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Qualitative and Visualization Methodologies for Modeling Social-Ecological Dimensions of Regional Water Planning on the Rio Chama

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Abstract: Courses in modeling often employ techniques based on mathematical or other computer-based quantitative models. In this article the authors update a range of social science qualitative and visualization methodologies presented to graduate students at an interdisciplinary modeling course on water issues related to climate change. In part the modeling course featured the coupling of natural and human system dynamics in the context of *acequias*, gravity flow irrigation systems in New Mexico that depend on winter snowpack for water supply in the form of spring run-off. While student teams were able to employ STELLA and other models, they were free to explore alternative approaches. As course instructors, we assigned a pilot case study that utilized qualitative methodologies along with visualization tools to model land use, built environment, geo-spatial, natural systems, and human settlement morphology. Our project described a social-ecological history of the Rio Chama, a tributary of the upper Rio Grande, where we applied a cross-disciplinary and inter-temporal approach on how the land and water resources of the Rio Chama have been developed over time. The case study highlights the social-ecological dimensions of regional water planning while demonstrating the potential of visualization methodologies as a unique approach to modeling distinct from models based on quantitative data.

Keywords: *Rio Chama watershed, social-ecology, visualization methodologies, New Mexico regional water planning, upper Rio Grande basin*

A research team at the University of New Mexico is currently investigating the coupling of natural and human systems within the Rio Chama basin of New Mexico as a case study of society at the regional scale. In scope we plan to characterize the social-ecological history of the Rio Chama by surveying the breadth of human and nature interactions that have shaped the region since the collapse of Chaco around 1200 AD. The final research monograph will conclude with an analysis of post-World War II urbanization and the attendant issues of population growth in the metropolitan centers of New Mexico into the new millennium. In June of 2012, we developed a pilot case study for use by graduate students from Idaho, Nevada, and New Mexico enrolled in an interdisciplinary modeling course on water issues related to climate change in the Western states. As a departure from the more standard use of models based on mathematical or statistical methods, we instead applied social science qualitative research and visualization methodologies derived from ethnographic histories, archeological surveys, geographic mapping, hydrographic survey maps, census data, along with the use of emerging theories into linked physical-social-ecological systems (Fernald et al. 2012).

In a background report for use by the modeling students, we presented a brief history of the Rio Chama basin as a resource system that has supported multiple and sometimes competing cultures over centuries of human occupation. For reader context this article will outline the historical role of the Rio Chama during early Hispanic land grant settlements, and how reclamation projects developed the river into a trans-basin delivery system for urban growth centers in the twentieth century. Next, the main body of the article will describe how visualization methodologies can unpack abstract ideas or data and translate them into images that enhance the understanding of complexity in the built and natural environment while bridging historical timelines with contemporary spatial information by way of cross-disciplinary mapping. Lastly, the article describes the results of the student modeling course, and concludes with the proposition that the modeling of landscapes in visual communicative forms can be used successfully to describe physical and natural systems in a way that will facilitate the development of collective strategies for water policy development.

The Rio Chama Watershed

Geographic and Hydrographic Extent

The Rio Chama watershed drains roughly 3,157 square miles, from the San Juan Mountains on the Colorado-New Mexico border in the north, to the confluence with the Rio Grande in the south, and is bounded by the Continental Divide and the Tusas Mountains on the west and east, respectively. The watershed is located in a bio-geographical transition zone, encompassing the edge of the Colorado Plateau and its associated shrub and steppe biome on its northwest, the southern reach of the Rocky Mountain region and its pine forests on the northeast, the Jemez Mountains on its southwest and the Rio Grande Rift valley on its southeast. The watershed's highest points are the ridge of 10,000-14,000 foot San Juan peaks that form its northern border in Colorado, and Brazos Peak at 11,410 feet located in Rio Arriba County of New Mexico (Rio Chama Regional Water Plan 2006). (Figure 1 about here, Study Area Map.)

The Rio Chama is only 130 miles in length but functions as a vital tributary of the Northern Rio Grande, and itself is fed by numerous creeks, streams and arroyos. Due to semi-arid conditions in the landscape, most of these tributaries are diverted by centuries old acequias for small-scale irrigated agriculture in the valley bottomlands: the Rios Tusas and Vallecitos that together flow into the Ojo Caliente, the El Rito, Canjilón Creek, Rito de Tierra Amarilla, and the Rio Brazos, among others. In the lower stretch below Abiquiu Dam, the mainstream Chama is diverted for acequia agricultural uses for about 28 miles before reaching the confluence with the Rio Grande at Chamita. The Rio Chama is a snowmelt-dominated river flowing into the Rio Grande north of the Otowi gauge, and this location makes it an important contributor to the Rio Grande index flow involved in water deliveries to the Middle and Lower Rio Grande of New Mexico as well as the interstate stream compact with Texas (New Mexico EPSCoR 2008).

Water Engineering History

The oldest Spanish acequia in New Mexico was constructed on the Rio Chama around 1598 under the direction of colonial Governor Juan de Oñate at San Gabriel, now Chamita. To recruit settlers from the central valley of Mexico the Spanish and Mexican governments offered community land grants within the remote province of *Nuevo México*, the northern frontier in the borderlands of New Spain (Rivera 1998). After the Santa Cruz land grant in 1692, settlements followed the Rio Chama in its northwesterly direction toward Abiquiu, Ojo Caliente, El Rito, and Cañones. This dispersal pattern eventually led to dozens of farm and ranch settlements on the expansive Tierra Amarilla land grant from 1821 to 1848. With the transition to U.S. rule in 1846-1848, resulting in the aftermath of the United States-Mexican War, roughly sixty five percent of the lands in the Rio Chama basin were transferred from communal ownership and use to Federal and Tribal control while much of the remaining land was partitioned, privatized or homesteaded (Rio Arriba County Comprehensive Plan 2009).

Additional and more dramatic impacts occurred during the early and middle twentieth century when the hydrology of the Rio Chama was reengineered by the construction of three reservoirs and an inter-basin tunnel. The first dam, El Vado, was built by the Middle Rio Grande Conservancy District in the 1930s to provide flow regulation for the irrigation district that stretches from Cochiti to San Marcial. The second dam, Abiquiu, was built north of the historic plaza of Abiquiu for flood and sediment control in the 1950s, and in the 1970s it was joined by Heron reservoir designated to hold San Juan-Chama Project water (Glaser n.d.). Constructed by the Bureau of Reclamation, the latter project diverts water from San Juan tributaries of the Colorado River to the Rio Chama through a tunnel carved beneath the Continental Divide. The water from the project enters Heron through Willow Creek and then passes through the Chama for utilization by a number of entities downstream, with the bulk of water contracted to the City and County of Santa Fe, the Middle Rio Grande Conservancy District, and the Albuquerque Bernalillo County Water Authority (Thomson 2012).

