OPTIMAL CROPPING AND THE POTENTIAL IMPACT OF A WATER MARKET ON AN AGRARIAN COMMUNITY: A CASE STUDY OF THE SAN LUIS VALLEY, COLORADO*

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ABSTRACT

The use of water for agrarian activities has become an increasingly debated topic in the US as water becomes relatively scarce due to increasing demand and declining supply. Potential impacts of climate change will further exacerbate problems in the future. Opponents of agriculture argue that agricultural water should be transferred to higher value uses. Consequently, interest in enhancing the efficiency of water use through cropping patterns, water banking institutions, or water markets, and the impact of changes on communities has increased. We develop a short run crop allocation model at the level of the individual decision maker within a water system. This model is particularly appropriate for areas in the Southwest where water availability is highly variable from year to year and decision makers must make their production decisions at the beginning of the growing season using the forecasted water availability. This model provides an information technology with which we can assess the economic impact of varying drought conditions in the area. With the model we find the optimal cropping pattern and assess the impacts of this decision on the local economy. We extend the model to assess the impact of a limited water lease market in times of drought.

We apply the model to Water District 21 in the San Luis Valley of Colorado (US). This agrarian community is located near the headwaters of the Rio Grande. The major crops include potatoes, grains, alfalfa, and meadow grass. There is no surface storage in the Valley, and so the agricultural sector is dependent solely on mountain front runoff and groundwater. We employ the model first to find the optimal cropping pattern for the District. Under full water allocations we find that a change in the cropping pattern could result in an almost $3 million impact. Second, we use the model results to develop a water-leasing model under a 20% drought scenario. We find a market could develop with an equilibrium water price of about $50 per acre foot. This market precipitates a further shift from lower value crops to potatoes, helps increase water productivity, and minimizes negative economic impacts on the community. This type of model provides decision makers with improved information with which to make production and allocation decisions. Furthermore, the model provides policy makers with a tool that can be used to assess the impact of proposed policy changes, such as a water market.

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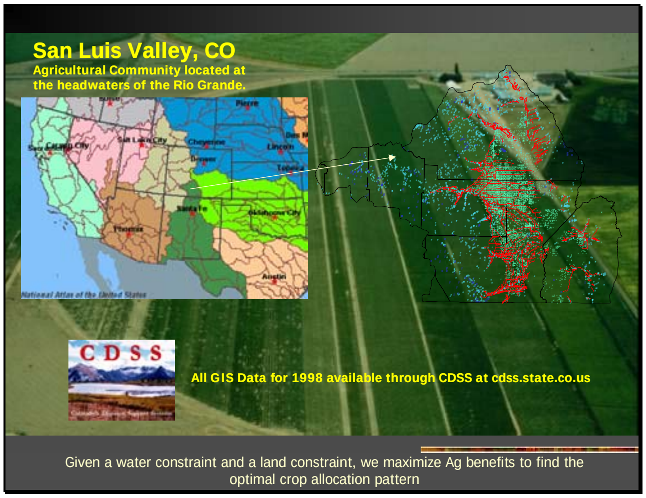


San Luis Valley, CO

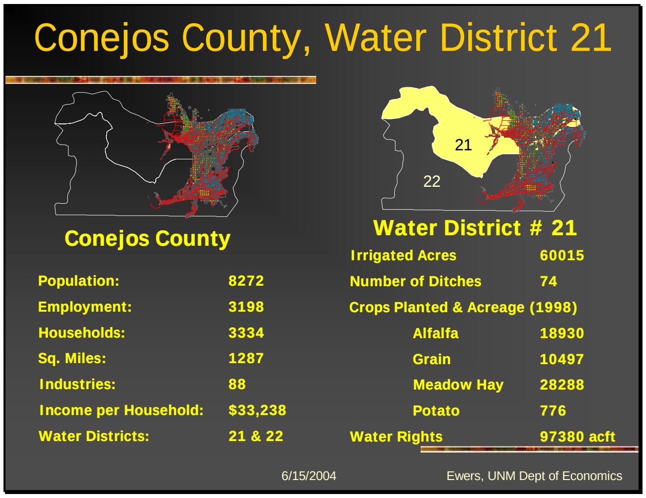
Agricultural Community located at the headwaters of the Rio Grande.

