Supplementary Materials: Modeling Acequia Irrigation Systems Using System Dynamics: Model Development, Evaluation, and Sensitivity Analyses to Investigate Effects of Socio-Economic and Biophysical Feedbacks

Benjamin L. Turner, Vincent Tidwell, Alexander Fernald, José A. Rivera, Sylvia Rodriguez, Steven Guldan, Carlos Ochoa, Brian Hurd, Kenneth Boykin and Andres Cibils

1. Systems Thinking and System Dynamics (SD) Iconography Orientation

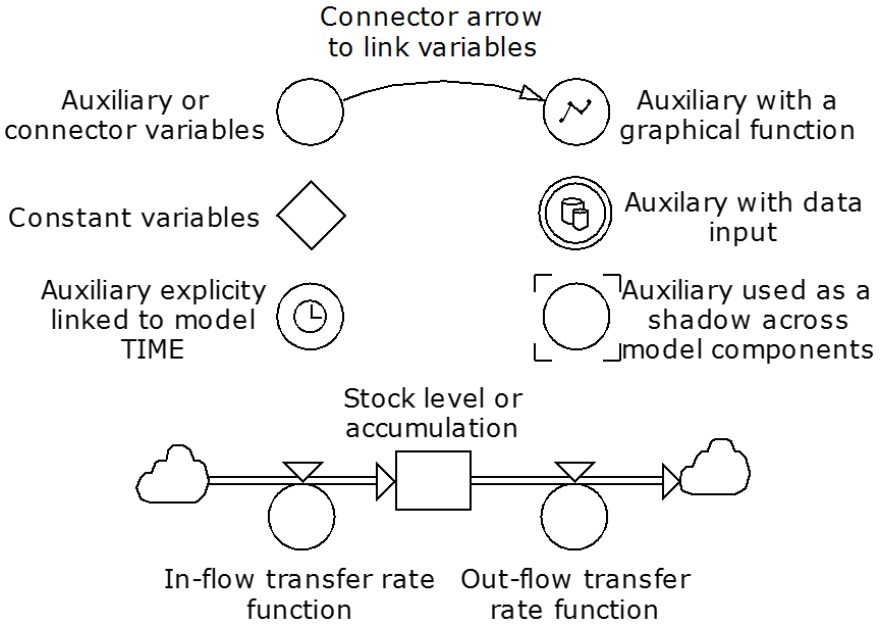

Figure S1. Symbols key of icon-based object used to construct the aceqiua SD model. Auxiliary variables are functions that connect or convert information from one location to be used in another (including delays, graphical functions, importing/exporting data, or acting as 'shadows' which connect multiple pages within a model). Constant variables are quantities assumed to be constant. Stocks are levels or accumulations over time in the parameter of interest and are influenced by inflows and outflows described as transfer rate functions. The thick black arrows pointing out of a variable denotes that the modeled data is exported to an external file at the end of each simulation. The clock hands of the auxiliary variables (or double line marks across a variable link) represent the time delays. The z-shaped line inside the auxiliary variable denotes the use of a graphical function to connect variables.

2. Supplementary Tables of Equations for Each of the SD Model System Building Blocks

Table S1. Key model equations for the Community Mutualism system building block.

Variable Name	Unit	Definition	Type
Mutualism needed to sustain acequia	cohesive	1	constant
Time needed to build mutualism	month	24<<month>>	constant
Mutualism gained through participation	cohesive	IF('Community participation strength'>0, ('Community participation strength'/4)*1<<cohesive>>, 0<<cohesive>>)	auxiliary
Building mutualism	cohesive/month	IF('Mutualism needed to sustain acequia'>'Acequia mutualism', 'Mutualism gained through participation'/'Time needed to build mutualism', 0<<cohesive/month>>)	auxiliary
Acequia mutualism	cohesive	0.85; Building mutualism - Eroding mutualism	level
Hypothesized stock of Acequia mutualism (or cohesiveness) of the community that is vital to maintaining agriculture and acequia hydrology components, time in agriculture, and therefore Community Participation Index.			
Time needed to erode mutualism	month	36<<month>>	constant
Eroding mutualism	cohesive/month	IF('Acequia leadership protecting mutualism'<=1, ('Acequia mutualism'/'Time needed to erode mutualism'), 0<<cohesive/month>>)	auxiliary
Acequia leadership protecting mutualism	dmnl	(('Commission support'+'Mayordomo strength')/2)	auxiliary
Change in CPI	month^-1	(('Acequia mutualism'/1<<cohesive>>) *'Acequia leadership protecting mutualism' *'Community participation index'/1<<month>>) -'Community participation strength'/1<<month>>	auxiliary
Community participation strength	cohesive	Change in CPI	level
Need to strengthen acequia leadership	month^-1	IF('Acequia mutualism'<'Mutualism threshold floor', 0.25/1<<month>>, IF('Acequia mutualism'>'Mutualism threshold floor' AND 'Acequia mutualism'<'Middle mutualism threshold', 0.15/1<<month>>), IF('Acequia mutualism'>'Middle mutualism threshold' AND 'Acequia mutualism'<'Upper mutualism threshold', 0.1/1<<month>>, 0/1<<month>>))	auxiliary
Mayordomo leadership quality	month^-1	0.9/1<<month>>	constant
Mayordomo changes	month^-1	MIN('Mayordomo leadership quality'+'Need to strengthen acequia leadership', 1/1<<month>>) - 'Mayordomo strength'/1<<month>>	auxiliary
Mayordomo strength	dmnl	1; Mayordomo changes	level
Commission support	dmnl	1	constant

Table S2. Key model equations for the Land Use system building block.

