Long-term Dynamics of Acequia Population in New Mexico

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Abstract

There is evidence that traditional irrigation communities in New Mexico, United States, which are also known as acequias, benefit the state's socio-economic-hydrologic systems in many respects. Despite their long-term resistance to their arid environment, these communities have been declining since 1980s. This paper identifies socio-economic-hydrologic mechanisms responsible for such decline and explores potential challenges that it may impose to both rural and urban life in New Mexico. Results show that current trend of urban growth is not sustainable. Turning the trend is shown to be extremely difficult, though. Sensitive areas of the system are identified and directions for future research are suggested. Additionally, the presented model provides a basis for future modeling in the political economy of acequias.

1 Introduction

Acequias[1]–a network of community managed irrigation systems–are key to sustainable extraction and distribution of water resources in the state of New Mexico, United States since the 16^{th} century. By diverting water throughout the floodplain, acequias provide the society with human (e.g., domestic water), agriculture (e.g., crop irrigation and livestock water), ecologic (e.g., riparian habitat support), and hydrologic (e.g., enhanced surface water-groundwater connectivity; aquifer recharge) benefits. However, system dynamics simulations, performed by Turner et al. [2016] and summarized in Figure 1, show that population of acequia community has been declining since 1980s. In fact, many acequia members, while still living in the rural areas, abandon the traditional practices in pursuit of higher incomes provided by external job opportunities in urban areas.

[1] The term acequia is derived from Arabic as-sāqiya, meaning water conduit.

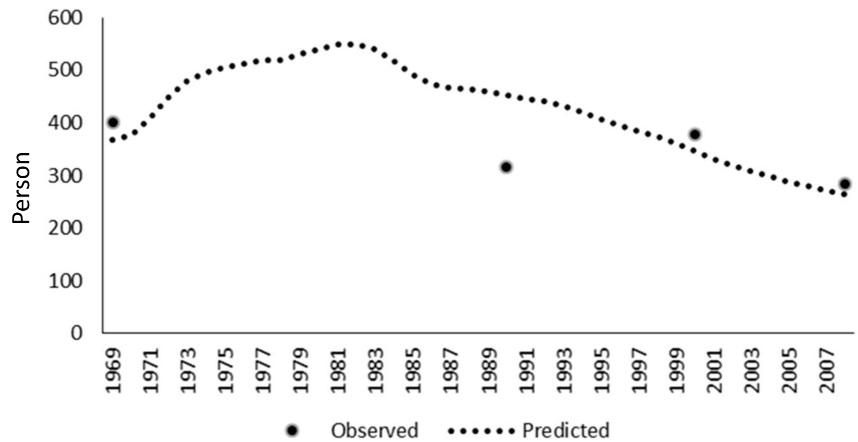

Figure 1: Estimated population of acequia community vs. actual data [Turner et al., 2016]

Historical data from Decennial Census, U.S. Census Bureau (retrieved from ICIP [2017]), illustrated in Figure 2 show that rural population, although growing in total numbers, has been declining significantly relative to urban population over the last century.

Considering the benefits that traditional agricultural activities provide for ecology of New Mexico, disappearance of rural population, in general, and acequia community, in particular, might cause serious challenges to the state. The challenges may be even harder if we take into account chronic drought that the state has been facing with over the past decade. Sustainability of the acequia community is indeed critical for the state to weather the future challenges.

The model that is developed in this paper predicts the potential challenges. Prediction of the system's behavior from 1900 to 2300 is shown in Figure 3. Despite significant decline of rural population until mid 21^{st} century, the urbanization trend decelerates and even reversed during 2030s and 2040s. Rural population then is stabilized at about 37%.

Reason for such a change in urbanization trend could be explained by overshoot and decline of urban capital. Exponential growth of urban capital until 2050s takes place due to the increasing urbanization trend and the economic investment associated with it. This expansion, however, undermines traditional agricultural activities which are extremely beneficial to maintenance of groundwater and other ecological systems [Groenfeldt, 2006, Raheem et al., 2015]. Consequently, natural capital declines. Urban growth which relies on support of natural capital decelerates and eventually goes negative (capital decay becomes greater than investment). As urban capital declines, pressure on natural capital decreases so a new steady state will be reached at a lower level than the

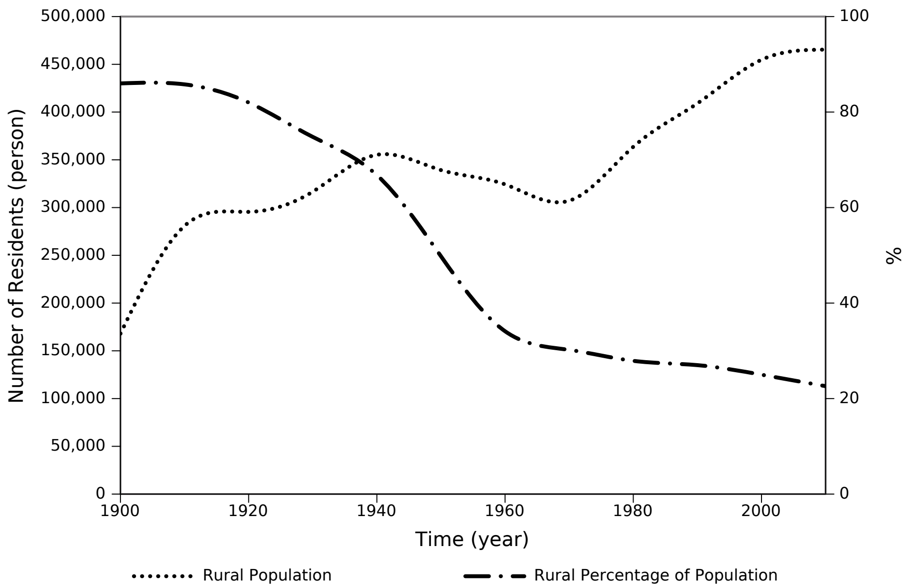

Figure 2: Historical trend of rural population in New Mexico [ICIP, 2017]

economic prime in 2050s.

