Agent Based Modelling and GIS for Community Resource Management: Acequia-based Agriculture

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1. Introduction

In northern New Mexico, water is a scarce and precious commodity. A traditional local system of water management involves landowners collectively maintaining and managing ditches which distribute water among the properties. This system of physical ditches and organization together are known as an acequia, and the landowners who maintain it are called parciantes. The water carried by the ditches is a shared resource, and the complex management system of the acequia has evolved to avoid Hardin's Tragedy of the Commons with regard to natural resources (Hardin 1968).

Despite the historical strengths of acequias, parciantes are increasingly pressured to convert farmland into residential space. Any effort to protect this traditional form of agriculture relies an understanding of how the different parts of the system interact and how rigorous the system is to perturbation. This simulation seeks to model land use in acequia-dependent Taos, New Mexico. As an example of the area, fig. 1, displays a map of the tracts of land associated with this form of agriculture. The goal is to construct a tool that will allow a researcher or policy-maker to understand and interact with the acequia system in an intuitive fashion. Fig. 2, is an example of the simulation interface.

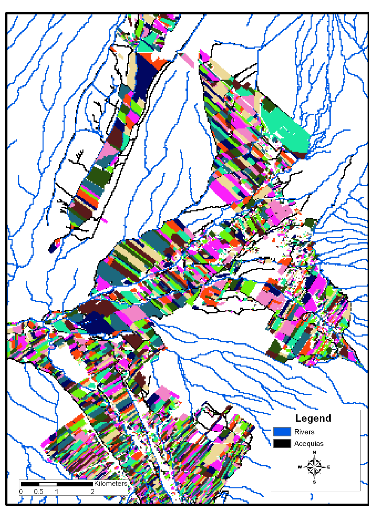

Figure 1. Tracts of land owned by parciantes in Taos, New Mexico.

2. Methodology

The simulation is a spatially explicit agent-based model programmed in Java using the MASON Simulation Toolkit (Luke et al, 2005). It is made up of modules which capture the physical, economic, and social processes that impact land use patterns in the Taos area. The model includes a series of maps showing the spatial environment, graphs which track statistics about parciantes and urbanized versus agricultural land use, and an interface which allows to user to hide layers of information or modify the parameters of the environment mid-run.

