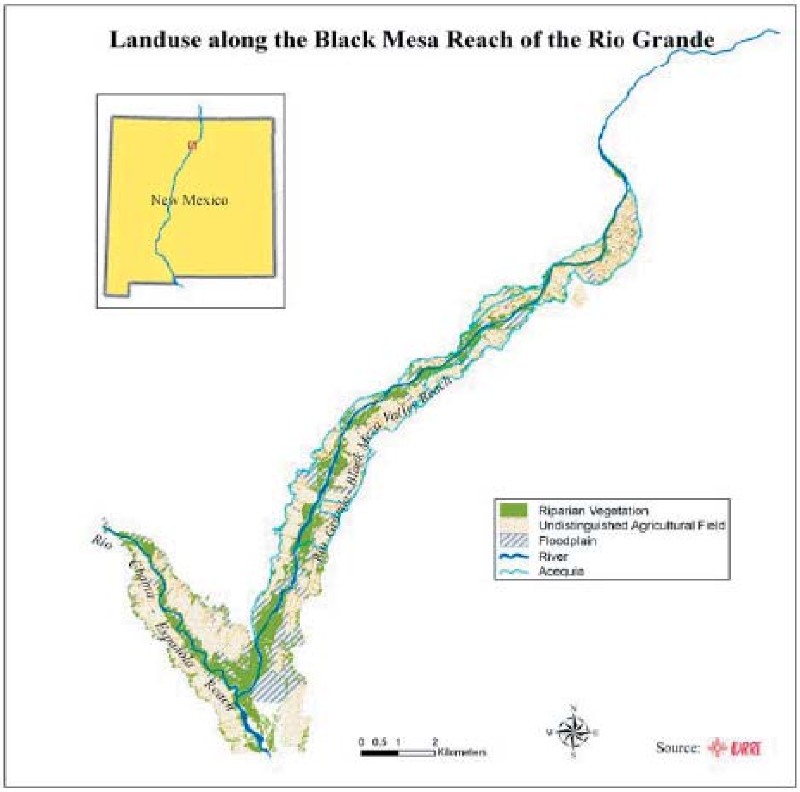

Figure 1. The area of investigation for this research project.

Details of the Study Area

As detailed in Figure 1, the Alcalde Reach of the Rio Grande is located in north central New Mexico. It is a region that is unique in both its physical and cultural landscapes. Land use along this reach includes irrigated cropland, rangeland, riparian vegetation, and small rural communities. For centuries the *acequia* system has traditionally supported agricultural practices in the region. The irrigated crops grown include alfalfa, apples, chile, sweet corn, and other crops of regional importance. Riparian vegetation grows along both the Rio Grande and along the *acequias* that are situated along this reach. Similar to other regions in northern New Mexico, this region is undergoing increasing pressures from rapid population growth to convert agricultural land and *acequia* delivered water to other uses. These qualities of the river reach and the presence of a New Mexico State University research station in the region make it a highly appropriate study area.[2]

Research Approach and Methods

Land use in the Alcalde region was mapped for the years 1962, 1997, and 2003. By employing aerial photography interpretation techniques, we mapped historical changes of land use and generated digital data layers for further analysis in the ArcGIS software package. For the 1962 land use, we obtained and scanned historic black and white aerial photography, which we then geo-rectified using the geo-referencing tools in ArcGIS. We employed a similar technique with digital orthophoto quadrangles obtained through cooperation with the United States Army Corps of Engineers to map the 1997 land use. The 2003 land use was mapped using QuickBird "pan sharpened" multi-spectral satellite imagery obtained from Digital Globe, which also required geo-referencing operations.

In addition to the GIS mapping, we ground-truthed the 1997 and 2003 land uses for clarification of mapping uncertainties, though some of the land use classifications in 1997 remain uncertain to some degree due to the nature of ground-truthing imagery that is nearly a decade old. To address this issue, we consulted with Mr. David Archuleta, a long-term resident of the valley and employee of the New Mexico State University Alcalde Research Station, who has been active in *acequia* management and operation of the research station. Mr. Archuleta provided invaluable local knowledge that aided us in the ground-truthing process. Using the same mapping process, we also examined changes to riparian vegetation cover along the banks of the Rio Grande and along the *acequia*, with the goal of exploring the impacts of land use change over time on the riparian ecosystems.