Causal structure responsible for the presented behavior is discussed in further details in Section 2. This is, in fact, an effort to develop a generic model to address the decline of acequia community and potential problems it may create for the state of New Mexico. The model is used to generate insights that may be helpful for alleviating the problems. To build confidence in the model's output, validation tests performed and sensitivity analysis conducted are reported in Section 3. Outcomes of the analysis are discussed in Section 4. And, Section 5 concludes the paper.

2 Model Structure

The model that is developed in this paper stands on the shoulder of a previously developed system dynamics model by Fernald et al. [2012] and Turner et al. [2016]. Most of the causal relationships of the current model are adopted from their work. However, there are some fundamental differences between the models. Most importantly, dynamics of urbanization and land and water markets were exogenous to the original model [Turner et al., 2016, p. 6]. In the current model, however, these dynamics are included as endogenous mechanisms. We believe that these mechanisms are key to explain decline of acequias. Another important difference between the models is their simulation time range. The simulation range of the origianl model is (1969,2007). The current model,

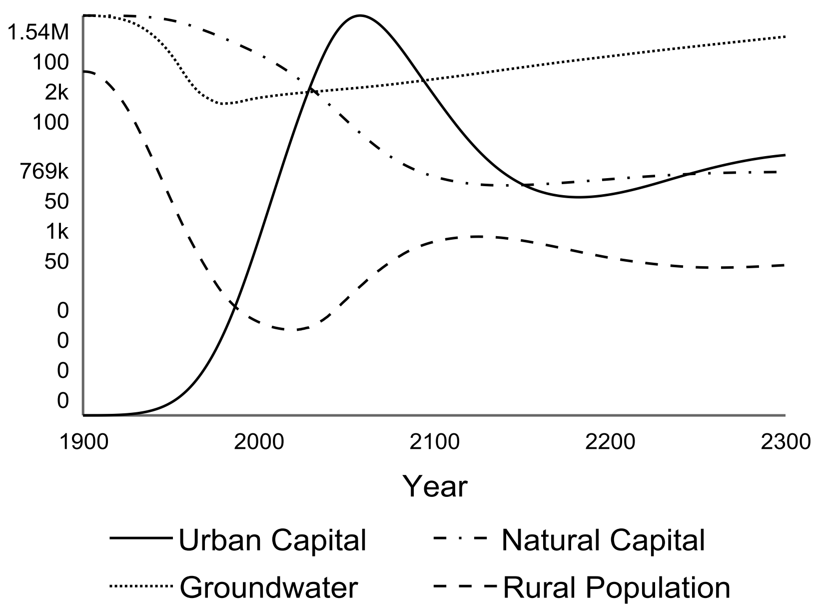

Figure 3: Distribution of population for the base case simulation

on the other hand, has a much wider simulation range spanning four centuries (1900,2300). In other words, the original model does not attempt to predict the future behavior of the system while the current model does. Finally, the original model uses many historical time series as exogenous drivers of the model's behavior—a practice that is deprecated by prominent system dynamicists. According to Forrester [2007, p. 365], system dynamics models must be "completely endogenous with no external time series to drive [them]." Therefore, the current model exclusively relies on endogenous structures.

The model is organized in 4 modules as shown in Figure 4. Modules are "population," "farming," "capital," and "hydrology." "Population" module affects "capital" and "farming" by providing workforce. It also impacts "hydrology" by consuming water. "Capital" has impact on the distribution of "population" through urbanization process as well as on the "hydrology" system through urban demand for water. "Farming" activities influence distribution of "population" by affecting farmers' attachment to the land. It also determines demand for irrigation water which impacts the "hydrology" system. In addition, "farming" might affect the "capital" module by changing the pace of urbanization. Finally, "hydrology" determines level of water availability for all other modules, thus affecting water use in industrial, agricultural, and residential sectors. Each module is described in the following subsections in further details.

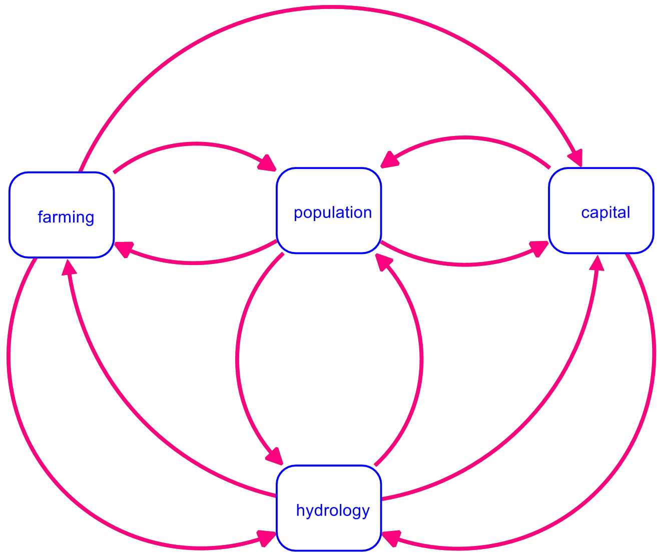

Figure 4: Module view of the acequia model

2.1 Population

Figure 5 shows the structure of "population" module. Population here is broken down into three categories:

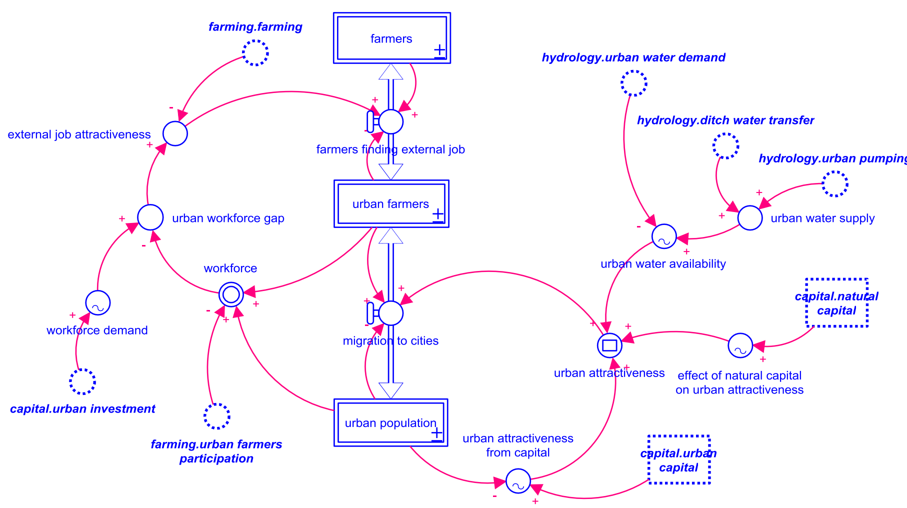

Figure 5: Structure of the population module

- **Farmers** work in the agricultural sector and reside in rural areas. They are primary contributors to the acequia activities.
- **Urban farmers**, although living in rural areas, have some occupation in urban areas. They may contribute to the acequia activities too but with a lower-than-normal rate.
- **Urban population** live in urban areas and primarily work in industry and (or) business.

The model does not track absolute numbers for each stock of population; instead, their relative values are computed. In other words, each stock of population represents a percentage of total population. Therefore, growth (decline) of total population is not addressed by this model[2].

Acequia farmers may find external jobs in urban areas and become less active in farming and traditional activities. This process is captured by the flow rate "farmers finding external job." This flow can be positive or negative[3] depending on attractiveness of external jobs. "External job attractiveness" is a function of prospects of farming relative to income opportunities in urban areas which is represented by "urban workforce gap." "Urban workforce gap," in turn, shows discrepancy between supply and demand[4] of workforce.

Farmers can permanently move to urban areas through the rate of "migration to cities." Migration happens if urban areas are more attractive than rural areas. "Urban attractiveness" is assumed to be a function of three major factors. First factor is urban development. As cities develop, more amenities will be available for citizens. In other words, material standard of living in cities increases. That means better healthcare provision, access to higher education, modern entertainment, etc. Second factor is the natural capital that supports urban areas. Natural capital provides services to urban areas without which urban life could become incredibly difficult. Preventing floods and sand storms, providing pleasant landscape and aesthetic features, and absorbing pollutants are a few examples of such services [Groenfeldt, 2006, Fleming et al., 2014]. Third factor affecting urban attractiveness is availability of water. While urban and natural capital may impact attractiveness with some time delays, water availability, as a function of urban water supply-demand ratio, is a crucial factor that impacts the urban life immediately. Indeed, no city can live without water.

2.2 Capital

Structure of "capital" module is shown in Figure 6. Urban capital is an aggregation of all sorts of equipment, facilities, constructions, infrastructure, etc. that support production and consumption in urban areas. Urban capital increases by "urban investment" and declines through "urban capital decay."

[2] This could be considered as a limitation of the model and is open for future modeling efforts.

[3] When the rate is negative, "urban farmers" quit their urban occupations and work exclusively on farms.

[4] Workforce demand is implicit in the model and is calculated from "urban investment."

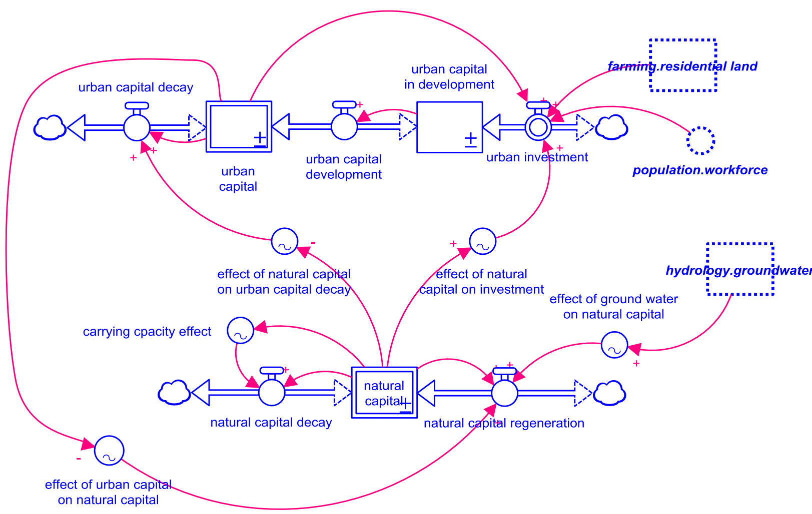

Figure 6: Structure of the capital module

Urban investment expands if there are enough "residential land," "workforce," and "natural capital." Natural capital also affects life cycle of urban capital. It helps to prevent many ecological hardships such as flooding and sand storms which may impose significant damage to infrastructure and amenities in urban settings.