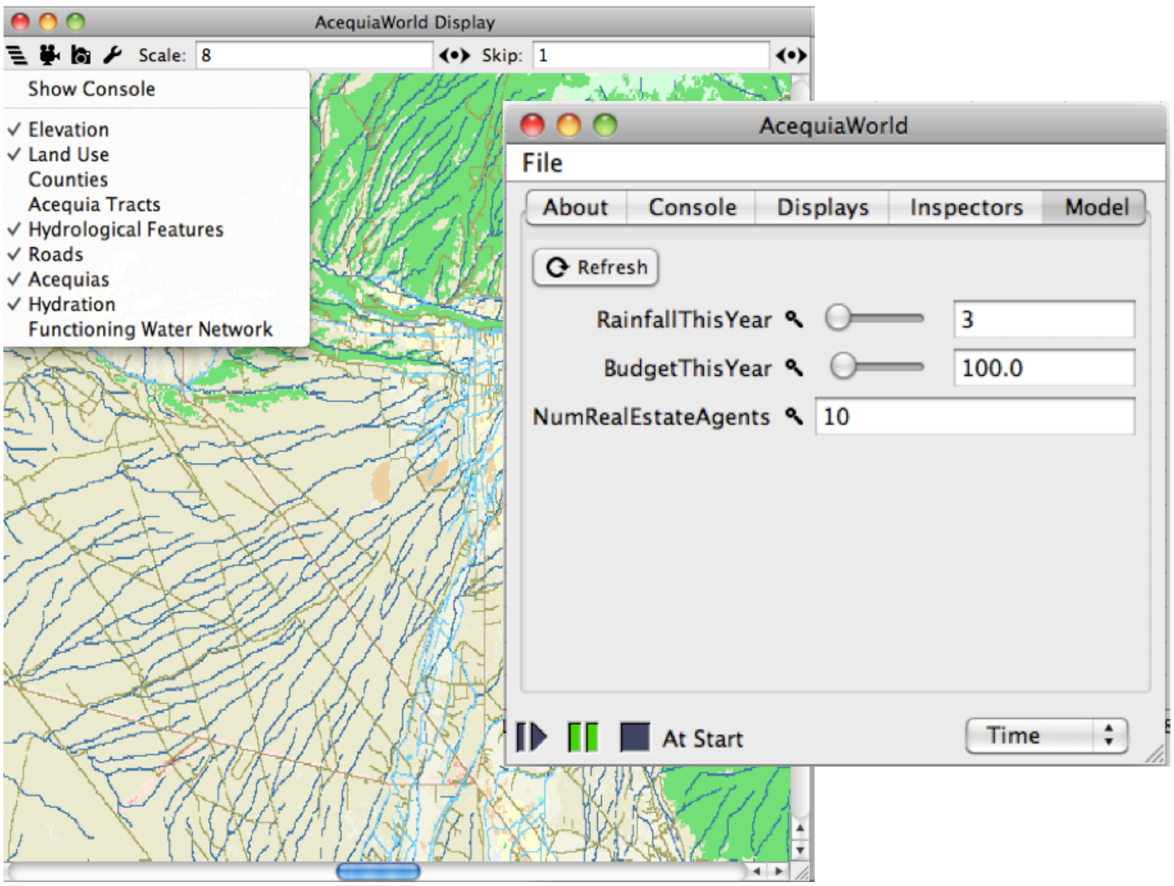

Figure 2. A sample run with user interface.

2.1 Data

Data utilized within the model as shown in fig. 3, comes from the work of Michael Cox (2010) and are supplemented with GIS information from the USGS's EarthExplorer. The area of study is the county of Taos, New Mexico and its surrounding area. The information was processed into 30m^2 raster grid cells. The land use classification utilized here is described in Homer's work about the National Land Cover database (2007).