The San Juan-Chama Project inextricably links two of the most vital water planning districts in the State of New Mexico: Region 12 in the Middle Rio Grande and Region 14 in the Rio Chama basin. In recent years, however, decreased snowpack in the San Juan Mountains of Colorado threaten the reliability of this imported water with curtailments on the horizon in response to dwindling reserves at Heron and El Vado alongside other pressures on the Colorado River basin where urban demands are rising and already exceed the supply (United States Bureau of Reclamation 2012). Figure 2 depicts a project map of the late 1940s for the proposed location of this trans-mountain diversion as well as other federal storage reservoirs of the Middle Rio Grande Project sponsored by the Bureau of Reclamation, not all of which were constructed. (Figure 2 about here, Middle Rio Grande Project Map-NM 1947.)

Socio-demographic Development

Most of the Rio Chama watershed lies within the boundaries of Rio Arriba County, a rural agricultural county with a land base about the size of the state of Connecticut. According to county records, there are approximately 30,000 acres of farmland in the Rio Chama Valley irrigated by surface water canals or community-based acequias (Rio Arriba County Comprehensive Plan 2009). In recent years the recession and its economic impact have resulted in significant cuts in federal funding to agencies such as Los Alamos National Laboratory and the United States Forest Service, causing job losses in the area and shifting the population growth pattern of the last three decades. At the time of the 2010 United States Census, Rio Arriba County had a population decrease of 2.3% over a decade and faces new challenges of outmigration by young adults. During this same period, prolonged drought, a reduced snow pack, and forest fires have placed additional pressures on the viability of acequia-based agriculture. Other stressors on limited water supplies have resulted from population growth in Santa Fe, New Mexico's capital city, and particularly in the urbanizing area located within the Middle Rio Grande Regional Water Plan, a New Mexico planning district that includes Albuquerque and fast growing Rio Rancho. The City of Albuquerque currently relies on forty percent of its water supply from the San Juan-Chama Project due to a diminishing underground aquifer, and according to the Albuquerque Bernalillo County Water Utility Authority, this dependency could rise to ninety percent in future years when the perpetual rights of up to 48,200 acre feet will be needed annually (Albuquerque Bernalillo County Water Utility Authority 2011).

In the coming decades of increased water scarcity, and the possible effects of climate change, the contest over water resources in the upper Rio Grande basin could emerge as a battle of sprawl development in downstream cities versus water uses in area of origin communities such as the historic acequias dependent on snowpack in the northern mountains. The population differences are dramatic. Whereas Rio Arriba County is home to 40,466 residents, the total population in the urbanized counties of Santa Fe, Sandoval, Bernalillo and Valencia is about 1,030,000 (United States Census Bureau 2011). And unlike Santa Fe and Albuquerque, the acequia farmers of the Rio Chama do not have storage rights at Heron reservoir and can divert water into their headgates only from their share of native water or natural flow existent prior to the construction of the San Juan-Chama Project (Watermaster's Report 2009).

Data and Study Methodologies

Social Science Research

Data made available to the students in the modeling course included: archival repositories of primary source documents, census data and other public records, ethnographic histories, archeological surveys, sociological reports, historic cartography of the region, field-based ethnographies, bibliographic references, along with data embedded in the Rio Chama hydrographic survey and regional water plan. Temporal and spatial data were intermixed covering events that led to major shifts in land use conditions. Analysis of historical context can help researchers comprehend the dynamic nature of landscapes in order to assess current conditions essential to informed resource management (Swetnam et. al. 1999). In addition to historical ecology as a conceptual model, we found that archival maps too can provide a visual tool for examining natural features, places, landscapes, and the connection of people and cultures to physical forms. New Mexico in particular has a rich cartographic history where archival maps represent hundreds of years in data points (Eidenbach 2012). A single map of *Nuevo México* drawn by Spanish cartographer Miera y Pacheco in 1778, for example, locates rivers, mountain ranges, among other physical features of discovered lands, but also depicts the human cultures previously existing such as the Navaho, Ute, Comanche, along with the Hopi, Zuni, and numerous other pueblo villages on the *Río del Norte* (now Rio Grande). In the inserted text, this cartographer notes that the *Provincia de Nabajoo* (Navajo Province) suffers from water scarcity, but the people manage to cultivate corn and legumes "*de temporal*," farming on dryland plots to supplement their economy of livestock raising and weaving (Figure 3 about here, Bernardo de Miera y Pacheco Map 1778.)

Visualization Modeling

Qualitative and quantitative methods are both needed to conduct cross-disciplinary studies and can be enhanced by the use of new visualization technologies to unpack and re-translate system complexity. Visualization methodology takes abstract ideas or data and translates them into images that communicate information about the built and natural environment. (Figure 4 about here, Unpacking and Data Translation Diagram.) Visualization modeling tools and techniques assist in the comprehension of factors that transform the cultural landscapes and explicate settlement morphology. Settlement morphology examines changes in urban form, resolution, and time that shaped and altered the built environment and natural systems (Camona and Tiesdell 2007). In the context of water planning, the modeling of landscapes in visual communicative forms can be used to engage community stakeholders in the understanding of physical and natural systems. Geo-spatial mapping of natural systems was originally developed by Ian McHarg (1969) to conduct analysis of regional ecological conditions by layering multiple data inventories such as riparian zones, slope, settlement patterns, and land use, a process that eventually led to the development of Geographic Information Systems. Today, in addition to GIS spatial mapping, water planners utilize a range of visualization tools such as three-dimensional modeling and geo-spatial software as a way to display graphic information that can integrate historical, qualitative and quantitative data to model cultural landscapes (American Planning Association 2006).

Qualitative visualization strategies in urban design and environmental planning derive from the same theoretical principles of visualization modeling in the scientific disciplines. According to McCormic and DeFanti (1987, p. 324), "visualization… transforms the symbolic into the geometric, enabling researchers to observe their simulations and computations. Visualization offers a method for seeing the unseen." Langendorf (2001, p. 324) expanded this notion of visualization methodology in the planning field because of its potential application, "… the NSF examples of scientific visualization are directed at displaying information about physical phenomena, always with spatial dimension, and often with temporal. Though some of this has been used in natural resource and environmental work, is has not impacted most other areas of planning." In the last decade, visualization modeling has allowed planners, urban designers, and decision makers the opportunity to experience the impact of policy on the built and natural environment. Cultural landscape morphology as a method and a research strategy spans the fields of geography, history, archeology, architecture and planning (American Planning Association 2006).

The challenge of contemporary mapmaking in modeling is the complexity of transforming multiple forms of data into interactive maps that can be used for analysis rather than communicative tools of representation. Our strategy is to go beyond the production of maps as graphic communication and to utilize visualization as an analytical tool in understanding the relationships and trasnformation of natural and human systems. "With the added scope and complexity of spatial data and methods of representation, and the possibility of interactivity, the interest of cartographers and spatial data users shifted from static maps to multiple views into the data, both concurrenlty and sequentially" (Langendorf 2001, p. 314). When mapping the social-ecological history of the Rio Chama watershed, at times we encountered difficulty in translating historical and archival maps into forms of data that are usable in a desktop mapping framework. The process of georeferencing historical maps, such as historic hydrographic surveys that are built into thematic spatial data, is difficult and often time consuming. However, when analog data is converted into usable mapping data sets, the result creates a deeper level of analysis into historic land use change as happened in our own Rio Chama visualizations.

