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Modeling the Transfer of Land and Water from Agricultural to Urban Uses in the Middle Rio Grande Basin, New Mexico

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Abstract

Social and ecological scientists emphasize that effective natural resource management depends in part on understanding the dynamic relationship between the physical and non-physical process associated with resource consumption. In this case, the physical processes include hydrological, climatological and ecological dynamics, and the non-physical process include social, economic and cultural dynamics among humans who do the resource consumption. This project represents a case study aimed at modeling coupled social and physical processes in a single decision support system. In central New Mexico, individual land use decisions over the past five decades have resulted in the gradual transformation of the Middle Rio Grande Valley from a primarily

rural agricultural landscape to a largely urban one. In the arid southwestern U.S., the aggregate impact of individual decisions about land use is uniquely important to understand, because scarce hydrological resources will likely limit the viability of resulting growth and development trajectories. This decision support tool is intended to help planners in the area look forward in their efforts to create a collectively defined 'desired' social landscape in the Middle Rio Grande.

Our research question explored the ways in which socio-cultural values impact decisions regarding that landscape and associated land use. Because of the constraints hydrological resources place on land use, we first assumed that water use, as embodied in water rights, was a reasonable surrogate for land use. We thought that modeling the movement of water rights over time and across water source types (surface and ground) would provide planners with insight into the possibilities for certain types of decisions regarding social landscapes, and the impact those same decisions would have on those landscapes. We found that water rights transfer data in New Mexico is too incomplete and inaccurate to use as the basis for the model. Furthermore, because of its lack of accuracy and completeness, water rights ownership was a poor indicator of water and land usage habits and patterns.

We also found that commitment among users in the Middle Rio Grande Valley is to an agricultural lifestyle, not to a community or place. This commitment is conditioned primarily by generational cohort and past experience. If conditions warrant, many would be willing to practice the lifestyle elsewhere. A related finding was that sometimes the pressure to sell was not the putative price of the land, but the taxes on the land. These taxes were, in turn, a function of the level of urbanization of the neighborhood. This urbanization impacted the quality of the agricultural lifestyle. The project also yielded some valuable lessons regarding the model development process. A facilitative and collaborative style (rather than a top-down, directive style) was most productive with the inter-disciplinary, inter-institutional team that worked on the project. This allowed for the emergence of a process model which combined small, discipline- and/or task-specific subgroups with larger, integrating team meetings.

The project objective was to develop a model that could be used to run test scenarios in which we explored the potential impact of different policy options. We achieved that objective, although not with the level of success or modeling fidelity which we had hoped for. This report only describes very superficially the results of test scenarios, since more complete analysis of scenarios would require more time and effort. Our greatest obstacle in the successful completion of the project was that required data were sparse, of poor quality, or completely nonexistent. Moreover, we found no similar modeling or research efforts taking place at either the state or local level. This leads to a key finding of this project: that state and local policy decisions regarding land use, development, urbanization, and water resource allocation are being made with minimal data and without the benefit of economic or social policy analysis.

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1.0 INTRODUCTION

A community's social practices are inscribed in the surrounding landscape. People create, develop and maintain landscapes that embody collective, sometimes conflicting understandings about what constitutes a safe and attractive place for living, working, recreating, and raising children. Sometimes, macro-level social trends or geological and climatic events force rapid change in a community. But even in the absence of such events, communities are in a constant state of flux because they represent emergent social phenomena. Over time, individual decisions result in collective lifestyle patterns. A community's evolution is propelled by the manifold decisions made at multiple temporal and spatial scales by individuals acting in their own interest within or around their communities.

As communities change, their geographical boundaries expand and contract, new centers for residence and commerce are developed as others decay. Social, ethnic, economic and cultural dynamics are expressed in public discourse about the community's past, its present identity, and its future. Because landscape is the most visible precipitate of a community's collective evolution, decisions about land use become a focal point for debates about what the community *is* as well as what it should *become*. Such debates tend to intensify during periods of growth, when population expands, the economy changes, and new demands are placed on existing social, political and natural resources.

Lifestyle patterns that emerge from individual actions can have unforeseen impacts on local ecologies. Ecological impact is perhaps most rapid and dramatic when the region in question is experiencing rapid immigration. This is because culturally and historically sanctioned practices for resource management that work effectively in one climatic region may have very different outcomes when immigrants pursue them in a new area. All of these phenomena taken together can have consequences that can lead directly to regional conflict over resource scarcity, or which can lead indirectly to conflict over social and cultural issues exacerbated by resource scarcity.

Because decision makers rarely understand the complex relationships between human society and the environment, they often make critical planning decisions with longer term consequences under conditions of high uncertainty. Increasing population, resource scarcity, and the social pressures associated with both have heightened interest in achieving greater control over the community development process at local, regional, national and international levels. Achieving greater control requires identifying key variables that influence community formation, the structure of relationships among those variables, and the dynamics associated with their interaction.

In the arid U.S. Southwest decisions about water use are of unique importance, as water availability shapes possibilities for physical, economic and social transformation of the community. Over the past five hundred years, successive waves of migrants have brought with them agricultural, lifestyle and aesthetic practices and technologies. Sometimes these practices were inherently well-suited to life in the dry, cold conditions of a high desert environment. For example, early Spanish and Mexican usufructory practices towards land and water management enabled relatively equitable access to shared resources for multiple generations of Hispanic communities for most of the eighteenth and nineteenth centuries.

Other lifestyle patterns are less sustainable in New Mexico's water-limited environment. The Middle Rio Grande Basin (MGRB), which encompasses the counties of Sandoval, Bernalillo, and Valencia in central New Mexico, provides a case in point. For several hundred years, the region was primarily inhabited by Hispanic farmers and Native American Pueblo people. However, since the early 1900s, the MRGB has experienced a boom in population, rapid diversification and growth of the local economy, and extensive residential and urban development. This accelerated in the postwar years and brought with it twentieth-century socioeconomic value structures with very real physical manifestations. Examples include suburban lifestyles that value water-intensive landscaping over native vegetation; ubiquitous home and office technologies powered by electricity; industry, retail and business operations whose work requires water – all of which have increasingly strained the region's hydrogeological resources.

As a result, since the 1980s, the region has seen growing conflict over water resource allocation in the basin, a conflict that since 1996 has been exacerbated by moderate to severe drought conditions throughout the state. Parties to the debate include urban interests, who argue that economic growth is linked to water availability; environmentalists, who argue that adequate water resources should remain available for riparian and wildlife needs; and agriculturalists, who argue that agricultural sustainability and rural lifestyles – both associated with agricultural water consumption – should be maintained (Tidwell and Passell 2004). The distinctions described above are overly simplified; in fact, there is considerable overlap among those positions, though public and media discourse tends to highlight differences. It is important to note as well that the debate often highlights cultural differences in the region as well, as arguments over water use are linked to the state's engagement with many different cultural streams, including the various Pueblos, the Navajo Nation, the Apache Tribes, Spanish and Mexican heritage, and Anglo-American.

Various regional, state and federal agencies and sovereign Indian nations are engaged in the effort to resolve water use conflicts. However, clear resolution will demand that stakeholders understand current trajectories of the social/physical system, which include transfers of water consumption, transformations of social and cultural patterns, and direct transformations of land uses. Understanding the trajectories is complicated by the complex nature of the interactions among all these components. It is further complicated by the multidisciplinary, multi-system nature of the problem, which unites climate, hydrology, ecology, economics, sociology, anthropology and law. New methods and tools are required for studying the complex interactions among all these diverse components, for characterizing system behavior, and for projecting possible system trajectories in the future.

For this study, we chose to study interdependent social, economic and physical trends by focusing on one area of transition: the movement of land and water resources from agricultural to urban applications in the Middle Rio Grande Basin. Specifically, we have investigated the socioeconomic trends related to the diversion of water and land resources from agricultural uses to industrial and residential applications throughout the MRGB.

In the past, the amount of riverside land under cultivation shrank when water supplies were limited – as during the drought of the 1950s – and swelled when more surface water was available. With increasing urbanization, the amount of land under cultivation depends more on population, policies that impact the ease of development, and property values. More specifically, farmers now have the option to sell their property for other uses, such as urban and industrial development, if farming is no longer financially feasible – regardless of water availability or drought. In this modeling effort, the change in the total amount of acreage provided the focal point for the researchers.

In developing the model, we attempted to identify and quantify the key variables associated with the movement of land and water from agricultural to urban. As originally envisioned, the model would use water rights as a surrogate for actual water consumption, as water rights represent transferable legal claim to a designated amount of 'wet water.' However, a paucity of state data on water rights sales and transfers, and the inaccuracy of existing data, made it impossible to focus solely on water rights as a dependent variable. Realizing that changes in land use are also indicators of changes in water use patterns, we expanded the study to include the movement of land out of the agricultural economy and into urban/suburban development. The variables that contribute to both land and water change are quite similar. These include physical phenomena, such as regional hydrology, climate, drought, irrigation techniques, and crop types; economic phenomena, such as land price, crop values, labor costs, values of water rights; and social phenomena, such as historic and cultural attachments to particular lifestyles, and migration of children away from farming communities.

We used a system dynamics approach to construct a model integrating these variables and their relationships with the intention of simulating the transfer of water rights and land from agricultural to urban uses over the years 1950-2002. We attempted to develop a model that would generate a curve to match historic data that shows a decrease in the area of land in the Rio Grande floodplain under cultivation between 1982 and 1992, and 1989 and 1999. In future work we intent to integrate this social model with an existing hydrological model of the MRGB (Tidwell and Passell 2004); this will help to explain the processes in the MRGB leading to social/physical landscape transformations, and assist in regional planning efforts.

The development of models that integrate across both social and physical systems will be valuable in the study of many other social/physical processes in other regions. We used the modeling effort described above to formulate a more generic modeling approach for integrating and simulating other social and physical processes in other regions. Those processes could include the transformations that occur within cities associated with changing property values and demographics; large scale human migratory patterns, such as those seen in the widespread global movement of people from rural to urban settings; international border dynamics, the demographic/economic/cultural gradients that exist across the borders, and the movement of individuals and capital through the borders; and, ultimately, ideological transformations in human populations associated with gradients in wealth, quality of life, social opportunities, historical patterns, and other variables.

This project uses the terms agricultural and urban to discuss various land and water use situations. The research team was most focused on land being taken out of agricultural production and hence changing water use in the region. For this project agricultural land is defined as any land that has access to irrigation water and hence has the potential to grow crops for sale or personal use. In this region agricultural land can be found in very small parcels of just a few acres as well as in large farms of multiple hundred acres.
Urban areas are characterized as being "built" -- the landscape is dominated by structures—and water is primarily for human use (indoor and outdoor). Interestingly, in this region there are examples of "urban agricultural" where small enclaves of productive farmland are surrounded by urban or suburban neighborhoods. Additionally, there are numerous areas in the region that are quite rural in their feel – low population density, low structure density – but that are not actively involved in agriculture. Water use in these areas is primarily for human wants and needs, both inside and outside their homes and businesses.

The final model is designed to analyze potential impacts arising as land that was once in agricultural production and used water to grow crops shifts to either a suburban setting or to a fully urban use with water being used primarily for residences, institutions and non-agricultural businesses.

2.0 MODEL CHOICE AND RESEARCH TEAM

2.1 System Dynamics Modeling

"Systems thinking" and "system dynamics modeling" refer to a paradigm for simplifying, representing, and modeling the real world in order to generate insight about the range of behaviors that emerge from interactions among the connected elements. System dynamics modeling and analysis was developed at the Massachusetts Institute of Technology in the 1950s, where researcher Jay Forrester identified systems analysis as a means of helping business managers understand the flows of goods and materials through supply and distribution chains. It has since been applied to problems of urban planning, national economic cycles, energy planning, and other areas of socioeconomic policy analysis.

System dynamics begins with the premise that all human cognition depends on mental models that individuals create to represent their worlds. Mental models are necessary abstractions for decision making, as they provide heuristics for judging the likelihood that an action will produce desired outcomes, given what is known about the world. However, heuristic mental models are not as useful in predicting longer-term behavior in complex, nonlinear systems, as people are limited in their ability to quickly perform the complex calculations required to integrate multiple sources of information from interrelated feedback loops over long periods of time.

In contrast, system dynamics tools enable people to formalize and analyze their mental models as dynamic, cyclic graphs. Rather than breaking the system into its constituent parts and studying behavior at an elemental level, system dynamics tries to replicate higher-order behaviors by studying and simulating interrelationships among elements. Using system dynamics software, users can manipulate model parameters to better understand how a decision made in one area of the system may impact other elements and lead to the development of unforeseen behaviors.

System dynamics models the world as a network of rates or *flows* (e.g. information, items, substances, people) and levels, or *stocks*, which are holding areas where flows accumulate. Stocks can be thought of as a bathtub with a faucet and a drain; as water (the flow) enters the tub, the tub fills; when the drain is opened, the water leaves the tub (outflow) and the tub empties. A system dynamics model usually has many stocks connected by feedback loops that channel the flow cyclically through the system. The movement of flows from stock to stock generates dynamism in the system. Equilibrium is reached when entry and exit rates are equalized across the system; however, rarely are real-world systems in equilibrium, as rates of inflow and outflow differ across stocks, leading to differential rates of accumulation.

Because flows can represent anything that moves from one entity to another – money, goods, people, work, energy – system dynamics models lend themselves to multiple applications. Even qualitative things, such as goodwill, public approval, social capital, or hostility, can be treated as flows that accumulate at varying rates in stocks throughout the system. Likewise, stocks represent any site where flows can accumulate, such as a bank account, an aquifer, even the collective mind of a community. The rate at which the stock fills may be dependent on the amount of the flow inside it, e.g., a bank account earns money more rapidly as accumulated interest causes the balance to grow, or public opinion of a leader worsens as the press publishes negative articles about his economic policies. System dynamics allows the modeler to vary the parameters of different stocks, to assess how imbalance in one area impacts the rest of the system. Insights generated from the model can be used to formulate plans and policies to effect change in the real world.

