FORECASTING WATER DEMAND AND VALUE FOR COTTON AND CORN PRODUCTION

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Abstract

An econometric model is proposed to estimate irrigation water demand and hence estimate water value through crop acreage committed to irrigation in the Mississippi Delta. This model combines a land allocation model with actual water use data for each crop. The land allocation model is based on a portfolio type analysis that not only combines measures of risks and returns but also allows for agronomic and other influences. A physical, engineering type model would not consider any changes in economic or institutional conditions. Therefore, it would not account for changes in crop mix over time due to economic or institutional changes. Our model takes into account such changes and reallocates irrigated acres in the new economic or institutional regime by accounting for substitution and expansion effects. Results indicate, the physical model predicts a decrease in water demand (and hence value) for corn while the econometric model showed an increase. The physical model also over-predicts the decrease in water demand for cotton. Due to the differences between the physical and econometric models, a 50,000 acres policy-induced decrease in irrigation in 2006 over 2005 would result in an increase of water savings of around 24% by shifting water out of irrigation from other crops (rice and soybeans) into corn and cotton.

Introduction

Limited water supply in many parts of the United States, including the Mid-south and Mississippi in particular, is a serious problem in agriculture (USGS, 2007). The aquifer level under the alluvial soil to the immediate east of the Mississippi River (Mississippi River Alluvial Aquifer) has been declining (YMD, 2007; Figures 1 and 2). A declining water supply has possibly been made worse due to the droughts of 2006 and 2007. Additionally, policies in the future that restrict usage of water for irrigating crops may be necessary to help protect the aquifer. Further, the recent interest in alternative fuels may create different crop mixes in the Delta region creating different water demands on the alluvial aquifer. Therefore, a method of evaluating the water needs of different crops and the value of water to each crop similar to Banerjee et al. (2007) would provide agricultural producers with valuable information.

Policymakers also need better tools to devise programs and policies to deal with such water shortages. A model is proposed to estimate irrigation water demand and hence estimate water value through crop acreage committed to irrigation. This model combines a land allocation model with actual water use data for each crop. The land allocation model is based on a portfolio type analysis that not only combines measures of risks and returns, but also allows for agronomic and other influences.