Natural capital itself could grow and decline independent of human intervention. However, it is assumed that it remains in a steady state if no human disturbance is occurred. Natural capital regenerates by a constant rate which could be affected by the level of groundwater. In fact, it is shown that groundwater plays a key role in maintenance of natural capital [Kendy and Bredehoeft, 2006, Groenfeldt, 2006, Fernald and Guldan, 2006, Fernald et al., 2007, 2012, 2015]. Therefor, it is assumed that level of groundwater positively affects natural capital regeneration rate. Urban capital also has a direct negative impact on natural capital through consumption of natural resources. To simplify, this impact is aggregated in formulation of natural capital regeneration rate. There are other factors influencing natural capital as well but they are out of the boundary of this study.

2.3 Farming

Figure 7 depicts structure of the "farming" module. There are three production factors contributing to farming: "farm land," "irrigation adequacy," and "active farmers." Adequacy of irrigation water is a function of water supply-demand ratio. Total supply of water for irrigation is equal to summation of "actual ditch delivery" and "irrigation pumping" which will be explained in Section 2.4. Total demand of irrigation is determined by the land that is used for farming, "farm land."

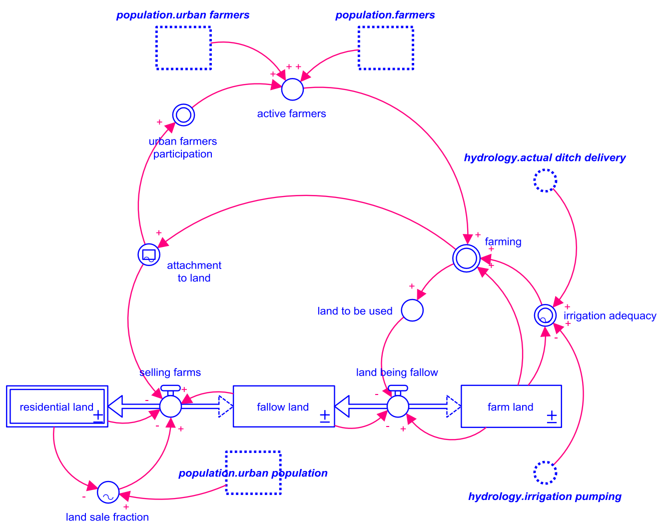

Figure 7: Structure of the farming module

Total land is assumed to be constant and is distributed to three different states. "Farm land" represents percentage of total land that is used for active farming. "Fallow land" represents percentage of total land that is left fallow. And, "residential land" represents the remaining land which could be used for residential, industrial, or business purposes. Farms could become fallow if desired land use ("land to be used") declines. Farms that remain fallow for a long time might be sold depending on two factors. First is the pressure from the urban population. If distribution of population moves toward urban areas then more "residential land" would be needed. That increases pressure on farmers to sell their lands—through a price mechanism that is implicit in the model. The pressure could be manifested by inflated land prices, for example. As more land is sold "residential land" increases, thus, "land sale fraction" declines. Second factor affecting farm sale is "attachment to land." Farmers who have spent many years doing farming on their land, become attached to it and feel a psychological barrier to sell their farm lands. This may prevent, or at least delay, the sale processes [Beedell and Rehman, 2000, Mayagoitia et al., 2012]. "Attachment to land" may also affect "urban" farmers' willingness to participate in acequia traditional farming activities which is called here as "urban farmers participation" [Mayagoitia et al., 2012, Fernald et al., 2012, Turner et al., 2016].

2.4 Hydrology

The hydrology system, as shown in Figure 8, consists of surface "water" system and "groundwater" system. Stock of (surface) water (measured in Cubic Kilometers) represents all transforming water on the surface and available water in channels including main river channel and artificial ditches. There are two rates flowing out of “water.” One is “ditch delivery” which is total farmers’ withdrawal for irrigation use. The other is “outflow” which aggregates all other streams out of the system of surface water.

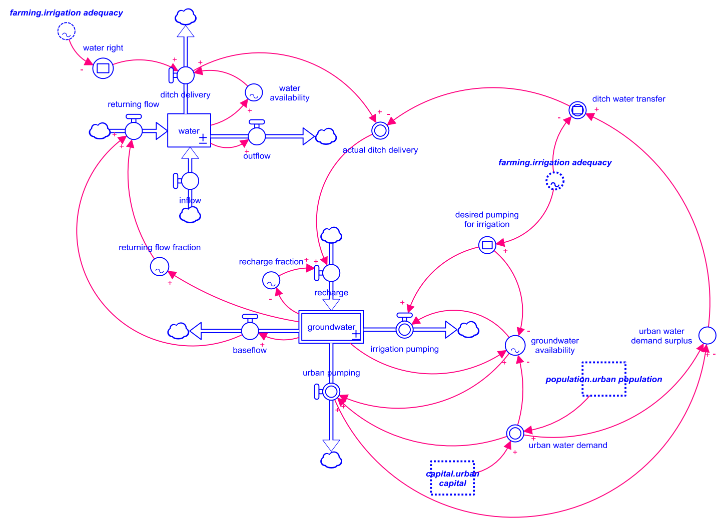

Figure 8: Structure of the hydrology module

“Ditch delivery” is usually equal to total “water right” of farmers. However, it may be bounded by availability of “water”: “ditch delivery” would decline if level of water declines. Water right could also change based on adequacy of water for irrigation. These changes, nonetheless, may be subject to very long delays.