All GIS Data for 1998 available through CDSS at cdss.state.co.us

Given a water constraint and a land constraint, we maximize Ag benefits to find the optimal crop allocation pattern

This study is about achieving agricultural efficiency while using a fixed amount of water. This study is NOT about water conservation. We want to maximize agricultural profits through optimal cropping given a fixed amount of water available. Our study takes place in San Luis Valley, Colorado, an agricultural community located at the head waters of the Rio Grande.

The image on the right was generated from GIS data available from cdss.state.co.us. The thin red lines are irrigation ditches that deliver water (from mountain runoff) to agricultural fields. The blue dots represent shallow wells or recharge ponds. Our study area is the lower left-hand county (outlined in black), named Conejos County.



Conejos County, Water District 21

Conejos County

Population:	8272
Employment:	3198
Households:	3334
Sq. Miles:	1287
Industries:	88
Income per Household:	$33,238
Water Districts:	21 & 22

Water District # 21

Irrigated Acres		60015
Number of Ditches		74
Crops Planted & Acreage (1998)		
	Alfalfa	18930
	Grain	10497
	Meadow Hay	28288
	Potato	776
Water Rights		97380 acft

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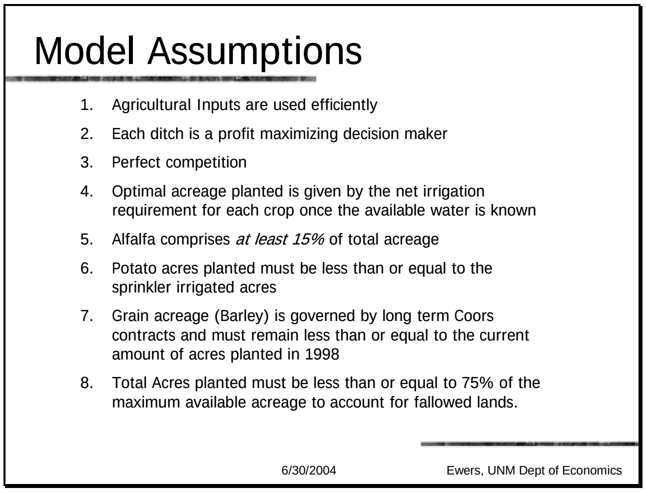
Conejos County is comprised of water districts 21 and 22. We analyze the cropping patterns of 1998 and use agriculture revenues and costs in a profit maximization model given land and water constraints.



Model Assumptions

1. Agricultural Inputs are used efficiently
2. Each ditch is a profit maximizing decision maker
3. Perfect competition
4. Optimal acreage planted is given by the net irrigation requirement for each crop once the available water is known
5. Alfalfa comprises *at least 15%* of total acreage
6. Potato acres planted must be less than or equal to the sprinkler irrigated acres
7. Grain acreage (Barley) is governed by long term Coors contracts and must remain less than or equal to the current amount of acres planted in 1998
8. Total Acres planted must be less than or equal to 75% of the maximum available acreage to account for fallowed lands.

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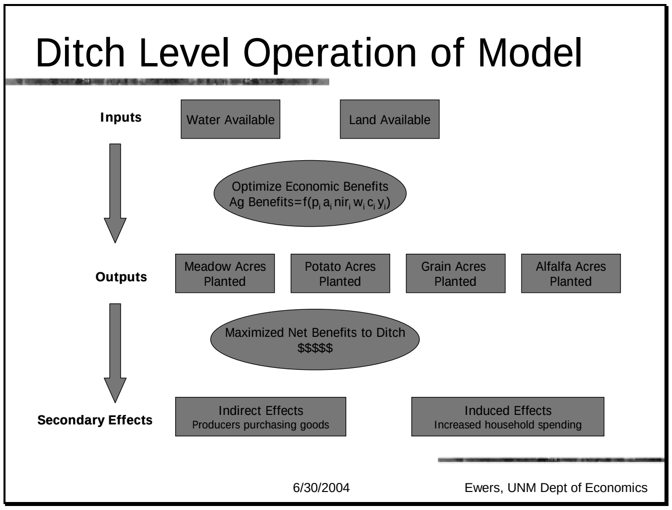
All models have assumptions. Assumptions 1-3 satisfy the fundamental rules of economics. No. 4 concerns the plant physiology. We assume that alfalfa will always need 33 in. of water per acre to grow a full stand. No. 5 accounts for the fact that while alfalfa is the least profitable crop, there exists a minimum amount of alfalfa necessary for inputs into other farm productions, such as dairy feed or cattle feed. No. 6 arises due to the fact that, in the San Luis Valley, potatoes are usually grown with a center pivot sprinkler irrigation system. Therefore potatoes can only be grown on those fields already equipped with center pivots. We are not allowing for a change in technology. No. 7 accounts for the long-term contracts that farmers have with The Coors Brewing company to grow barley (grain). No. 8 incorporates the standard practice of fallowing land to replenish the soils.