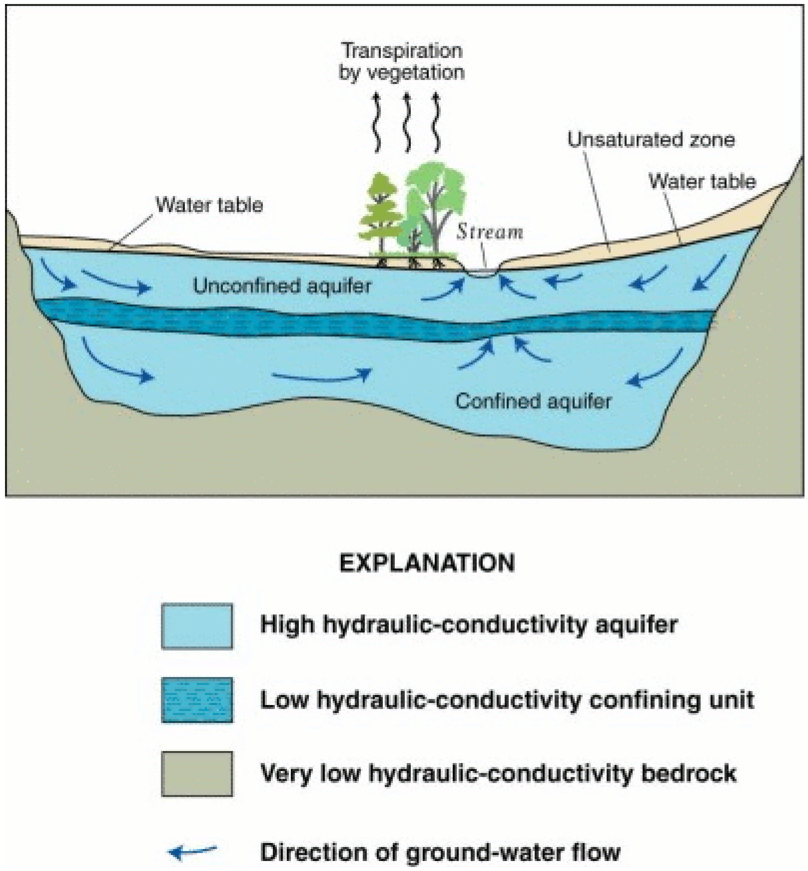
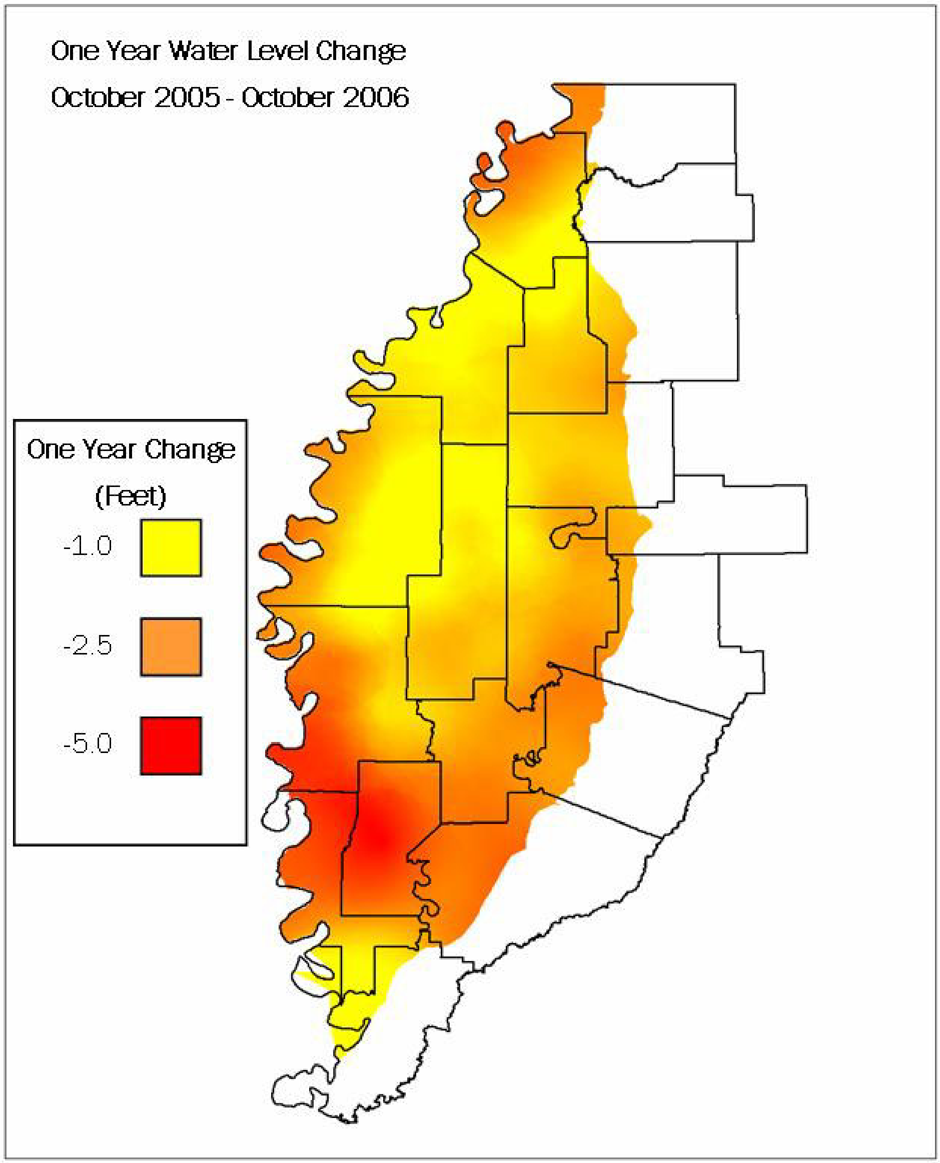


Figure 1. Schematic of an Aquifer



Source: *Yazoo Mississippi Delta Joint Water Management District*'s Water Use and Aquifer Trends in the Mississippi Delta 2006 Report

Figure 2. Water Level Change

Objectives

The overall objective of this study was to develop a method of precisely forecasting agricultural water demand for irrigating cotton and corn in Mississippi. In particular, the following steps let us fulfill the basic objective of developing such a forecasting method:

1. Develop an econometric model of crop irrigated acreage allocation based on expected prices, expected yields, expected crop returns, variances and covariances of crop returns, and total irrigated acres by crop.
2. Employ the acreage forecasts from the estimated econometric model to the relevant actual water use data in Mississippi to estimate water demand by crop, and compare and contrast the forecast results from this econometric

approach against those from the traditional, engineering/physical approach that uses the initial crop distribution to forecast water demand.

