An Analysis of the Economic Impact of Water Transfers from Agricultural to Urban Uses

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Abstract

A two stage nonlinear optimization model was developed to account for the major surface and groundwater hydrologic features and cropping patterns in Colorado's San Luis Valley. Conjunctive use of surface and groundwater is included to assess changes in crop patterns and producer income from water exports outside the valley.

Introduction

Existing institutional arrangements in the southwestern United States, particularly water transfer restrictions, may prevent allocation of water to its highest economic value and do not encourage conservation (Burness and Quirk, 1979; Tietenberg, 1992). Water is allocated in most western states by the Doctrine of Prior Appropriation whereby the first person or organization that applies water for beneficial use obtains a decree amount and the highest priority right to that water through adjudication in water courts. In general, water markets that could theoretically allocate water to its highest value use do not exist or are poorly organized. Brajer and Martin (1990) contend that water is a social good and vital necessity with attributes beyond its market value, so it should not be treated as a normal commodity and that water is not becoming scarce, but rather 'cheap' water is becoming scarce.

In the arid western U.S. agricultural production accounts for 85-90% of consumptive water use (Office of Technology Assessment, 1995; Gibbons, 1986) and competes with urban demands for limited supplies. Irrigated agriculture uses surface water, with uncertain flows from year to year, and groundwater from aquifers with declining water levels. Non-consumption of applied irrigation water by plants during crop growth and inefficient irrigation technologies serve to recharge aquifers from both surface diversions and groundwater pumping. Sustained and severe droughts alter the interactive properties of surface and groundwater supplies and contribute to the uncertainty of agricultural production. Increased demand from growing metropolitan areas also influences the value of water and threatens to change its historic use.

Like most other western rivers, the Rio Grande begins as snowmelt in the San Juan Mountains in Colorado and flows through New Mexico and Texas to the Gulf of Mexico (Office of Technology Assessment, 1995). Water demands along the river are increasing as population along the Front Range of Colorado and especially in Albuquerque, New Mexico and El Paso, Texas increases. Transferring water from irrigated agriculture to urban use appears an easy solution to satisfy increasing demands since urban use represents the highest use compared to the low value for many crops.

The potential of transferring water from the San Luis Valley (SLV) of southern Colorado to cities along the Front Range has been frequently discussed at public meetings and in newspapers. The SLV represents an important agricultural region that has abundant surface and groundwater resources. The SLV has a rich agricultural history of growing relatively high value crops. Total revenues from field crop production in 2000 were nearly $174 million and high prices in 2001 provided total revenue from potatoes alone of nearly $204 million (Dillon, 2001). Agricultural production accounts for nearly 97% of consumptive water use in the SLV where surface water is obtained from Rio Grande diversions and groundwater is pumped from an unconfined aquifer which underlies much of the valley. Sustained droughts reduce snow melt, the predominant source of Rio Grande flow, so not only is less surface water available for irrigation, recharge to the aquifer is reduced. The Rio Grande drainage basin is the most severely impacted by the current drought with more than 15% of agricultural producers expected to experience irrigation water shortages (USDA-NRCS, 2003) Water transfers outside the SLV will change aquifer levels, even surface water is the source of water transfers from the valley.

Agricultural producers adapt to increased groundwater pumping costs, higher market values for voluntary water transfers and environmental constraints on water through improved irrigation efficiency and reduced consumption (Moore, Gollehon and Carey, 1992). Irrigators in the SLV have already adopted efficient irrigation technologies, so this analysis focuses on how cropping patterns and expected income are affected by water transfers and drought. The main objective of the study is to assess the effect on agricultural production of exported surface and groundwater to metropolitan areas. The effects of water transfers combined with a sustained drought are also analyzed.

The population increases along Colorado's Front Range metropolitan areas combined with the five year drought in the region are placing demands on limited water supplies that cannot be sustained indefinitely. Existing institutional arrangements and lack of formal water markets makes allocation of water to its highest economic use difficult. Limited examples of leasing water rights have been used to satisfy increased urban demands, but urban demand continues to increase. Some cities, such as Broomfield, Colorado, have already purchased agricultural areas strictly for the water rights.