We developed a map series to examine the evolution of settlement patterns beginning with riverine Pueblos before the arrival of Europeans, expansion of villages in the basin during the Spanish and Mexican land grant periods, and transformation of community form with the arrival of the railroad and Anglo Americans starting in the territorial period and into statehood of

New Mexico in 1912. The modeling of adaptations in land use practices provided insights into how community land uses were altered and changed after subsequent historical events such as World War II. To analyze the cultural landscape evolution in the Rio Chama basin, the study team mapped early human colonies by geocoding Puebloan riverine village locations. A sample of Puebloan communities from the period 1300 AD to 1540 AD identified in archeological surveys were then geocoded and mapped in relationship to existing towns. (Figure 5 about here, Riverine Settlements Map.) Drawing from archeological investigations of building complexes, organization of agricultural grids and gravel-mulched plots, we developed an understanding of land use practices and systems of water management by Pre-Columbian Pueblo farmers (Anschuetz 1998).

In formulating social ecological narrative of the Rio Chama, we constructed additional map sequences to demonstrate the expansion of human colonies upon the arrival of Hispanic village settlements into the territory controlled by nomadic tribes such as the Navajo, Comanche, Ute, Apache, and Kiowa. As the next step, additional archival and historic maps were interpreted and regenerated into spatial data and map overlays onto existing geographic information for further analysis and reinterpretation. For example, historic maps from cartographers such as Alexander von Humboldt in 1804 detailing nomadic tribal contested territory, in addition to a second Bernardo de Miera y Pacheco Map of 1777, were geo-referenced and projected onto a 1983 North American Datum State Plane coordinate system. Through the comparison of maps generated and verification of archival documents, the study team began to understand geo-spatial territory of the Rio Chama watershed by settlement date, land use practices, and territorial control by various populations, a key step in developing the social-ecological narrative for the case study. Figure 6 depicts the timeline of Hispanic settlement expansion from Santa Cruz to the upper reaches of the Chama Valley from 1692 to the late 1880s. (Figure 6 about here, Adaptation of Bernardo de Miera y Pacheco Map 1777.)

In order to illustrate land use change at the community scale, the study team also formulated a mapping catalog of settlements along the Rio Chama to document land use change from 1935 to 2011. In a community scale mapping series, each localized map provides detailed information of settlement form, agricultural parcel size, spatial organization of the acequia network, in addition to assessing riparian conditions along the Rio Chama. To analyze land use change within the Rio Chama, morphology mappings were developed for Tierra Amarilla, Los Brazos, and Los Ojos in the upper basin in addition to El Rito, Abiquiu, and Hernandez in the lower stretch of the Rio Chama. These maps provide key information on how land use conditions have been altered and what land use alternatives may be considered in planning for long term drought mitigation in the basin.

To produce the settlement pattern maps, base mapping of key physical elements in built and natural systems were traced over 1935 aerial photography (Earth Data Analysis Center 2010). The 1935 aerial photography is one of the most important mapping series in the context of studying land use change for several reasons: (a) 1935 is the first deployment of aerial photography technology in the Rio Chama basin; (b) the photography was produced at the advent of World War II which brought significant changes in technology and farming practices in the region; and (c) the high resolution of the imagery is such that landscape and settlement features allows for fine grain mapping at the community scale. Community scale maps provided the study team with a baseline data set for understanding land use conditions along the Rio Chama such as diverse crop types, smaller farm plots, compact settlement form, and a more natural riparian network characteristic of a pre-channelization river system. In addition, the same geographic layers were mapped over the 2011 aerial photography for each of the selected village settlements. We were then able to analyze localized land use change from 1935 compared to the 1961 hydrographic survey data of the Rio Chama below El Vado (Office of the State Engineer 1961). Findings from the community scale morphology study revealed larger farm plot size, a dispersed settlement form, less crop diversity, and a restricted channelized riparian condition. (Figure 7 about here, Abiquiu, New Mexico, 1935-2011 Land Use Settlement Morphology.)

Three dimensional modeling in software programs such as 3d GIS in ArcScene and Google SketchUp, in addition to the use of photo montage imagery, were among other visualization tools used in modeling of the study area. Regional 3d visualization of landscape terrain at such a large scale as the Rio Chama basin is a useful tool to describe regional complexity of systems and networks as well as engaging community members. Regional and community scale terrain models were developed in 3-d GIS based on digital elevation data and existing land use classification data generated by the study team (United States Geological Survey 2004). We then developed terrain models to illustrate physical spatial features at the community and regional scales. (Figure 8 about here, El Rito Valley Terrain Model.) Terrain model visualization provides the ability to communicate abstract geographic locations in an understandable graphic form as a useful tool in regional water planning. The rendering of basin scale three dimensional modeling animations of land use conditions and settlement patterns can help acequia based communities in framing land use policy alternatives based on the possibility of prolonged drought conditions. Mapping visualization products create an opportunity for developing policy and land use alternatives in working through complexity of social and natural factors (Corner 2011). (Figure 9 about here, Rio Chama 3d Land Use Conditions Model.)

Participatory three dimensional modeling in community capacity building has become widespread practice involving institutional and traditional community perspectives in natural resources planning. For example, in 1999 participatory modeling was used in the resource management planning at the El Nido-Taytay Managed Resource Protected Area in the Palawan coastal region of the Philippines (Rambaldi 2006). The planning process at El Nido-Taytay integrated visualization modeling while involving local fishermen in mapping fishing areas in addition to information about coastal and marine ecosystems. "… P3DM (Participatory 3 dimensional modeling) has been gaining increasing recognition as an efficient method to facilitate learning, analysis and proactive community involvement in dealing with spatial issues related to territory. If properly administered, P3DM can support collaborative natural resource management initiatives and transcend the local context by establishing a peer-to-peer dialogue among communities and central institutions, agencies, and projects." (Rambaldi 2006, p. 541).

Discussion and Results

Student Report and Presentation

How do climate change, water scarcity, and continued urban population growth challenge acequia water uses in the Rio Chama watershed, and conversely, how do acequia operations affect water flows of the Rio Grande downstream into the middle Rio Grande valley? Are there water policy alternatives that can encourage water sharing and conservation among rural and urban stakeholders and reduce conflict over water demand? Can system dynamics modeling help to facilitate collective strategies that might lead to improved communication and a transparent process for decision making as some modelers advise (Gupta et al. 2012)?

Those were among the questions posed to the team of modeling course students in June of 2012 as a pilot case study of the larger Rio Chama research monograph that is still in progress. The task for the students was to develop and evaluate future conditions of potential urban growth impacts on acequia-based communities in the Rio Chama watershed driven by climate change and other socio-economic factors within the context of the upper Rio Grande basin as a whole. We presented the students with three "what if" scenarios that linked both water planning regions, the Rio Chama and the Middle Rio Grande: a Status Quo Policy with no changes in water use by stakeholders in the two regions; a Moderate Shift Policy with some water conservation practices adopted for both urban domestic and rural agricultural uses; and a Significant Change in Water Use Policy where municipal water consumers reduced per capita water use by 50% and the acequia communities increased on-farm irrigation efficiencies.