A system dynamics analysis begins with construction of a mental model to represent key aspects of the reality of interest. Concepts and if/then relationships are the components of the model: for example, concepts in a water demand model might include "water," "drought," "conservation," and "demand." A mental model of the relationships among these concepts might be described in a simple if/then statement, "If there is a prolonged drought, people are more likely to conserve water by installing xeric plants. If there is no drought, people are less likely to conserve water by planting xeric plants."

From qualitative causal descriptions like these, one identified the political, physical, social, economic or other elements that bear examination in the model. From the statement above, the key elements might be *xeric landscaping*, *perception of drought severity,* and *propensity to conserve water*. These elements are organized into a *causal loop diagram,* or CLD, that indicates the general direction of hypothesized relationships between elements (Senge 1994). Causal loop diagrams are also known as influence diagrams or influence networks. The loops in a CLD may be reinforcing, meaning that movement through the loop will produce stronger behavior, either negative or positive; loops may also be balancing, meaning that movement through the loop over time leads to equilibrium. Reinforcing loops are unsustainable, while balancing loops represent behavior that is sustainable over time.

Below is a sample causal loop diagram, which indicates the following relationships:

- As drought increases, perception of drought severity increases.
- As perception of drought severity increases, so does the propensity to conserve water.
- As the propensity to conserve water increases, so does xeric landscaping.
- As xeric landscaping increases, demand for water drops.
- As demand for water increases, the propensity to conserve water falls.

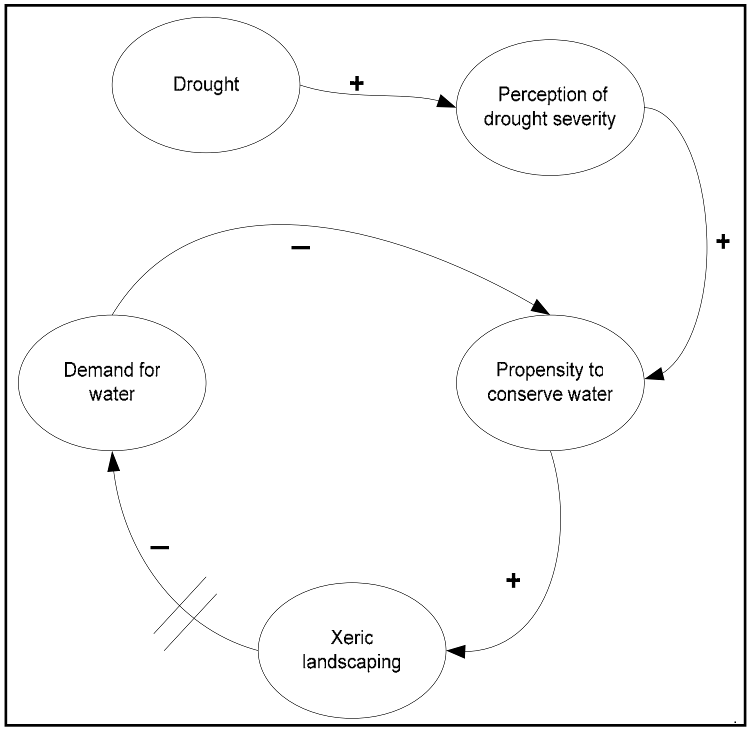

Figure 1. Sample Causal Loop Diagram.

In the above diagram, the arrow on the arc indicates a cause-effect relationship, while the positive or negative sign indicates the directionality of the relationship. A double slash through an arc indicates a time delay, meaning that the effect will not be felt until a significant period of time has passed. This is often a source of imbalance in a system, as time delays cause pressure to build in one area of the system and can create spillover effects.

CLDs are useful for mapping the directionality of relations among elements in a system, but lack a mechanism for representing dynamism. Hence a CLD must be transformed into a stocks-and-flows representation before a full-scale, computable model can be developed. While there are no set rules for transforming a CLD into a stock-flow representation, the idea is to use the CLD to generate ideas for how a cause produces an effect, and to represent this “how” as a process of inflows and outflows. For example, propensity to conserve water causes an increase in xeric landscaping because people are choosing to landscape their homes with plants that use less water. One way of expressing this relationship is to say that the stock of xeric residential landscapes in the city increases as the rate of people tearing out their lawns and installing xeric plants increases. Likewise, the stock of xeric landscapes falls as people tear out cactus and install lawns instead.

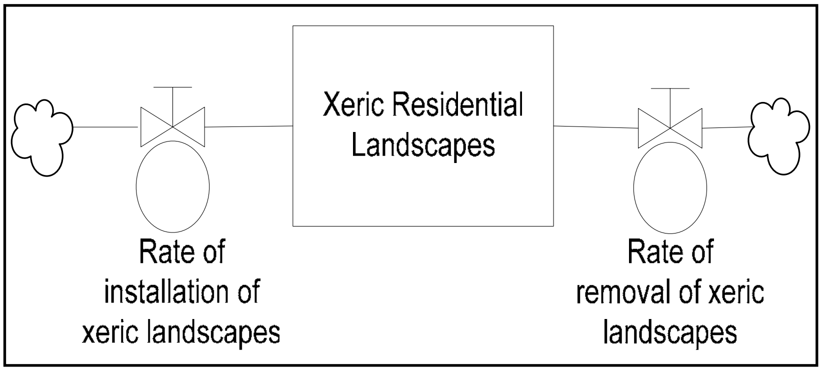

Figure 2. System Dynamics "Stock and Flow" Schematic

2.1.1 Water Model Stocks and Flows

The present model was developed using system dynamics architecture because we wanted to couple the new model to the original MRG model, which is a system dynamics model that explores the economic and environmental variables driving water demand (Passell *et al*. 2003). In this new model, we are analyzing the movement of water rights and land parcels across different use categories. More specifically, we are modeling the movement of these flows from stocks representing agricultural uses to stocks representing urban or suburban development. This effort required us to pursue the following tasks:

- Quantify the rates at which agricultural water rights and/or agricultural land were being transferred to non-agricultural applications, including residential and industrial use;
- Develop hypotheses about the system-level social, economic, political factors influencing individual decisions to put water and land holdings up for sale;
- Iteratively develop a set of causal loop diagrams to express our emergent understandings about this process, including directionality and strength of relationships among the stocks
- Identify data sources to test hypothesized relationships and to populate the model
- Develop and populate the model
- Conduct hypothesis testing and simulate "what-if" scenarios

System dynamics models are convenient insofar as they represent reality as a structured network of cause-and-effect relationships. Hence it is possible to construct a useful system dynamics model at a gross level and gain insight into the system's possible evolution, even when individual system elements are poorly understood. Indeed, this LDRD team concluded that the modeling process and the model itself would have value even if the model cannot be correlated to any existing data. The modeling process demanded a rigorous examination of regional dynamics, which led to greater understanding of system behaviors and interactions. Part of this examination was manifest in actual operation of the model, as the relationships between variables were tested in sensitivity analyses and in management scenario evaluation. The modeling process also clearly identified data required for a better understanding of regional land and water use dynamics.

2.2 The Research Team

Since the model was intended to span various academic and professional disciplines, the creation of a diverse, multi-disciplinary team to oversee project and model development was seen as critically important to the success of the modeling project. That team involved economists, a hydrologist, modelers, an ecologist, anthropologists, a policy analyst, a lawyer, and a farmer.

Accordingly, this project drew on a wide range of perspectives and skill sets among individuals and institutions in the Middle Rio Grande region. The team consisted of approximately a dozen people representing Sandia National Laboratories, the University of New Mexico, Galisteo Consulting Group, GRAM Environmental Health and Safety, and the regional farming community. It was important to strike a balance between diversity and complete representation of all facets of the system with the need to maintain a team of manageable size. It was also important to balance representation of the physical and life sciences (hydrology, ecology) with the social sciences (anthropology, sociology). It was critically important to engage at least one farmer in the team, since a purely academic approach in our effort to model agricultural dynamics would certainly be inadequate. The team might have been stronger with another farmer on the team, and perhaps with a representative of commercial realty or city planning.

Individual contributions varied from consultation and comment to intensive theorizing, modeling and data collection. Sandia staff developed the system dynamics framework for the model, while the other participants provided input on the structure and content of the model and identified and gathered data sources. Overall efforts were coordinated by Sandia National Labs staff member Howard Passell.

Although the entire team met on a monthly basis to share ideas and review progress in developing the model, several sub-teams met more frequently to focus on specific task sets. These included a social science sub-team, a model development sub-team, and a data collection sub-team. In addition, several individuals acted as consultants to the larger project and/or all three sub-teams. The discussion below describes primary research activities and is a little misleading, in the sense that many of the team members contributed to each others' efforts, so the boundaries between sub-teams were at times quite fluid.

- The data collection sub-team consisted of Gretchen Newman and Kiran Pallachulla, of GRAM, Inc., and Paul Van Bloemen Wanders, a summer intern for SNL. Using guidance from the economists and the model development team, the GRAM staff searched – sometimes with difficulty – for data sources that would provide insight into some of the socioeconomic processes and relationships hypothesized by the social science and model development teams. Susan Kelly of the Utton Transboundary Resource Center at the University of New Mexico and Janet Jarratt, an agricultural community activist and water resources expert from Valencia county provided guidance in identifying and interpreting data sources, developing questionnaires, and contacting interviewees.

- The social science sub-team consisted of two anthropologists, Laura McNamara of Sandia and Jessica Turnley of Galileo Consulting Group, and Kristan Cockerill, a policy analyst from the University of New Mexico. This team worked to identify the social and cultural issues that impact individuals' decisions about selling land and water resources and to frame these as sets of concepts and relationships that could be transformed into a system dynamics model. Jarratt and Kelly supported the social science team in developing the interview protocol and contact lists as well.
- The model development sub-team was the linchpin in the project's evolution. This team included Passell and Cockerill; Sandia economists Len Malczynski and Peter Kobos, and Vince Tidwell, a Sandia hydrogeologist. UNM economist Janie Chermak provided input and guidance to the model development process and assisted the team in identifying potential data sources for the model. Jarratt, Turnley and McNamara participated occasionally model development meetings.   Economists Malczynski and Kobos were primarily responsible for developing the system dynamics framework, but they also identified economic issues to address the market aspects of land transfer not directly addressed in the social science model. Together, the model development team was responsible for integrating the sociocultural and economics perspectives into a system dynamics framework, including stocks and flows, identifying the strength and directionality of the relationships, and populating the model with data sources. They also developed the user interface for the final draft of the model.

All team members communicated frequently and regularly between meetings, which ensured that new ideas received attention and incipient problems were quickly addressed.

3.0 PROBLEM CONTEXT

Understanding the forces that shape today's debates over water use and water rights first requires some understanding of the state's history, water rights categories and law, and urban development in the Middle Rio Grande Basin.

3.1 Water and Regional History

The history of population growth and change in New Mexico is one of successive waves of immigration, occupation and development, beginning with Native American peoples who migrated to the area some ten thousand years ago. Every wave of immigrants, from the Pueblo Indian groups that settled the middle Rio Grande valley in 900 AD through the most recent migrants from other parts of the United States, has carried with it beliefs about the relationship between human beings, their communities, and their environment. The arrival of newcomers to New Mexico has each time resulted in attempts to implement new perspectives on what constitutes a proper landscape, often leading to conflict, exploitation and competition for resources. Water use intimately tied to this; from the very earliest days of European occupation of the region, land ownership or usufructory rights have been demonstrated through irrigation. These beliefs have been quite literally imprinted on the landscape in the form of land use and agricultural practices that, in turn, formed the basis for a sense of common identity, heritage and culture.

For over a thousand years, the central Rio Grande basin has consistently been one of the most densely populated areas in the state, drawing migrants with rich alluvial soils and a moderate climate. Spanish settlers who arrived in the early sixteenth century found the densest settlements of Pueblo Indians clustered along the middle Rio Grande basin. Until the arrival of the Spanish in the late fifteenth century, agricultural practices were limited to basic subsistence farming, supplemented through hunting and gathering. From the 1400s until the mid 1800s, the Spanish and later Mexican territorial governments granted huge tracts of land to favored individuals and families for settlement and cultivation. In the communities that sprung up within these settlement areas, water and land were communally managed for the good of all residents. The Spanish and Mexican managed scarce surface water resources through an extensive network of irrigation channels, or *acequias*, that ensured a relatively consistent supply of water to their crops, even during times of drought. *Acequia* organizations formed the backbone of community life and social organization throughout Hispanic New Mexico for hundreds of years and remain an important institution in Hispanic communities throughout the state today.

However, when Anglo migrants began to colonize New Mexico after the Treaty of Guadalupe Hidalgo in 1848, they brought with them new farming and water management practices, as well as new understandings about the primacy of individual – not communal – ownership and management of resources. The Anglo ethos might be described as one "based on the maximum harvest of resources for maximum profit" (Scurlock 1998: 331). Backed by federal legislation and military force, the new territorial government supported Anglo speculators who marked and laid claim to large tracts of land, many of which overlapped or encompassed Spanish and Mexican land grants. As a result, many Hispanic townships throughout the state lost enormous amounts of farm and rangeland (see especially Scurlock 1998; also Briggs and Van Ness, 1987). Conflicts over ownership of land and water resources remain an important source of interethnic tensions into the present day.

