Econometric versus Engineering Prediction of Water Demand and Value for Irrigation

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Introduction

Agriculture in many parts of the United States, including the Mid-south in general and Mississippi in particular, has been plagued with the nagging problem of limited water supply in recent years (USGS, 2007). For example, the aquifer level under the alluvial soil to the immediate east of the Mississippi River (Mississippi River Alluvial Aquifer) has been declining (YMD, 2008; Figures 1, 2, and 3). A declining water supply has possibly been made worse due to the droughts of 2006 and 2007. Additionally, policies in the future may further restrict usage of water for irrigating crops. Last but not least, 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 that combines a land allocation model with the crop- and region-specific water use coefficients (proxy for net irrigation water requirements by crop) is proposed to estimate irrigation water demand and hence estimate water value through crop acreage. This land allocation model is based on a portfolio type analysis that not only incorporates measures of risks and returns, but also allows for agronomic and other influences.

Objectives

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

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 predicted results from this econometric approach against those from the traditional engineering approach that uses the initial crop distribution to predict water demand.

Steps 1 and 2 allowed 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 prediction 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 (Tareen, 2001; Banerjee, 2007).

Data and Research Methods/Procedures

Data for this study was primarily obtained from *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 (2008) (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 as the latest irrigated acreage data available for all crops for comparison were until 2005.

Theoretical Modeling

- The representative firm maximizes expected utility (EU) from total profits under competition.
- Stochastic prices and yields make profits of a farming enterprise uncertain.
- Given this uncertainty, acreage allocation is modeled using the EU hypothesis where farmers are assumed to be risk-averse.
- Water demand is a derived demand, derived from the optimal choice of irrigated acreage allocation.
- The appropriate acreage response modeling strategy is to examine the changes in the cropping mix patterns committed to irrigation when the economic and institutional parameters of the problem, such as profitability of different crops and availability of total irrigated acreage, change.
- Farmers apply water on a per-acre basis and water application is a function of the crop planted to those acres. This makes these models theoretically consistent with the risk-averse farmer's decision-making framework.
- Therefore, the representative farmer is assumed to maximize his/her utility of profits (Π_i) and come up with an optimal choice of irrigated acreage (A_i) for each crop:

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

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 of the four crops (corn, cotton, rice, and soybeans) were then linearly regressed on expected profits, variances and covariances of profits from all four crops, and total irrigated acres (Figure 4). This yielded a set of crop acreage predictions (Banerjee et al., 2007).

Step 2: Irrigated acreage forecasts obtained from the acreage allocation equations were employed to the actual water use data (Figure 5) available from YMD (2008) for obtaining the current and future water demand estimates. Specifically, predicted acreage times the relevant water use coefficient (2002-2007 annual average water used by each crop) equaled the average annual water demand in acre-inches for each crop.

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 two consecutive years (2004 and 2005). 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 and contrasted with the conventional alternative, physical/engineering, approach through the calculation of "slippage." This provided insights into the appropriate model for forecasting crop acreage, and hence for forecasting agricultural water demand (Table 1).

In addition, as an out-of-sample forecast, prices projected by *Food and Agricultural Policy Research Institute* (FAPRI) (2008) for 2016 were used to forecast water demand through irrigated acreage predictions. Based on this simulation, the conventional engineering approach was compared with the econometric approach proposed.

Results and Discussion

Respective R^2 values for the corn, cotton, rice, and soybean equations are 0.92, 0.95, 0.96, and 0.91. 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 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 25%, as measured by “slippage,” by shifting water out of irrigation from rice and soybeans into corn and cotton (Table 1). [The same for a policy-induced 33,000-acre reduction (FRDPA, 2001) in a study on the Flint River Basin in Georgia was between 19% and 24%, depending on if acres were reduced simultaneously with prices or sequentially, like in the current study (Banerjee et al., 2007).]

Using 2016 FAPRI price projections ($2.99/bushel for corn, $0.60/lb for cotton, $8.87/cwt for rice, and $6.37/bushel for soybeans), the slippage is also approximately 25%, with all the directional impacts (shifts in water demand) of relevant crops as shown in Table 1, and hence not reported. The FAPRI projections use ending stock prices, and the projections for all the crops under study are not different enough to illustrate a greater change in the difference between the two approaches than already illustrated using 2006 prices. However, with higher prices resulting in a major shift in acres from cotton and other crops to corn in 2007 and 2008, this percentage savings of water is presumed to be more pronounced for a study using current commodity prices.