Variable Name	Unit	Definition	Type
Acequia land fragmentation rate	dmnl	((('Homestead size'*'Land sales rate and newcomer introduction')*-'Percentage of land sold')/'Total land')	auxiliary
Using the number of parciantes who are selling land (Land sales rate), the Percentage of land sold (assumed constant), and Homestead size, an estimate of sold acres is made. This estimate is divided by Total land to estimate a percentage, or rate, of fragmentation occurring within the acequia.			
Fallow from production and land sales	dmnl	IF('Land to fallow or produce by percentage'<0, 'Land to fallow or produce by percentage'+'Acequia land fragmentation rate', 'Acequia land fragmentation rate')	auxiliary
This variable is the combined effect of acequia land fragmentation and fallow land taken out of production for the next year.			
Percentage of land to fallow	dmnl	IF('Fallow from production and land sales'>0, 0, -'Fallow from production and land sales')	auxiliary
Variable represents the percentage of land that must be moved to Fallow for the next year in the simulation.			
Fallow adjustment	acre/month	IF('Land in production'>0<<acre>>, PULSE(MIN('Land in production'*'Percentage of land to fallow','Land in production'), 12<<@month>>, 12<<month>>), PULSE(0<<acre>>, 12<<@month>>, 12<<month>>))	auxiliary
Variable represents the amount of current Land in Production that is going into the Fallow stock for the next time-step.			
Land in production	acre	1200 <<acre>>; Cropping decision - Fallowing decision - Loss of ag land	level
Variable represents the amount of land used for agriculture production. Land is partitioned out into various commodities within the 'Crop production' sub model.			
Fallowing decision	acre/month	DELAYMTR('Fallow adjustment',6<<month>>,1,'Fallow adjustment')	auxiliary
Flow transfers the Fallow adjustment into the Fallow land stock.			
Fallow land	acre	1200<<acre>>; Fallowing decision - cropping decision - loss of fallow land	level
Variable represents the amount of agricultural land not being used for production of any kind and has yet to be developed for residential.			
Cropping decision	acre/month	DELAYMTR('Cropland adjustment',6<<month>>,1,'Cropland adjustment')	auxiliary
Flow transfers new land for production from Fallow to production.			
Cropland adjustment	acre/month	IF('Fallow land'>0<<acre>>, PULSE(MIN('Fallow land'*'Percentage of land to production', 'Fallow land'), 12<<@month>>, 12<<month>>), PULSE(0<<acre>>, 12<<@month>>, 12<<month>>))	auxiliary

Table S2. *Cont.*

Variable Name	Unit	Definition	Type
Variable represents the amount of current Fallow land that is going into the Land in Production stock for the next year in the simulation.			
Land to fallow or produce by percentage	dmnl	(('Adjusted land to fallow or produce'/'Working farm size')+'Leased land into production' - 'Generational transfer effect on land sales') *'Parciante responsiveness'	auxiliary
This variable, defined by a difference equation, tells the model how much land (in percentage of what land is in use) to move to fallow out of production or into production out of fallow. It does this by taking the new Percent to fallow and subtracting Current percentage of land in fallow. Positive differences signal that not enough land is in fallow, while negative differences signal that too much is in fallow.			
Percentage of land to production	dmnl	IF('Land to fallow or produce by percentage'>0, 'Land to fallow or produce by percentage', 0)	auxiliary
Variable represents the percentage of land that must be moved to Land in Production for the next year in the simulation.			
Loss of ag land	acre/month	IF('Land in production'>0<<acre>>, MIN('Residential development rate'/2, 'Land in production'/1<<month>>), 0<<acre/month>>)	auxiliary
The residential development rate assumes that land is developed for housing from both land in production and fallow land. Thus, the residential development rate is divided by two between each and flowed into Residential land.			
Loss of fallow land	acre/month	IF('Fallow land'>0<<acre>>, MIN('Residential development rate'/2, 'Fallow land'/1<<month>>), 0<<acre/month>>)	auxiliary
The residential development rate assumes that land is developed for housing from both land in production and fallow land. Thus, the residential development rate is divided by two between each and flowed into Residential land.			
Residential development rate	acre/month	MAX('Change in acequia population'*'Residential acres required per person', 0<<acre/month>>)	auxiliary
Amount of land developed per month based on the estimated change in acequia population and the residential land required to accommodate that change. If population decreases no residential land is added.			
Residential land	acre	185<<acre>>; Loss of ag land + loss of fallow land	level
Variable represents the amount of residential land within the acequia community. We assume that residential land will not change use over the simulation horizon. Therefore this stock acts as a sink from which land does not change use.			

Table S3. Key model equations for the Economics and Time Management system building block.

Variable Name	Unit	Definition	Type
Crop profit	dollar	'Crop revenues'-'Total farm costs'	auxiliary
Grazing profit	dollar	'Grazing revenue'-'Animal mgmt cost'-'Cattle invest'-'Total feed costs'	auxiliary
Agricultural profit-loss	dollar/month	PULSE('Grazing profit'+'Crop profit', 11<<@month>>, 12<<month>>)	auxiliary
Flow represents combined profits from cropping within the acequia and cattle grazing upland of the acequia.			
Ag profit-loss	dollar	5000<<dollar>>; Agricultural profit-loss - Agricultural income per year	level
Stock represents the profit or loss from all agricultural operations (cropping and cattle grazing). The stock is continuous as land use change and ag markets continuously change profitability of operators at any given time.			
Agricultural income per year	dollar/month	PULSE('Ag profit-loss', 6<<@month>>, 6<<month>>)	auxiliary
Flow accounts for agricultural profit (or loss), any income from external employment, and living expenses to go into Year end profit-loss.			
Year end profit-loss	dollar	0<<dollar>>; Agricultural income per year + Other income sources - Living expenses per year - Year end adjustment cumulative income	level
This stock is an accumulation of all the years activities to be moved into the Cumulative profit-loss stock.			
Living expenses per year	dollar/month	IF('Year end profit-loss'>0<<dollar>>, 'Applied living expenses'/1<<month>>, 0<<dollar/month>>)	auxiliary
Applied living expenses	dollar	'Living expenses per'*(1+'Inflation rate input')^'Months since start'	auxiliary
Living expenses per month takes on an assumed value at the beginning of the simulation and increases with the Inflation rate input.			
Year end adjustment in cumulative income	dollar/month	IF ('Year end profit-loss'>0<<dollar>>, 'Year end profit-loss'/1<<month>>, 0<<dollar/month>>)	auxiliary
Flow represents a discrete-time event for moving year end profit (loss) to cumulative profit (loss) at the end of each year in the simulation.			
Cumulative profit-loss- income met needs or shortfall?	dollar	Initial savings'; Year end adjustment cumulative income - Annual spending	level
Stock represents a life-time profit-loss that adjusts once per year based on the value of Year end adjustment flow value.			
Annual spending	dollar/month	PULSE('Cumulative profit-loss- income met needs or shortfall', 6<<@month>>, 12<<month>>)	auxiliary
Generational transfer-non returning losses are due to the 'leakage' of community members who don't return to the acequia. The transfer assumption is based on the idea that not all parciantes will return to a family operation, but only those sibling most interested in staying in the acequia. Therefore, some of the cumulative savings are likely passed on to siblings leaving the acequia when resources are split between sibling parciantes.			
Initial savings	dollar	5000<<dollar>>	constant