Steps 1 and 2 allow a precise estimation of crop irrigated acreage a year in advance, thus enabling us to calculate the value of water saved in terms of irrigated acreage.

3. From the above water demand estimates for the econometric and engineering approaches, use simulated forecasting scenarios to determine responsiveness of the econometric approach vis-à-vis the engineering approach to certain economic and institutional variables, and calculate "slippage" – a measure to distinguish between the two approaches. The value of water saved by differing the crop mix allows the calculation of the value per acre-inch of water on a crop-by-crop basis. Calculation of "slippage" (one minus the ratio of the econometric change to the physical change in total water demand) enables us to visualize this difference as in related literature (Banerjee et al., 2007).

Data and Research Methods/Procedures

Data for this study was primarily obtained from the *U. S. Department of Agriculture – National Agricultural Statistics Service* (USDA-NASS) (2007) (data on state planted and irrigated acres by crop, and yields by crop), *Commodity Research Bureau* (data on futures prices by crop), *U. S. Department of Agriculture – Economic Research Service* (USDA-ERS) (2007) (data on variable costs by crop), and *Yazoo Mississippi Delta* (YMD) *Joint Water Management District* (2007) (data on water use by crop). A time series for Mississippi starting in 1984 and ending in 2003 was chosen for the sample. Years 2004 and 2005 were chosen for out-of-sample forecasts.

Theoretical Modeling

The representative farmer maximizes expected utility (EU) from total profits (Π_i) under competition and comes up with an optimal choice of irrigated acreage (A_i) for each crop:

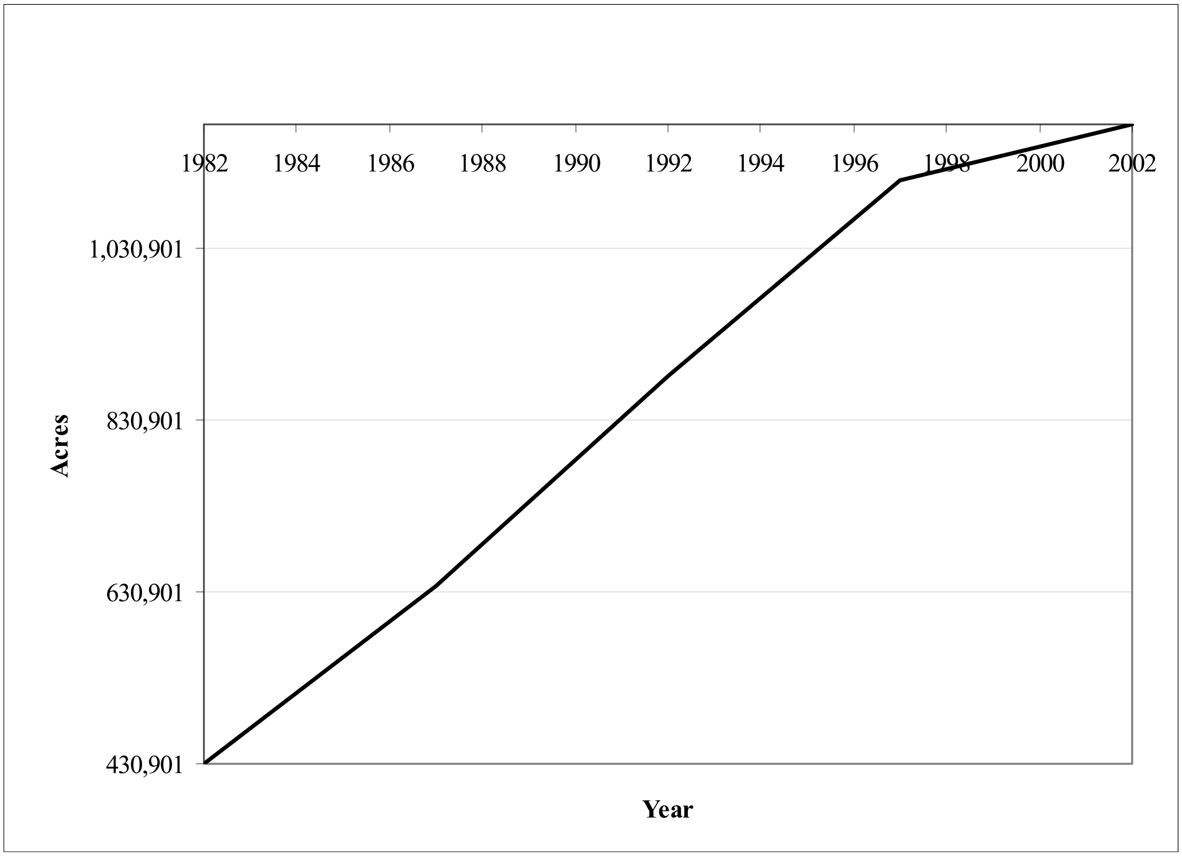
$$A^*_i = A_i(\Pi_j, \sigma_{jj}, \sigma_{jk}, A, \bar{T}, \bar{G}), \quad i, j, k = 1, \ldots, n, \quad j > k,$$