Previous analyses have used econometric (Nieswiadomy, 1985; Ogg and Gollehon, 1989; Moore and Negri, 1992) and mathematical techniques (Bryant, Mjelde and Lacewell, 1991; Kulshrestha and Tewani, 1991) to describe water use by agricultural producers and to derive the value of water to crop production. Existing models that address river diversions for agriculture have excessive data requirements and most do not consider the Doctrine of Prior Appropriation. Wurbs and Walls (1989) developed a model that addresses prior appropriation by accounting for water rights assigned to reservoir storage facilities in Texas. Bredehoeft and Young (1983) analyzed a river basin delivering water to a single irrigation ditch for three areas with hypothetical rights and decrees allocated.

The purpose of this paper is to develop a model that simulates the Doctrine of Prior Appropriation in Colorado and identifies producer response to restricted water supplies. This study provides a foundation for studies that relax institutional constraints by developing an analytical method for identifying the value of irrigation water for agricultural production. The area of study is the Closed Basin portion of the San Luis Valley in south-central Colorado. A model addressing the major surface and groundwater hydrologic features and the cropping patterns of producers in the region is developed. The value of irrigation water to agricultural production in the study area is determined by analyzing income changes due to low water flows.

Study Area

The San Luis Valley in southern Colorado covers nearly 3,200 square miles with an average elevation of about 7,700 feet. The average annual rainfall is 7 to 10 inches with more than half of the precipitation occurring between July and September, making crop production difficult without supplemental water for irrigation. The short growing season of 90-120 days also limits the choice of crops (Doesken and McKee, 1989). The predominant crops in the region are potatoes, barley, and alfalfa.

Surface water for agricultural production in the study area is derived from the Rio Grande where available water is a function of river flow at Del Norte, Colorado and the delivery requirements to New Mexico, Texas and Mexico specified in the Rio Grande Compact of 1938. The Rio Grande, like many other water sources in the arid west, has been over-appropriated - more water has been allocated to users than is generally available from the river. Compact requirements limit diversions because they have the highest priority. Municipal and industrial uses are not considered in the analysis because agriculture accounts for 97% of water use in the San Luis Valley.

Conjunctive use of surface and groundwater are used to irrigate agricultural crops in the San Luis Valley. Groundwater is obtained from the unconfined aquifer. The study area is internally drained because an alluvial divide prevents water diverted to irrigation ditches or pumped from the aquifer in the Closed Basin from draining into the Rio Grande. Therefore, water not used by evapotranspiration is either lost to evaporation or recharges the unconfined aquifer.

The SLV was selected as the study region for three reasons. First, historic records indicate that the Rio Grande accounted for over 93% of actual diversions from 1986 to 1995 and 70% of the diversion rights in a region where 91 other creeks and streams provide water (Colorado Division of Natural Resources, 1997). Second, attributes of the Closed Basin simplified the analysis by eliminating the need to simulate return flows to the river. Third, irrigated agricultural production represents a predominant aspect of the area's local economy.

Model

A two stage nonlinear optimization model is used to analyze agricultural production response to decreased water supplies and to assess what happens to surface and groundwater. The model accounts for the major surface and groundwater hydrologic features and cropping patterns in the region to simulate crop choices and subsequent income changes that result from decreased water availability. The first stage of the model estimates diversions from the Rio Grande to five irrigation ditches based on river flow, priority and decree amount, to account for adjudicated water rights to the irrigation ditches. The model explicitly accounts for decree amount and priority of water rights for diversions from the Rio Grande to five irrigation ditches. The irrigation ditch companies own the water rights and producers own shares of the irrigation ditches from which they divert water for agricultural production.