Main input to stock of “water” is “inflow” which includes precipitation, upstream flow, and returning water (from upland back to lower reach). Another input is “returning flow” which includes seepage of irrigation after evaporation returns to the river. A fraction of “baseflow” returns to the surface water depending on level (thickness) of groundwater. As level of groundwater increases, a larger fraction of baseflow flows back to the surface water.

Baseflow is groundwater recession flow that streamflows back from surrounding groundwater. Other than baseflow, there are two other outflows from groundwater: “urban pumping,” and “irrigation pumping.” “Urban pumping” represents amount of water that is extracted from groundwater for urban (residential, industrial, etc.) use and depends on “urban water demand” and availability of groundwater. If the level of groundwater is sufficient for current demand, then water will be pumped out as much as needed; otherwise, the extraction will be limited.

Urban demand for water is a function of “urban population” and “urban capital.” Higher levels of urbanization require higher levels of water consumption. Water consumption per unit of urbanization is assumed as constant. Since population is measured in relative terms (percentage), it should be safe to assume no relative evolution in water conservation technologies.

Urban consumption is not the only usage of groundwater, though. Agriculture is the other user and is controlled by "irrigation adequacy." If current supply of water is not adequate for irrigation demands, "desired pumping for irrigation" would increase and vice versa. Not as much as irrigation water that is desired may be extracted though. Similar to urban use, this pumping requirement might face with a limit which is imposed by "groundwater availability" indicator. Availability of ground water is a function of groundwater demand relative to total groundwater available. If demand relative to available groundwater increases then the "availability" indicator declines.

Finally, groundwater could be recharged through seepage from irrigation. In fact, a fraction of water that is used for irrigation ("actual ditch delivery") could return to the aquifer. That fraction is dependent on thickness (level) of groundwater. As level of groundwater increases "recharge fraction" declines [Lutz et al., 2014, McMahon et al., 2011].

"Actual ditch delivery" is equal to "ditch water transfer" subtracted from "ditch delivery" i.e. amount of water that remains for irrigation after transfers to urban users. Based on local water right policies [Brown et al., 1992], farmers and local rural residents can transfer their water right to other users in order for the state to improve efficiency of water consumption. Water transfers may occur if there is a demand pressure from urban areas and if there is adequate water for irrigation.

3 Model Validation

Confidence building in a model's output is a gradual process. There are many validation tests that a model should pass through [Forrester, 1973, Forrester and Senge, 1980, Barlas, 1996]. The model presented in this paper has been subject to most of these tests including dimensional consistency, integration error, extreme conditions, behavior anomaly, surprise behavior, and sensitivity analysis. Current version of the model can successfully pass these tests. Boundary adequacy tests, structure assessment tests, and parameter assessment tests are also conducted but only at a rudimentary level[5].

3.1 Behavior reproduction

The model, although focused on New Mexico, is still a generic model that should be able to address a class of family member problems with similar characteristics as possessed by the acequia problem. We know that historical fit is a weak test for model validity of such generic models [Forrester, 1973, Forrester and Senge, 1980, Sterman, 1984, Radzicki, 2004]. As Forrester [2013, p. 30] has written:

[5]Deeper and more comprehensive analysis, which as our next step, are still needed to increase confidence in the model's results.

> There is no reason that a generic model should reproduce any specific historical time series. Instead, it should generate the kind of dynamic behavior that is observed in the systems that are being represented. If one runs the model with different noise sequences one will get simulations that have the same character, but not the same values at different points in time. Likewise, the time series from an actual economy represent only one of a multitude of detailed behaviors that might have occurred if the random effects in the real system had been different. In other words, historical data from a real economy should be interpreted as only one of a multitude of possible data histories.

However, qualitative replication of historical behavior (reference mode) is necessary to build confidence in a model's output [Sterman, 1984]. Hence, base run simulation of the model for the variable "rural population" which represents percentage of population living in rural areas—as the main variable of the model—is compared with the historical data in Figure 9. As we can see, the model reproduces historical decline of rural population relative to urban population reasonably well[6].

3.2 Sensitivity analysis

To test sensitivity of the model to its parameters, 3 simulation runs are performed for each parameter. Run 1 represents the base case with default parameter value. Run 2 represents the simulation with a lower-than-default value of the parameter. And, Run 3 represents the simulation with a higher-than-default value of the parameter. The sensitivity analysis[7] reveals that the model's behavior is sensitive to the following parameters.

3.2.1 Capital life

This parameter represents average life cycle of urban capital such as infrastructure, equipment, technology, construction, etc. which support production and consumption activities in urban areas. Default value of the parameter is assumed to be 20 years. Variation range is (10,40). Figure 10 shows the results for two key variables of the model ("rural population" and "urban capital"). Longer capital life—equivalent of a system with cheaper capital maintenance—generates disastrous outcome. Urban capital collapses dramatically after 2050s and consequently, urban population moves (almost completely) to rural areas. Shorter capital life—representing a system with more expensive capital maintenance—yields a smoother outcome, although with a lower steady state level of urban capital at the end of simulation. There is no collapse is this case. However, rural population almost disappears which may not be a desired outcome.