Table S3. *Cont.*

Variable Name	Unit	Definition	Type
Initial savings is an assumption about how financially stable parciantes are at the beginning of the simulation, 1969.			
Annual savings needed	dollar	'Initial savings'*(1+'Inflation rate input')^'Months since start'	auxiliary
Ratio of cumulative profit to goal	dmnl	MIN('Cumulative profit-loss- income met needs or shortfall'/'Annual savings needed', 1)	auxiliary
Cumulative profit and loss funds are effective only to the point that they keep up with standards of living. Therefore, the Cumulative profit is divided by the Cumulative profit to maintain quality of life. This fraction represents the level at which earnings are keeping up with life quality goals. A value of greater than or equal to 1 means that earnings are keeping up with quality goals. Any value less than 1 mean that earnings are not keeping up with quality goals and this will impact the amount of time spent in agriculture in future years of the simulation.			
Cumulative income effect on time in agriculture	dmnl	GRAPH('Ratio of Cumulative profit to Goal',-1,.2, {-0, 0, 0, 0, 0, 0, 0.213, 0.53, 0.85, 0.987,1//Min:0;Max:1.2//})	auxiliary
This graphical function returns a fractional value using Ratio of Cumulative profit, and is used in the Percent time in agriculture function (long term effect), Acequia mutualism (community effect), and Agriculture time-preference (short term economic opportunity cost).			
Mutualism effect on time spent in acequia area-valley	dmnl	GRAPH('Acequia mutualism', 0<<cohesive>>, 0.1<<cohesive>>, {0.0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1//Min:0;Max:1.1//})	auxiliary
The graphical look up variable is an estimation of the impact that acequia community engagement has on an individual's allocation to time in agriculture. It is hypothesized that the level of engagement of remaining community members has a positive effect of each others' decision to work in acequia agriculture-related activities. The graphical function, negatively sloped, is translated as "greater community engagement, little impact on time in agriculture; reduced community engagement, more impact on time in agriculture".			
Agriculture-time preference	dmnl	1; Change in short term behavior	level
This stock is a measure of preference given to working in agriculture versus commuting to external jobs. Potential values range between 0 and 1.			
Percent time in agriculture	dmnl	MAX(MIN((('FUNC cieoat'+'Agriculture-time preference'+'FUNC meotsia')/3), 3), 0)	auxiliary
Percent time in agriculture is defined by long-term economics (Cumulative income effect on time in agriculture), short-term economics (Agriculture-time priority), and community relations (Acequia mutualism). These variables are indexed to values between 0 and 1. The values are averaged, with 1 being full time employment in agriculture and 0 being fully employed outside the acequia.			

Table S3. *Cont.*

Variable Name	Unit	Definition	Type
Hours to agriculture	hr	'Full employment per month'*'Percent time in agriculture'	Auxiliary
Variable represents the number of hours spent per month in acequia agriculture based on full time employment constraint (140 hrs/month) and estimated time spent in agriculture.			
Full employment per month	hr	160 <<hr>>	auxiliary
Full time employment per month is the amount of work (hours) one individual can allocate assuming 40 hours per work week and four weeks per month.			
Hours external per month	hr	'Full employment per month'-'Hours to agriculture'	auxiliary
Variable represents the balance of Full time employment and hours dedicated to agriculture.			
External income earned	dollar	'Applied wage rate'*'Hours external per month'*12	auxiliary
Applied wage rate	dollar/hr	'Wage rate import'[INDEX(INTEGER('Months since start'))]*1<<dollar>>/1<<hr>>*'Economic market strength'	auxiliary
Wage rate input for non-agricultural labor, from Rio Arriba and Taos county averages.			
Profit from land sales	dollar	IF ('FUNC stpeols'>0, 'Estimated profit from land sales', 0<<dollars>>)	auxiliary
Profit from land sales is the Estimated profit value if short term agricultural profitability is low such that parciantes are willing to sell.			
Other income sources	dollar/month	PULSE('External income earned'+'Profit from land sales', 13<<@month>>, 12<<month>>)	auxiliary
Annual flow for income sources other than agriculture.			

Table S4. Key model equations for the Cattle Production (part of the Farm and Ranch system building block).

Variable Name	Unit	Definition	Type
Gestation delay	month	9<<month>>	constant
Weaning rate	dmnl	0.85	constant
Weaned stock inflow	animal/month	('Breeding rate'*'Weaning rate')/'Gestation delay'	auxiliary
Weaned stock	animal	34<<animal>>; Weaned stock inflow - Restocking - Weaned calf sales - Calf allotment reductions	level
Calf allotment reductions	animal/month	('Reductions required from allotment changes'/2)/1<<month>>	auxiliary
Reductions required from allotment changes	animal	IF('Cattle herd size'>'Potential average herd size', 'Cattle herd size'-'Potential average herd size', 0<<animal>>)	auxiliary
Weaning delay	month	6<<month>>	constant
Weaned calf sales	animal/month	'Weaned stock'/'Weaning delay'	auxiliary

Table S4. *Cont.*

Variable Name	Unit	Definition	Type
Livestock maturation time	month	17<<month>>	Constant
Restocking	animal/month	'Replacements needed'/'Livestock maturation time'	auxiliary
Cattle herd size	animal	60<<animals>>; Restocking + Herd expansion - Allotment reductions - Culling sales	level
Cattle herd size is the number of livestock owned by an individual parciante, controlled by restocking and culling. The units for cattle herd size is animal/person rather than total animals because we are concerned with profitability per parciante, not profitability of the entire acequia or region. Total animal units are tracked through the 'Climate and grazing area effects' box that calculates the total number of cattle that can graze the surrounding uplands.			
Herd expansion	animal/month	MAX(0<<animal/month>>, 'Livestock purchases'/6<<month>>)	auxiliary
Allotment reductions	animal/month	('Reductions required from allotment changes'/2)/1<<month>>	auxiliary
Livestock purchases	animal	IF(('Mgmt Restocking decision'/9<<month>>)>Restocking, ('Mgmt Restocking decision')-Restocking*1<<month>>, 0<<animal>>)	auxiliary
Bio culling rate	month	108<<month>>	auxiliary
Biological (natural) culling rate to maintain herd productivity at stationary state.			
Replacements needed	animal	'Cattle herd size'/'Bio culling rate'*12<<month>>	auxiliary
Breeding rate	animal	'Cattle herd size'*'Fertility rate'*'Offspring per year'	auxiliary
Offspring per year	animal	1	constant
Fertility rate	dmnl	0.85	constant
Culling sales	animal/month	('Cattle herd size'/'Bio culling rate')+'Management culling decisions'	auxiliary
Management culling decisions	animal/month	IF('Expected change in herd size'<0<<animal>>, -'Expected change in herd size'/12<<month>>, 0<<animal/month>>)	auxiliary
Cattle sold	animal	0<<animal>>; Weaned calf sales + Culling sales - Total cattle sold	level
Marketing delay	month	1<<month>>	constant
Total cattle sold	animal/month	'Cattle sold'/'Marketing delay'	auxiliary

Table S5. Key model equations for the Forage Inventory (part of the Farm and Ranch system building block).