Examination of land use change over time also allowed us to explore the potential impacts of the increase in the use of on-site wastewater treatment systems on regional ground water resources. The entire study region is outside of any centrally managed wastewater collection and disposal network; accordingly, all increases in residential land use relie on these on-site systems for wastewater disposal. On-site wastewater systems have been acknowledged as a potential source of risk to ground water aquifers, especially in areas with shallow depth to ground water (Harris 1995, Geary and Whitehead 2001).

The use of GIS to examine a range of water quality issues has proven useful in past research (Brito et al. 2005). Hess (2001) specifically examined health risks due to the interaction of shallow ground water and agricultural chemicals using GIS tools in southeastern Pennsylvania. Through the use of GIS-based cartographic modeling techniques (Tomlin 1990, 1991), we examined the spatial co-occurrence of these on-site systems with shallow ground water areas obtained from the WATERS database compiled and managed by the New Mexico Office of the State Engineer (New Mexico Office of the State Engineer 2005). The output of this analysis shows areas of the underlying aquifer that are vulnerable to contamination.

Research Results

Land Use Change

Land uses were classified into six categories: residential, riparian, orchard, undistinguished row crop, pasture, and fallow. The mapping results showed some key land use conversions in the region, and these changes are detailed in Table 1 and Figures 2 through 4. The total orchard acreage has changed considerably since 1962. By 1997, orchards had decreased to 100 acres from 289 acres in 1962, a decrease of approximately 65 percent. The orchard acreage had further decreased by 2003, encompassing only 88 acres. Similar to orchards, row crops have also decreased. In 1962, row crops consisted of 415 acres. In 1997, row crops made up half of that figure with only 207 acres and, by 2003 there were only 192 acres. Another major change in the region was residential land use, which has increased significantly since 1962. Residential land use consisted of 139 acres in 1962. By 1997 residential land use increased to 639 acres, and the 2003 figure was 908 acres. The total riparian acreage doesn't appear to have been significantly affected by land use change during this time period. The total riparian cover in 1962 was 436 acres; in 1997 it was 382 acres; and by 2003 it was 420 acres. It is difficult to identify whether the riparian increase was a result of actual growth, or if the spatial resolution of the imagery used for mapping determined these figures. The main result we see is that the extent of this land cover classification has not varied more than 10 percent over the time period being examined.

Table 1. Land use changes in Alcalde (units are acres), 1962-2003.

Land Use	1962	1997	2003	% Change
Orchard	289.3	100.40	88.3	-69%
Row crop	415.2	207.50	193.0	-53%
Fallow	N/A	15.00	14.9	0%
Pasture	422.2	607.90	621.9	+47%
Riparian	436.9	382.29	420.5	-3%
Residential	139.1	639.49	908.8	+553%

Water Quality

With increasing development in and around Alcalde and a lack of a centralized wastewater treatment and disposal system, the water quality in the region is at potential risk, particularly from the increased use of on-site septic tank systems. One objective of our project was to build a framework with which to determine potential risks to ground

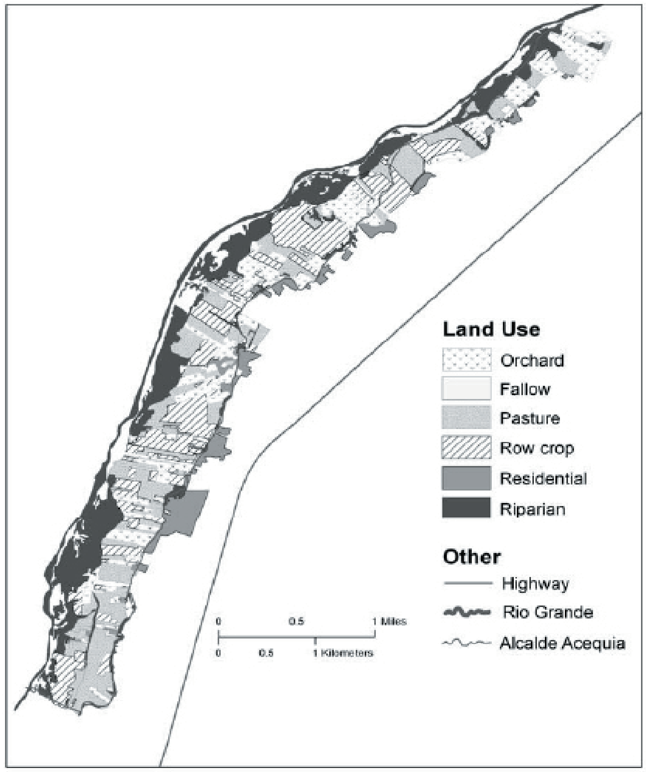

Figure 2. Land use in Alcalde, 1962.