At the end of the course, the students made a final presentation and submitted a written report. In our view, the students successfully completed the assignment and managed to integrate a number of modeling approaches, both quantitative and qualitative, and included cross-disciplinary analysis that covered Rio Chama settlement history, social and cultural aspects of acequia agriculture, socio-economic demographic data, urban growth impacts on water demand into future years, and a discussion of the policy regimes presented in each of the three scenarios. The socio-economic modeling focused on the Rio Chama Regional Water Plan followed by a series of land use analysis maps depicting rural low development and agricultural uses and concluded with a MacHargian Land Suitability Analysis Terrain Map. For system dynamics modeling the students utilized STELLA to incorporate a diverse array of data and to conduct the Rio Chama policy alternatives sensitivity analysis, and also GAP Habitat for modeling changes in species richness in the Rio Chama basin.

As to lessons learned when integrating models across disciplines, such as spatial (GAP) models and systems driven models (STELLA), the student team noted that interdisciplinary modeling holds substantial value albeit with difficult challenges to keep the group dynamics in sync given inherent differences within each of the models used, the different languages across disciplines, and the fact that different analysis types employ units of measurement that are not always compatible. With more time, and more learned experience on how to work in teams, they concluded that the process of interdisciplinary group modeling will result in projects that can be "both effective and efficient for addressing issues such as acequia land, water, and community dynamics" (Corrao et. al. 2012).

Future Policy Collaborations

The upper Rio Grande basin does not produce an adequate water yield to satisfy the multitude of conflicting values and demands based on current conditions and uses. These competing uses include a growing human population in the cities, irrigated agriculture resistant to water transfers for urban consumption, and declining reserves in the storage reservoirs of the Rio Chama. These factors are exacerbated by a period of multi-year drought and the uncertainty about impacts of climate change on mountain sources of water in the upper Colorado River basin and the Rio Grande (NM EPSCoR 2008; United States Bureau of Reclamation 2012). Public engagement in an interactive modeling community-based process, as we conclude and propose here, will help promote dialogue about water conservation and other options drawn out by a number of "what if" scenarios that stakeholders can consider and evaluate if provided with equal access to relevant scientific data (see Tidwell et al. 2004 for an example of system dynamics community-based water planning with application to the Middle Rio Grande).

To aid with the translation of abstract numerical models, we contend that qualitative analysis and visualization methodologies can make a difference, level the playing field, reduce uncertainties, generate a multitude of ideas, and set the stage for collective decision making across stakeholders, water planners and resource managers at local, state and regional levels.

Beyond the pilot case study developed for the June 2012 modeling course, additional iterations of this cross-disciplinary and inter-temporal approach will be conducted in the fall of 2013 at stakeholder workshops along the Rio Chama. To facilitate the workshops the study team will present the social-ecological history of the Rio Chama watershed in a visual narrative form to deconstruct and unpack complexity of system dynamics modeling and then re-organize information so that stakeholders can develop alternatives based on possible future land use and water policy scenarios. As happened already with the modeling course, these workshop presentations will likely result in further improvements in the use of qualitative and visualization methodologies as tools for community-based water planning.

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References

Albuquerque Bernalillo County Water Utility Authority, 2011. *San Juan-Chama Drinking Water Project* (Update May 03, 2011). Available at : http://www.abcwua.org, accessed 01/13/2013.

Anschuetz, K. F., 1998. *Not Waiting for the Rain: Integrated Systems of Water Management by Pre-Columbian Pueblo Farmers in North-Central New Mexico.* Ph.D. dissertation, Department of Anthropology, University of Michigan Ann Arbor: UMI Dissertation Service.

American Planning Association, 2006. *Planning and Urban Design Standards*. John Wiley and Sons: Hoboken, New Jersey.

Carmona M. and S. Tiesdell, 2007. The morphological dimension. Pages 61-62 in Matthew Carmona and Steve Tiesdell (eds.) *Urban Design Reader*. Elsevier: Oxford, UK, 375pp .

Corner, J., 2011. The agency of mapping: Speculation, critique and intervention. Chapter 1.12 in Martin Dodge, Rob Kitchin and Chris Perkins (eds.) *The Map Reader; Theories of Mapping Practice and Cartographic Representation*. John Wiley & Sons, Ltd.: Oxford, UK.

Corrao, M., M. Eckstut, D. Kopp, C. Maxwell and A. Montrone. 2012. *The Rio Chama Basin: Land, Water, and Community.* RGSC 618-Interdisciplinary Modeling: Water Related Issues and Changing Climate. Student report, June 20, 2012, on file with instructors, José A. Rivera and Moises Gonzales, University of New Mexico

Earth Data Analysis Center, 2010. 1935 Aerial Photography of Rio Arriba County. Image Archive and Data Service. Albuquerque, New Mexico: University of New Mexico.

Eidenbach, P. L., 2012. *An Atlas of Historic New Mexico Maps, 1550-1944*. University of New Mexico Press: Albuquerque, NM.

Fernald, A., V. Tidwell, J. Rivera, S. Rodriguez, S. Guldan, C. Steele, C. Ochoa, B. Hurd, M. Ortiz, K. Boykin and A. Cibils, 2012. Modeling sustainability of water, environment, livelihood, and culture in traditional irrigation communities and their linked watersheds. *Sustainability* 4: 2998-3022.

Glaser, L. S., n.d. *San Juan-Chama Project History*, United States Bureau of Reclamation. Available at: http://www.usbr.gov/projects, accessed 01/13/2013.

Gupta, H. V., D. S. Brookshire, V. C. Tidwell and D. P. Boyle, 2012. Modeling: A basis for linking policy to adaptive water management. Pages 9-24 in David S. Brookshire, Hoshin V. Gupta, and Olen Paul Matthews (eds.) *Water Policy in New Mexico: Addressing the Challenge of an Uncertain Future*. Resources for the Future Press, New York, 288pp.

Langendorf, R., 2001. Computer-aided visualization: possibilities for urban design, planning, and management. Paper 12, pages 308-359 in Richard K. Brail and Richard E. Klosterman (eds.) *Planning Support Systems.* ESRI Press: Redlands, CA, 443pp.

McCormick, B. H., T. A. Defanti and M. D. Brown, 1987. Cited in Langendorf, R., 2001, Computer-aided visualization: possibilities for urban design, planning, and management. Paper 12, pages 308-359 in Richard K. Brail and Richard E. Klosterman (eds.) *Planning Support Systems.* ESRI Press: Redlands, CA, 443pp.

McHarg, I. L., 1969. *Design with Nature*. John Wiley and Sons: New York, NY.

New Mexico EPSCoR, 2008. *Climate Change Impacts on New Mexico's Mountain Sources of Water, RII 3*. Proposal submitted to the National Science Foundation, award #0814449. Available at: http:// www.nmepscor.org, accessed 01.13.2013.

Office of the State Engineer, 1961. Rio Chama Hydrographic Survey. Santa Fe: State of New Mexico. Available at: http://www.ose.state.nm.us/legal-ose-hydro-rio-chama.