Variable Name	Unit	Definition	Type
MAX store forage potential	lb	MAX('6 month forage','12 month forage')	auxiliary
Winter feed input	lb/month	PULSE('MAX store forage potential'+'Purchased winter feeds', 7<<@month>>, 12<<month>>)	auxiliary
Forage reserved	lb	50000<<lb>>; Winter feed input - Winter feeding	level
Stock to accumulate forage reserves for cattle winter feeding.			
Winter feeding	lb/month	'Annual winter feed demand'/12<<month>>	auxiliary
Annual winter feed demand per head	lb/(month*animal)	750<<lb>>/1<<animal>>/1<<month>>	constant
Annual winter feed demand	lb	'Cattle herd size'*'Expected annual winter feed demand'	auxiliary
Assumed winter feed required to feed one cattle through the winter each year.			
GAP in forage reserve	lb	'Forage reserved'-'Annual winter feed demand'	auxiliary
Purchased winter feeds	lb	IF('GAP in forage reserve'>0<<lb>>, 0<<lb>>, -'GAP in forage reserve')	auxiliary

Table S6. Key model equations for the Acequia Irrigation Diversion (part of the Acequia Hydrology system building block).

Variable Name	Unit	Definition	Type
Estimated water diverted per acre	cm/month	150<<cm/month>>	constant
Stream gauge monthly flow rate	cfs	'Embudo stream flow input'*'Projected precip forcing'	auxiliary
Flow variable to send Pulses from each month for each year through the simulation.			
Flow rate input	cfs	'Stream gauge monthly flow rate'	auxiliary
This flow variable represents the average amount of water and velocity reaching the head gate, or diversion dam, of the acequia. The variable can be defined by an assigned distribution (the Stream Gauge Flow Input tab) or imported data from Excel for a specific acequia community.			
Estimated water diversion percentage	dmnl	('Estimated water diverted per acre'*MAX('Land in production', 0<<acre>>))/'Flow rate input'	auxiliary
Acequia water diversion rule	Acm/month	IF(TIME>1<<@month>>, IF('Flow rate input'> 'Minimum streamflow delivery rate', ('Flow rate input'*'Estimated water diversion percentage'*'Irrigation months'), 0<<Acm>>/1<<month>>), 0<<Acm>>/1<<month>>)	auxiliary
The acequia diversion rule should mimic the headgate/diversion dam managed by the acequia or mayordomo. If the stream flow source for the acequia channel, in this case the Flow rate input, is great enough to support acequia flow, then the headgate is opened (i.e., the Acequia water diversion rule allows flow and is therefore positive). If the stream flow source is low such that it cannot support acequia water flow, then the diversion rule is cut off (i.e., diversions=0).			

Table S6. *Cont.*

Variable Name	Unit	Definition	Type
Irrigation months	dmnl	{0, 0, 0, 1, 1, 1, 1, 1, 1, 0, 0}	Auxiliary
The months of each year for which irrigation is possible, April through October.			
Minimum streamflow delivery rate	cfs	100<<cfs>>	constant
Minimum amount of stream flow required by mayordomo before the acequia headgate is opened for acequia flow.			
Acequia water flow	Acm/month	'Acequia water diversion rule'	auxiliary
Acequia water flow is equal to the diversions minus and marketed water, however in this case marketed water should remain at 0.			
Crop field runoff	cf/s	MAX('Acequia water flow'-'Ag crop ET'-'Crop seepage', 0<<cf/s>>)	auxiliary
This variable accounts for a portion of the water balance equation by estimating the return flows from field runoff by subtracting seepage and ET values from acequia ditch flow.			
Darcian flow	AF/month	'River aquifer head gradient'*'Hydraulic conductivity'*'Reach length'	auxiliary
Surface water losses	cf/s	'Ag crop ET'+'Reach ET'+'Total riparian consumption'	auxiliary
Surface water losses constitute a key portion of the water balance and are applied to Monthly flow adjustment pulse, which includes the other water balance equation components.			
Monthly flow adjustment	cf/s	'Flow rate input'-'Acequia water flow'-'Surface water losses'+'Darcian flow'+'Crop field runoff'	auxiliary
This outflow represents the stream flow below the acequia desague. It is a Pulse because it must be sure to eliminate any preceding months flows in the "irrigation account" and therefore remain on the monthly time step without interrupting acequia hydrology linkages. The Pulse occurs once per month to empty the irrigation account and then incorporates the necessary water balance equations by adding return flow gains (seepage effects) and subtracting surface water losses (Ag ET and surface ET).			

Table S7. Key model equations for Surface Water-Groundwater Interactions (part of the Acequia Hydrology system building block).