The Doctrine of Prior Appropriation is addressed in the first stage of the model to allocate surface water from the Rio Grande to irrigation ditches and canals holding the highest priority. Four of the 101 irrigation ditches in the SLV account for over 60% of the water rights in the study area. Explicitly included in the model are the Rio Grande Canal, Farmer's Union Canal (now the San Luis Valley Irrigation District Canal), Prairie Ditch and the San Luis Valley Canal. Each irrigation ditch owns a suite of water rights with different priorities and decree amount, which is included in the model (Colorado Division of Natural Resources, 1997). Delivery requirements specified in the Rio Grande Compact are accounted for outside the model. All river flow at the Del Norte gauging station is accounted for in the model through diversions to irrigation ditch companies. A fifth irrigation ditch is included in the model to account for diversions that occur outside the study area. Diversions to the ditch outside the study area represent a significant portion of the river flow because the priorities are high with large decree amounts. When river flow is not sufficient to satisfy all diversions, this ditch still captures a significant amount of available water.

A mass balance river flow model that diverts water by priority and decree amount using a monthly time step is developed in GAMS (Brooke, Kendrick and Meeraus, 1988) with the Minos Solver (Murtagh and Saunders, 1987). River flow is simulated for the cropping season over six time periods from April to September with delivery requirements specified by the Rio Grande Compact estimated outside the model. When river flow is not sufficient to satisfy all users, junior decrees are not allocated water. Available water is used in the second stage of the model to simulate crop growth and estimate the value of crop production.

Water rights for ditches with consecutive priorities were grouped together and considered a single water right with a single priority, which reduced the number of water rights in the region from 337 to 123. The objective of the first stage of the model is to maximize total water diverted (*Ditch*) constrained by the priority and decree amount of each irrigation ditch and river flow (Eq. 1). This weighted equation limits diversion of water to any upstream ditch surface water right (i) to zero in each time period (t) if there are downstream ditches with higher priorities and river flow is not sufficient to satisfy all rights.

(1) $$Maximize \sum_{i=1}^{123}\sum_{t=1}^{6}\frac{1}{\text{Priority}_{\text{i}}^{2}}\times Divert_{i,t}$$

Subject to: $Divert_{i,\text{t}} \leq \text{WaterRight}_i$ (i = 1,…,123; t = 1,…4),

$Divert_{i,t} \leq Flow_{i,t}$,

$$Flow_{1,t} = \text{Inflow}_t,$$

$$Flow_{i\text{-}1,t} = Flow_{i,t} - Divert_{i\text{-}1,t}.$$

Diversions at each node must be less than or equal to the decreed water right held by the ditch at that node for each time period and less than or equal to the amount of water available from the river. River flow at the first node is determined outside the model using historic Rio Grande Flow data in the baseline simulation used to calibrate the model (USGS, 2003). Flows at each subsequent node are a function of the reduced river flow resulting from water diverted by upstream ditches. Equation 1 establishes the amount of surface water available for irrigation which is allocated to each ditch based on the priority and decree amount. Surface water is diverted to irrigation ditches by summing over all priority and decree amount for each ditch owner:

$$(2) \qquad Ditch_{l,t} \leq \sum_{i=1}^{123} Divert_{i,t}$$

where the owner of the right and priority is *Ditch* (*l*). The amount of water available for irrigation from the ditch cannot be more than the amount of river flow diverted to the ditch.

The second stage of the model estimates the profit maximizing crop mix based upon the conjunctive use of available surface water derived in the first stage of the model, and groundwater sources. Groundwater is obtained from an unconfined aquifer that underlies the study area. Precise data for the amount of water in the unconfined aquifer are not available, but were estimated using the surface area and depth to the blue clay series (area that separates the unconfined from the confined aquifer) that represents the aquifer floor. The specific yield of the aquifer material is approximately 0.20 (Emery, 1970; Woodward-Clyde-Sherard and Associates, 1967). Using the surface areas above the aquifer cells, which range from 4,480 to 65,920 acres, the estimated water holding capacity of the aquifer cells is 2.5 million acre feet, which compares favorably with other estimates (Woodward-Clyde-Sherard and Associates, 1967). To simplify the simulation and account for varying depths, the unconfined aquifer was divided into nine cells determined by depth, with each aquifer cell containing an amount of water dependent upon its volume. Groundwater pumping from the unconfined aquifer also requires a water right. An irrigation efficiency of 80% for both surface and groundwater application is applied in the model, so 20% of the water applied to crops is lost either to evaporation or returns to the aquifer. Return flow to the aquifer from inefficient irrigation and because all water is not consumed by plants is accounted for within the model.