Ditch Level Operation of Model

Inputs

Water Available

Land Available

Optimize Economic Benefits
Ag Benefits=f(p_i, a_i, nir_i, w_i, c_i, y_i)

Outputs

Meadow Acres Planted

Potato Acres Planted

Grain Acres Planted

Alfalfa Acres Planted

Maximized Net Benefits to Ditch
$$$$$

Secondary Effects

Indirect Effects
Producers purchasing goods

Induced Effects
Increased household spending

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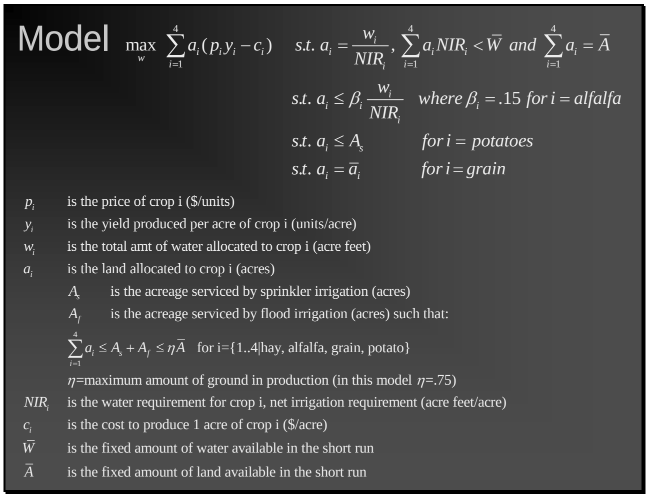
We assume a fixed amount of land and a fixed amount of water "inputs" available for the growing season. Given the profit made on each crop type, and the farming practice constraints, we then calculate our "outputs" or acreage planted for each crop type. After maximizing the benefits to each ditch, we calculate the secondary effects from the increased incomes the farms will receive.



Model

$$\max_{w} \sum_{i=1}^{4} a_i (p_i y_i - c_i) \quad s.t.\ a_i = \frac{w_i}{NIR_i},\ \sum_{i=1}^{4} a_i NIR_i < \bar{W} \ and \ \sum_{i=1}^{4} a_i = \bar{A}$$

$$s.t.\ a_i \le \beta_i \frac{w_i}{NIR_i} \quad where\ \beta_i = .15\ for\ i = alfalfa$$

$$s.t.\ a_i \le A_s \quad for\ i = potatoes$$

$$s.t.\ a_i = \bar{a}_i \quad for\ i = grain$$

p_i	is the price of crop i ($/units)
y_i	is the yield produced per acre of crop i (units/acre)
w_i	is the total amt of water allocated to crop i (acre feet)
a_i	is the land allocated to crop i (acres)

A_s is the acreage serviced by sprinkler irrigation (acres)

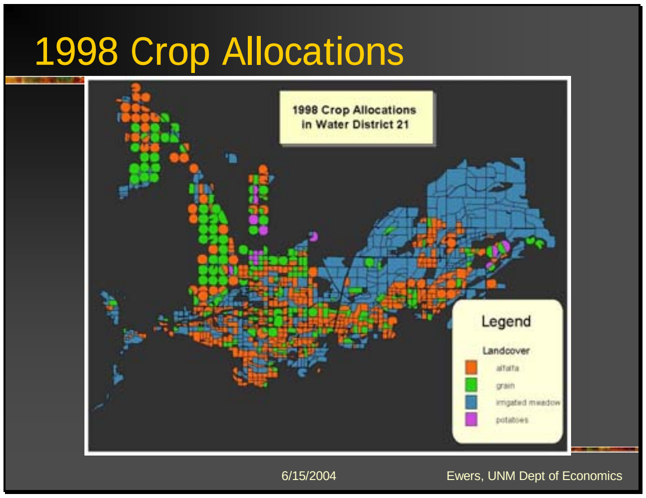
A_f is the acreage serviced by flood irrigation (acres) such that:

$\sum_{i=1}^{4} a_i \le A_s + A_f \le \eta \bar{A}$ for i={1..4|hay, alfalfa, grain, potato}

η=maximum amount of ground in production (in this model η=.75)

NIR_i	is the water requirement for crop i, net irrigation requirement (acre feet/acre)
c_i	is the cost to produce 1 acre of crop i ($/acre)
$\bar{W}$	is the fixed amount of water available in the short run
$\bar{A}$	is the fixed amount of land available in the short run

This is a profit maximization model. The important thing to note on this slide is that water actually enters the equation system twice. W is the total amount of water applied to a crop type and is measured in acre feet. NIR, on the other hand, is the water requirement for the crop to grow (biological, physiological…) and is measured in acre feet per acre.



1998 Crop Allocations

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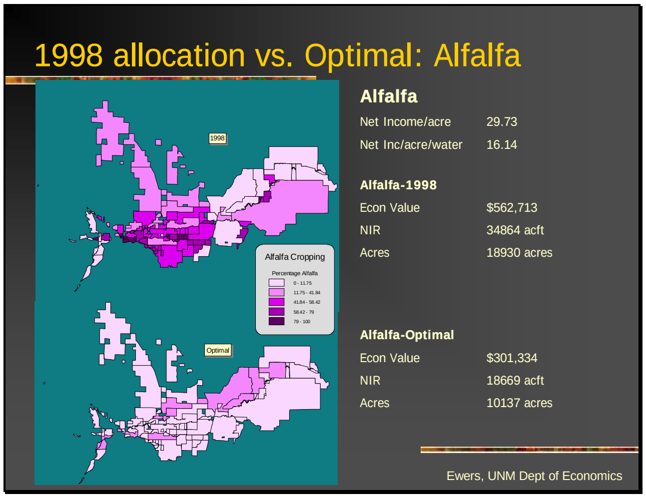
This is the GIS depiction of individual fields in water district 21. The circular fields are sprinkler irrigated while the square and rectangular fields are usually flood irrigated. We do not allow for a change in technology.



1998 allocation vs. Optimal: Alfalfa

Alfalfa

Net Income/acre	29.73
Net Inc/acre/water	16.14

Alfalfa-1998

Econ Value	$562,713
NIR	34864 acft
Acres	18930 acres

Alfalfa-Optimal

Econ Value	$301,334
NIR	18669 acft
Acres	10137 acres

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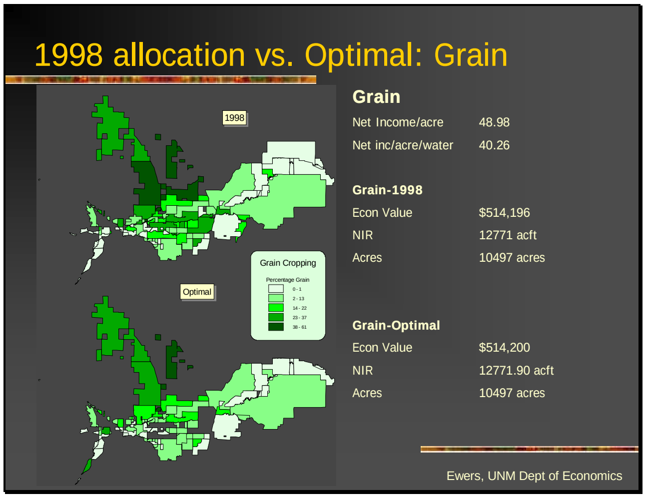
After running the model, we find that the optimal amount of alfalfa acreage decreases when compared to the 1998 allocations.