[6]Currently, we are collecting data for other variables of the model so that a more comprehensive model calibration becomes possible in our future modeling efforts.

[7]Complete results are reported in the document that is submitted along with the paper as supporting material.

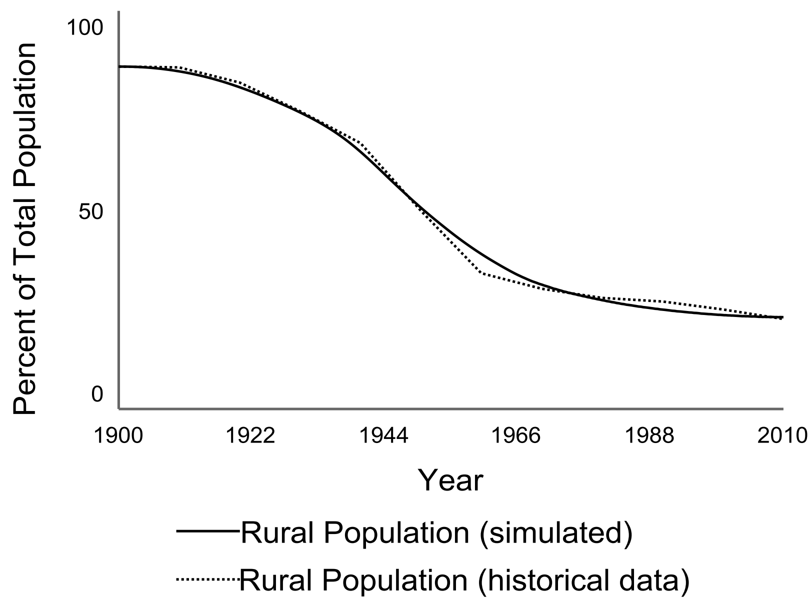

Figure 9: Rural population as a percentage of total population (simulated vs. historical data)

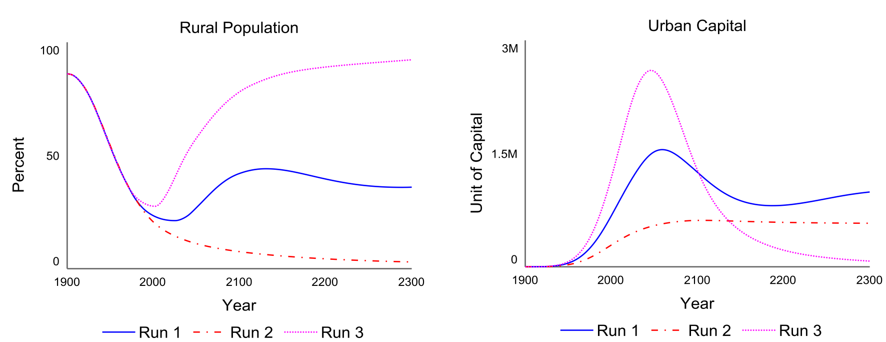

Figure 10: Sensitivity of the model's behavior to "capital life"

3.2.2 Urban investment exponent

Urban investment is a form of Cobb-Douglas function as shown in Equation 1. Elasticity of the function could be adjusted by a parameter (represented here by α), default value of which is assumed to be 0.5.

$$investment = (production factors)^{\alpha} \tag{1}$$

The model is extremely sensitive to this parameter. As shown in Figure 11, a small variation in the parameter dramatically changes the model's behavior. Therefore, a more precise modeling should employ a carefully estimated production function for the urban investment.

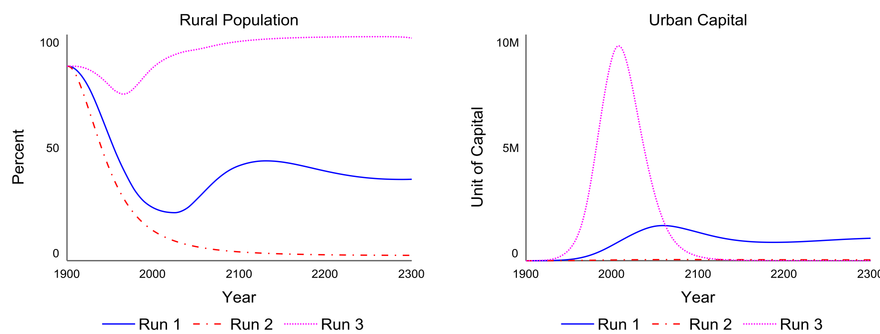

Figure 11: Sensitivity of the model's behavior to "urban investment exponent"

Implication of this test is very similar to the previous one: more expensive investment (i.e. smaller α) generates smoother urban growth while cheaper investment (i.e. larger α) leads to aggressive overshoot and decline of the urban capital.

3.2.3 Farming exponent

"Farming exponent" represents elasticity of the "farming" function. "Farming" indicates acequia traditional agricultural activities. It changes from 0 (no activity at all) to 1 (maximum level of activities). Sensitivity of the model to this parameter is shown in Figure 12. Default value of the parameter is 0.5 with variation range of (0.1,0.9). The model is not sensitive to higher values of the parameter but it is to the lower values (¡0.5). When the value is lower, "farming" is more likely to be closer to 1, thus representing a more resistant acequia system. This resistance sustains the rural population at a higher level with no major upheaval. Urban capital grows at a much lower rate, in turn.