Most agricultural producers in the study area divert surface water to recharge pits where it percolates to the aquifer (Curtis). In the model, it is assumed that surface water applied to recharge pits is not available for pumping until the next time period (one month). The aquifer is also recharged through inefficient irrigation and non-consumption of applied water by crops. The amount of aquifer recharge from surface and groundwater sources is dependent upon the irrigation technology used. Recharge from inefficient irrigation is considered to be the same in each representative agricultural area because center pivot irrigation systems are used for all production activities. Aquifer recharge from underground springs, percolation from irrigation ditches and canals, watershed runoff, precipitation, and leakage from artesian wells are not included in the model.

Groundwater rights are required to pump water from the aquifer. For simplicity, the proportion of an aquifer cell that may be pumped by a representative agricultural area is based upon their proportion of total surface area above the aquifer cell. Representative areas are constrained to pumping less than the minimum of the groundwater right plus the amount of recharge from recharge pits, their pumping capacity, or the proportion of the amount of water available in the aquifer cell based upon the surface area. An irrigation efficiency of 80% for both surface and groundwater application is applied in the model, so 20% of the water applied to crops is lost either to evaporation or returns to the aquifer. Return flow to the aquifer from inefficient irrigation and because all water is not consumed by plants is accounted for within the model.

The volume of water in the aquifer cells throughout the cropping season is a function of the initial conditions plus the amount of water added from recharge pits, plus the drainage of water not consumed by crops, less the amount of water removed by pumping activities. The pumping capacity for the representative agricultural areas is based upon 1500 gallons/minute per well. For simplicity, each well has one center-pivot system associated with it. The number of center pivots was estimated for each agricultural area assuming 130 acres per center pivot.

The model does not explicitly simulate crop production activities on individual farms. Instead, the study area is partitioned into thirty-three representative agricultural areas determined by similar soil characteristics, source of surface water (the ditch from which water is received) and source of groundwater (aquifer cell). The study area is predominated by sandy and sandy loam soils. The representative agricultural areas range in size from 154 to 12,847 acres. All agricultural areas own surface water rights through ownership of irrigation ditch shares, but not all have groundwater rights. The agricultural areas are restricted to diverting surface water from a single irrigation ditch and can pump groundwater from one of the nine aquifer cells when they own a groundwater right.

Crop growth coefficients for the model were generated using a simulation model developed by Cardon (1990) that generates relative crop yields under various irrigation strategies. The crop growth model employs a daily time-step to simulate the relationship between water, soil, plant growth, yield and evapotranspiration (ET) to derive relative yield parameters based upon available water. It simulates water movement through the soil profile and water uptake by plants. Equations for matric potential (Rawls, Ahuja and Brakensiek, 1992 ; Ghosh, 1977; Campbell, 1974), hydraulic content measurement and moisture retention function (Campbell, 1974), and total porosity and matric potential at the inflection point (Hutson and Cass, 1987) are used in the crop growth simulation model. The model estimates crop yield using the ratio of model generated ET to potential ET (USDA, 1988) for the study area. Irrigation schedules were derived from expert opinion (Colorado State University Cooperative Extension at the San Luis Valley Research Center; Agro Engineering). To limit the number of simulations required, pair-wise combinations of irrigation strategies (from the 16 to 24 irrigation events) were simulated for each crop (potato, barley and alfalfa) for the two different soils. The output resulted in water production functions that provide relative yield, as shown in Figure 1. Relative yield is estimated with the following equation with a general functional form using coefficients (Table 1) derived from linear regression to determine the best fit:

(3) $$RelY_{M,c} = \alpha_{M,c} + \beta_{1_{M,c}} w_{M,c} + \beta_{2_{M,c}} w_{M,c}^2 + \beta_{3_{M,c}} w_{M,c}^3 ,$$

where:

$$w_{M,c} = Wapprate_{M,c} \times 12$$

$$Wapprate_{M,c} \times Acre_{M,c} = Sapp_{M,c} + GWapp_{M,c}$$

$$\sum_{c=1}^{3} Sapp_{M,c} \le \sum_{t=1}^{6} Sapp1_{M,t}$$

$$Sapp1_{M,t} \le SurfApp_{M,t}$$

$$SurfApp_{M,t} \leq SurfWater_{M,t} \text{ if farm does not have groundwater right,}$$
$$\leq SurfWater_{M,t} - Rcsurf_{M,t} \text{ if groundwater right is positive.}$$

$$GWapp_{M,c} \leq \min(\text{PumpCap}_{M,q}, \text{GWright}_{M}, AqLev_{q} \times \text{AqShare}_{M,q})$$

where relative yield varies by farm (*M*) and crop (*c*) by amount of irrigation water (*w*) applied. *Wapprate* is a free variable determined by the model multiplied by 12 to convert from acre-feet of applied water to inches. The total amount of applied water must equal the amount of surface plus groundwater applied water. The sum of surface water applied to each crop ($Sapp_{M,c}$) must be less than surface water available to the farm from each irrigation ditch ($Sapp1_{M,t}$) summed over all six time periods. Surface water may be applied only if the agricultural area does not own a groundwater right, otherwise, only water not added to recharge pits may be applied to crops, at a significant cost to encourage use of recharge pits. Groundwater ($GWapp_{M,c}$) must be less than the minimum of the pumping capacity, groundwater right or the farm's share of the available aquifer.

Crop yield per acre is determined in the model by multiplying relative yield by the long-term average yield for each crop (Table 2):

(4) $$Y_{M,c} = RelY_{M,c} \times \text{AY}_{M,c},$$

where *Y* is the estimated yield used to determine net returns and AY is the long term average crop yield for each crop by farm.

Producers in the study area are considered price takers in the market-place because production of any of the crops considered is not significant enough to influence national production and therefore prices. Costs of production were developed from enterprise budgets generated by Colorado State University (Dalsted et al., 1995), data from Colorado State University custom rates survey (Tranel et al.), and local data generated by Agro Engineering. Variable and fixed costs for all pre-harvest, harvest, and operating expenses are included. Equipment complements and financial status of most farms in the study area are similar, and are therefore treated as such in the model.

The objective of the second stage of the model is:

(5) $$Maximize \sum_{M=1}^{33} TotNet_M$$

Subject to: $$TotNet_M = \sum_{c=1}^{3} NetRet_{M,c} ,$$

$$NetRet_{M,c} = ((\mathrm{P_c} - \mathrm{Pyvc_c}) \times Y_{M,c}) \times Acre_{M,c}) - \mathrm{Pavc_c} \times Acre_{M,c} -$$

$$Sappcost_{M,c} - Pumpcost_{M,c},$$

$$Acre_{M,c} \leq \mathrm{AcLimit}_{M,c},$$

where the acreage that may be planted to crops ($Acre_{M,c}$) must be less than the historic average acreage that was planted to the crops ($\mathrm{AcLimit}_{M,c}$) to account for biophysical constraints that preclude continuous cropping of any crop. Crop prices ($\mathrm{P_c}$), variable costs per unit of production ($\mathrm{Pyvc_c}$), and variable costs per acre of production ($\mathrm{Pavc_c}$) (Table 3) are derived from historic average output prices and enterprise budgets. The cost to apply surface water ($Sappcost_{M,c}$) is calculated as a fixed charge ($5.00 ac^{-1}) multiplied by the total acres with surface application. Pumping costs are derived as follows (Rogers and Alam, 1999):

(6) $$Pumpcost_{M,c} = (\mathrm{TDH_q} \times \mathrm{Fuel} \times \mathrm{Energy}) \times GWapp_{M,c},$$

where $\mathrm{TDH_q}$ is the total dynamic head, a function of lift, which varies by aquifer cell, and pressure (average pressure for Colorado irrigation is 33 psi). The predominant energy source for irrigation in the study area is electricity, which requires 1.551 $\mathrm{kwh}^{\text{-ac-ft-ft}}$

(Rogers and Alam, 1999). The average electricity cost in the study area for irrigation is \$0.06 kwh^{-1} (SLV Development Resources Group, 2002).