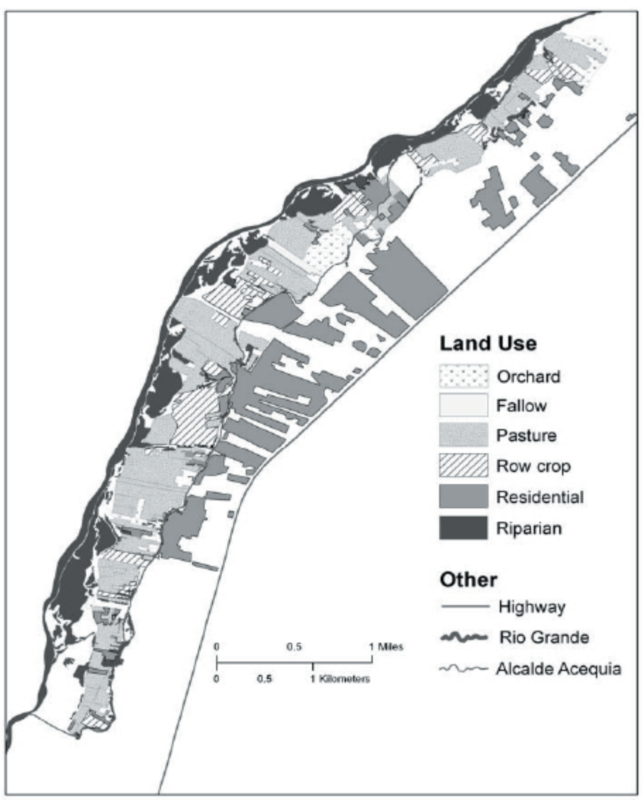

Figure 3. Land use in Alcalde, 1997.

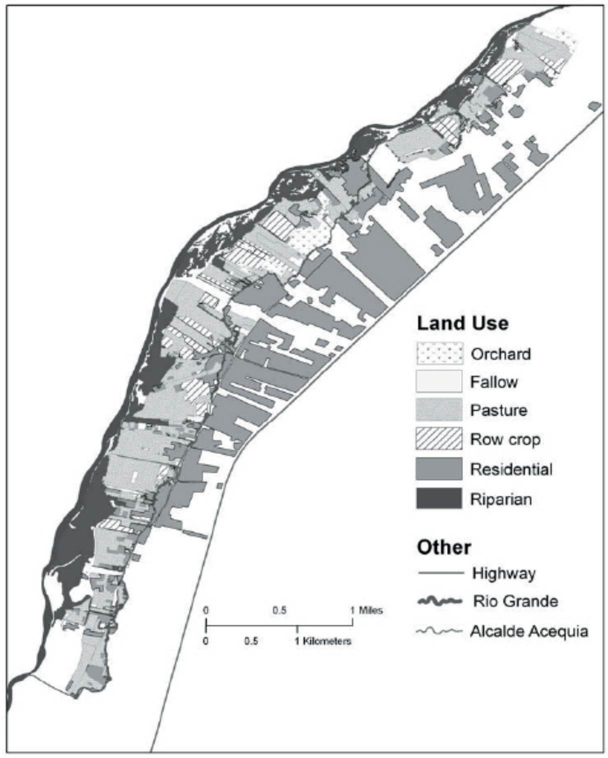

Figure 4. Land use in Alcalde, 2003.

water quality along the Alcalde Reach, using GIS tools as detailed above in the discussion of methods. Septic tank data for 2003 extracted from the 2003 satellite imagery was used, as well as data from the New Mexico Office of the State Engineer and New Mexico State University Alcalde Science Center, Natural Resource Conservation Service soils data, and the United States Geological Survey Digital Elevation Models.