The railroad played a particularly important role in changing the social landscape of the state. When the railroad reached the Middle Rio Grande Basin in 1880, Albuquerque was a small farming and mercantile community of roughly 5,000 primarily Hispanic residents. By 1910, the city's population had more than doubled. A burgeoning tourist economy brought Anglo migrants from the East to establish farms and ranches, or to recover from illness such as asthma, tuberculosis, and arthritis in New Mexico's sunny, arid climate. Migrants provided a steady source of economic and population growth through the interwar years, but the real boom occurred after World War II, which established New Mexico's central role in the nation's incipient military-industrial-technology economy. Between 1940 and 1950, Albuquerque's population grew from 35,000 residents to nearly 100,000; by 1960, Albuquerque was home to over 200,000 people, the majority of them migrants from out of state. Albuquerque's economy boomed again in the late 1970s, and between 1980 and 1990, over fifty thousand new residents established twenty thousand new households in Albuquerque's city limits.

As newcomers settled in, the grasslands on either side of the Rio Grande were gradually transformed into suburban developments and business center. Perhaps more importantly, a "greater Albuquerque" metropolitan area emerged, encompassing the communities of San Ysidro, Ponderosa, Jemez Springs, Rio Rancho, Placitas, Bernalillo, Los Ranchos, and Corrales in the north; Bosque Farms, Los Lunas, and Belen in the south, and Cedar Crest to the east. Defined by the U.S. Census Bureau as a Metropolitan Statistical Area, with Albuquerque as the economic epicenter for the region, the area by 1990 was home to roughly forty percent of the state's total population, or 712,000 people.

3.2 Understanding Water Rights

The water rights system in New Mexico involves extremely complex legal and historical issues that make it difficult for most New Mexicans to understand if they own a water right or how the market works – much less engage in the sale and/or transfer of water rights. This complexity makes it difficult for the public to fully appreciate the consequences of water rights transfers.

The state's Water Code was established for surface water in 1907 and extended the jurisdiction of the Office of the State Engineer to ground water in 1931. Under this law, the term "water right" refers to the right to divert and consume a certain amount of surface water. The law recognizes the hydrological connectivity between surface water and groundwater and commits the state of New Mexico to a method of conjunctive management that acknowledges that connectivity. The transfer of water rights from one owner to another does not represent an actual transfer of "wet water," but rather the transfer of a right to consume a certain amount of water. That diversion and consumption most commonly comes from the Rio Grande. In the Middle Rio Grande Basin, this means that any use of groundwater, except for domestic wells, requires a permit and offsetting surface rights. This, in turn, means that surface water rights are a valuable commodity during times of drought and/or population growth and city development, as urban and industrial developers seek access to groundwater.

However, state water law is complicated by the fact that water rights also represent a property right subject to the Doctrine of Prior Appropriation. Individuals and communities establish seniority of claims to a limited resource based on the amount of time they have been using that resource; when supplies are limited, the most recently recognized user is the first to lose access to the resource. Where basins are unadjudicated, however, such as the Middle Rio Grande, the doctrine is rarely enforced except to honor the prior and paramount rights of the Pueblos.

Historically, the priority system was based on available water, most of which was surface water. Drilling technology enabled the state's residents to decrease dependency on surface water even as population boomed throughout the twentieth century. One important implication is that water rights, as a system for allocating water based on the demonstrated seniority of claims, are not balanced physically or quantitatively with the actual amount of wet water available for use. Indeed, recent hydrogeological research in the region indicates that the Middle Rio Grande Basin's groundwater resources have been overestimated. It is becoming increasingly apparent that over the past century, the state's residents have made many more claims to water than actual water available. Few of the state's basin areas have been adjudicated, so many priority claims are not legally formalized; and many water uses were established before the OSE required permits and only come under the permitting requirements of the OSE if a change in place and/or purpose of use is proposed. In fact, the only sure statement that can be made about much of New Mexico's water is this: the number of claims to the resource is quite likely far greater than the actual amount of wet water, especially during times of drought.

The state's Water Code also recognizes different kinds of water rights that represent historic traditions for managing water, and this creates even greater complexity in the state's water rights system. For example, in most of the northern New Mexico, Hispanic farming communities rely on *acequia* or ditch associations to ensure the equitable distribution of water among community farmers. In these communities, *acequias* represent a communal water right, managed by the *acequia* association for the benefit of the *parciantes*, or users. While some individual *parciantes* may choose to sell their water right, many *acequia* associations have rules that require their *parciantes* to request permission from the other members before attempting to sell their surface water rights. Moreover, because *acequias* are intimately tied to Hispano identity in the state, most associations and their *parciantes* have viewed the sale of water rights as a threat to the integrity of their communities.

In contrast, much of the surface water in the Middle Rio Grande Basin is managed by the Middle Rio Grande Conservancy District (MRGCD). The MRGCD itself is a division of New Mexico state government, whose board members are elected by individuals who live and own property within the benefited area. The MRGCD was formed in the 1920s to control the Rio Grande, which at that time was prone to flooding due to elevated sedimentation levels that raised the water table. Moreover, there was no central system for providing irrigation water to the areas' farmers, making farming a difficult and haphazard enterprise. The MRGCD took control of approximately 150 miles of the river basin, and more than 70 historic acequias, from Cochiti Pueblo in the north to San Marcial in the south. The District created dams to control the river's flow and built hundreds of miles of irrigation channels to provide water for agricultural use. The MRGCD also assumed control of ditch systems once controlled by area acequia associations. Even today, MRGCD remains the central mechanism for delivering surface water to the region's farmers. Because they exist under the collective ownership of the Conservancy District, surface water rights in the area benefited by the MRGCD are not a private property interest.

In addition to the acequias and the MRGCD, several types of surface and sub-surface water rights are active in the MRGB.

Prior and Paramount Water Rights. These are the most senior of the Pueblo water rights that, in general, are unquantified, meaning that there is no allotment of acre-feet assigned to these rights. As senior water rights of sovereign nations, these are not regulated by the OSE and are under the stewardship of the Federal government. The ruling in the *Aamodt*[1] litigation states that Congress fixed the quantity of this category of rights in 1924, but this remains an outstanding issue in several adjudications.

Pre-1907 Surface Water Rights. This category includes all water rights that were in place prior to 1907, when New Mexico's Territorial Governor appointed the first state engineer. Prior to 1907, any person could draw surface water for any use without seeking state permission. This changed with the new State Engineer, who established a permitting system for diverting surface water to agricultural uses. These water rights are considered vested rights.

Pre-Basin Water Rights. These are groundwater rights that pertain to the water consumption through well diversions at the time that the Middle Rio Grande Basin was recognized in 1956. Several municipalities, principally Albuquerque, have vested pre-basin water rights, meaning that they are not required to offset pumping effects on the river by retiring other water rights. Irrigation and other supply wells that existed prior to 1956 fall into this category as well. Many are undocumented.

San Juan/Chama Water Rights. This includes claims to water imported from the San Juan Basin via a tunnel from northern New Mexico. Most of this water is under contract to central New Mexico municipalities and/or the MRGCD. In fact, the City of Albuquerque and the MRGCD are the two primary contractors for this water, with 68,000 acre-feet claimed between them.

This study is primarily concerned with pre-1907 water rights, which do not exist independently of a piece of land. Neither do they represent a preexisting legal claim that can be exercised at the holder's discretion. Instead, pre-1907 water rights are usufructory rights established and maintained through demonstrating consistent beneficial use dating back to 1907. Practically speaking, this means a record of continuous irrigation for the past century.

Lastly, it is important to understand that OSE policies regarding the validity and transfer of water rights has changed over time due to new policies, case law, and many other factors. These changes have a direct impact on the water rights market, which further complicates using water rights transfer data as a basis for the model.

[1] *New Mexico v. Aamodt*, 618 F. Supp. 993 (D.C. N.M. 1985).

3.3 Selling and Transferring Water Rights

When a piece of land changes owners, the right to draw surface water for irrigation remains with the property if purchase is in fee simple, without reservation.. If it is not exercised by the new owner, the strength of that claim begins to wane. Land owners who can demonstrate the longest and most consistent history of irrigation have the strongest claims to an allotment of acre-feet during times of drought under the priority system. However, in an unadjudicated basin, actual water delivery may be made on some other basis.

Although water rights in this category are appurtenant to a piece of land, they are also transferable, assuming the owner can demonstrate continuous beneficial use. Indeed, the usufructory ethos that underlies the Doctrine of Prior Appropriation breaks down when a land owner decides to divorce the water right from the land. When this occurs, the appurtenant benefit becomes a separate, transferable, legally salient claim to a shared resource. This is complicated legal process that requires the owner to demonstrate that the water right is "perfected," meaning that the individual's claim to the water right is upheld by a pattern of consistent irrigation over time.

This has important implications for holders of individual surface water rights in central New Mexico. Under the Conservancy district model, once a surface water right is sold to a new user, or the point of diversion is shifted to another location, the former point of diversion is no longer allowed unless surface water is leased from the District. To date, a transfer of a pre-1907 water right from a groundwater diversion to a surface water diversion for irrigation has never been allowed, making any transfer of a senior right point of diversion from surface to ground permanent. This has many implications for the transferring of water rights resulting in dramatic and permanent changes in land use. In other words, the formal transfer of a surface right represents a permanent change in the application of that right, either because the new holder is claiming the water for use in another location, or because the diversion point is being shifted. It is possible to legally reactivate the point of diversion by selling the water back to its original use, to reestablish its appurtenance to the land, but this is a time-consuming and expensive legal process and rarely happens because there are other options for irrigation – namely, "double dipping."

Indeed, the sale of a water right does not mean that the land is never cultivated again, as double dipping enables people who have sold all of their water rights to continue irrigation. Double dipping represents a situation in which a paper transfer of water occurs, moving water from one location to another – but wet water use continues at *both* the original and the new location.

In practice, double dipping takes several forms. Farmers can sell their water rights to a municipality or other urban user and then lease those water rights back from the new owner, and continue to use the water as before, making the transfer invisible until some future date. Although not sanctioned by the New Mexico Office of the State Engineer, MRGCD rules make it legal lease water from the Conservancy District's water bank to irrigate, even after one has sold the surface water right appurtenant to the land being irrigated. Some farmers simply continue to irrigate illegally. Lastly, municipalities and other buyers of water rights may hold their legal right to the water but not use the water until a future date.

Another form of double dipping takes place when a water rights holder sells all or part of a water right, then subdivides the appurtenant land holding for residential development and drills domestic wells for each of the new properties. This last form of double dipping has important hydrological implications. A surface water irrigation right represents delivery of 3 acre-feet per acre, with an assumed consumption of 2.1 acre-feet per acre. This latter value (2.1 acre-feet/acre) is the consumptive value, and represents a transferable property right. On ten acres of land, the appurtenant transferable water right would represent twenty-one acre feet of water. Hypothetically, the owner of that ten acre parcel could sell the 21 acre-feet of water rights for the market value of the rights, then subdivide the appurtenant land into three-quarter acre lots for urban development – the standard allocation for septic tank spacing. Upon application and approval of a domestic well permit, each ¾ acre lot would be eligible for delivery of 3 acre-feet of water. Under such a scenario, the ten acres once irrigated by 21 acre-feet of surface water, would now represent a potential demand of *40* acre-feet of groundwater for domestic purposes. Even assuming a 50 percent return flow rate, such a scenario would result in 20 acre-feet of water consumption for ten acres. This use would be occurring at same time that the original 21 acre feet of water are being pumped from the ground at another location – in other words, an effective and legal doubling of wet water use.

Anecdotal evidence from our discussions with farmers indicates that even "triple dipping" may occur. For example, an agricultural landowner could sell her/his original water rights, then decide to subdivide the land. Even after the developer drills domestic wells and builds homes, it is sometimes possible for the new houses to gain access to surface water for irrigation, perhaps through the MRGCD or, at times, by illegally tapping into a local ditch..

The movement of water rights from agricultural to urban uses not only represents the movement of water from one parcel of land to another; it may also represent a change in the use pattern. Surface water used for agriculture represents an intermittent seasonal use pattern, with rates of water use changing with the agricultural cycles. Most urban uses are not as directly tied to related to season, climate, or wet water availability. Moreover, the effects of groundwater pumping are cumulative and extend well past most city and regional planning horizons, which span 25 to 50 years. All these factors allow a lag to exist in some cases between a transfer of water rights and a transfer in water consumption. Indeed, the project team identified double dipping as a major valve preventing the buildup of enormous economic pressure in the basin's water rights market, Double dipping also renders the transfer of water rights invisible, making a public outcry about changing land uses unlikely.

4.0 THE PROJECT

4.1 Initial Track: Why Model Water Rights?

Initially, we chose to model transfers of water rights under the assumption that trends in this market could provide some indication of future growth, and therefore water use, patterns in the Middle Rio Grande Valley. Because water rights represent the holder's legal entitlement to extract and use water, trends in water rights transfers may be used to indicate future trends in water use and demand, while physical factors would indicate trends in water supply. The goal of the model was to couple these two entities to better understand system-level behavior over time, as social demand for water encountered physical constraints on its availability. Moreover, because water rights are a commodity that individuals can (and do) sell or purchase, they lend themselves to being modeled as a flow in a system dynamics model, with different stocks representing classes of water rights owners with particular use patterns.

Anecdotal evidence suggested to us that, over the past two decades, government and industrial entities have become increasingly interested in acquiring water rights from owners willing to sell them. Projected demand of the urban areas and urban development, combined with drought and awareness of the limited water supply, are the primary drivers behind this corporate interest in water rights. For example, the City of Albuquerque's water strategy report, issued in February of 1997, identifies acquisition of water rights a key element of the city's water planning initiative. Industrial users that rely on water for their operations, such as PNM and Intel, are also purchasing water rights to ensure that they have clear access to water in the future. The New Mexico Subdivision Act states that before they approve a final plat for a subdivision, county commissioners may require residential developers to have obtained a permit from the State Engineer determining whether there is sufficient permitted water for indoor and outdoor domestic uses (NMSA 47-6-11.2).