Rambaldi, G., 2006. Participatory 3D Modelling. Book Section P, Pages 538-541 in Stewart Marshall, Wal Taylor, and Xinghuo Yu (eds.) *Encyclopedia of Developing Regional Communities with Information and Communication Technology*. Idea Group Reference, Hershey, PA, 744pp.

Rio Arriba County Comprehensive Plan, Adopted January 24, 2008/Amended and Adopted May 20, 2009. Prepared by Community By Design in association with Abeita Consulting Southwest Planning and Marketing.

Rio Chama Regional Water Plan, 2006. Rio de Chama Acequia Association and Rio Arriba County, in collaboration with La Calandria Associates, Inc. Available at: http:// www.ose.nm.us/isc_regional_plans14, accessed 01.13.2013.

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

Swetnam, T. W., C. D. Allen and J. L. Betancourt, 1999. Applied historical ecology: Using the past to manage the future. *Ecological Applications* 9 (4): 1189-1206.

Tidwell, V. C., H. D. Passell, S. H. Conrad and R. P. Thomas, 2004. System dynamics modeling for community-based water planning: Application to the Middle Rio Grande. *Aquatic Sciences* 66: 1-16.

Thomson, B. M., 2012. Water resources in New Mexico. Pages 25-55 in David S. Brookshire, Hoshin V. Gupta and Olen Paul Matthews (eds.) *Water Policy in New Mexico: Addressing the Challenge of an Uncertain Future*. Resources for the Future Press, New York, 288pp.

United States Bureau of Reclamation, December 2012. *Colorado River Basin Water Supply and Demand Study*. U.S. Department of Interior: Washington, D. C. Pre-Production Copy accessed December 13, 2012.

United States Census Bureau, United States Department of Commerce. State and County Quick Facts. Population 2011 Estimate. Available at: http://quickfacts.census.gov.

United States Geological Survey, April 2004. National Elevation Dataset 10 meter 7.5 minute guadrangle Data. *National Elevation Database*. Texas, USA: National Cartopraphy and Geospatial Center.

Watermaster's Report, Rio Chama Mainstream, 2009. Stermon M. Wells, Office of the State Engineer of New Mexico, Santa Fe. NM. Available at: http://www.ose.state.nm.us/water_info_awrm_rio_chama_lower_master_reports, accessed 01/13/2013.