Wells that had a depth to water less than 130 feet were selected and, we assumed that wells deeper than this would not see notable risk from seepage from on-site wastewater disposal systems. From this selection we created a new shapefile of point features with spatially referenced depth to water data, and we then used the Ordinary Kriging method of interpolation (Environmental Science Research Institute 2006) to generate a continuous depth to water surface. We then converted this surface to a fill contours shapefile, which was then converted to a raster file. Finally, we reclassified this raster based on depth to water values.

The soils data layer was clipped to the study area polygon that was digitized around the wells layer to generate a more accurate depth to water surface. Based on the infiltration characteristics and insight gained from the work of Brito et al. (2005), we classified the clipped soils shapefile and converted it to a raster dataset. We also confirmed that this dataset was geo-referenced to the other raster data layers being examined in the GIS analysis.

Two Digital Elevation Models that covered the study area were downloaded from the seamless.usgs.gov website and converted to Environmental Systems Research Institute-compatible raster datasets. We then used tools within the Environmental Systems Research Institute Spatial Analyst extension to generate a surface of slope for the two Digital Elevation Models, and these files were merged into one seamless slope raster data file for the study area.

To generate a surface of aquifer vulnerability, we completed weighted raster calculations using Map Algebra routines, specifically, the raster calculator in the Spatial Analyst extension of ArcMap. To generate an infiltration surface, we combined the slope and soil datasets, weighting the slope layer by a factor of 0.4 and the soils by a factor of 0.6. The next calculation included both the infiltration raster and depth to water raster, with the infiltration surface being multiplied by 0.4 and the depth to water surface being multiplied by 0.6. The final

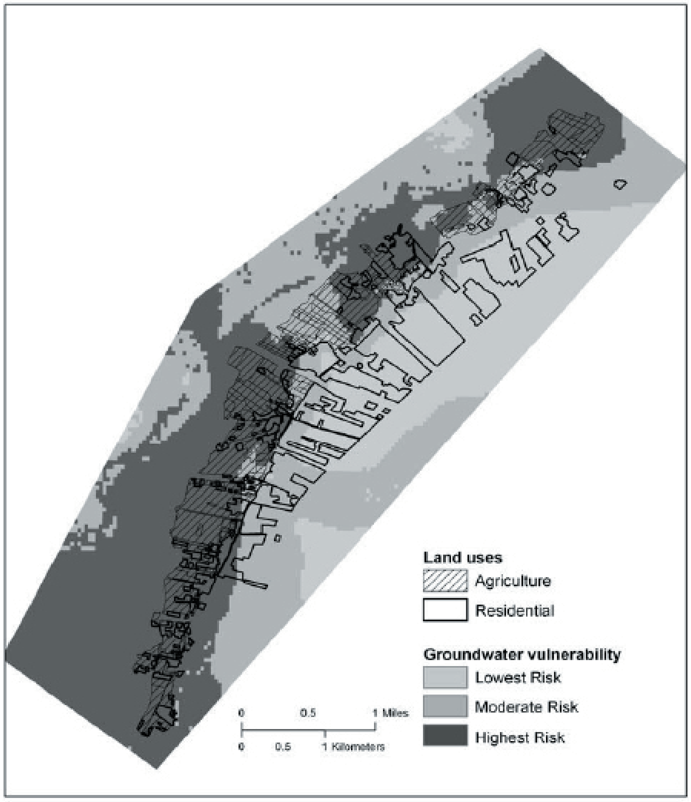

Figure 5. Relative groundwater risk in the Alcalde region.

step was to overlay the weighted raster datasets using the raster calculator in ArcMap, which provided us with the final aquifer vulnerability areas, as depicted in Figure 5. Inspection of this map indicates that the sub-regions of the study area that are at the highest risk largely coincide with agricultural land use. Accordingly, efforts at preserving agricultural areas that are already underway and supported by the region's residents may have an additional benefit in preventing large scale residential development that present risks to ground water quality due to the use of on-site wastewater treatment systems.

Conclusion

In the research described in this paper, we deployed a series of geo-spatial analysis tools to examine land use change in the Alcalde region of the Upper Rio Grande Basin from 1962 to 2003, specifically exploring the potential impacts on regional water resources and related agricultural and economic activities. The GIS tools we used provided a very useful spatial framework and analysis capability, allowing the integration of aerial photography, satellite imagery, readily available Digital Elevation Models, local well data, and expert local knowledge. The results that we uncovered include a documented decrease in row and orchard crops and an attendant increase in residential development in the area of investigation. We also developed a relative risk assessment tool that yielded a map of aquifer vulnerability due to on-site wastewater treatment systems and shallow depth to ground water.