Moore, Gollehon, and Carey (1994) determined that the choice of acres on which to produce crops is the first decision made by producers, and the cost of water was second. Therefore, the costs for shares of irrigation ditch water are not included in the optimization, but are subtracted from returns that are net of other costs.

Results and Discussion

Available water from Rio Grande flow and from the unconfined aquifer is varied from 100% to zero to determine how crop production levels and water use change. Over 2.46 million acre feet of water are available from the unconfined aquifer in the baseline scenario, with average available water from the Rio Grande for diversions to irrigation ditches over 188 thousand feet. Rio Grande flow is considerably larger than this, but Rio Grande Compact diversions and diversions to the irrigation ditch outside the study area capture their water before it enters the model.

Net returns (table 4) from production of alfalfa, barley and potatoes in the study area with full surface and groundwater availability are \$91.8 million. When full water is available, all farms in the model produce crops applying over 175 thousand acre feet of water. As shown in table 7, ending aquifer levels are less than 48,000 acre feet lower than at the start of the cropping season when river flow and initial aquifer levels are 100% of the historic average. Seepage and infiltration from mountain runoff to the north of the valley are likely sufficient to make up this loss, but without the recharge from surface diversions, the aquifer volume is only large enough to maintain this level of water mining for less than fifty years. Thus, water transfers that change the dynamic interaction of applied irrigation water and aquifer recharge will have a profound effect on the sustainability of the aquifer.

Production should be shifted away from lower to higher value crops to attain the highest net returns when water becomes scarce. Net returns decline by nearly ten percent when river water deliveries are reduced to zero, as shown in table 4. As shown in table 5, acres dedicated to barley production is decreased the most (12.7%) followed by potatoes (10.5%). Barley requires less irrigation water than either potatoes or alfalfa, but returns from barley are less, so it is expected that barley production will be reduced first so water may be applied to the higher valued crops. Acres in alfalfa production are decreased by 10%. Total production of each crop declines by approximately the same percentage as the reduction in acres (table 6). All of the reduced acreage and production is from agricultural production areas that do not own groundwater rights.

Agricultural producers should be able to withstand short term droughts according to the model. River flow during the 2002 cropping season was 33% of normal flow (USGS, 2003) which the model shows would not have a substantial impact on crop production. Aquifer levels at the end of the season are not significantly impacted by the drastically reduced river flows, as shown in table 7. This indicates once again that SLV agricultural production can withstand short term droughts.

Net returns continue to be strong when the aquifer level is reduced by half because the aquifer is large enough to satisfy all demands in the short term. However, even when 100% of surface water is available, aquifer mining is required to satisfy production demands. At the end of the cropping season, more than half (table 7) of the groundwater has been removed from the aquifer when the initial aquifer level is half the baseline. Recharge from surface water applications is not adequate to sustain this rate of consumption in the long term. Diversions of aquifer water to urban uses would have the same effect, but would take longer to reach these critical levels.

When there is no water in the aquifer at the start of the production season, acres planted to crops, total production, and net returns are reduced significantly, particularly when surface water is also reduced. Recharge from surface water applications and inefficient irrigation actually allow the aquifer to end the production season with a positive amount of water. The aquifer remains depleted with less water than is required for profitable crop production.

The value of irrigation water to SLV agricultural production varies from \$524 af^{-1} when aquifer levels are full and surface water flows are normal to \$1200 af^{-1} when river flow is half of normal and the initial aquifer level zero. These estimates represent the minimum value of irrigation water to agricultural production in the SLV of Colorado. Therefore, the value of surface or groundwater sources that could be transferred to urban uses is from \$500 to \$1200 af^{-1}.