where Π_j is the expected profit accruing from the j^{th} crop,
σ_{jj} denotes the variance in profit for the j^{th} crop,
σ_{jk} the covariance of profit between the j^{th} and k^{th} crops,
A is total irrigated acres,
$\bar{T}$ is technology, and
$\bar{G}$ governmental programs.

The vector of covariances accounts for the mechanism of risk spreading by farmers via the portfolio effect. Technology and government programs were considered fixed in estimating the model.

Empirical Modeling

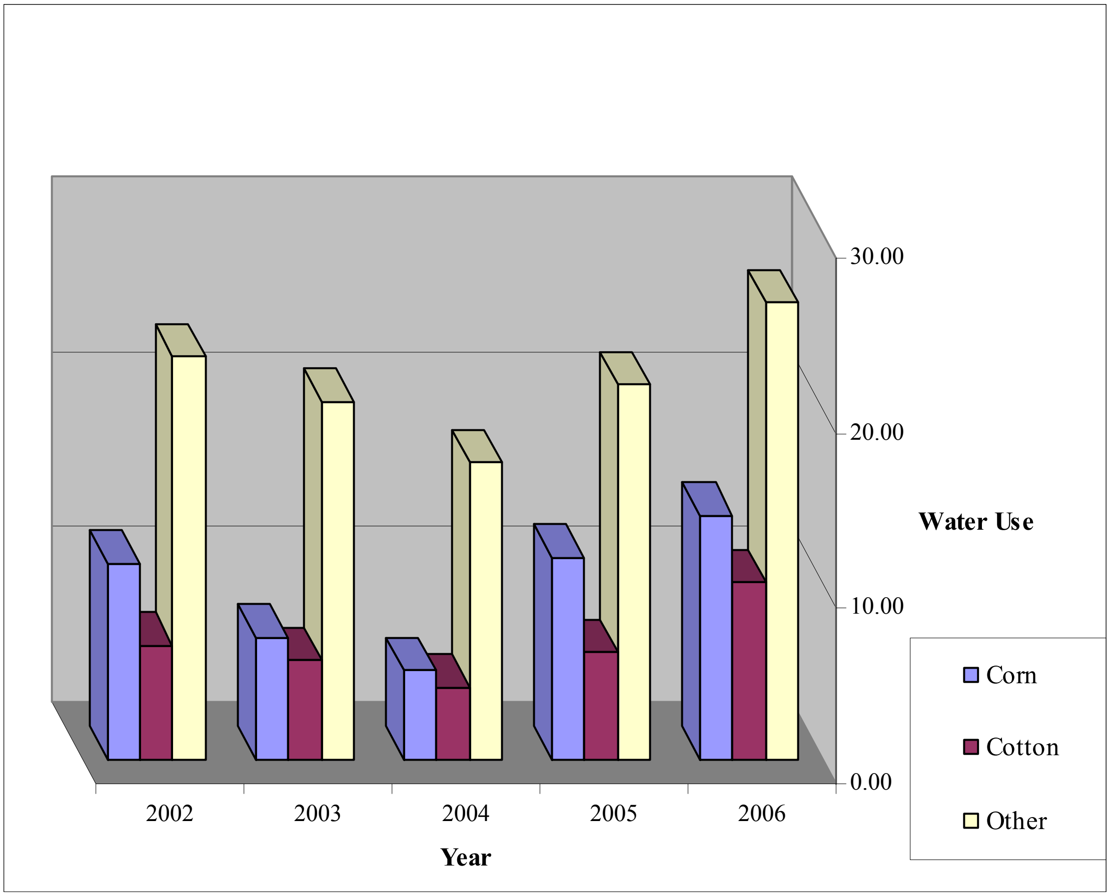
Step 1: Expected profits and the variances and covariances of expected profits were calculated using futures prices, past yields (Holt, 1999) and covariances between those prices and yields (Bohrnstedt and Goldberger, 1969). The irrigated acres of each crop were then linearly regressed on expected profits, variances and covariances of profits from each crop, and total irrigated acres (Figure 3). This yielded a set of crop acreage predictions (Banerjee et al., 2007).