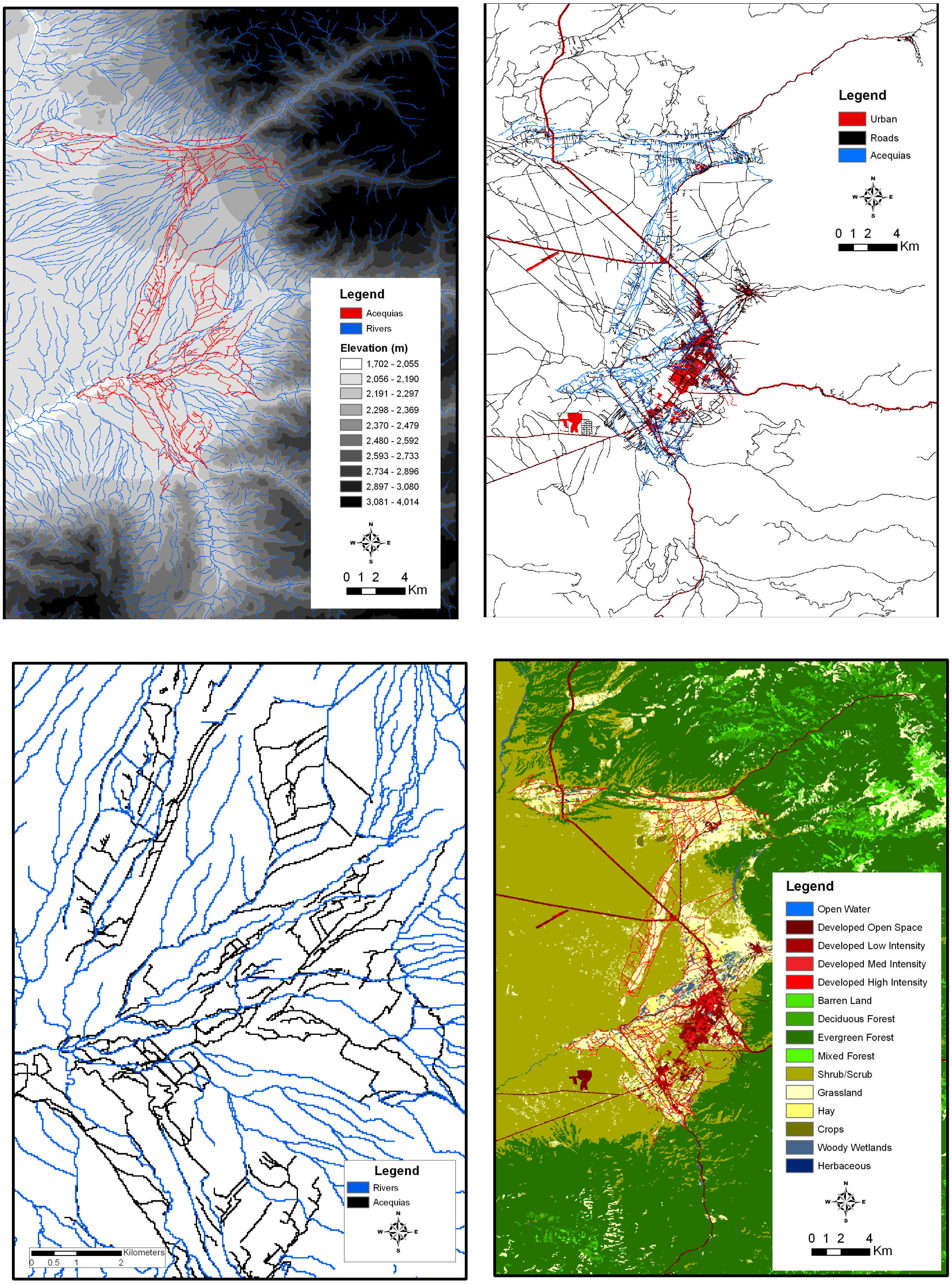

Figure 3. GIS data used within the model include (in clockwise order) elevation, urbanization, land use data, and waterways.

2.1 Simulation

Acequias are a complex system, and the importance of low-level dynamics makes it difficult to understand the macro-trends in local development. In this simulation, water, land, parciantes, and real estate agents are all simulated to try to explain the turnover of agricultural land into urbanized, residential space as the process is impacted by the ever critical question of access to water.

The propagation of water through the environment is accomplished by a network of rivers and acequias. Acequia links are special because acequias build up sedimentation - or decay the weight of the relevant water system link - every year unless they are maintained. A fraction of the water that flows through the decayed link is lost. An unmaintained section of acequia can thus eventually cut off all ”downstream” nodes from access to hydration.

Land is a passive object, in that it is irrigated by the water network and cultivated by Parciantes. Parciantes can choose to grow various kinds of crops on their parcels of Land tiles, and the income from a parcel of tiles P on which a crop C is planted is given by equation 1.

$$I_p = C_{price} \ast P_{size} \qquad (1)$$

The income derived from various crops is user-determined. As Parciantes hold multiple units of land as part of their land parcel, it is possible for one Parciante to plant a different crop on each of his units of land.

Parciante agents represent the individual acequia owners who make land use and acequia maintenance choices in the real world. In the context of the simulation, Parciantes choose whether to maintain their acequias, plant crops, and sell their land. They have a number of attributes, including a set of Land tiles, a sum of money, and a ’strategy’. The money attribute reflects agent resources, and if its value dips below a certain level the Parciante is forced to sell his land to any bidder. Money is expended when the agent helps maintain his acequia: the cost is a function of the length of the acequia A and the number of Parciantes N as shown in equation 2.

$$C = A_{length}/N \qquad (2)$$

To reflect the importance of cultural heterogeneity and personal preference in these decisions, Parciante agents are further endowed with a ’strategy’ that defines their approach to land use decisions. One example of such a strategy is the Traditionalist, who values his land and will hold onto it as long as his money holds out. A different strategy, the Sheep, leads the Parciante to observe what his neighbours are doing, and emulate the behaviour of the majority.