Figure 1: Study Area

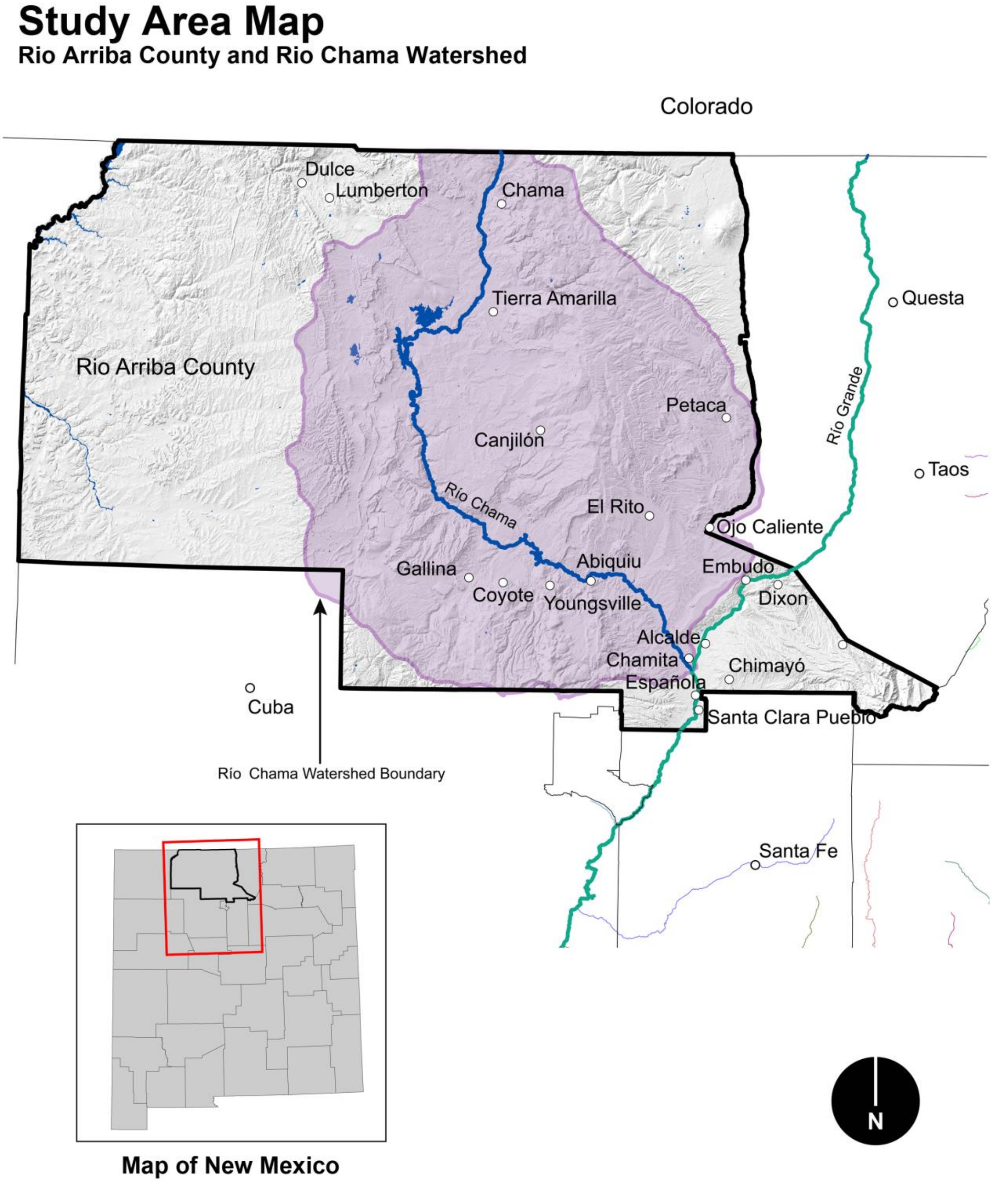

Figure 2: Bureau of Reclamation, Middle Rio Grande Project – NM 1947

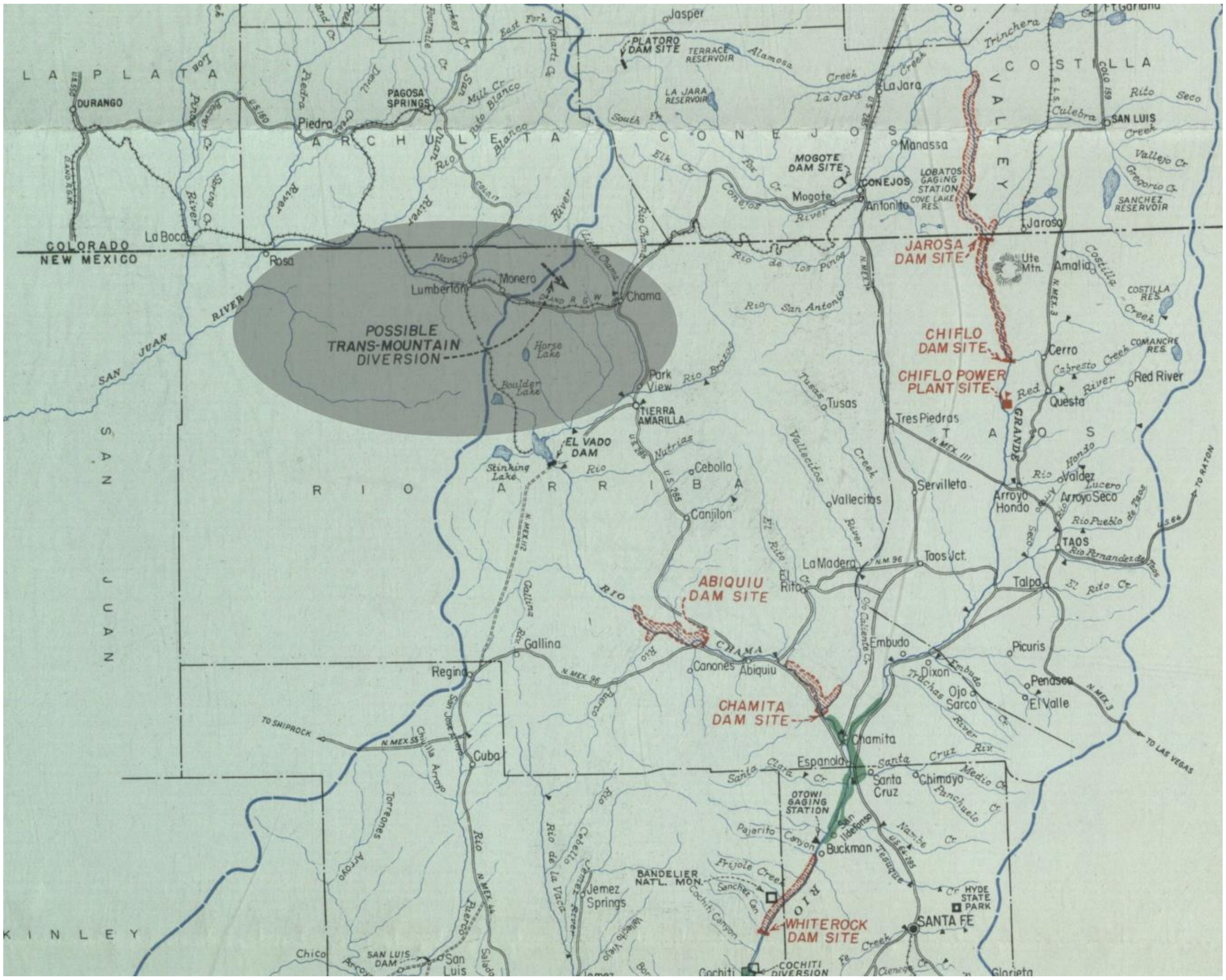

Figure 3: Bernardo de Miera y Pacheco Map 1778

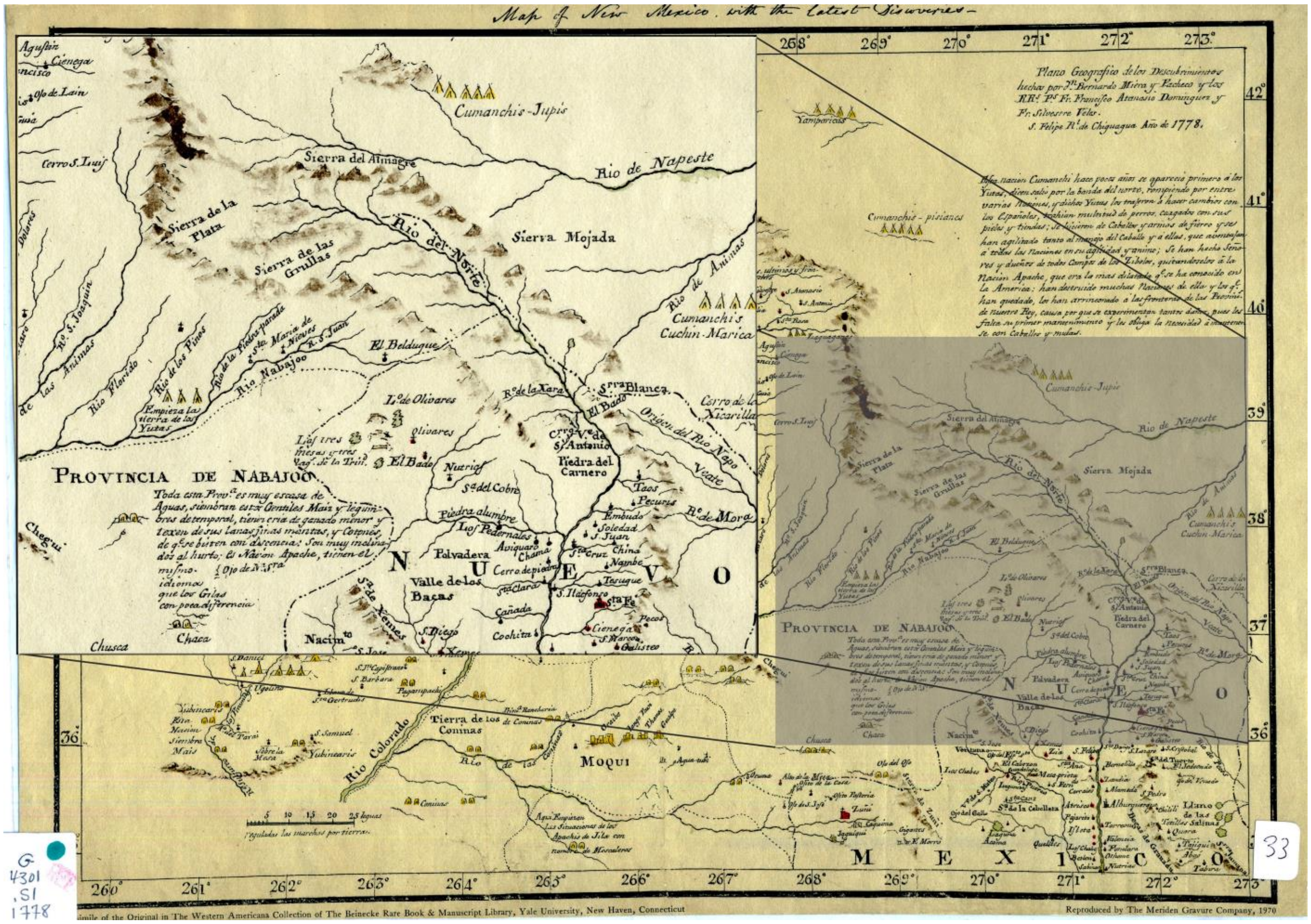