Variable Name	Unit	Definition	Type
Aquifer area	m^2	'Total land'	constant
Specific yield	dmnl	0.15	constant
Initial aquifer volume	m^3	'Aquifer area'*'Specific yield'*11<<m>>	constant
Upland source recharge	cfs	0.5<<cf/s>>	constant
Acequia seepage	dmnl	{0.00,0.00,0.00,0.17,0.12,0.12,0.12,0.12,0.08,0.12,0.05,0.00}	
Mean ditch seepage value reported by Fernald and Guldan 2008			
Crop seepage	AF/month	'ARRSUM Ag crop ET X Acres'*'Crop seepage factor'*'Irrigation reduction factor'	auxiliary
This variable represents the seepage effect of water losed through soil absorption below the root zone of irrigated fields. The value is derived by multiplying acequia flow by a seepage factor, empirically derived (Fernald and Guldan 2008). Although there is variation in the observed data, we assume a constant value here close to the observed mean.			
Groundwater inflow	AF/month	'Crop seepage'+'Upland source recharge'+'Acequia seepage'	auxiliary
Shallow groundwater aquifer	AF	Initial aquifer volume'+20500<<AF>>; Groundwater inflow - Groundwater head reduction	level
Fluvial aquifer head	m	(MAX('Shallow groundwater aquifer', 0<<AF>>))/('Aquifer area'*'Specific yield')	auxiliary
Distance to acequia	m	281.2<<m>>	constant
River aquifer head gradient	m	('Fluvial aquifer head'^2-'River head'^2)/(2*'Distance to acequia')	auxiliary
River head	m	IF(TIME<1<<@month>>, 8<<m>>, 'River bottom elevation relative to aquifer'+'Alcalde river stage estimation')	auxiliary
River bottom elevation relative to aquifer	m	8<<m>>	constant
Alcalde river state estimation	ft	((0.00000008*('Flow rate input'/1<<cfs>>)^2)+(0.0018*('Flow rate input'/1<<cfs>>))+2.1469)*1<<ft>>	auxiliary
Reach length	m	3000<<m>>	constant
Assumed reach length used for calculating evaporative losses of stream surface flows.			
Hydraulic conductivity, K	m/da_1	25<<m/da_1>>	auxiliary
Darcian flow	AF/month	'River aquifer head gradient'*'Hydraulic conductivity'*'Reach length'	auxiliary
Bosque riparian water demand	Acm/month	'ET reference'*'Bosque ET coefficient'*'Bosque area'	auxiliary
Estimated water demand from total Bosque area residing nearest to the stream bank corridor.			
Domestic pumping	cfs	'Total acequia population'*'Rural consumption'	auxiliary
Rural consumption	cfs/person	75<<gal/person/da_1>>	constant

Table S8. Key model equations for the Ecosystem Health system building block.

Variable Name	Unit	Definition	Type
Riparian habitat	acre	Total Alcalde land'*'Percentage of other land riparian'-'Bosque area'; Change in riparian area	level
Bosque area	acre	'Bosque width'*'Reach length'	auxiliary
Estimated permanent Bosque area along the river bank corridor, using length of stream reach and assumed width of plant community along the bank.			
Percentage of other land riparian	dmnl	0.28	constant
Total Alcalde land	acre	'Land in production'+'Fallow land'+'Residential land-impervious cover'+'Riparian habitat'+'Range-woodland'+'Long term fallow'	auxiliary
This is a check to verify conservation laws apply to total land in the model.			
Change in riparian area	acre/month	('Estimated change in riparian area'-'Riparian habitat')/'Riparian growth rate'	auxiliary
Estimated change in riparian area	acre	IF('Riparian water needs met?'>1, 'Riparian habitat'-'Riparian habitat'*'Riparian longevity-drought tolerance'*('Riparian water needs met?'-1), 'Riparian habitat'+'Riparian habitat'*'Riparian longevity-drought tolerance'*(1-'Riparian water needs met?'))	auxiliary
Riparian water needs met?	dmnl	'Additional riparian water demand' DIVZ0 'Additional riparian water input'	auxiliary
Riparian longevity-drought tolerance	dmnl	0.5	constant
Riparian growth rate	month	12<<month>>	constant

Table S9. Key model equations for the Acequia Community system building block.

Variable Name	Unit	Definition	Type
Total population	person	400<<person>>; Acequia births + Returners and newcomers - Acequia absentees - Acequia deaths, nonreturners, nonacclimating	level
Stock to aggregate acequia parciantes from all population chain factors.			
Acequia births	person/month	Births	auxiliary
Addition to Acequia population through births. Birth rates used for Acequia youth (age 15-17 only) and Acequia adults were averaged for accumulated age cohorts reported in New Mexico Information for Community Assessment (NMICA) available at mica.health.state.nm.us/nmindex.html; Bernalillo County 1999; also shown in Sandia Labs System Dynamics Toolbox.			
Births	person/month	IF(ARRSUM(Childbearers*'Birth rate')>0<<person/month>>, ARRSUM(Childbearers*'Birth rate'), 0<<person/month>>)	auxiliary
Returners and newcomers	person/month	'Returning to acequia'+'Newcomers to acequia'+'Returning retirees'	auxiliary
Newcomers to acequia	person/month	0<<person>>/1<<month>>+'Newcomer move-in time'/1<<month>>	auxiliary
Returning retirees	person/month	MAX('Absentee acequia members'/'Retirement time', 0<<person/month>>)	auxiliary
Returning to acequia	person/month	IF('Absentee acequia members'>0<<person>>, 'Potential generational transfers', 0<<person/month>>)	auxiliary
Acequia absentees	person/month	'Adult leaving acequia'	auxiliary
Flow variable from Acequia population that combines Youth and Adult decisions to leave acequia.			
Adult leaving acequia	person/month	MAX('Becoming absentee members'/1<<month>>, 0<<person>>/1<<month>>)	auxiliary
Flow for adults who leave the acequia as adults who may return due to generational transfer, retirement, or potentially not return at all.			
Acequia deaths, non-returners, non-acclimating	person/month	'Youth deaths'+'Member deaths'+'Elder deaths'+'Non-returning members'	auxiliary
Accumulated reductions in Acequia population due to deaths, non returners and nonacclimating members.			
Youth deaths	person/month	MAX ('Acequia youth'*((0.000065/12)/1<<month>>), 0<<person>>/1<<month>>)	auxiliary
Member deaths	person/month	MAX('Acequia members'*((0.000168/12)/1<<month>>), 0<<person/month>>)	auxiliary
Elder deaths	person/month	IF('Acequia elders'>0.5<<person>>, 'Acequia elders'*'Elder death rate', 0<<person/month>>)	auxiliary
Non-returning members	person/month	IF('Absentee acequia members'>0.01<<person>>, 'Nonreturning members rate', 0<<person/month>>)	auxiliary