Real Estate Agents represent the rising demand for housing in the area, and their goal is to buy and develop as much land as possible. These agents are endowed with a certain budget and make offers to individual Parciantes. The offer prices follow the model of Filatova et al. (2009), that given an agent with budget B bidding on a parcel with transport cost T (proportional to the distance of the parcel from the road), the utility U is a function of the amenity A (here, the parcel size) and normalized distance from the economic centre P weighted by a factor b. The offer price O is thus determined by equations 3-5.

$$Y = B - T \quad (3)$$
$$U = A^{\alpha} P^{\beta} \quad (4)$$
$$O = Y\, U^2/(b^2 + U^2) \quad (5)$$

If the Parciante agent accepts the Real Estate Agent's offering price, the parcel of land is urbanized and the Parciante removed from the simulation. The distribution of Real Estate Agent budgets is determined by the user and can be modified mid-run. Fig. 4, sketches out the interactions between the agents in the simulation.

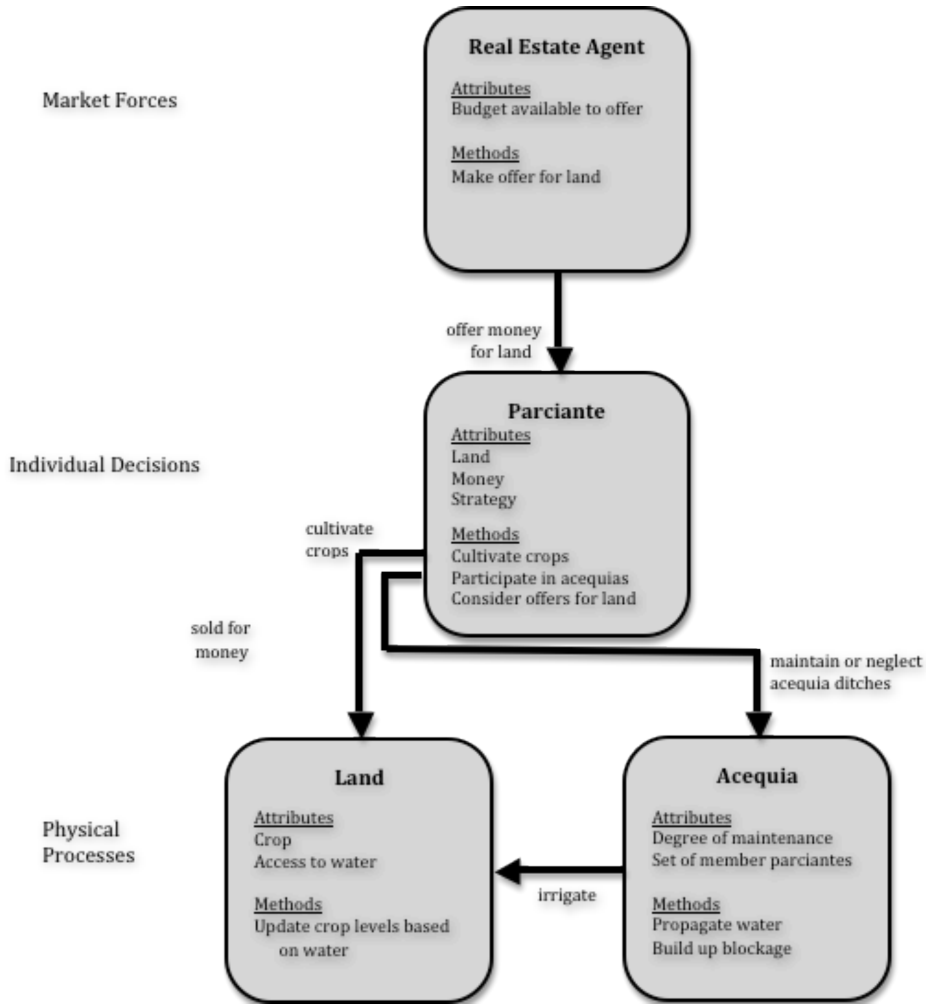

Figure 4. A flowchart of interactions between different kinds of agents.