3.2.4 Water demand constant

This parameter represents amount of water that is needed per unit of urban capital-population. Default value of the parameter is 0.010 Cubic Kilometers per year and it varies within the range (0.005,0.020). Figure 13 shows the model's response to the variation. As we can see, the sensitivity is considerable.

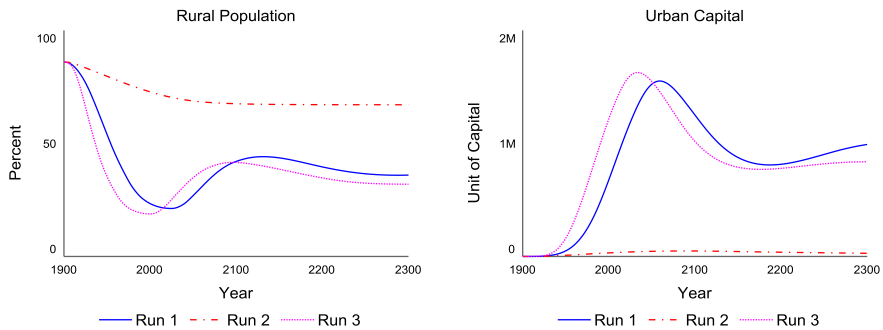

Figure 12: Sensitivity of the model's behavior to "farming exponent"

Interestingly, however, more efficient use of water in urban areas will not change the final steady state value of the urban capital significantly. This case causes an even more violent upheaval in urban development and leads to demise of rural population. In fact, more efficient use of water helps the urban capital grow faster. The accelerated urban growth continues until the natural capital declines to critical point where further growth becomes very difficult. Urban capital starts to collapse but urban population do not move back to rural areas because agriculture, and thus rural life, is almost extinguished now.

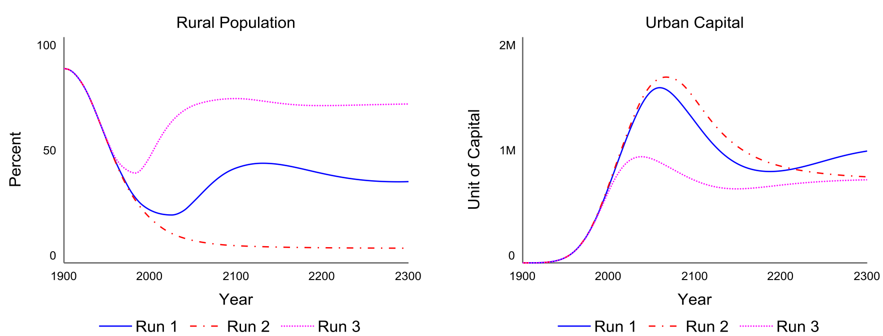

Figure 13: Sensitivity of the model's behavior to "water demand constant"

4 Discussion

Our study shows that current urban growth in New Mexico may not be a sustainable trend. Excessive growth of urban population and capital is predicted to irreversibly damage natural capital through decline of groundwater resources which have remained intact due to acequias' sustainable water management practices over centuries. These results are achieved from a relatively simple model in absence of population growth and long-term drought that have been the case over the past decade. In other words, unsustainable behavior of the system is caused by its internal mechanisms that are inherent in it and not by external, uncontrollable factors.

Urban capital life, urban investment, farming, and water demand constant, are identified as the sensitive points of the model. For example, investment to improve efficiency of water use in urban areas turns out to be an abortive solution for the decline of water resources which causes the urban capital to fail. This potential solution may even deteriorate the collapse by accelerating the growth process and thus causing a more sever overshoot and decline.

In general, policies that promote urban growth may work in the short- and mid-term but they undermine natural capital in the long-run and cause the urban capital to collapse. The average gain of the society from the urban growth over the long-run might be significant though. However, there is a political choice that the society must make between two cases: more significant material standard of living with higher levels of consumption vs. more stable (sustainable) material standard of living with higher quality—but lower levels—of consumption. Experimentation with the model reveals that it is almost impossible to achieve both simultaneously.

Demise of traditional agriculture in general, and acequias in particular, is not only a problem for the traditional communities, identity of societies, and the culture[8], but also a bigger challenge for the urban and modern settings. Urban population cannot survive without maintenance of the natural capital—a service that has been provided by acequias for many years [Fernald et al., 2012, 2015, Raheem et al., 2015].

Acequias' traditional agriculture enhances vegetative cover and diversity, support wildlife habitat, recharge shallow aquifers, sequester carbon, improve air and water quality, retain storm-water flow, and control flooding. They also provide nutrient cycling and soil formation, ecotourism and environmental education, extension of the irrigation season, and aesthetic enrichment in ecological landscape diversity [Fleming et al., 2014]. Furthermore, acequias provide a nexus of cultural and social continuity, preserving the historic settlements and local cultures spanning major periods of political development from 1598 to the modern period [Rivera, 1998].

Our analysis also reveals that policies that merely target growth of acequias will ruin urban life. For example, consider a ban on water right transfer. Acequias are allowed to transfer their irrigation water right to others which might eventually be used for non-agricultural activities. Urbanization is alleged to play a key role in emergence of such transfers. Farms convert to residential lands so farming activities decline. Less water will be needed for irrigation then, thus the

[8]These issues have actually been excluded from our analysis. Nonetheless, one could easily realize that inclusion of these factors would strengthen the argument posed by this paper.

unused water will be transfered. These transfers are deemed to explain parts of the urbanization trend as well. Farmers sell their water so there will be less water available for irrigation. Farm lands become fallow as a result, so land sale becomes a more attractive choice [Fernald et al., 2012]. This creates a vicious positive feedback loop that causes the acequias community to decline. The policy that is tested here tries to break this positive feedback loop by eliminating possibility of water right transfers. Figure 14 shows the impact of the policy on the model's behavior.