1998 allocation vs. Optimal: Grain

Grain

Net Income/acre	48.98
Net inc/acre/water	40.26

Grain-1998

Econ Value	$514,196
NIR	12771 acft
Acres	10497 acres

Grain-Optimal

Econ Value	$514,200
NIR	12771.90 acft
Acres	10497 acres

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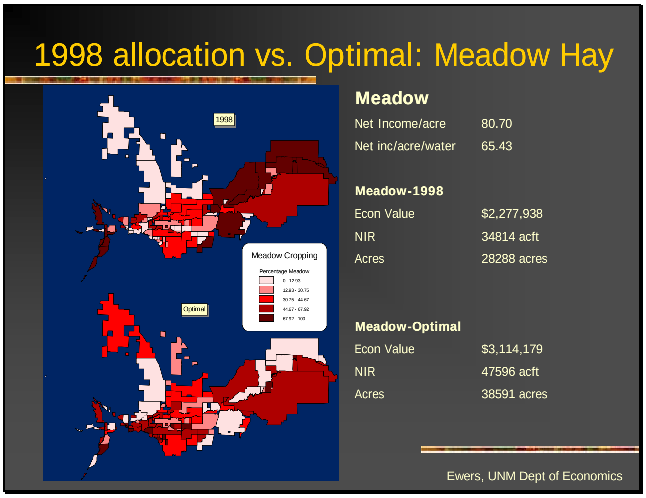
The optimal amount of grain to be grown is fixed due to long-term contracts with the local brewery. However, we do see some shifting in the locations of the grain grown from lower marginal revenue producers to higher marginal revenue producers.



1998 allocation vs. Optimal: Meadow Hay

Meadow

Net Income/acre	80.70
Net inc/acre/water	65.43

Meadow-1998

Econ Value	$2,277,938
NIR	34814 acft
Acres	28288 acres

Meadow-Optimal

Econ Value	$3,114,179
NIR	47596 acft
Acres	38591 acres

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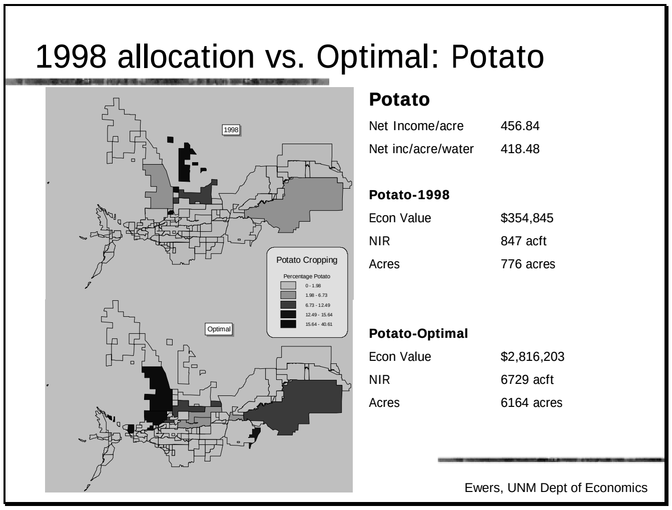
The farms that grow less alfalfa will switch to either meadow hay or potatoes. However, since potatoes are constrained to the center pivot fields (circles), a square or rectangular field must switch to meadow hay.



1998 allocation vs. Optimal: Potato

Potato

Net Income/acre	456.84
Net inc/acre/water	418.48

Potato-1998

Econ Value	$354,845
NIR	847 acft
Acres	776 acres

Potato-Optimal

Econ Value	$2,816,203
NIR	6729 acft
Acres	6164 acres

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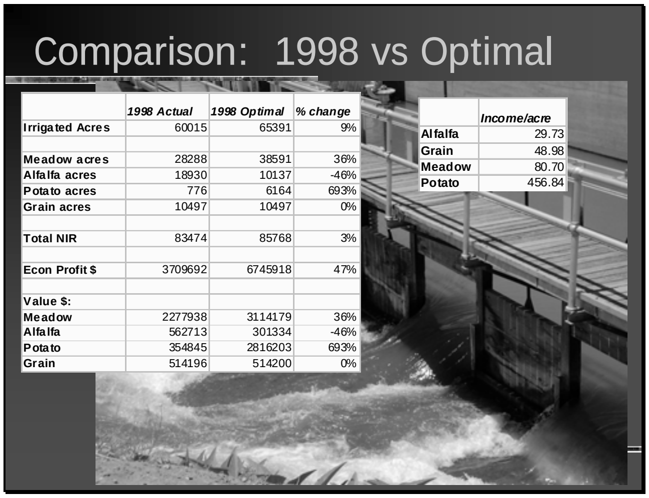
Potatoes are the most profitable crop at $456/acre. However, they can only be grown on circular fields. The optimal potato acreage increases significantly when compared to the 1998 allocation.