Such evidence is backed up by analyses of satellite data from 1982 to 1999, which show that the area of land in agricultural cultivation in the MRGB declined in a linear fashion ($r^2 = 0.99$) from about 24,000 to 16,000 acres (Passell *et al.* 2004). In the years 1980 to 2000 the human population in the city of Albuquerque (COA), the largest city in MRGB and in New Mexico, grew from about 332,900 to 448,600 (~ 35 percent; Bartolino and Cole, 2002), and other municipalities around Albuquerque grew at similar rates. Growing human population in the city creates a higher demand for water, and so for many years the City of Albuquerque has been purchasing surface water rights from agricultural uses and transferring those rights to the City. From 1982 to 1999 the quantity of water transferred with those water rights increased in a linear fashion ($r^2 = 0.46$).

We hypothesized that identifying patterns in the transfer of water rights could forecast trends in demand and use of wet water itself. For example, if agricultural water rights owners decided to sell most of their holdings to the City of Albuquerque, this could allow the City to develop infrastructure to support increased urban (meaning suburban residential and industrial) growth. Likewise, we hypothesized that landowners, sensing increased demand for their water rights, could also decide to hold their water rights as longer-term investments, rather than realize short-term financial gain through selling them. Individual decisions made by water rights holders could play a significant role in permitting or restraining urban growth in the region.

As we discuss later, the basic premise we adopted – that multiple socioeconomic factors are driving agricultural water users to relinquish their properties to urban development – remained an important focus for our research. However, the focus on water rights changed as data collection problems forced us to look at land use patterns instead.

4.2 Developing the Model

Representing the water rights market in the MRGB required us to frame the basin as a system composed of entities connected by flows of water rights. The goal for the model was to keep it as simple as possible, while still capturing the system structure and variables at a level of granularity that would permit the emergence non-intuitive outcomes.

Since the movement of water rights is a one-way flow, from agricultural or agronomic uses to urban applications, the highest level model structure was fairly simple. At the highest level, the model would capture the movement of water rights from an initiating stock, “Non-Urban Holdings” – to a terminal stock, “Urban Holdings.” An intermediate stock, “Willingness to Sell,” was also designated to mark the key transition phase at which non-urban water rights owners developed an interest in placing their rights on the market.

Developing the model further required some consideration of granularity. The goal was to keep the model as simple as possible while adequately representing the key elements in the system. Hence we had to decide whether or not to model at the “grassroots” level of specific players in the water market (such as supplemental farmers and urban developers) or to maintain a more abstract picture with multiple larger-scale variables that we could manipulate to include specific attributes for different water market players. The task of identifying categories of key players and understanding their motivation for participating in the water rights market was one of the main research areas for the social science team.

4.2.1 Sociocultural Issues and Decision Theory

Modeling the decision pressures that might influence an individual’s decision to sell their land and/or water rights required considering a tangle of interrelated social, economic and historical issues. More specifically, a cultural perspective argues for understanding “agricultural land holders” not as rational, utility-maximizing decision makers in a classical economics sense, but more broadly as a cross-cutting social category that includes individuals from New Mexico’s mosaic of ethnically, geographically, economically, and politically delineated sub-communities.

Ethnographic research emphasizes that people self-identify across multiple social categories, each of which is marked by a set of common historical experiences that shape perceived interests, opportunities, and constraints among their members. Examples of such sub-communities in New Mexico include multigenerational Hispano agriculturalists, acequia associations, multigenerational white farmers and ranchers, environmental activists, community activists, part-time farmers, landowners who engage only minimally in the agricultural economy, individuals who are moving their land out of agricultural applications and into urban or suburban development. Again, it is important to stress that any particular individual landowner may self-identify with the interests and motivations of any of these categories. Extensive primary ethnographic research would be required to map the identity dynamics around land use more thoroughly than can be done in this project.

With this cultural perspective on motivations for decision making in mind, the social science team emphasized that *identity* would play an important role in the model, because identity plays a mediating role in shaping the individual's response to the larger social trends that impact decisions about water use. In other words, we hypothesized that an individual's perceptions about land and water use, and their decisions about what to do with their land and water holdings, would be strongly influenced by that individual's experience and location in the state's mosaic of cultural, economic, and social-"scapes." Hence, the motivations that shape individuals' decisions about how to best use their land and water rights cannot be understood as purely market-driven, but include social, cultural and historic factors as well.

Lexicographic Preference Theory

In discussion with the economists involved in the effort, we came to the conclusion that economic theory actually supports hypotheses about the cultural factors influencing decision making. Economics has several variations on 'utility theory'. Generally, utility theory develops in such a way that one can assign a value to goods and services. The notion that a good can embody a quantitative value is called commensurability. Assuming an individual assigns relative values to two goods, and these goods are interchangeable at some desired level of substitution, the individual is said to exhibit a preference function. If good Y is preferred over good X, and the two goods are commensurable and substitutable, then an individual with this preference function will gain more utility from substituting good Y for good X. This example of derived utility assumes that preferences are complete, reflexive, transitive, and continuous. Addressing the validity for each of these assumptions, however, is beyond the scope of this paper. For the interested reader, Gowdy and Mayumi (2001) challenge the theoretical underpinnings of these assumptions as they relate to consumer choice theory.

Situations may arise, however, where people cannot (or will not) assign a value to an item, and therefore it may not be commensurable, which rules out the possibility that their preferences are continuous. An individual who strictly prefers one item (or bundle of items) to another is said to exhibit lexicographic preferences. This contrast to standard neoclassical utility theory was first described by Georgescu-Roegen (1954) and has been particularly useful to describe hierarchies in values. An individual may hold a certain disposition or set of beliefs that preclude them from trading one good for another before setting a minimum or threshold in their preferences. Figure 1 illustrates a lexicographic preference order for goods X and Y.

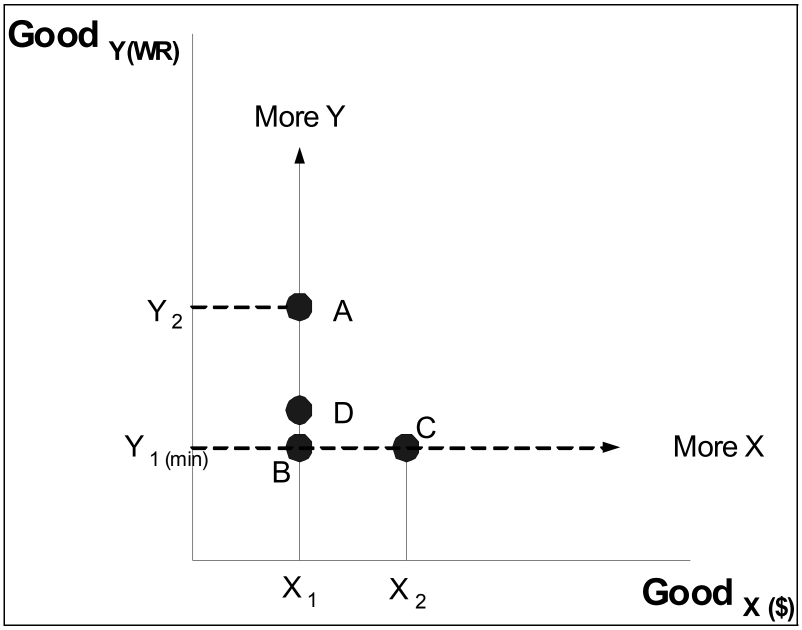

Figure 3. Lexicographic Preferences (adapted from Binger and Hoffman 1998).

In this example, the bundle of goods X and Y represented by point A is preferred over point B because ($y_2 > y_1$). Similarly, the bundle of goods at point C is preferred over that of bundle B because ($x_2 > x_1$). However, the individual may also have a strictly preferred balance of goods X and Y such that they exhibit no willingness to accept payment to reduce their amount of good y_1 (e.g., water rights (WR) are preferred over $) below a minimum level. Additionally, if an individual states a preference for good Y over good X then the bundle of goods at point D may be preferred over that at point C.

Individuals may hold a hierarchy in their preference structure for several reasons. One of the most common reasons for this structure is based on an ethical, rights-based view of nature and species preservation (Spash 2000, Rosenberger 2003). Similarly, if a change in environmental policy has the potential to adversely affect a key environmental driver, such as an ecologically important species, but the uncertainty around these affects is considered high, economists apply what has become known in ecology and policy circles as the 'precautionary principle.' This principle generally supports the notion that a threshold may exist – for example, losing a key species in an ecosystem – that should not be crossed until/if ever their role is more clearly defined (Gollier and Treich 2003, Brauer 2003). Additionally, individuals or groups of individuals may also express a hierarchy in their preferences because of non-reducible utility functions, ambivalence when comparing difficult substitution options, the inability to place commodity value on environmental or life-sustaining goods, and religions and/or cultural doctrines (Rosenberger 2003).

Applying Lexicographic Preference Theory to Water Rights Transfers

The difficulty in applying the perspective of lexicographic preference in the model, we discovered, was developing an appropriate abstraction of the issues, to create a conceptual model about how an individual landowner's socioeconomic location might lead to a decision to maintain (or, conversely, to sell) a land and/or water holding – namely, the decision of interest for this project. Initially, we considered the idea of holding focus groups and/or conducting interviews with water rights holders to get at least a sketchy map of the decision making community. However, interviews and focus groups are a time-intensive data gathering method that would require review by Sandia's Human Subjects Review Board, screening interview subjects, and paying participants. When we presented the idea to the larger modeling team, they felt that the interviews would be too resource intensive for the project, assuming that publicly available data sources such as census information and water rights transfer data from the OSE would fill in most of the gaps. The social science team agreed to try this tack and went off to develop hypotheses of what a water rights holder in the state might "look like." As we discuss below, it would later turn out that interviews would indeed play a critical part in the research and many of our initial assumptions about data accessibility and accuracy would prove erroneous requiring some shifts in focus.

Hypothesizing Decision Makers and the Water Rights Market

The social science team began by brainstorming different types of decision makers. We found, however, that the discussion invariably veered towards the "how" in model development issues, rather than the "what" we might be modeling. The solution was to develop individual hypothetical cause-and-effect narratives, based on our collective experience studying the history, culture, and public discourse about water in central New Mexico. Social scientists often develop ideas in narrative format, so this form of knowledge representation was an easier way to get ideas out without falling into the trap of worrying about the model process. We then met to compare and discuss our narratives.

Our narratives allowed us to focus on the problem of hypothesizing general categories of water rights holders and to consider some of the factors that might play into their decisions about whether or not to hold or sell water rights. In reviewing the narratives, we found a great deal of overlap in the way we were conceptualizing the problem, providing a robustness to the end results.

It is important to point out that the social science sub-team did not work in isolation from the rest of the project. The entire project team met regularly to review and discuss the categories, characteristics and data sources identified in the research. Since the larger project team included several water rights experts, including a farming advocate, a water rights lawyer, and a UNM economist who studies the state's water economy, this provided the social science team with important feedback and criticism of its categories. The results of these discussions are presented below.

Water Rights Holders

The social science sub-team identified four types of non-urban water rights holders – the individuals who will be deciding whether or not to place their water rights holdings on the water market.

- Primary income and supplemental income farmers need to generate sufficient income from their farms to provide for all (subsistence) or part (supplemental) of household needs. In these cases, one of the strong factors impacting the continuation of farming as a way of life is its real and perceived ability to generate income. Its real ability is a function of environmental factors (such as drought) and the economics of agriculture (including such factors as cost of seed, equipment, and the like). Its perceived ability is the perceived relative difficulty of generating a dollar through agriculture versus the difficulty of generating a dollar through non-agricultural employment. The difficulty of generating a dollar through non-agricultural employment is a function of the economy as expressed in general economic indicators such as unemployment rates.

- Some significant subgroup of subsistence farmers likely come from families (primarily Hispanic) who have been attached to the same community and/or piece of land for generations, often for centuries. In these cases, personal history or a sense of place would weigh heavily against a decision to sell. Attachment to a community or place among this group is often expressed in lifestyle terms with reference to the existential value[2] of the agrarian environment.

- Rural lifestylers are a distinctly different group from the farmers we have described above. Rural lifestylers own surface water rights, but derive their primary household income from some non-agrarian source such as a job. Their primary interest in the surface water rights and associated land is a lifestyle one. They are probably well-educated and certainly well-off. They place strong value on the existential value of the agrarian or non-urban landscape. Environmental concerns such as endangered species also would weigh heavily with them. Factors pressuring them to sell would include significant increases in the value of the land or the water right, or transitivity in lifestyle (they move out of the area).

- Our final category of decision-maker is a corporation or other entity that purchases land as an investment. Decision factors related to selling that land are primarily economic. They would include the price of the land and the rate of growth of the metropolitan area (i.e. the projected future price of the land). Anecdotal evidence suggests that these entities may purchase land and attempt to perfect surface water rights through agricultural activity (such as a sod farm) before turning the land over to urban development.

Each of these types of decision-makers can be identified through a constellation of social and demographic factors. Each, in turn, places different weights on different factors when faced with a (potential) decision to sell or transfer a water right. The social science team also considered the

[2] 'Existential value' is distinguished from 'usufructory value.' In the former, the thing has value simply by virtue of its existence. In the latter, value is derived from the uses to which it is put.

problem of data sources that could be used to explore these hypothesized characteristics, so that the data collection team could build a county-by-county picture of the decision-making (impacted) population. Lastly, a water rights market requires more than decision makers; it requires consideration of supply side factors and demand side factors. Hence, in addition to developing general categories of water rights holders who might become water rights sellers, we noted that each type of potential seller would be subject to different sets of decision pressures when choosing to maintain or sell a water right. Even when potential sellers experienced similar decision pressures, individuals in different categories would probably assign different weights each assigns to each type of pressure.

Table 1 lists hypothesized pressures by decision-maker type. It also lists the types of data that we hypothesized might be used to describe each of these pressures, and provides some potential sources for these descriptive data.