3. Supplementary Auxiliary Variables Used to Link System Building Blocks throughout the SD Model

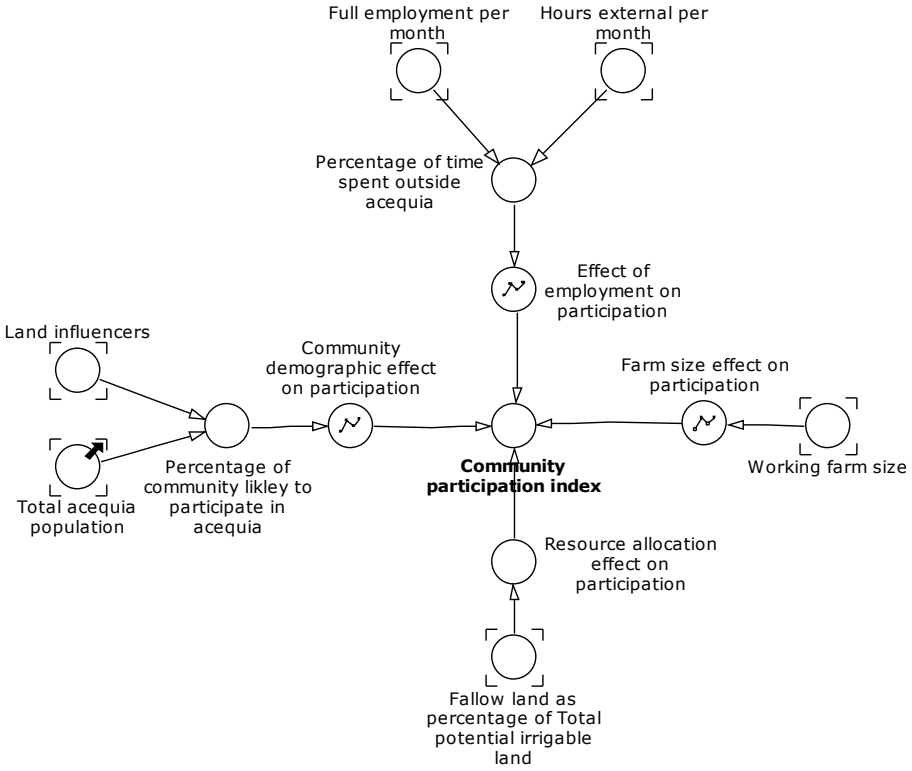

Figure S2. Variables used in construction of the community participation index, with inputs from the community (percentage of community likely to participate in acequia), farm and ranch (farm size effect on participation and fallow land as percentage of total potential irrigable land), and economics and time management components (effect of employment on participation).

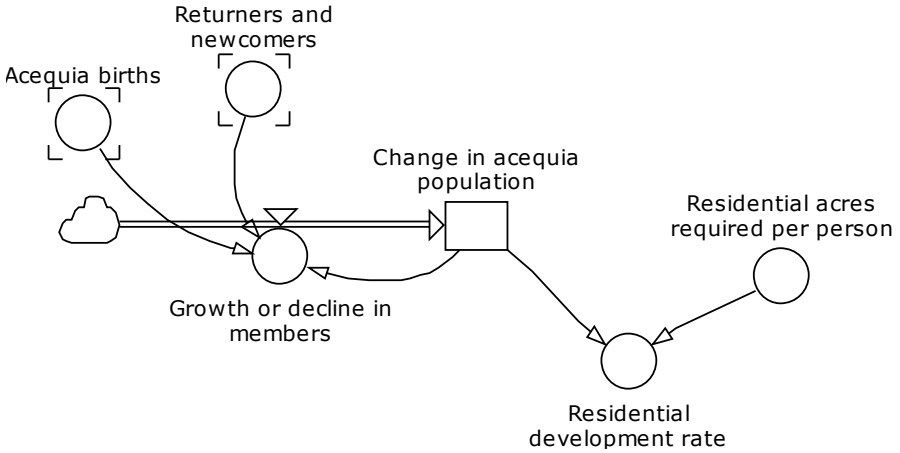

Figure S3. Variables used to link changes in community to land use through the *residential development rate* variable.

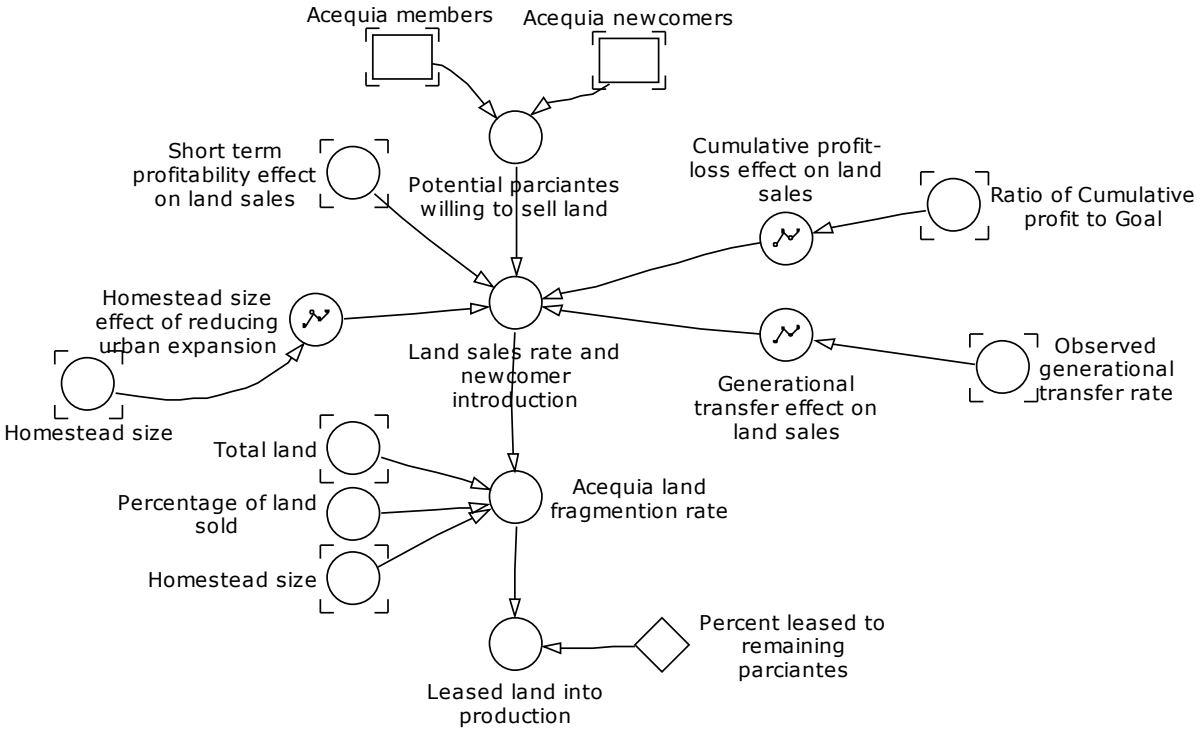

Figure S4. Variables used to link various system building blocks (Economics and time management: cumulative profit-loss effect on land sales and short term profitability effect on land sales; Land Use: homestead size effect of reducing urban expansion; and Community: generational transfer effect on land sales) to land sales and newcomer introduction, acequia land fragmentation, and land leased into production.