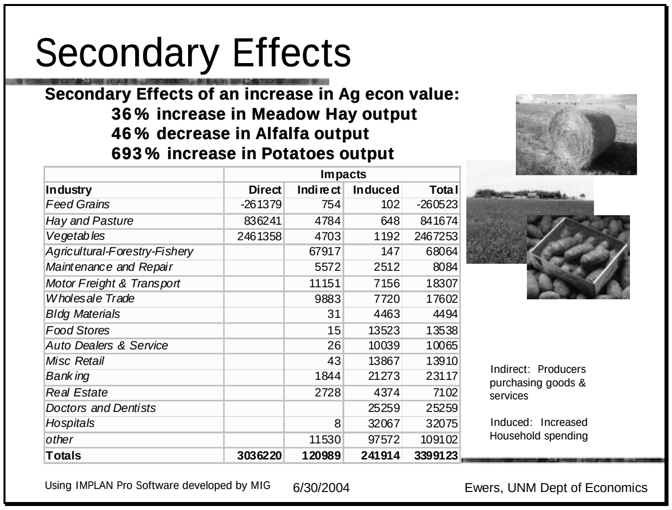


Comparison: 1998 vs Optimal

	1998 Actual	*1998 Optimal*	*% change*
Irrigated Acres	60015	65391	9%
Meadow acres	28288	38591	36%
Alfalfa acres	18930	10137	-46%
Potato acres	776	6164	693%
Grain acres	10497	10497	0%
Total NIR	83474	85768	3%
Econ Profit $	3709692	6745918	47%
Value $:			
Meadow	2277938	3114179	36%
Alfalfa	562713	301334	-46%
Potato	354845	2816203	693%
Grain	514196	514200	0%

	Income/acre
Alfalfa	29.73
Grain	48.98
Meadow	80.70
Potato	456.84

The optimal cropping pattern, which maximizes ag profit while using the available water, adds $3 million dollars to the community.



Secondary Effects

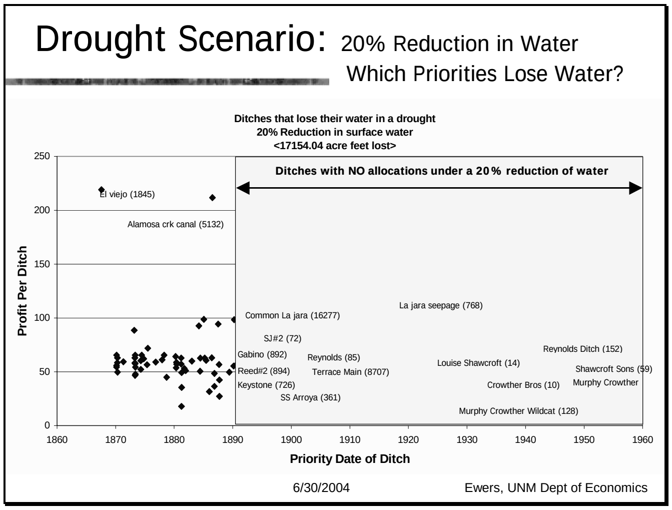
Secondary Effects of an increase in Ag econ value:
36% increase in Meadow Hay output
46% decrease in Alfalfa output
693% increase in Potatoes output