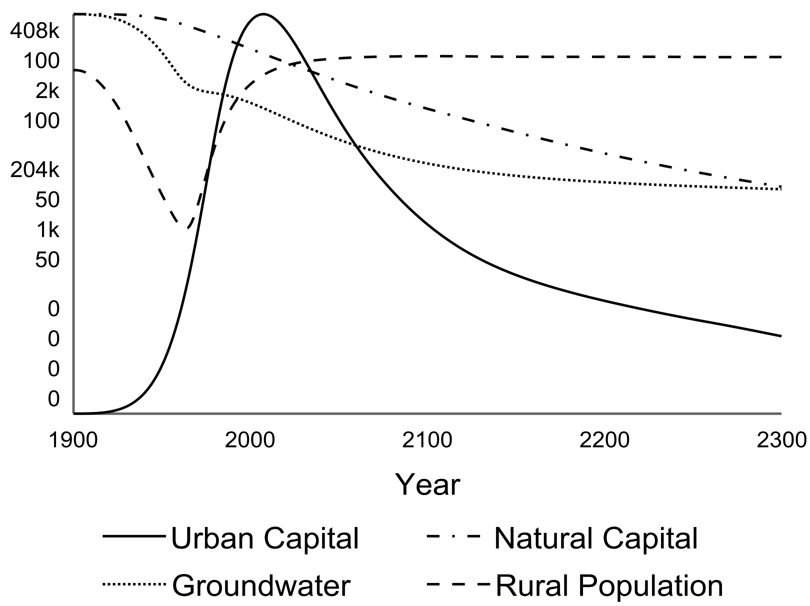

Figure 14: Impact of water transfer ban on long-term dynamics of the acequia model

Although the policy revives the rural population but it also causes the urban capital to collapse. In fact, water shortage in urban areas reduces attractiveness of urban life. Collapse of urban life is harmful for the rural population. Through external jobs, urban capital provides added income, independent of farming, which could be considered as a coping strategy for acequias to weather periods of drought. In fact, external jobs have a positive impact on acequias' survival by providing additional sources of income [Fernald et al., 2015]. Moreover, urban growth creates demand for the farmers' products. Indeed, a balance between urban and rural growth must be achieved in order to maximize aggregate social welfare.

Another interesting finding is that acequias' lifestyle is mainly based on the preservation of savings rather than on the production of profit. Their traditional agriculture is to pass a way of life on to their offspring. From the farmer-rancher standpoint, their agricultural operations are successful as long as they do not create debt [Fernald et al., 2012, p. 3014]. The equation of "farming" in our model follows this general rule and is fundamentally different from formulation of "urban investment" in which the concept of growth is dominant. It is not difficult to show that how the model would behave differently if the formulation of "farming" was based on "growth" rather than on "maintenance." It will be an interesting topic for future research to investigate the role of farmers' pro-sustainability mindset in their historical decline. In other words, we argue that acequia community would not have been declined as much as they have if their mental model targeted economic growth instead of sustainability. And that could, of course, create another problem: growth of a rural population as destructive (toward natural capital) as the urban population. And, that would not have been sustainable either. Origins of this particular mentality is not clear. It might be due to nature of agriculture sector that is not as profitable as industrial and service sectors; so, over years, expectation of farmers have been adjusted to the situation. Or, maybe some more fundamental issues are responsible for the phenomenon.

5 Conclusion

In this paper a generic model of acequia population dynamics is developed based on a previously developed system dynamics model [Fernald et al., 2012, Turner et al., 2016]. The goal was to provide a basis for future modeling of acequia population dynamics and to predict qualitative behavior of the system over the long-term. More precisely, we hypothesized that current decline of traditional agricultural activities as practiced by acequia community in New Mexico could be detrimental not only to the rural population but also to the urban settings.

Simulation outputs support our hypothesis. It is shown that any attempt to promote urban growth will help prosperity of urban population in the short- and mid-term but with the expense of a disastrous collapse in the long-run. Our analysis also identifies sensitive areas of the system. This will help future studies to focus on high impact points of the problem. The points include urban capital life, urban investment function, farming function, and water demand constant.

Although the model has been subject to many validation tests but there are some limitations to the work. First, the model does not include population growth. Rural and urban population change as a percentage of total population. Inclusion of population growth could generate more interesting results. Nevertheless, we believe that it will not change implication of our results.

Second, demographics of the population is an important aspect of the problem which is also excluded from this analysis for the sake of simplicity. For example, younger people tend to be more open to migration. As they get older they become more sensitive to morality of farming and agriculture, thus more resistant to the temptation of migration. These factors affect dynamics of acequia population. Future modeling efforts could break down the current population structure so that demographics of the problem is also taken into consideration.

Finally, a comprehensive policy analysis has been avoided in this paper. This is mainly because the model is generic and not appropriate to prescribe tailored policies. Initial settings are set so that the model starts in equilibrium (not shown in the paper) and replicates the historical behavior. Many of the parameters, however, could be estimated by collecting real data from formal databases. A more careful estimation of parameters is required so that the model becomes more reliable for a real-world policy analysis.

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