Conclusions

The analysis demonstrates the importance of the unconfined aquifer to crop production in the Closed Basin of the San Luis Valley. Net returns from crop production decline sharply when aquifer water is depleted but they are relatively unaffected by declining river flows. Only those agricultural areas lacking groundwater rights fail to produce crops when there is no surface water. The remaining farms increase the amount of groundwater applied to substitute for the lack of surface water. These results should be interpreted with caution because cropping decisions in a static single season simulation do not account for adjustments that would likely be made to cropping patterns to protect declining water levels. More robust findings would result from a dynamic model that accounts for declining aquifer levels within the cropping decisions made by producers.

A dynamic model is required to account for cropping decisions over time. The simulation model presented in this analysis indicates that groundwater is more critical for agricultural production than surface water. However, surface water is required to recharge the aquifer. In the present model, producers were free to deplete groundwater supplies because short run decisions address only the current time period and do not consider future production possibilities. A single season static simulation model, as presented here, does not address forward looking production decisions.

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Figure 1. Example of crop growth model relative yield results for alfalfa on a sandy soils and regression line used for crop growth coefficients in model.

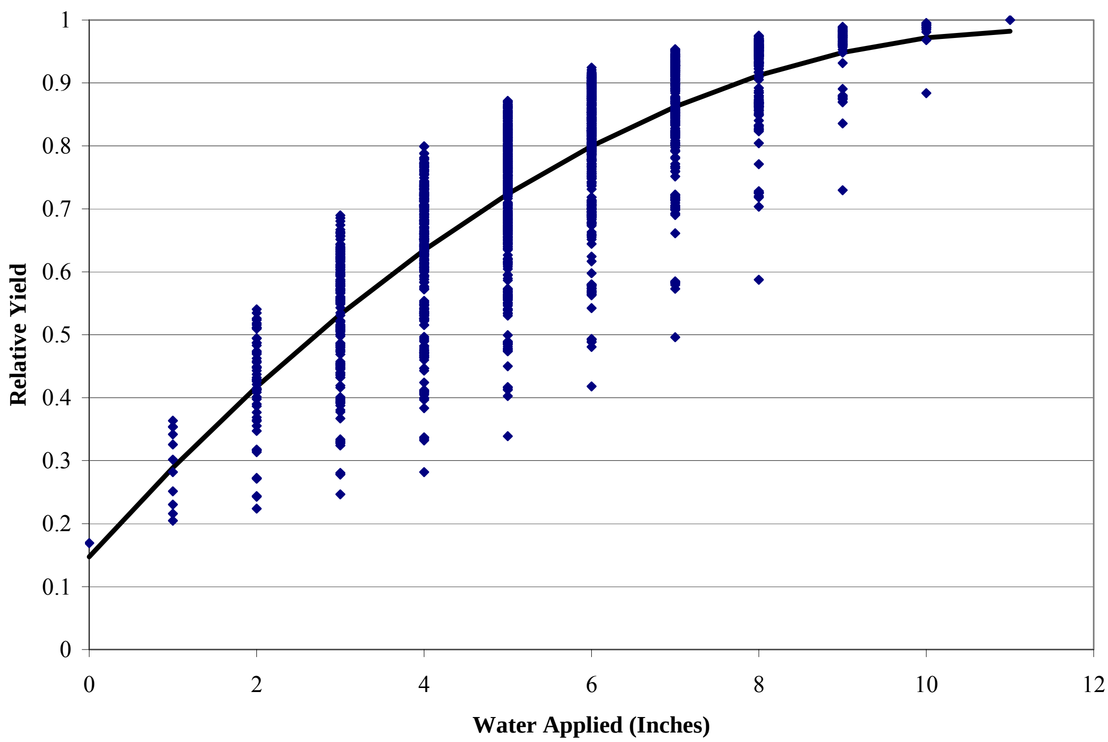

Table 1. Crop growth coefficients derived from regression analysis of relative yield crop growth simulation model from general equation: Rel y = $\alpha + \beta_1 w + \beta_2 w^2 + \beta_3 w^3$ where w is applied irrigation water.