Table 1 Hypothesized Supply-Side Decision Factors by Decision Maker Category

Seller Decision Makers	Characteristics	Decision Pressures	Descriptive Data	Possible Sources
Primary income farmers	Identified ‘farming’ as principal occupation and included farms with sales of $10,000 or more	History /sense of place; Perceived health of agricultural economy; Perceived health of non-agricultural economy	Length of time in community (length of time on present farm); Presence / absence of acequia; Net cash return/loss per farm; Perception of drought severity; Agricultural subsidy programs; Price of water right, price of land; ABQ MSA economic indicators	New Mexico Acequia Association; Census of Agriculture; possible textual analysis; Extension office; Real estate records; State of NM, DOL; US Census
Supplemental income farmers	Farms with sales under $10,000 Other income not to exceed $20,000[3] Size of farm <10 acres	Health of agricultural economy; Health of non-agricultural economy; Price of land	Drought severity; Federal agricultural subsidy programs; Price of land[3]; Net cash return/loss per farm; Economic indicators from ABQ MSA	Hydrological records; Ag extension office; Real estate records; Census of Agriculture; State of NM, DOL, national sources;
Rural lifestylers	Farms with sales under $10,000; Other income exceeding $20,000; Education above high-school level	Price of land; Transitivity; Perception of health of environment	ESA issues, drought	Real estate records, Court records, Hydro records, textual analyses Census of Agriculture

[3] We assume here that if farm income is less than one-third total household income, the purpose of farming is not income-generating but consumptive.

Note that some of the descriptive data in Table 1 are themselves the result of other factors. For example, the price of land is a function of increased population, while the health of the agricultural and non-agricultural economies is a function of many different factors.

Who's Buying? Hypothesizing the Demand Side

We decided to separate decision makers into buyers and sellers of water rights for the simple reason that the majority of water rights sold in the MRGB are purchased by large corporate entities, such as developers or the cities of Rio Rancho and Albuquerque. Other purchasers include some primary income farmers who purchase water rights or additional agricultural land to expand operations, as well as private entities involved in water intensive activities, such as residential developers, utilities, and technology.

Table 2 Demand-Side Decision Factors by Decision-Maker Type

Buyer Decision Makers	**Decision Pressures**	**Descriptive Data**	**Possible Sources for Descriptive Data**
Urban centers (Rio Rancho and Albuquerque)	Population growth rates; water use rates; Desire to maintain area's rural culture	Population: numbers, distribution; City and water provider data City policy on what types of rights to purchase	Census; water policy and planning documents; discussions with city officials
Primary income farmers	Economies of scale – how much water does it take for me to farm land and make a profit?	Size of farm, income realized from farming	Agricultural census, interviews with primary income and large farmers
Large Developers and/or corporations (PNM, Intel, cement, others)	Real estate market, price of land, perceived competition for water rights	Type of industry, size of corporation, how water intensive is their activity?	Interview to learn water rights purchases over past 20 years

Characterizing the Water Rights Market

Lastly, we reviewed some of the research about the state's water rights market. For example, a study in 1977 noted that the major factors impacting the emergence of an active water rights market in the state was lack of public awareness that water rights were a marketable commodity, the lack of a central mechanism for trading water rights, and high transaction costs for water rights sales and transfers (Khoshlakhlagh, Brown and DuMars 1977). Public opinion is another significant factor: with rising public concern about drought comes increase public awareness and debate over the best uses for water. As public debate waxes and wanes in intensity, political decision makers may respond by increasing efforts to collect water rights, or by seeking other mechanisms to meet the area's forecasted water demand, as the City of Albuquerque has done with the San Juan-Chama agreements.

Table 3. General Factors Affecting the Water Market.

Factor	**Descriptive Data**	**Possible Sources for Descriptive Data**
The transparency of the water rights market (Transactions Costs)	Number of protests Costs per transaction	State records, water rights market studies in other states; discussions with water rights market experts/water bankers
The existence of a water rights market	Sales of water rights with land Sales of water rights without land; Legislative / Judicial climate	State records (OSE), water rights brokers, NM water lawyers, legal research
Continued adjudication of water rights and the level of enforcement of water law	Evolution of water right (i.e. potential for in-stream flow); "Public Welfare" Over-appropriation potential Uncertainty/Trust factors Double dipping index Environmental effects of transfers	Legal research; Economic research, polls of environmental and rural values Hydrologic water balance studies, Cockerill (CITE) Ditch rider records Groundwater-Streamflow-habitat models
Public Opinion	Polls, environmental valuation	UNM Economics Dept, Institute for Public Policy

4.3 System Representation: Causal Loop Diagrams

Using the narratives and categories developed by the social science sub-team, the modeling sub-team began transforming the hypothesized categories, decision pressures, and the water market into a causal loop diagram.

4.3.1 Creating the Causal Loop Diagram

After discussing the decision maker categories, drivers and characteristics that the social science sub-team had developed, the modeling sub-team – which included two of the four social science sub-team members - met to transform the social characteristics of the market players and understandings about the market itself into a causal loop diagram.

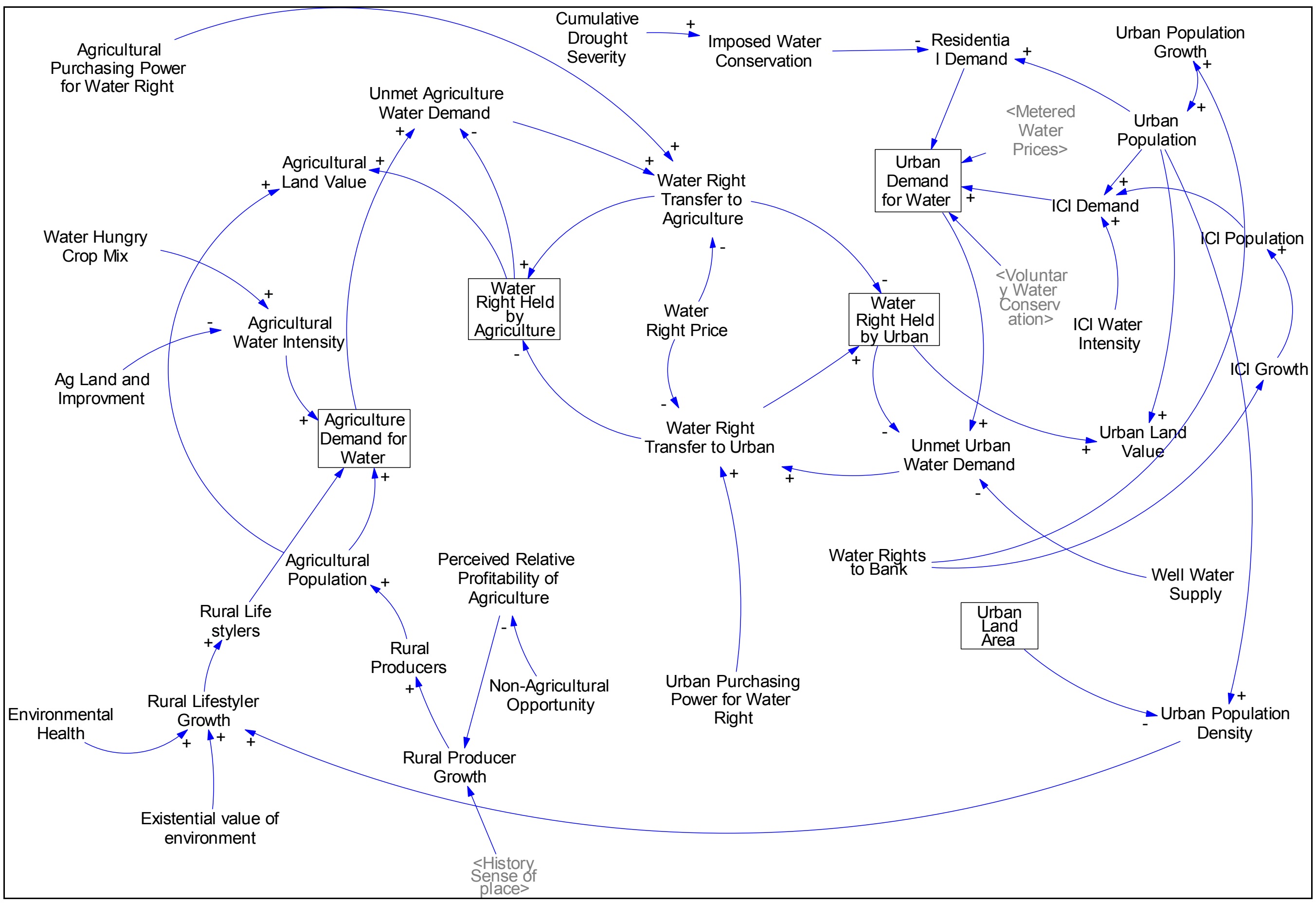

Figure 4. Causal Loop Diagram.

The CLD above displays chains of relationships (edges) that link concepts (nodes) identified as significant for purposes of the study. A "plus" sign along an edge indicates that as the value of the source node increases, the value of the destination node will increase as well, while a "minus" sign along an edge indicates that as the value of the source node increases, the value of the destination node drops. For example, as the number of water rights transferred to urban use increases, the number of water rights held for agricultural uses decreases. Nodes framed in boxes indicated the key variables that the project would attempt to model; nodes without boxes represented intermediate variables that would be considered for inclusion in the model, and nodes in grayscale indicated concepts that were hypothesized to impact the destination node, though the actual direction of the relationship was not clear.

4.3.2 Building the Initial System Dynamics Model

The modeling sub-team met several times in April and collectively drew stock and flow diagram to encompass all aspects of the project. Discussions revolved around what modules the model would require to demonstrate the relationships inherent in water use shifting from agriculture to urban. The central piece was the stock of agricultural water rights flowing to urban water rights via the "willingness to sell" parameter. The key pieces influencing this central piece were the inputs to farming, the subsequent "profit" and "perceived profit", the gap between those two and the variables that influence how wide that gap may be at any given time.

The team took "profit" as a central concept for understanding how participants in the water market make decisions. Discussions about the idea of profit in this context generated a set of causal relationships around the idea that perceptions about profit, both past and future, would play a major role in mediating the decision about whether or not to sell a water right. Profit was defined in two ways: as the objective amount of money derived from farming, and as *perceived* profit, a broader definition that encompasses one's perception of financial as well as other non-material gains realized from engaging in farming and holding a water right. In essence, the team hypothesized that the profit that an individual expects to realize in a short-term decision period (five years) could act as a "tipping point," in decision making. For example, an individual who expects poor to negative profits would be more willing to sacrifice a water right than an individual expecting reasonable to high profits from their activity.

To represent the difference between present and future benefits, the modeling sub-team developed the concept of a "profit gap," or the difference between an individual's historical perceived profit from farming, and the potential profit the individual could realize from the sale of their water rights. Several variables "modulate" this gap, widening it or narrowing it and hence adjusting the overall "willingness to sell" attribute. This concept of "gap modulation" remained a key construct in the model, focusing the research team's efforts on identifying data and conducting interviews to determine what factors would influence an individual's willingness to part with land and/or water rights.

4.4 Data Sources and Issues

As the modeling sub-team was developing the causal loop diagram and the stock-flow diagram, the data collection team was investigating the data sources suggested in the work of the social science sub-team. The data sources that the data team was seeking were not only important for populating the model, but for establishing a better sense of the directionality of the relationships among the key variables.

In general, attempts to identify and collect relevant data sources were frustrating. For one thing, the model building and data collection processes took place on parallel tracks, which – as we discuss later – created some communication problems that slowed the project's progress. More importantly, the data collection team hit multiple dead ends because so many of the data sources that the social science team had identified as directly relevant to the issue of water rights transfers were neither accurate nor reliable. While higher quality data sources, such as the agricultural census data from the National Agricultural Statistical Service, were more reliable, the data were also more difficult to relate to the questions we were asking. The following sections discuss the variety of data sources tapped and the issues the team faced in working with existing data.

4.4.1 Office of the State Engineer

At the outset, flows of water rights were the primary focus of the modeling effort. Accordingly, data collection was one of the major focus areas of the project, which was developed under the assumption that the state would be able to provide records documenting the sale of water rights over the time period of interest. The logical first place to being seeking data on trends in and the direction of water rights transfers in the MRGB was the Office of the State Engineer, which is charged with overseeing the adjudication, transfer, and sale of water rights throughout the state. Not only would data on water rights transfers indicate directionality and slope for the causal loop diagrams, but historical data could be used to calibrate the model against a curve showing the transfer of irrigation water rights to municipal water rights over time from 1950-2000.

The OSE maintains an office in downtown Albuquerque and was quite willing to provide us with all the water rights data it had available. In February, OSE staff provided a CD that contained the most recently updated digital version of the state's water rights database, including information from Sandoval, Bernalillo, Valencia and Socorro Counties. The CD came with a warning from the OSE, however, that the database was neither accurate nor up to date. Although OSE staff would be conducting quality assurance within the next month, the process would be time consuming, because database information would have to be physically cross-checked with the survey maps that OSE uses to create a visual record of water rights transfers. Vetting the database would require an individual to check each transfer on every map and enter the information about the transfer into the OSE database. Initially, OSE planned to begin this effort in March, but postponed the quality assurance work until June – too late for this model effort.

Warnings about data quality notwithstanding, OSE's data was the most extensive and centralized database available, so several team members decided to conduct exploratory analyses to determine if the data might be useable for the model. They spent several weeks cleaning the data and plotting irrigation water right transfers from Sandoval, Bernalillo, and Valencia counties. Plots from each county showed water right transfers over time, the percentage of transfers to various user types, and the percentage of water transferred to a particular new owner. After completing the individual county plots, data from all three counties was combined in aggregate plots.