Source: http://www.nass.usda.gov/Statistics_by_State/Mississippi/Search/index.asp

Figure 3. Total Irrigated Acres, Census Years, MS, 1982-2002

Step 2: Irrigated acreage forecasts obtained from the acreage allocation equations were employed to the actual water use data available from YMD (2007) for obtaining the current and future water demand estimates. Specifically, predicted acreage times the relevant water use coefficient (2002-2006 annual average water used by each crop, Figure 4) equaled the average annual water demand in acre-inches for each crop.



Source: 2006 Water Use Survey Results, *Yazoo Mississippi Delta Joint Water Management District*

Figure 4. Water Use, Acre-Inches, MS Delta, 2002-2006 Annual Average

Step 3: By varying some of the economic and institutional parameters, the responsiveness of irrigated acres was determined. Specifically, once the base simulation was created at the end-point within the sample, 2003, several types of simulations were conducted out of the sample to determine how our model compared with the physical model. This was done by altering prices, yields, costs, and total irrigated acres to reflect out-of-sample data for three consecutive years (2004-2006). One such simulation assumed an institutionally forced reduction of total available irrigated acreage by 50,000 acres. The resulting water demand estimates obtained by our econometric approach were compared with the alternative engineering/physical approach through the calculation of "slippage" (Table 1).

Results and Discussion

R^2 values are 0.92 and 0.95, respectively, in the corn and cotton equations. About 50% of the variables are significant with their expected signs, and about 80% of the significant variables have their expected signs. Perhaps the most interesting result emerging from the irrigated acreage model is the expected profit of cotton per acre in its own equation is negative and significant, indicating that cotton producers tend to shift cotton acres out of irrigation and into dry land, reducing the percentage of irrigated cotton, when expected profit from cotton production goes up and vice versa.

Reduction-in-Irrigation-Capacity Scenario

Assuming there was a 50,000 acres policy-induced decrease in irrigation in 2006 over 2005, the differences between the physical and econometric models would result in an increase of water savings of around 24%, as measured by "slippage," by shifting water out of irrigation from other crops (rice and soybeans) into corn and cotton (Table 1). Between these two latter crops, the econometric model showed water demand (and hence value) for corn increased by 118,360 acre-inches, while the physical model indicated a decrease by 33,080. The physical model also over-predicts the decrease in water demand for cotton. With higher prices resulting in a major shift in acres from cotton and other crops to corn in 2007, the percentage of water savings is presumed to be more pronounced for a study using current commodity prices.

Table 1. Slippage in Measuring Change in Water Demand,[a] Mississippi, 2005 - 2006

Crop	Water Use[b]	Change in Water Demand[c]	
		Physical	Econometric
Corn	9.72	-33,080	118,360[d]
Cotton	6.48	-113,590	-27,443
Other[e]	21.56	-453,039	-832,453
Total		-599,709	-741,536
Slippage[f]			-0.2365

[a] Change in water demand is measured in acre-inches (1 acre-inch = 27,150 gallons).
[b] Measured in acre-inches per acre, based on 2002-2006 annual average (YMD, 2007).
[c] Change in physical (econometric) water demand = physical (econometric) crop distribution times the change in crop irrigated acreage times the relevant water use coefficient. Crop distribution assumes no other major users of water. The only other major water user in the state is catfish, but it has not used groundwater every year in the period 2002-2006 (YMD, 2007).
[d] A positive (negative) change indicates an increase (decrease) in water demand.
[e] Other includes rice and soybeans.
[f] Slippage = 1 – (econometric change in water demand / physical change in water demand).

A physical/engineering model would not consider any changes in economic or institutional conditions. Hence it would not account for changes in crop mix over time due to economic or institutional changes. Our model takes into account such changes and reallocates irrigated acres in the new economic or institutional regime by accounting for substitution and expansion effects.

Conclusions

Dependable and predictable water supply is vitally important for agricultural producers and hence for the general well-being and economic development of a state/region. The proposed method is based on water requirements of individual crops, thus capturing the intrinsic value of each crop relative to its water-requiring potential. Thus, with the successful introduction and implementation of the proposed model, farmers will have a better and more scientific method of anticipating water demand and value for their crops not only in the wake of a short supply due to natural causes, but also due to government policy that restricts water use. Policymakers will have a more precise method to calibrate acreage reduction programs to meet targeted levels for reductions in agricultural water use. Future research could focus on a county-level study with otherwise similar irrigation data.

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