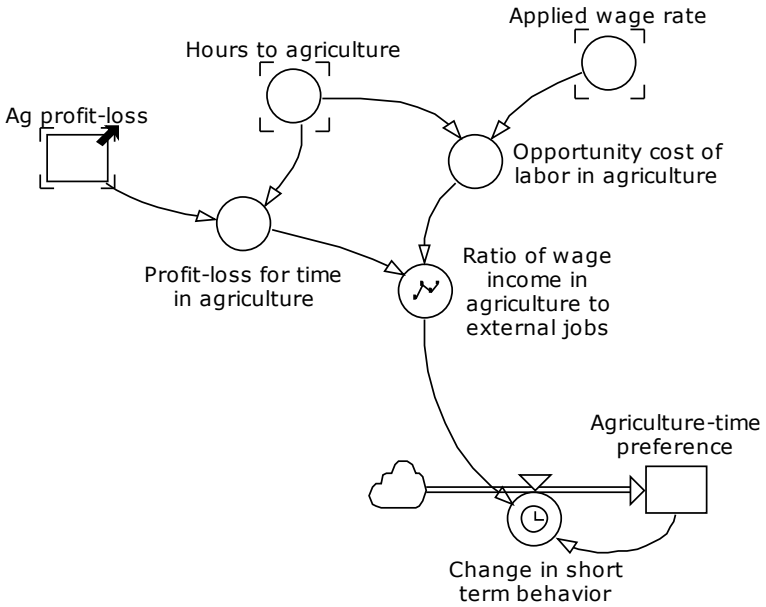

Figure S5. Variables used in the Economics and Time Management system building block to estimate *agriculture-time preference* based on *opportunity cost of labor in agriculture* and *profit-loss for time in agriculture*.

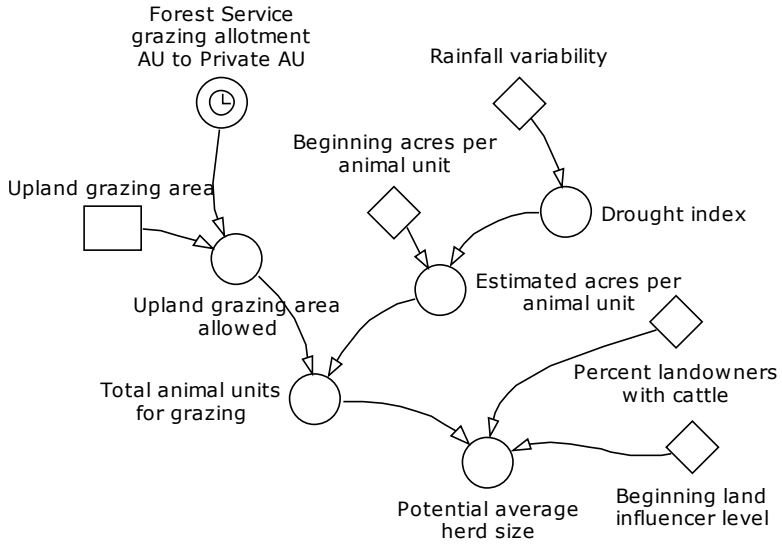

Figure S6. Variables used in construction of the cattle herd production components, with inputs from the upland characteristics (*upland grazing area*; *Forest Service grazing allotment AU to Private AU*; and beginning *acres per animal unit*, which was used in sensitivity testing).

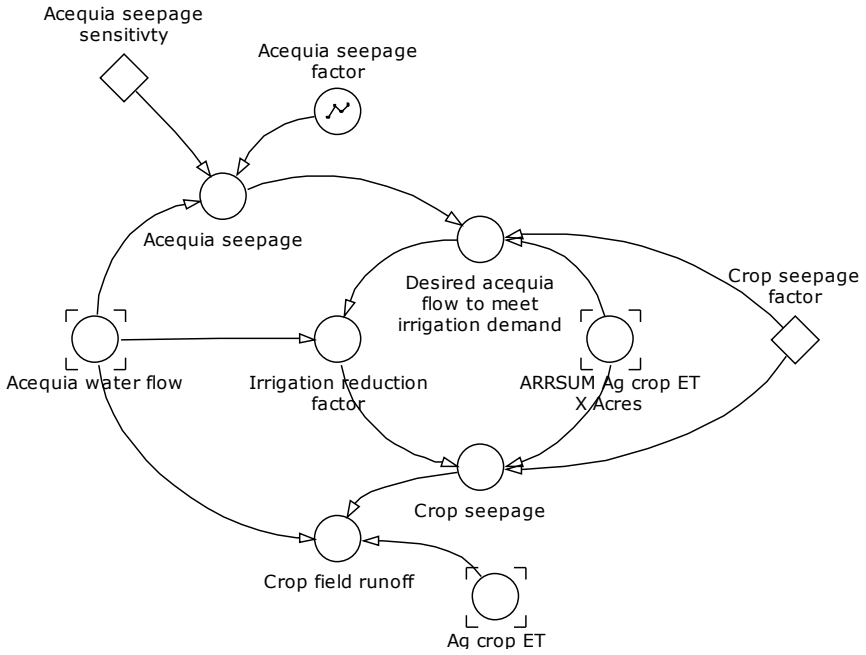

Figure S7. Variables used in partitioning water in the Acequia Hydrology system building block, accounting for *acequia (ditch) seepage*, *crop seepage*, and *crop field runoff*, with estimates for changes in irrigation (*irrigation reduction factor*) based on available water supply (*acequia water flow*).