One option to address the lack of OSE data was to find surrogate sources of information about water rights sales and purchases in the region and to compile this information into a sketchy database. Since a few major purchasers account for most of the movement of water rights in the valley, and there are many sellers, we decided to focus on the former. These included the cities of Albuquerque and Rio Rancho as well as several private corporations that require water for their activities. Team members used their own experience in water issues to identify contacts among the major purchasers of water rights in the MRGB. It was assumed that these entities would maintain records of their water rights purchases and that we might be able to obtain this information. Accordingly, GRAM staff contacted several of these entities to determine if they would be willing to provide us with information on their water rights purchases. We had minimal response to our requests; some of the private corporations were reluctant to provide information about their water rights purchases, while others would provide only general estimates of their purchases. In the end, the team decided that the data quality would not be that much higher than the OSE data, so the effort was set aside.

4.4.2 Secondary Sources: Surveys and Related Projects

Early in the project the team posted a request on an anthropology oriented listserv to gather information on other water projects in the Rocky Mountain region. The request asked researchers to inform the team of projects dealing with shifting public perception of drought, and the impact of public perception on water use trends. One unique response came from David Casagrande, an Arizona researcher conducting a project on water use and drought perceptions in the Phoenix area. While the Casagrande and the WRT project explore similar issues, there are significant methodological differences between the two, as the Arizona project is an in-depth, structured qualitative effort consisting of interviews and ethnographic research. Because both projects were in their preliminary stages when the initial correspondence occurred, both teams decided that regular communication would be more useful after a year or so of work. The WRT team believes that any future iterations of the Sandia model may be strengthened by drawing on the Arizona study, which will provide deeper insight into the relationship between public perception of water trends and the impact of perception on the actual use of water.

The team also looked into the possibility of using data collected by other water management research projects in the Middle Rio Grande Basin. For example, the Institute for Public Policy at the University of New Mexico had conducted an extensive survey on public perceptions of water availability and patterns of water use. Although the IPP was willing to supply the project with its data, several team members had concerns with data gathering techniques and some specific questions asked in the survey. The data was therefore not used directly in the project.

4.5 From Water to Land

By April, realizing that data on water rights transfers would not be forthcoming, the team began focusing on identifying surrogate data sources that could be used to get a general idea of the trends we would be modeling and to develop a calibration curve for the model. We revisited our research question: what are the major drivers contributing to the transformation of the MRGB from a primarily agricultural to an urban landscape, and how might water constrain this evolution over time? In doing so, we came to the realization that water rights transfers were actually a suboptimal indicator of the process we were studying. Although water rights transfers are of great importance in explaining the fifty-year transition of the valley from an agricultural to an urban center, the movement of land from agricultural to urban uses was of equal, if not greater, importance. Urban development requires that water rights be removed from agricultural use and put towards other uses, but the movement of agricultural land out of farming is a significant driver for that process.

This was a turning point in our effort, as we shifted focus from changes in water use to changes in land use. Using the same social categories, we turned to sources of data that could be used to document the movement of land from agricultural to urban applications.

4.5.1 Why Do People Choose to Move Out of Agriculture? A Land Sales Regression Model

With land as the dependent variable, the team decided to focus its efforts on finding data that could be used to indicate the factors most significant in an individual's decision to sell their agricultural land holdings and leave farming. The team hypothesized several scenarios that could influence this decision: the price of land in the region, the number of people in the region selling their land for development, the economic and social benefits of engaging in agricultural activity, the costs of engaging in agricultural activity, and the overall economic health of the region. Unfortunately, we did not know the direction of the relationships between these factors and the rate of agricultural land sales in the MRGB. Accordingly, we decided to run a multiple regression model to identify key variables. We decided that this model, when coupled with focus group data (see discussion below), would provide some indication of the strength and directionality of these relationships, and that this information could be used to structure the gap modulation part of the model.

The modeling subteam, under the leadership of the project's two economists, developed a regression model to assess the significance of social and economic factors related to land sales and identified the kinds of data needed for input parameters. An equation for the model was defined with the following parameters needed from Sandoval, Bernalillo, and Valencia Counties.

Land Sales = Ag Land Sales + Price of Land + Ag Benefits + Ag Costs + Economic Health

Agricultural Land Sales data was not available for all the three counties. Various county agencies including the county assessors in all three counties, the office of county clerk, zoning department in Bernalillo county and Coldwell Banker realtors were contacted. None had specific data available for "Ag Land Sales" on record from the sale of properties. Agencies do not track the sale of properties by land use and do not record what the properties primary use was prior to sale nor record if a change in land use occurred after sale of property. Therefore a project decision was made to combine the equation parameters "Ag Land Sales" and "Economic Health" to "Measure of Economic Health"

Land Sales = Ag Land Sales + Price of Land + Ag Benefits + Ag Costs + Economic Health

Working with the data collection team, the economists developing the regression model helped to identify types of data that might be used to populate this model, while the data collection team highlighted data sources that might be relevant to the economists' questions. The list of suggested data sources is found in table 4.

Realizing that information on the number of acres of agricultural land sold into urban or other development would be impossible to get without conducting a survey of recent sellers and purchasers, the data collection team suggested that it might be possible to use the "Total Number of Irrigated Acres" as the dependent variable. Since the project question focused on changes in the ratio of rural/agricultural land to urban land, data showing the number of irrigated acres could be used to show trends in the amount of land under cultivation in the region. The regression equation could then be run to determine if the hypothesized factors bore any significant relationship to changes in the number of acres under irrigation over time.

Initially, this seemed to be a feasible way to baseline the model, since the data collection team was able to identify several sources of data that could be used to quantify trends in the amount of land under cultivation. For example, the New Mexico Department of Agriculture keeps annual counts of the number of irrigated acres in the MRGB, while the National Agricultural Statistical Survey conducts a census of agricultural activity every five years. Moreover, the team's farming expert noted that the MRGCD had recently asked its ditch riders – the individuals who monitor surface water use along the basin's ditches – to begin collecting data on cropping and water use in their districts.

Table 4. The Requested Variables for the Model and the Data Sources.

Variable	Data Source
Sales of Agricultural Land	--------
Price of Land	National Agricultural Statistics by NASS for the Years 1950, 1954, 1959, 1964, 1969, 1974, 1978, 1982, 1987, 1992, 1997
Farmland Area	National Agricultural Statistics by NASS for the Years 1950, 1954, 1959, 1964, 1969, 1974, 1978, 1982, 1987, 1992, 1997
Irrigated Area	National Agricultural Statistics by NASS for the Years 1950, 1954, 1959, 1964, 1969, 1974, 1978, 1982, 1987, 1992, 1997
Irrigated Cropland	New Mexico Agricultural Statistics for NMDA
Total Value of Agricultural Markets	----------
Total Costs for Agriculture	National Agricultural Statistics by NASS for the Years 1950, 1954, 1959, 1964, 1969, 1974, 1978, 1982, 1987, 1992, 1997
Cash Receipts: All Commodities	New Mexico Agricultural Statistics by NMDA
Farm Earnings	http://censtats.census.gov/cgi-bin/usac/usasel.pl U.S. Census Bureau, Last visited: 7/20/2004
All industries Earnings	http://censtats.census.gov/cgi-bin/usac/usasel.pl U.S. Census Bureau, Last visited: 7/20/2004
Population NM	http://censtats.census.gov/cgi-bin/usac/usasel.pl U.S. Census Bureau, Last visited: 7/20/2004
Total GSP for NM	http://www.bea.doc.gov/bea/regional/gsp/ Bureau of Economic Analysis, Last visited: 7/20/2004
GSP per capita	http://www.bea.doc.gov/bea/regional/gsp/ Bureau of Economic Analysis, Last visited: 7/20/2004
Per Capita Gross Domestic Product (real GDP per capita)	http://www.eh.net/hmit/gdp/ Economic History Resources, Last visited: 7/20/2004
Population	http://censtats.census.gov/cgi-bin/usac/usasel.pl U.S. Census Bureau, Last visited: 7/20/2004
Population in Agriculture	http://censtats.census.gov/cgi-bin/usac/usasel.pl U.S. Census Bureau, Last visited: 7/20/2004

Accordingly, the data collection team conducted searches to locate data defining acreages for irrigated cropland within Sandoval, Bernalillo, and Valencia Counties. Staff searched for state, county, and agricultural census data including National Agricultural Statistics Service (NASS), New Mexico Department of Agriculture (NMDA). NM State Gross Domestic Product (GDP) data was one possible source; however, the data did not define individual counties within the state. A search of the National Agricultural Statistics Service (NASS), New Mexico Department of Agriculture (NMDA), and New Mexico Agricultural Statistics Service (NMASS) statistical data also revealed some problems with using these sources for the regression analysis.[4]
As we reviewed the data sources, we discovered that none of these were in consistent agreement. Indeed, the data collection team discovered that in some years, the numbers cited by each agency did not agree, while in other cases, they were identical. In many of the years for which data was available, each source cited a different figure for the amount of irrigated land in each of the three counties under study. For example, in Valencia County, data for the year 1999 ranged from 16,000 acres under irrigation (NMDA) to 84,000 (NASS) acres under cultivation. Had the rate of change been consistent across all three data sets, we might have been able to use the data in the model; however, the rate of change was inconsistent as well.

There are some explanations for the inconsistencies in the datasets. For one thing, different agencies rarely use the same protocol for data collection, and protocols and definitions may change over time. Moreover, the NASS data is self-reported data, which is prone to error and bias as people report information according to perceived self interest. Because the NMDA reports yearly changes as farmers make changes in cropping patterns and place land in fallow, these data sets are also prone to inconsistency, depending on how individuals are using their land each year. Lastly, the team's farming expert indicated that farmers in the MRGCD have reason for being reluctant to share accurate information about their land and water use. These reasons are rooted in the usufruct nature of water rights in the region. For example, farmers who are not using their entire allocation of surface water might fear that accurately reporting the amount of water used for irrigation could be detrimental in the event they choose to adjudicate the claim.

Ultimately, because of the difficulties in quantifying the dependent variable, the team determined that a regression model would not be forthcoming and decided to halt this effort.

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[4] A few more notes on data: NMDA records for irrigated croplands (in acreage) for year 2000 to the present were available on their website (http://nmdaweb.nmsu.edu/stat.html). Other data 1962 through 1999 was found at University of New Mexico (UNM) Parish library. After collectively plotting the data from the library and Internet source, the graph showed that the data varied from 1963-1978. The yearly sums of acreages irrigated remained constant from 1979 to the present for all three counties. The same value for 1979 was used for 1980, 1981, 1982 through 2003. The NMDA was contacted to determine why this was so; we were told that the New Mexico Agricultural Statistics Service (NMASS) prepares and publishes the NMDA statistics. The State Engineer's office provided some of the data for the irrigated cropland and another portion from the National Agricultural Statistics Service (NASS) census performed every 5 years. The NMASS also stated that county level crop data was collected by telephoning farmers that were provided on a list of willing participants held at the office of NMASS. The crop data consists of acreage amounts per crop type farmed in each county. Another trip to UNM Parish library was made to collect and copy all the county level data by crop type. The data was entered onto a spreadsheet and analyzed for crop acreage totals and variability within the data. Finally, the data collection team contacted Eric Robinson at the State Engineers Office to find out why the number of acres seems to have the same value after 1979. Robinson stated that the data was actually collected every five years, although he was not sure about the reason why it stayed the same between the years 1979 - 2003.

4.5.2 Qualitative Data Collection

In the initial model, variables and their causal relationships were hypothesized based on the team's experience and knowledge. The team decided that obtaining original data was required to understand this question of gap modulation and to get some idea about what might explain a posited lexicographic preference for land over cash. This lexicographic presence could play a very important role in slowing growth, if enough people have it. Also, we hypothesized that it may be possible for this kind of preference to spread and hence create a community value – i.e., if enough people think that holding onto land for the future, to preserve heritage and community and such, is important, does that lexicographic preference become embedded in the identity of the community?

To address this data need the team discussed conducting focus groups with farmers from the region. Focus groups provide a means of gathering perceptions quickly and cheaply to enable the team to structure this part of the model. The social sub-team drafted a protocol for focus groups (see Appendix) and began the process for gaining Human Subject Review Board approval.

Discussions with the farmer on the team, however, concluded that we might have had limited success in recruiting participants for the focus groups, especially within the timeframe needed to complete the project. Therefore, the team shifted its attention to conducting individual interviews with farmers, as discussed below.

Interviews

We conducted interviews with seven land holders with access to irrigation water in the Middle Rio Grande Valley to collect primary data to validate the pressure-to-sell variables posited through research and analysis of secondary sources. The interview sample was primarily a judgment sample, with a small snowball dimension. All except one of the respondents were identified by a member of the research team (judgment sample) and were recruited on the strength of the connection with her.[5] The remaining interviewee was identified by a member of the initial interviewee group (providing the 'snowball' dimension). All interviews were conducted by the same interviewer in the interests of consistency. Interviewees were paid $75 for participating. We also note that survey data conducted by the Cooperative Extension Service at New Mexico State University was used as a secondary source to compare results from interviews conducted for this project. Input from a staff member at the US Department of Agriculture's Natural Resources Conservation Service was also used to assess the representativeness of the information we obtained via interviews.

It is important to note that the farmer on the research team member had been characterized by others in the New Mexico water issues community as an 'activist farmer.' Since participation in the research by the targets was enabled by their personal relationship with the research team member (or, in the one case, by a relationship with another respondent), we can reasonably suppose that one might characterize these respondents as more 'activist' than not. We felt, however, that this was not necessarily a negative bias for purposes of this research. It would be precisely this population (the 'activist farmers') who, almost by definition, would be most likely to articulate concerns about changing landscapes and most vocal in their advocacy positions.

[5] This recruiting method was selected, to a large extent, because of known hostility towards Sandia National Laboratories among the targeted population. The labs in general were seen as inimical or, at best, indifferent to the needs of this population. We believe that it was the personal relationship of the sample population members with the research team member that enabled their participation.