3. Results

We have only begun to explore the vast range of experiments that the model presented here can represent. Verification has been completed and advanced validation is underway and will be presented at the conference.

The model was built in an iterative fashion, ensuring that each of the submodules demonstrates the appropriate behaviour over the space of inputs it can accept. The water network, for example, was tested by deactivating all of the Parciantes and allowing the acequias to go unmaintained for several decades as shown in fig. 5. As for validation, the land use output of the model looks reasonable upon inspection, but we plan to extend the validation process further by comparing it with the real land use patterns of the area derived from land cover data collected in 2008 using the Map Comparison Kit (Visser and de Nijs, 2006).

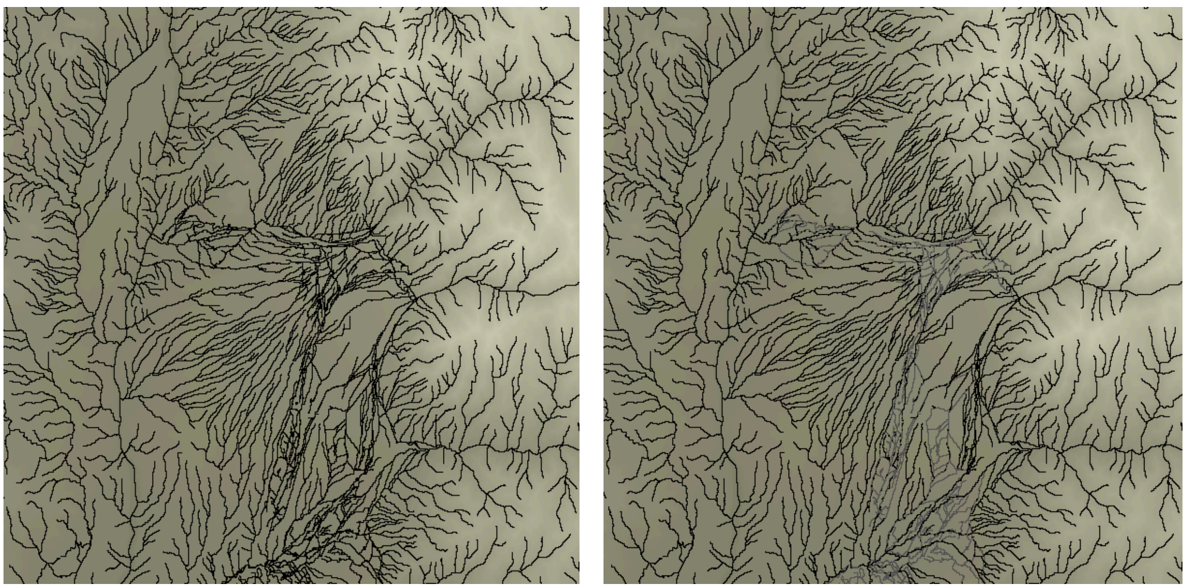

Figure 5. A view of the water network link weights at the beginning (left) and after 30 years of neglect (right). Darker links are stronger.

4. Conclusion

The model presented here uses empirical GIS data to build a realistic model of a complex socio-physical system. By representing the interacting physical, economic, and social processes, the interconnected nature of the acequia system is more precisely represented. It is the authors' hope that this model will be used by researchers seeking to answer questions about the rigorousness of this community resource management system, its specific strengths and critical weaknesses, and how to protect this traditional way of life.

5. Acknowledgements

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