Figure 4: Unpacking and Data Translation Diagram

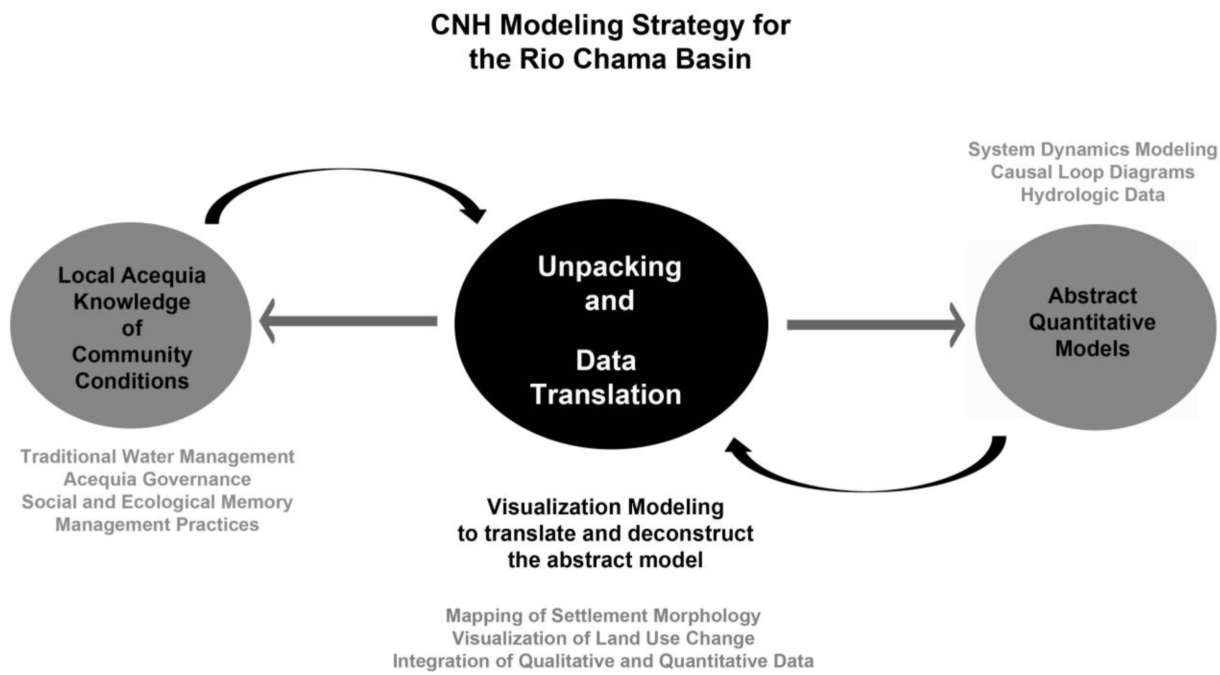

Figure 5: Riverine Settlements Map Adapted from Anschuetz 1998

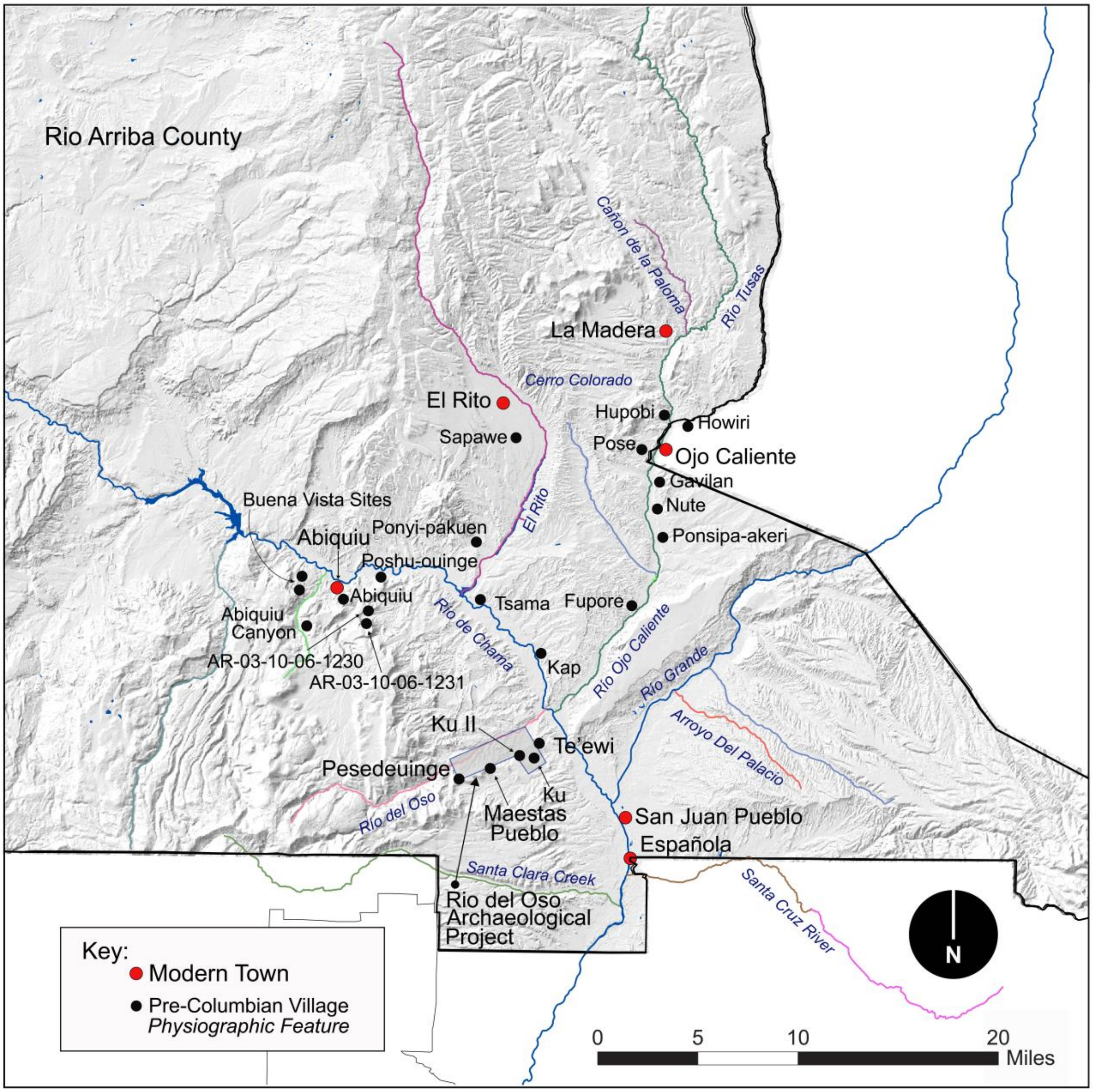

Figure 6: Adaptation of Bernardo Miera y Pacheco Map 1777