Our sample size of seven is small relative the target population. Our sample also did not appropriately represent the different dimensions of rural 'type' identified in the model development process. Only one of the respondents was a subsistence farmer—meaning that the farm was the sole source of income. This also was the only interviewee with substantial land in agricultural production (350+ acres owned and leased vs. holdings in the 10-40 acre range for the supplemental farmers[6]), and the only interviewee involved with dairy farming. Only one of our respondents was Hispanic. Only two respondents were native to the area. This curtailment of size and scope was driven by project time constraints. However, we believe that the interview results were aligned closely enough with secondary source and other data to provide reasonable confidence in the selection and definition of model variables. Furthermore, given that one of the purposes of this model development project was to explore methodological issues related to the incorporation of social variables into this type of modeling exercise, important lessons were learned about procedure and timing of certain types of data collection efforts. These lessons will be incorporated into subsequent model development processes.

4.6 Findings

The perceived or understood relationship of land to water rights, as well as the felt nature of the status of those rights set the context for the discussions. At the outset of each discussion interviewees were told that the project was about land use and related water use in agriculture in the region. Almost all respondents emphasized their commitment to an agrarian lifestyle. Water was instrumental in this lifestyle; it was a means by which that lifestyle could be realized and/or continued. Physical health was another frequently mentioned instrumentality.

That the end value is an agrarian lifestyle has important implications for it suggests the possibility of alternate geographies. If certain aspects of an agrarian lifestyle become impossible to realize in a particular place because of the absence or curtailment of specific enablers, practitioners could conceive of reconstructing that lifestyle in other places. This was reinforced by comments from respondents who said that they had grown up on farms elsewhere in the country and wanted to continue or re-create that experience when they moved to New Mexico. In fact, one respondent had already relocated within the region saying that the initial area being farmed became too developed and another respondent has land elsewhere in the region as an "escape" should his current area become untenable. One respondent had grown up farming in the region, but in a different community. Her son, however, still farms the family farm. She is the only respondent who is a member of three generations to be involved continuously with a particular piece of property. A significant exception to the connection with a specific community was the Hispanic informant who grew up in the farming community where he now lives. While he has remained in the community, he is not a multi-generational land holder. His parents sold all of their land in 1959 and when the respondent decided to farm, he bought his own land. His comments focused heavily around community and connection to the community as realized through a particular lifestyle.

The difference between investment in a community and investment in a lifestyle was underscored by respondents' comments about their neighbors. As the urban environment encroached upon the rural, several of the respondents' neighborhoods became more urban in character. Respondents reported

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[6] The small size of most of the holdings reflects the history and may project the future of the area. The large Spanish land grant holdings were only recently broken up (within the last two or three generations). Each successive generation divides its holdings amongst its heirs, further reducing the size. As the history of farming in California and the Midwest has shown, these small holdings are highly uncompetitive in the commercial agricultural market.

that neighbors became critical of the ‘smell’ of agricultural pursuits, and brought in mobile homes and other accoutrements of a non-agricultural lifestyle that were called ‘trash’ by the longer-term residents. Increases in drug use and crime rates were cited by one respondent as other indicators of a loss of the agrarian lifestyle.

Water was seen as a critical enabler for the agricultural lifestyle. Significantly, it was not the quantity of water but the management of water delivery that dominated most respondents’ responses to questions in this area. Several respondents noted that a farmer needed to have reasonable certainty as to when water would be delivered and how much would be delivered. This information was critical to crop planning (type and timing). The Middle Rio Grande Conservancy District’s management policies in this area were unanimously seen as woefully inadequate. The uncertainty surrounding water access/delivery was cited as a primary pressure to sell by several. Of course, respondents who offered solutions differed in their perceived best approach to handling water deliveries.

The status of water rights also was seen as uncertain. Although several respondents had proved their rights, the general tenor of comments in this area was that the burden of proof lay on the purported water right holder. The State Engineer’s Office assumed non-validity of the right unless it was proved otherwise. This added additional uncertainty to the water equation.

A second commonly mentioned pressure to sell was not the price of the land *per se*, that is, the money the holder could get for the land if it was sold, but the taxes that were assessed due to the putative selling price. As urban boundaries move outward, the price of immediately adjacent rural (agricultural) land increases based on its potential for development. Taxes increase concurrently, moving towards an untenable burden for the owners.

The age of the farmer was a strong factor in the longevity of the relationship of the current owner to the land. Most of the respondents commented on the physical hardship of an agricultural lifestyle yet, three of the seven informants were confident that their children would take over the land and keep it in agriculture for at least one more generation. Other respondents did not mention their children as possible future land owners, implying that this was not likely. Two of the respondents said that they had been pursuing conservation easements to protect the rural nature of the property. Only one seemed resigned to its loss, although others were clearly unsure of the future of their land.

4.7 Impact on Model Variables

The primary research confirmed most of the variables and dynamics that we had developed through secondary research. There were a few new variables to add, and some changes to a couple of those originally proposed.

We had initially proposed some value loosely labeled ‘community cohesiveness’ as a negative pressure to sell. Our respondents were reasonably involved in the community – probably involved in more groups than a comparable socio-economic urban sample would be. However, with the exception of the single Hispanic informant, respondents’ loyalty was to a lifestyle and the land that enabled it, not a community. As we mentioned earlier, this raises the potential for executing that lifestyle in alternate geographies. The decision factor should be re-labeled as ‘lifestyle commitment.’ By the same token, ‘time on the land’ may be combined with ‘lifestyle commitment’ as the relevant dimension appeared to be ‘time engaged in agricultural lifestyle.’

The efficiency of water management institutions was a big factor in pressures to sell. The lack of efficiency in MRGCD's management capability had a significant impact on the farmers' ability to execute crop planning and achieve profitability. Therefore, there needs to be a variable labeled 'perceived efficiency of water management institutions.'[7]

The variable labeled 'price of land' may need to be modified. For many respondents, it was not the price of land itself but the impact of the putative price on assessed value and hence on taxes. The pressure on the respondents to sell was not the money they could get directly for the land but the impact the price had on their ability to keep existing property.

The importance of the assessed value of the land and its relationship to its attractiveness to developers, and the impact that the increasing number of non-agricultural neighbors had on the farmers might be captured in some variable related to density of agricultural property holders. As that density drops, propensity to sell rises. That density also has an inverse relationship to the property tax burden on the remaining agricultural landholders (see previous paragraph).

The age of the farmer clearly affected willingness to sell. Several respondents commented on the physical difficulty of a farming life. Almost half believed their children would continue the agricultural use of the land. Although they had children, other informants were seeking conservation easements as a way to keep their land in agriculture, implying that they did not believe that their children were interested in maintaining the agricultural lifestyle.

This result suggests the addition of a new variable – the ease of obtaining conservation easements. For some respondents, this was seen as a path to maintaining their current lifestyle. It also was seen as a way of protecting the rural nature of the land even in the face of future generations' disinterest.

In general, the interviews supported the variables and dynamics identified through the secondary research. However, while the interviews did not identify critical variables that were significantly different from those initially posited with the possible exception of the ease of obtaining the conservation easement, there were some important nuances that did come to light. We also believe that performing the interviews earlier in the model development process might have shortened the time necessary to identify these variables, and pointed towards some data collection efforts that may now precluded by project schedule (such as density of agricultural holdings).

[7] This is supported by Brown and Ingram's argument that an important dimension of what they call the 'community value of water' is one of fairness. This differs significantly from equality. Fairness relates to the level of community control in determining allocation procedures, and the absence of arbitrariness in administering them (Brown, F. Lee and Helen Ingram Water and Poverty in the Southwest University of Arizona Press. Tuscon, AZ. 1987:35-36)

5.0 THE FINAL MODEL

Despite problems with inconsistencies in raw data sources at both the state and the federal level, the team learned a great deal about water and land use in the Middle Rio Grande Basin. We ultimately were able to develop a simple systems dynamics model that incorporated the concept of "gap modulation," supported through the interview data, to represent some of the decision factors related to lifestyle changes and land and water rights sales. An image of the causal loop diagram, as well as an image of the model interface in PowerSim, are both shown and discussed below.

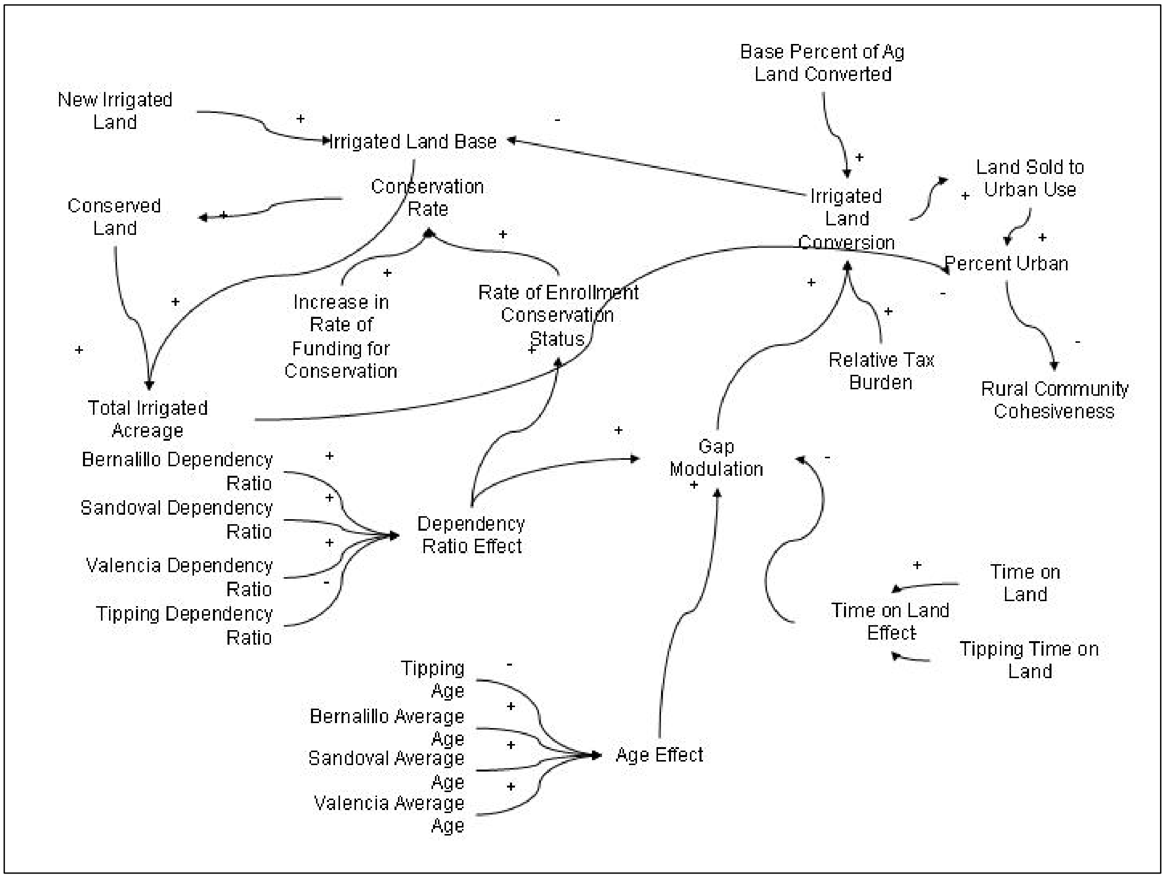

Figure 5. Causal Loop Diagram Representation of PowerSim Model.

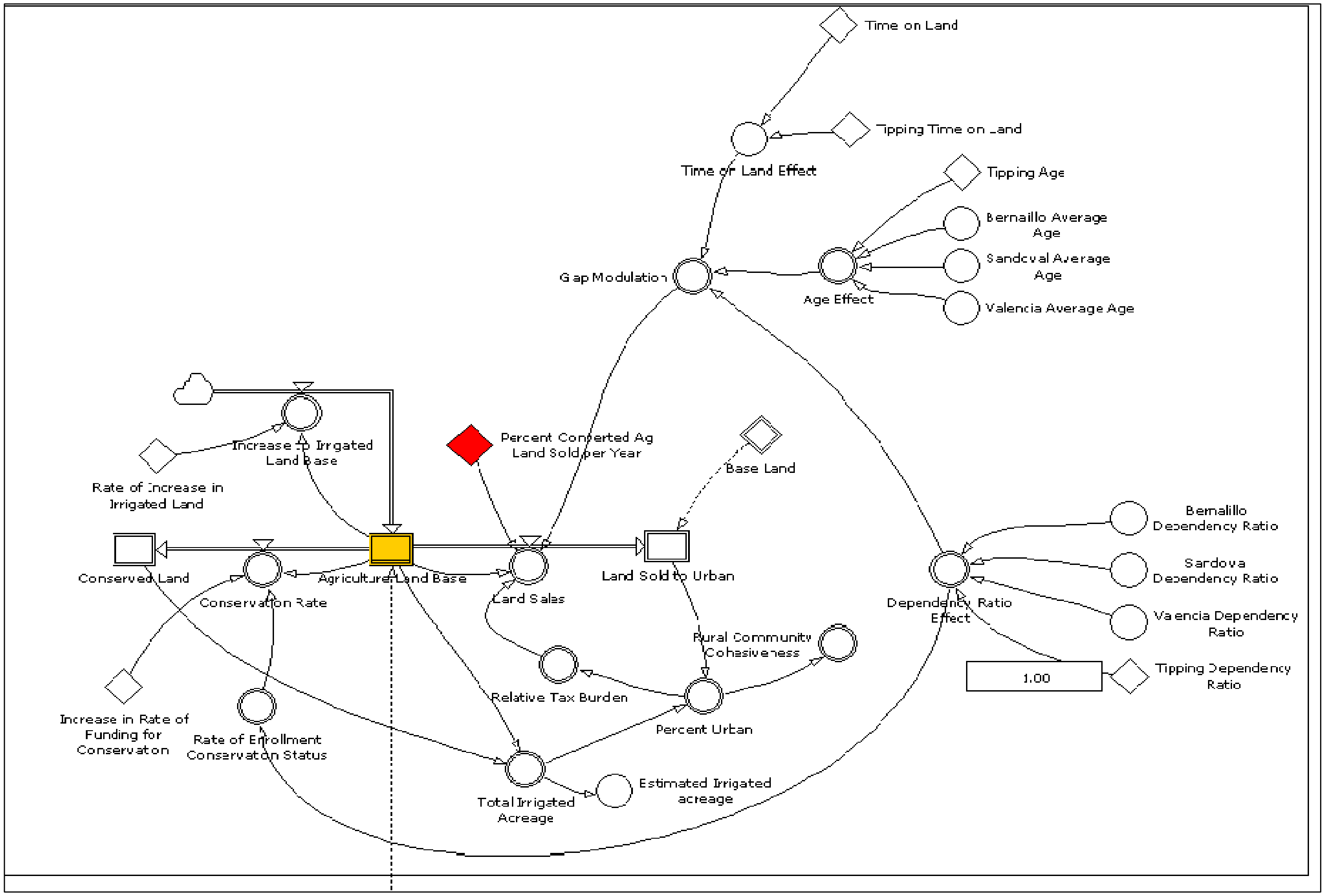

Figure 6. PowerSim Interface for Land Resources Transfer Model.