	Estimated Parameters				
	α	β_1	β_2	β_3	Adj. R^2
Sandy Soil					
Alfalfa	0.147292	0.148099	-0.00656	-	0.66
	(8.8)	(23.9)	(-11.9)		
Barley	0.505286	0.070212	-0.00248	-	0.78
	(27.6)	(13.1)	(-6.7)		
Potatoes	-0.03948	0.13753	-0.00423	-	0.78
	(-3.6)	(36.8)	(-13.9)		
Sandy Loam Soil					
Alfalfa	0.532754	0.033621	-	-	0.65
	(164.5)	(59.6)			
Barley	0.519422	0.060182	-	-	0.56
	(35.3)	(17.5)			
Potatoes	0.605425	0.103601	-0.00845	0.000199	0.74
	(78.6)	(24.6)	(-11.6)	(4.9)	

Table 2. Long term average crop yield for the San Luis Valley, Colorado.

	Long Term Average Yield		
	Alfalfa ($t\ ac^{-1}$)	Barley ($bu\ ac^{-1}$)	Potatoes ($cwt\ ac^{-1}$)
Sandy Soil	4	130	310
Sandy Loam Soil	5	150	350

Table 3. Price and variable costs for alfalfa, barley and potatoes.

	Alfalfa	Barley	Potatoes
Price (Unit of production)$^{-1}$ ($)	85 ton^{-1}	3.26 bu^{-1}	5.50 cwt^{-1}
Variable Cost Ac^{-1} ($)	126.60	179.66	596.12
Variable Cost (Unit of production)$^{-1}$ ($)	24.25 ton^{-1}	0.34 bu^{-1}	0.12 cwt^{-1}

Table 4. Net returns from production of alfalfa, barley and potatoes when levels of river flow and aquifer are varied.

River Flow (%)	*Aquifer Level (% of historic average of 2.46 Maf)*		
	100	50	0
	Million $		
100	91.8	91.3	82.3
50	87.8	86.8	63.9
0	82.9	82.8	-

Table 5. Acres of alfalfa, barley and potatoes produced with various levels of river flow and aquifer levels at the start of the growing season.

River Flow (%)	*Aquifer Level (% of historic average of 2.46 Maf)*								
	100			50			0		
	Alfalfa	Barley	Potatoes	Alfalfa	Barley	Potatoes	Alfalfa	Barley	Potatoes
	(Thousand Acres)			(Thousand Acres)			(Thousand Acres)		
100	27.2	74.9	61.7	23.0	74.9	61.7	22.6	73.1	57.6
50	26.5	72.3	59.0	17.2	72.2	59.0	2.7	52.9	54.0
0	24.4	65.4	55.2	24.4	65.5	55.2	0	0	0

Table 6. Total production from alfalfa, barley and potatoes when available water from the aquifer and river flow are varied.

River Flow (%)	*Aquifer Level (% of historic average of 2.46 Maf)*								
	100			50			0		
	Alfalfa	Barley	Potatoes	Alfalfa	Barley	Potatoes	Alfalfa	Barley	Potatoes
	(1,000 bu)	(mil. bu)	(mil. cwt)	(1,000 bu)	(mil. bu)	(mil. cwt)	(1,000 bu)	(mil. bu)	(mil. cwt)
100	122	10.5	20.4	106	10.5	20.4	90	9.1	19.0
50	119	9.9	19.6	82	9.9	19.6	8	5.2	16.9
0	111	9.2	18.3	111	9.2	18.3	0	0	0

Table 7. Ending aquifer level when available water from the aquifer and river flow are varied.

River Flow (%)	*Aquifer Level (% of historic average of 2.46 Maf)*		
	100	50	0
100	2,413,861	1,176,307	38,099
50	2,323,168	1,099,049	4,803
0	2,310,382	1,070,336	-