	Impacts			
Industry	**Direct**	**Indirect**	**Induced**	**Total**
Feed Grains	-261379	754	102	-260523
Hay and Pasture	836241	4784	648	841674
Vegetables	2461358	4703	1192	2467253
Agricultural-Forestry-Fishery		67917	147	68064
Maintenance and Repair		5572	2512	8084
Motor Freight & Transport		11151	7156	18307
Wholesale Trade		9883	7720	17602
Bldg Materials		31	4463	4494
Food Stores		15	13523	13538
Auto Dealers & Service		26	10039	10065
Misc Retail		43	13867	13910
Banking		1844	21273	23117
Real Estate		2728	4374	7102
Doctors and Dentists			25259	25259
Hospitals		8	32067	32075
other		11530	97572	109102
Totals	**3036220**	**120989**	**241914**	**3399123**

Indirect: Producers purchasing goods & services

Induced: Increased Household spending

Using IMPLAN Pro Software developed by MIG 6/30/2004 Ewers, UNM Dept of Economics



Drought Scenario: 20% Reduction in Water Which Priorities Lose Water?

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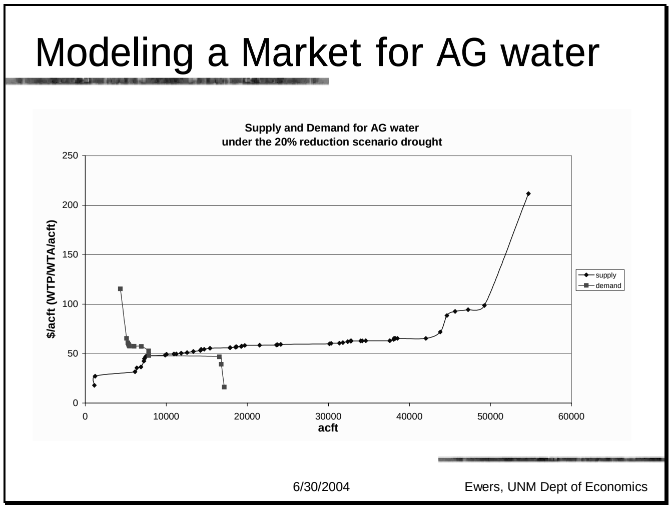
Now let's model a 20% reduction in water supply. San Luis Valley water rights are based on prior appropriation. The priority dates are continuous. A 20% reduction is equivalent to 17154 acre feet lost. We know the amount of water that each ditch has a "right" to use, or is decreed. We also know the priority date of each right. The graph above orders the ditches by priority date. If there is a "call on the river," the state engineer will start to cut off water at the most junior rights and move toward the most senior rights. The ditches in the shaded area will be "cut off" in this drought scenario. These ditches become our demanders of water. By using their "profit per ditch per acre foot used" as a "willingness to pay" for water we can create a demand schedule. Those ditches that did not lose their water comprise our supply schedule.



Modeling a Market for AG water

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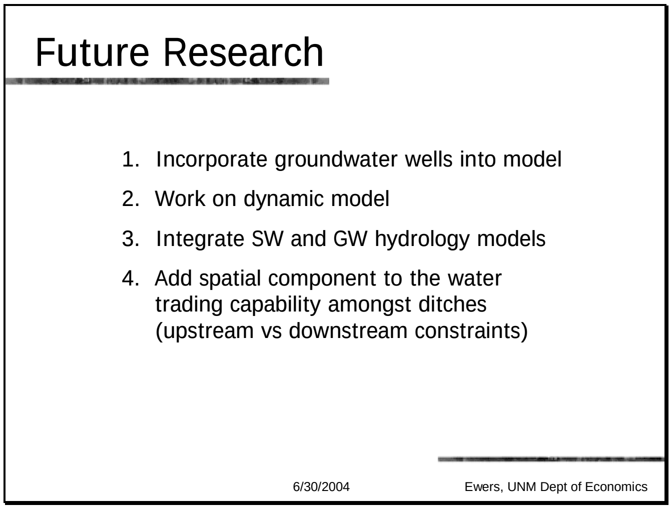
This graph depicts our demand schedule and supply schedule of ditches under a 20% reduction in water. Equilibrium occurs at a price of $50 per acre foot of water. Keep in mind that this is the price to lease water for one season and does NOT represent the permanent sale of the water right.



Future Research

1. Incorporate groundwater wells into model
2. Work on dynamic model
3. Integrate SW and GW hydrology models
4. Add spatial component to the water trading capability amongst ditches (upstream vs downstream constraints)

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