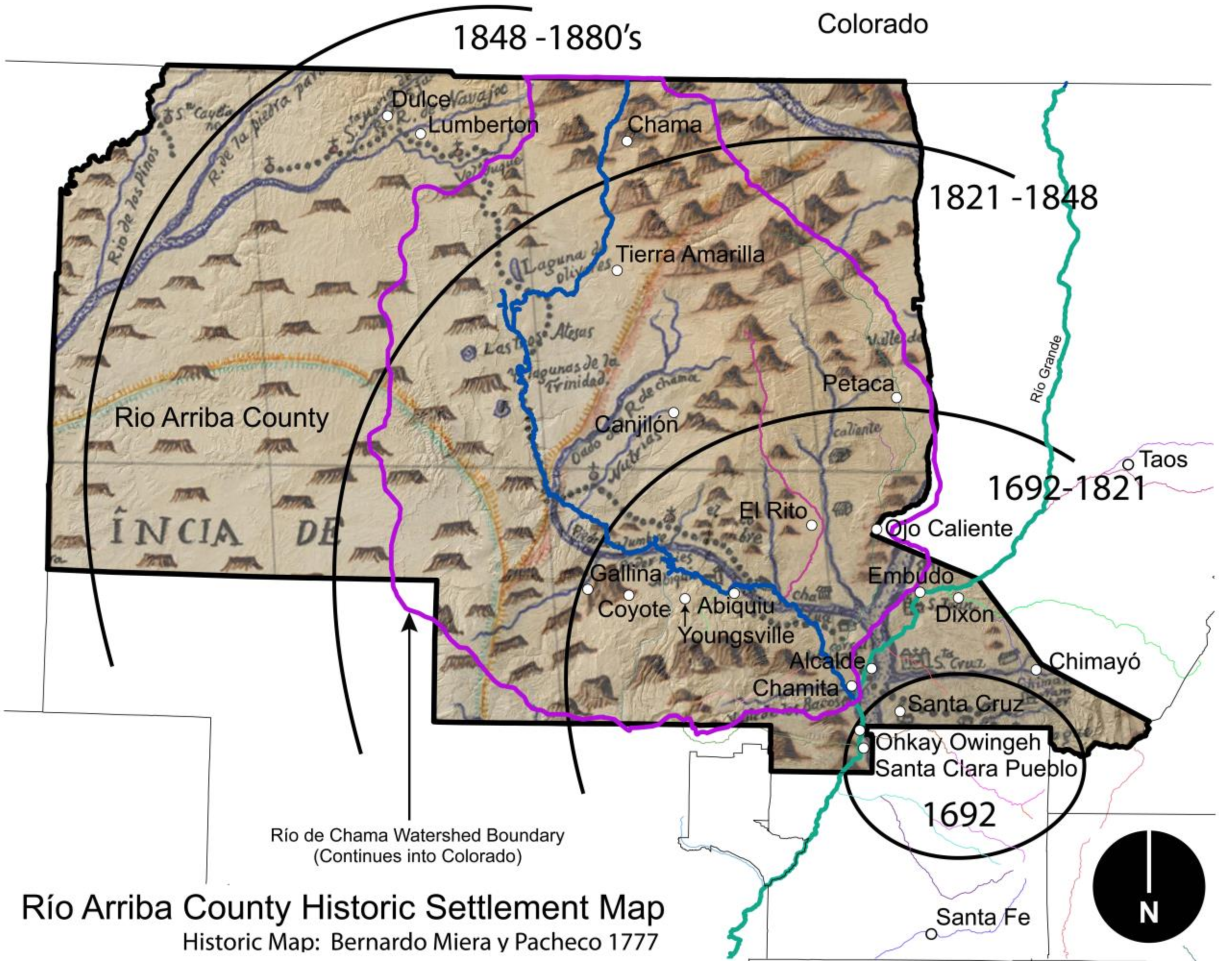

Figure 7: Abiquiu, New Mexico, 1935 – 2011 Land Use Settlement Morphology

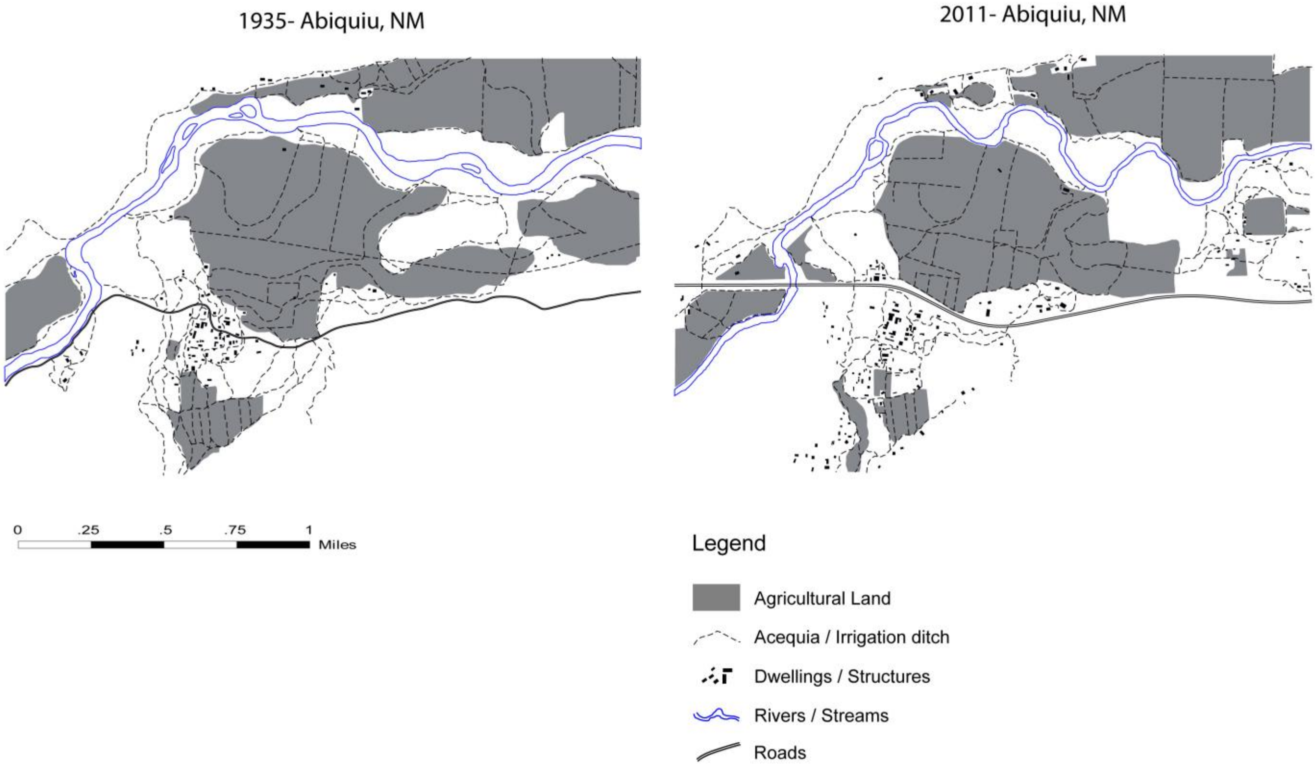

Figure 8: El Rito Valley Terrain Model

Figure 9: Rio Chama 3d Land Use Conditions Model