The results of this work provide useful insight into areas where future land use conservation efforts may yield the greatest benefit, and the techniques employed in this work may be useful to other researchers interested in similar questions in other mountainous regions in the American Southwest. In future work, we will examine how the land uses we have documented are impacting underlying cultural values in the region, with a special focus on potential insights that may aid in future cultural preservation efforts.

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Endnotes

1. An *acequia* or community irrigation ditch is an institution common to the native people of the American Southwest for irrigation (Lovato 1975). *Acequias* are usually historically engineered canals that carry snow runoff or river water to agricultural fields. Most *acequia*s were established more than 200 years ago and continue to provide a primary source of water for farming and ranching ventures in areas of the United States once occupied by Spain or Mexico. Known among water users simply as the *acequia*, an *acequia* association is an institution that governs members' water usage that is based on local precedents and history. An *acequia* organization is lead by a *mayordomo* or ditch rider who administers usage of water from a ditch and regulates which water-rights holders can release water to their fields on what days (Crawford 1988 and Norstrand 1992).
2. The NMSU Sustainable Agriculture Science Center at Alcalde is located directly in the heart of the study area, and one of the co-authors of this article, Dr. Steve Guldan, is the Station Director. The station and staff are *parcientes* or members of the Alcalde *Acequia* Association, and the station enjoys a strong connection to the *acequia* water resource management regime that is the focus of this study.

References

Annela, A. and J. Wright. 2004. *Saving the Ranch: Conservation Easement Design in the American West.* Island Press,Washington DC.

Brito, M. G., C. N. Costa, J. A. Almeida, D. Vendas, and P. H. Verdial. 2005. Characterization of maximum infiltration areas using GIS tools. *Engineering Geology* 85: 14–18.

Crawford, S. 1988. *Mayordomo: Chronicle of an Acequia in Northern New Mexico*. University of New Mexico Press, Albuquerque, New Mexico.

Environmental Science Research Institute (ESRI). 2006. Spatial Analyst and ArcMap documentation describing various interpolation routines. ESRI, Redlands, California.

Geary, P. and J. Whitehead. 2001. Groundwater contamination from on-site domestic wastewater management systems in a coastal catchment. *On-Site Wastewater Treatment, Proceedings of the Ninth National Symposium on Individual and Small Community Sewage Systems, 11-14 March 2001, pp. 479-487. Fort Worth, Texas.*

Harris, P. 1995. Water quality impacts from on-site waste disposal systems to coastal areas through groundwater discharge. *Environmental Geology* 26 (4): 262-268.

Hess, M. 2001. *Spatial Analysis of Breast Cancer Incidence Rates and Well Depths in the Octoraro Watershed*. Unpublished Masters Thesis, Department of Geography and Planning, West Chester University, West Chester, Pennsylvania.

Lovato, P. 1975. *The Community Ditch Systems of Northern New Mexico: A Reprint of Las Acequias Del Norte*. Water Resources Research Institute Report Number 060.

New Mexico Acequia Association (NMAA). 2006. *El Congreso de las Acequias.* Annual Meeting of Acequia

Association members hosted by the NMAA in Taos, NM, 2 December 2006.

New Mexico Office of the State Engineer (NMOSE). 2005. *Water Administration Technical Engineering Resource System (WATERS) Online Database*, available at http://iwaters.ose.state.nm.us:7001/iWATERS/, accessed 27 September 2005.

Norstrand, R. 1992. *The Hispano Homeland*, The University of Oklahoma Press, Norman, Oklahoma.

Rivera, J. A. 1998. *Acequia Culture: Water, Land, and Community in the Southwest*. University of New Mexico Press, Albuquerque, New Mexico.

Tomlin, C. D. 1990. *Geographic Information Systems and Cartographic Modeling***.** Prentice Hall, Englewood Cliffs, New Jersey.

Tomlin, C. D. 1991. Cartographic modeling. In Goodchild, M., D. Maguire and D. Rhind. (Eds). *Geographical Information Systems: Principles and Applications*. Longman Group Ltd., Harlow, Essex, United Kingdom.