In the final model, we made a series of hypotheses, based in the interviews and data exploration we had conducted throughout the previous year, to explain why land might move out of agricultural use and into development. We decided that contributing factors could be demographic and economic, as well as decision elements that are more difficult to measure, such as a sense of community cohesion. The model represents the hypotheses we developed; different sections of the model are discussed below.

The key stock of interest is highlighted in yellow: Agricultural Land Base. This stock may increase as more land is put into agricultural production; its level falls when land is put into conservation easements or sold to urban/industrial development. The rate of land sales is influenced by three inputs: a base percentage of agricultural land that is sold each year; the relative tax burden on agricultural vs. urban landowners; and a gap modulation, which addresses the issue of socioeconomic factors on individual decisions about land use.

The gap modulation section of the model uses several "tipping points" to quantify the impact of social and demographic changes on land use decisions.

- "Time on land" was hypothesized as having a negative effect on an individual's decision to sell their land for urban development. The longer a piece of land has been in an individual's family, the less likely they are to sell the property.
- We hypothesized that the older the farming family, the higher the family's propensity to sell their land, as advancing age makes it difficult for people to continue farming, a physically demanding occupation.
- The dependency ratio represents the number of many people below 15 and greater than 75, divided by people in the middle range. This is a measure of the support requirements for agricultural landholders of working age. In other words, it measures the number of working adults to the number of dependent children and elderly. We assumed that as the dependency ratio increases, so to does the propensity to divest oneself of an agricultural landholding and move to a different occupation. This ratio also captures the idea that as children of farmers choose non-agricultural employment, their elderly parents are left with a greater share of labor, which may make them more likely to sell their land.

The time on land, age and the dependency ratios were assigned "tipping points," or discrete values at which individuals would decide to sell their land. These age and dependency ratios were calculated using demographic data from the UN Bureau of Business and Economic Research (BBER) for all three of the counties in the study. The time on land figure was hypothesized from the qualitative interview data.

Of importance as well in the decision being modeled are issues of urbanization and taxation, which have an impact on an individual's ability to retain ownership of large areas of land. This is a key feedback loop. In areas where farming lands are being built into urban and industrial developments, the tax burden on agricultural landowners increases in relation to urban populace for several reasons: agricultural landowners own more property, agricultural non-land properties – such as cows and horses – are subject to taxation; and because the population density is lower in agricultural areas, rural residents use less of a community's total services as a proportion of overall population. The higher the tax burden, the fewer people can afford to remain in farming.

In the model, this is represented as the "Percent of land urban," a ratio that divides the amount of land in urban use by the total amount of irrigated acreage. As more land moves into urban use, the higher the tax burden on farming families. This, in turn, has a negative impact on "Rural Community Cohesiveness." Although we did not represent it in the model, it is assumed that falling community cohesiveness makes it easier for individuals to sell their land for urban development, without the regret that might be felt by in habitants of a tightly knit farming community.

We note, however, that moving oneself out of agriculture does not necessarily mean that the land will no longer be cultivated. Some agricultural landowners will no doubt choose to sell their property to urban or industrial developers. However, nongovernmental environmental organizations like the Nature Conservancy, as well as state and local conservation programs, do offer choices to individuals who want to keep their land green. Agricultural land trusts and conservation programs may offer an attractive option for individuals who do not want to see their family lands subdivided into housing lots.

This choice is represented in the model as a stock of Agricultural Land, which can move to a stock of either "Conserved Land" or the stock of "Land Sold to Urban." The rate at which land moves from agricultural to conservation status is represented in a "Conservation Rate," which is influenced by the "Rate of Enrollment," – the rate at which people choose to enroll in these programs and the "Rate of Funding for Conservation," either from government or private sources.

When we actually ran the model, using some demographic data from BBER, hypothesized figures estimated from our data collection and interviewing activities, the model generated the curve that we had expected, showing a downward trend between 1980 and 2000 in the amount of land under cultivation (see page six). We then experimented with changing some of the values for key variables in the model. When we changed the funding levels for land conservation programs, the rate of land conservation in the model increased, and the rate of land going to urban development fell.

Given the limited time the team had to run the model, we developed a list of tasks and topics we would pursue, given additional time and funding. One team member suggested that we correlate the NASS and NMDA numbers with aerial survey data of the MRGB. This would help establish a better understanding of how much land has actually moved out of agricultural use and into urban development. It would also establish a baseline for the rate of landscape change in the region. Another suggestion was to reverse engineer state and local decisions recently made about land and water use, to see if we could figure out which of the several datasets might have been used to make that decision. Others wished to collect more economic and social data for incorporation into the model, including measures of economic health, changes in the costs and profits of agricultural activity, land sales information; as well as more detailed interview data to explore individual decision making frames for selling agricultural property.

6.0 FINAL DISCUSSION

We identified certain pressures or factors that would apply to all decision-makers. These included the existence of a water rights market; the transparency of the water rights market; and the continued adjudication of water rights and the level of enforcement of water law in the state. As described above, nearly all water rights in New Mexico are sold appurtenant to a piece of real estate. The emergence of publicly recognized, active water rights market could significantly change the dynamics of the buy-sell process in New Mexico.

However, the degree of public participation in developing and using a model would depend on its transparency, or the ease with which an individual could engage in a water rights transaction without requiring the assistance of a water rights law expert. Less transparency would mean higher transaction costs and, therefore, less widespread participation in the market. This could be managed in the model using a qualitative scale such as very transparent, moderately transparent, or opaque.

Lastly, continued adjudication of water rights and the level of enforcement of water law is important to study because of the potential for conflict and tension between the culturally grounded emphasis on communal ownership and management of natural resources, and a legal structure that values individual rights. For example, the law says that only individuals have standing in water rights protests. However, there is a clause in the body of water law that says disputes must take 'public welfare' into account. The courts have not yet addressed the question of making this clause operational and the phrase remains ill-defined. Acequias are an example of the institutionalization of a community-based approach to water management, but they often find themselves on the opposite side of the table from state legal staff in approaches to water management. The degree to which the individual-versus-community aspects of water law will be applied could have significant impact on the water market.

We recognized as well that non-urban outmigration patterns are dependent on such social variables as the local economy, ethnicity, and income. For example, rural communities that offer limited economic opportunities to younger residents will experience proportionally higher levels of youth outmigration than urban communities with a more diverse job market. Such patterns may be further influenced by ethnic and cultural variables, such as a strong tradition of family land ownership that may induce younger residents to remain in the area, or to find sources of income that enable them to maintain their family's holdings into the future.

Some of the entities that were identified in our discussions of the MRGB's social landscape were not included in the model. For example, the social category "rural lifestylers" represents an important segment of the population, insofar as this category includes wealthier urban residents who own formerly agricultural land and water rights, but whose livelihood comes from non-agricultural activities. We hypothesized that these individuals will hold the water rights that enable them to enjoy the amenities of rural living. Moreover, this category has not exhibited significant growth or decay in the past two decades, especially in comparison to other urban demographic and geographical categories. For example, many such individuals reside in Albuquerque's North valley, where demographic patterns have been relatively stable for many years.

6.1 Lessons Learned

As noted earlier, this project studied interdependent social, economic and physical trends by focusing on the movement of land and water resources from agricultural to urban use in the MRGB. Certainly one of the purposes was to learn about those interdependencies and how they affected (and were affected by) policy decisions. A second purpose was to contribute to knowledge about the modeling process itself—what (if any) are the challenges in incorporating many different types of factors in a single model? We anticipated that there would be significant process challenges in addition to any technical challenges. This section speaks specifically to the process challenges.

The project team was a multi-disciplinary team composed of individuals from different institutions. This heterogeneity was specifically designed to reflect both the diversity of input types (ranging from social to economic to other types of data) and potential users (including farmers/the general public, public sector institutions such as the City of Albuquerque, and research or intellectual support institutions such as the University of New Mexico and private sector consultants). This same heterogeneity generated a diversity of approaches, both to the development of the model framework and to the identification and collection of data.

6.1.1 Process

It is particularly important to note that the team quickly discovered the value in interdisciplinary, inter-institutional dialogue. The team met regularly as a large group. The PI for the project adopted a facilitative rather than a directive approach. This proved to be beneficial for this team with multiple voices and potentially unknown perspectives. It is highly likely that a more directive approach would have favored areas and approaches comfortable for the PI to the (unintended) exclusion of less familiar approaches. The project team found that the sacrifices in efficiency required by the facilitative approach were more than compensated for by the additional creativity and opportunity to contribute afforded by the discussions and relatively open-ended structure.

In addition to the large team meetings, each of the subteams felt it advantageous to meet as a smaller group and then ‘report out’ to the larger group. These smaller subteam discussions gave the participants the opportunity to discuss in more depth areas of interest, purpose, and approach specific to their disciplinary and/or content specialty.

The value of these subteam meetings was particularly apparent in the construction of the model framework. This team was particularly fortunate as most of the members, including the social scientists, had some familiarity with modeling and the system dynamics approach in particular. However, although the agendas of several of the large team meetings were directed specifically to the review of the model, most of the time was taken over by discussions related to data collection and variable identification. Most of the model construction was accomplished in subteam meetings.

6.1.2 Model Purpose

The team immediately discovered that different members had different views of the question the model was addressing. This was partially an artifact of the activity history of some of the project team members. Some team members, particularly the social scientists were new to the project. Others, specifically several members of the core modeling team, had worked together on the hydrological model. As a result, the modelers quickly focused on specific variables related to water, using water rights as the social re-presentation of the 'wet water' they had modeled in the hydrological model.

The social scientists, most of whom were new to the project, were not immediately comfortable with the modeling of water rights transfers as the statement of purpose for the model. They met as a subgroup to discuss the identification of potential variables for inclusion in the model, and the collection of data associated with those.

As part of their subteam dialogue, the social scientists developed a statement of broader purpose for the modeling project, focused around the need of potential model users to move towards a "desired social landscape" for the MRGB. The social scientists saw this project as moving toward an understanding of how socio-cultural values impact decisions around land use as a contribution to developing that social landscape. In the context of the desert southwest and the MRGB in particular, they further posited that water use can be seen as a surrogate for land use. The subteam then endorsed the modelers' use of water rights as a surrogate for 'wet water' or water use.

The research team as a whole agreed on the broader statement. The social science team suggested focus groups and/or other means of primary data collection to identify pressures on individuals in the MRGB to sell water rights, testing (among other things) the legitimacy of using water rights as a surrogate for water use in this context. This data also would contribute to the identification of the model elements (variables) and the relationships among them. However, given time constraints and other process imperatives, the research team began to move forward with the collection of secondary data relative to water rights transfers without this primary research into the legitimacy of their standing as a surrogate for water use. As a consequence, it was not uncommon for team members to repeatedly question what the model was trying to accomplish. A quick review of model purpose and assumptions at the beginning of each team meeting might have kept the project more focused without subverting the facilitative approach adopted by the PI.

As described elsewhere in this report, it was only far into the project that the team as a whole finally concluded that the secondary data on water rights was so incomplete and inaccurate that it was not useable for this purpose. In addition, primary data collected through interviews showed that water rights per se were not the issue for most landholders. After the team reviewed the contribution of the primary data to the conceptual framework and how it changed some of the model variables, most members agreed that it would have been valuable to have collected that type of data earlier in the model development process. Overcoming the cost and process bias to this type of data collection by those outside the social science field could be an important issue in this type of research.

Along these lines, another important methodological finding was the difference in expectations between the quantitative, physical scientists and the social scientists. The quantitative scientists were focused to the end on making the model work as a measure of project success. Social scientists, on the other hand, are taught not to expect that an outcome envisioned at the beginning of a project will necessarily be the primary finding or benefit of the research. This is because social science data is often unwieldy, difficult to access, and/or time consuming to collect. The process of exploring the data is valued as an opportunity to discover issues that may not have been forecast when the project was being planned.

For the social scientists, the process revealed the importance and utility of computational modeling as a novel, potentially highly useful mode of representing and manipulating qualitative knowledge. This form of knowledge representation is quite different from the narrative form favored by qualitative social scientists. As one of the social scientists pointed out, computational modeling in the social sciences may have an analogous role to that of math in the physical sciences, insofar as both computational models and mathematical expressions force individuals to express their thoughts and represent their logic rigorously.

7.0 CONCLUSION

In this particular effort, issues around data sources and data quality and availability revealed an important problem; namely, that statewide policy is being made using incomplete, inconsistent, and minimal data about land and water resource use. Since changes in water policy and water use patterns may not make their impacts felt for several decades, this means that policy decisions could have significant and unforeseen impacts on future generations of MRGB inhabitants.

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