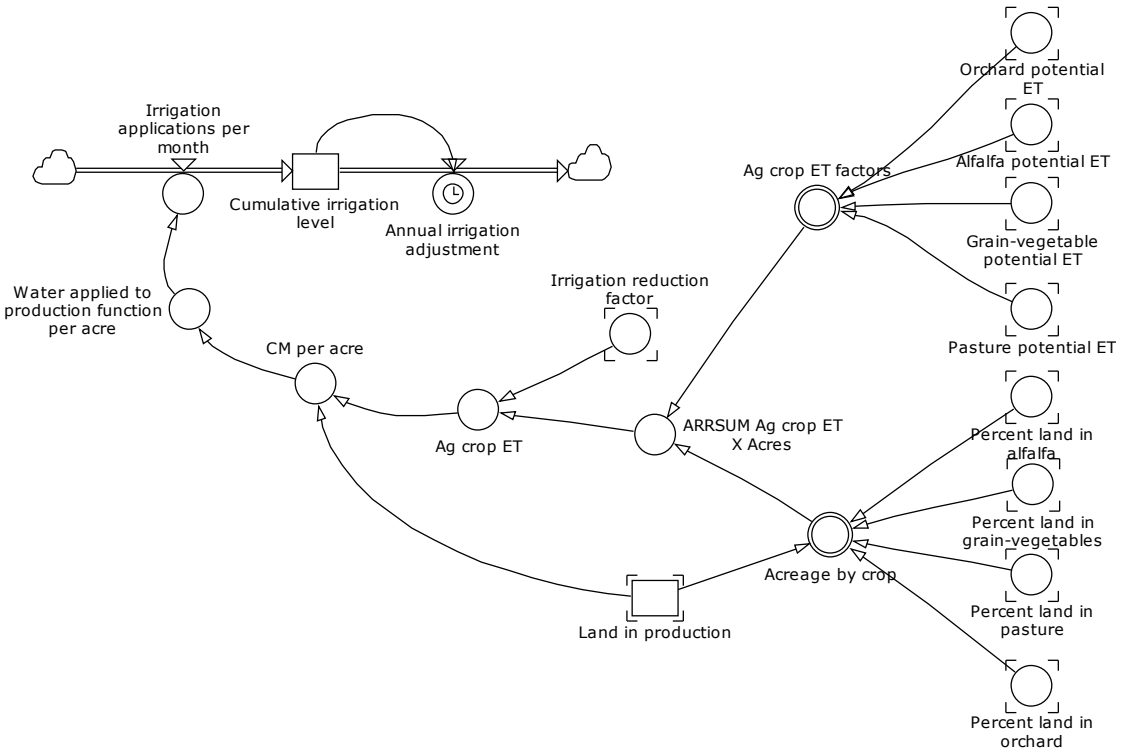

Figure S8. Variables used in applying irrigation from the Acequia Hydrology to the Farm and Ranch Activity system building blocks, using *acreage by crop*, *ag crop ET factors*, and *irrigation reduction factor* to estimate irrigation applications per month (*CM per acre*) and per growing season (*cumulative irrigation level*).

4. Additional Time-Series Plots Resulting from the Socio-Cultural Sensitivity Analyses (See Table 6 and Figure 17 of the Text)

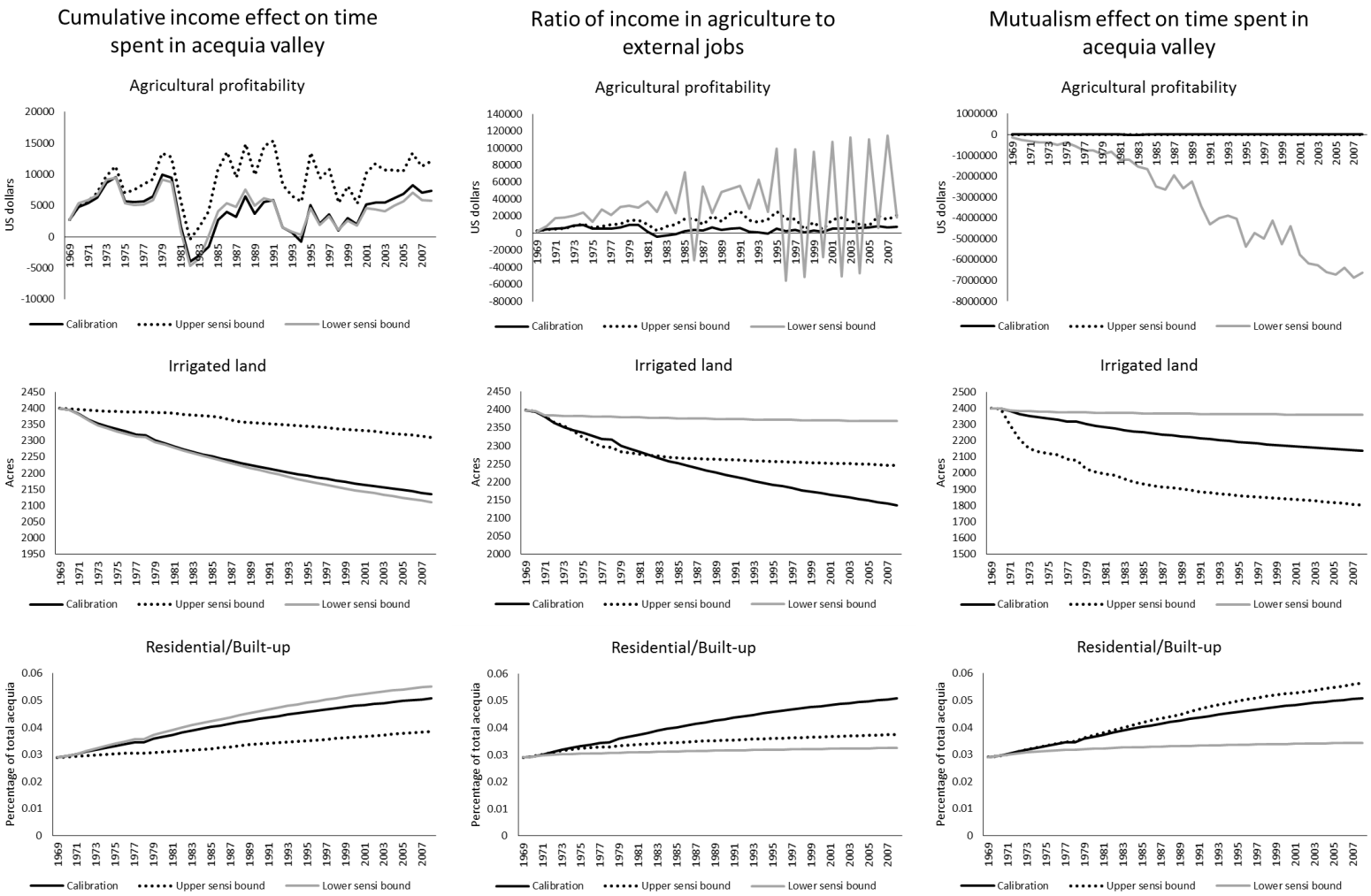

Figure S9. Additional sensitivity plots of socio-economic processes (see Table 6 and Figure 17 of the text).