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. 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. 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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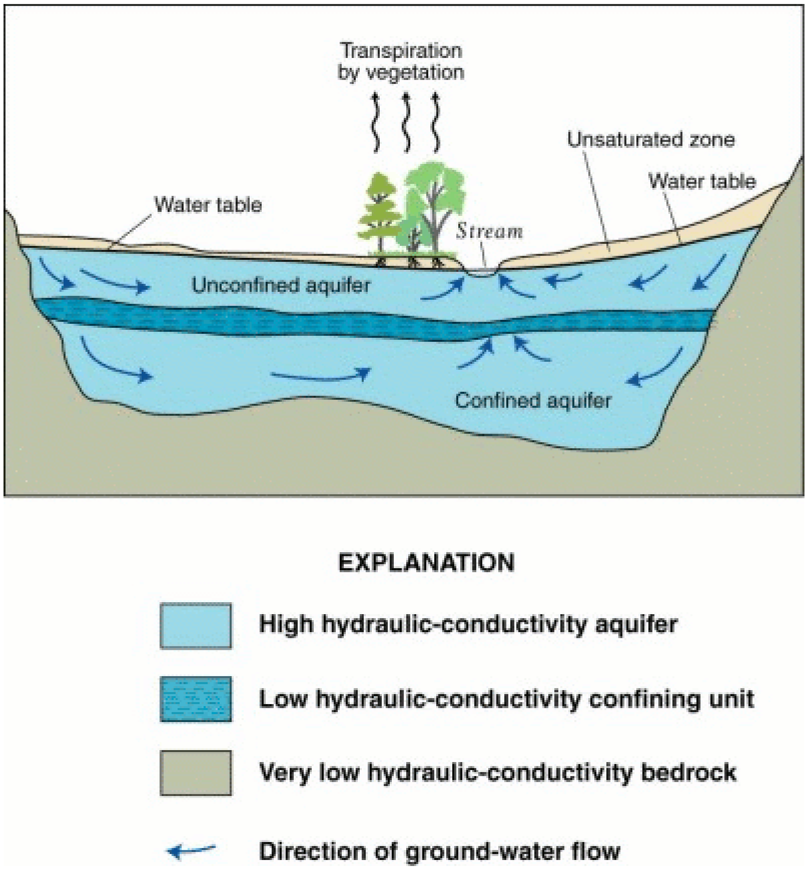
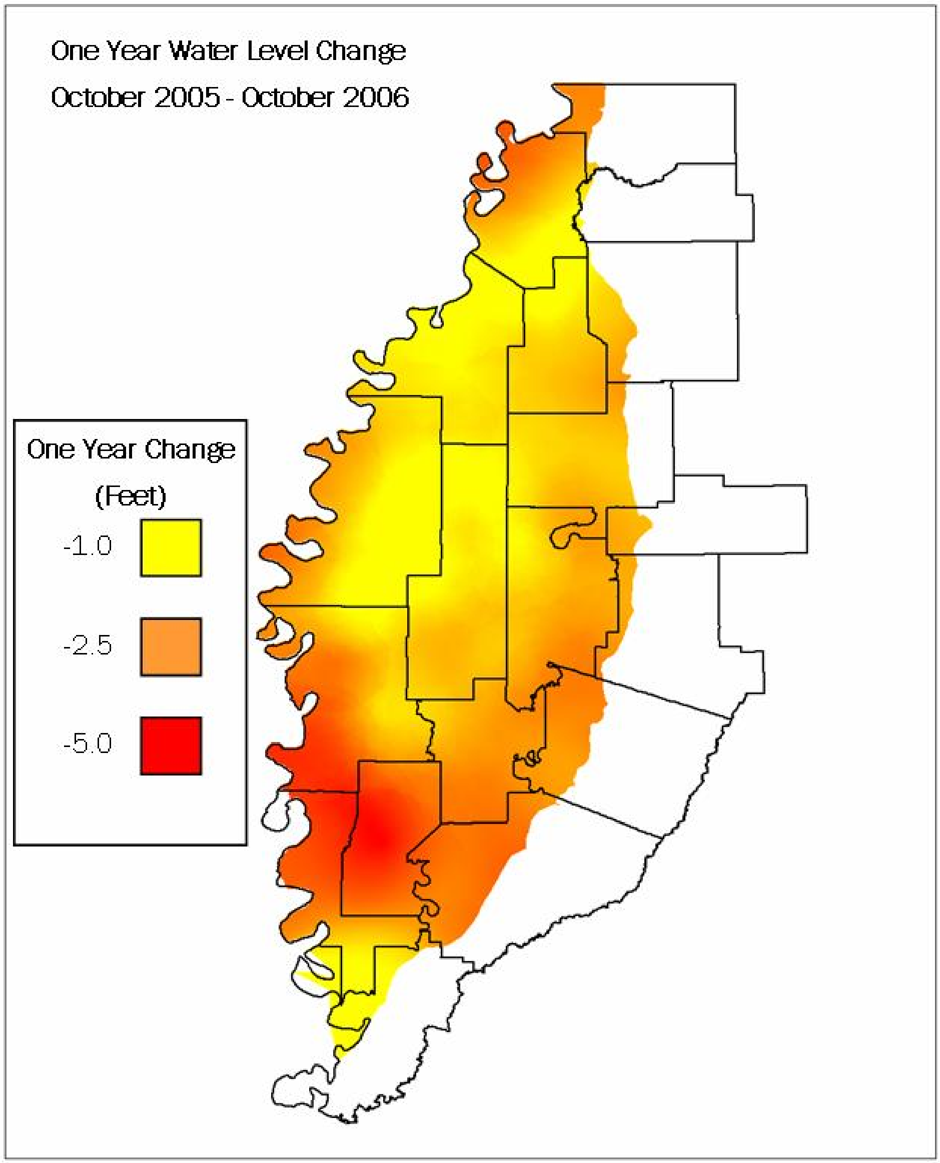
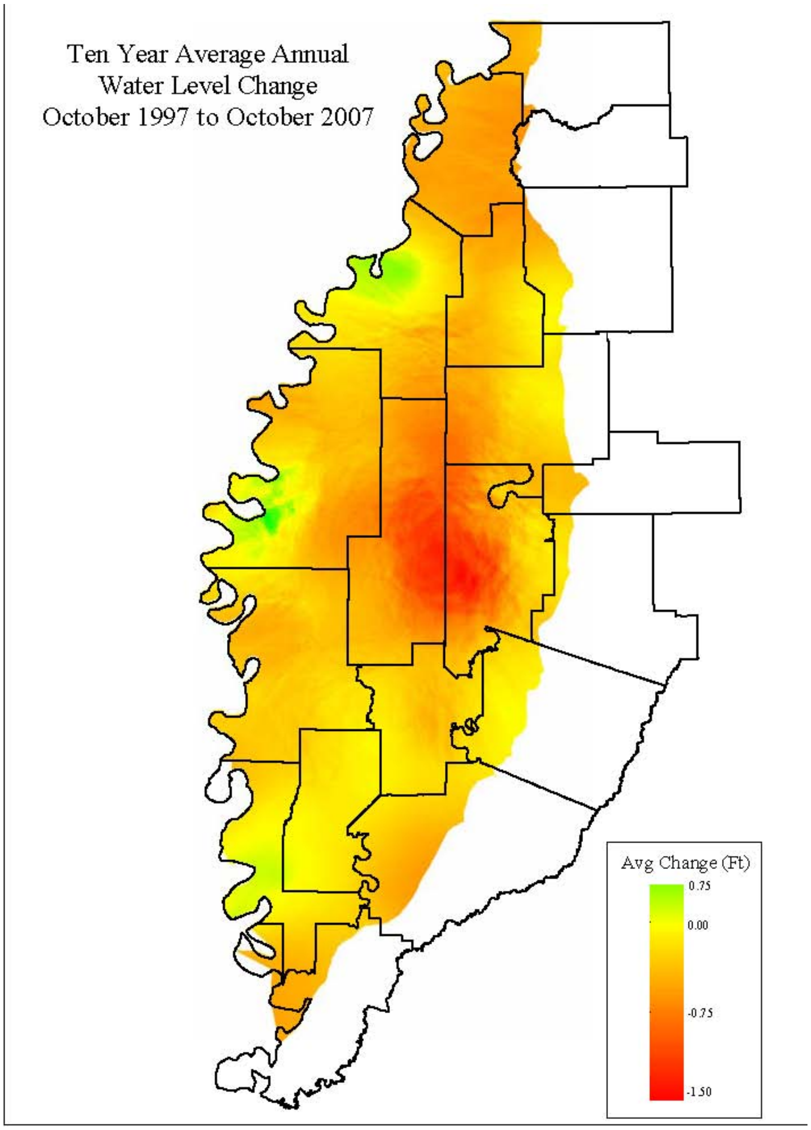


Figure 1. Schematic of an Aquifer



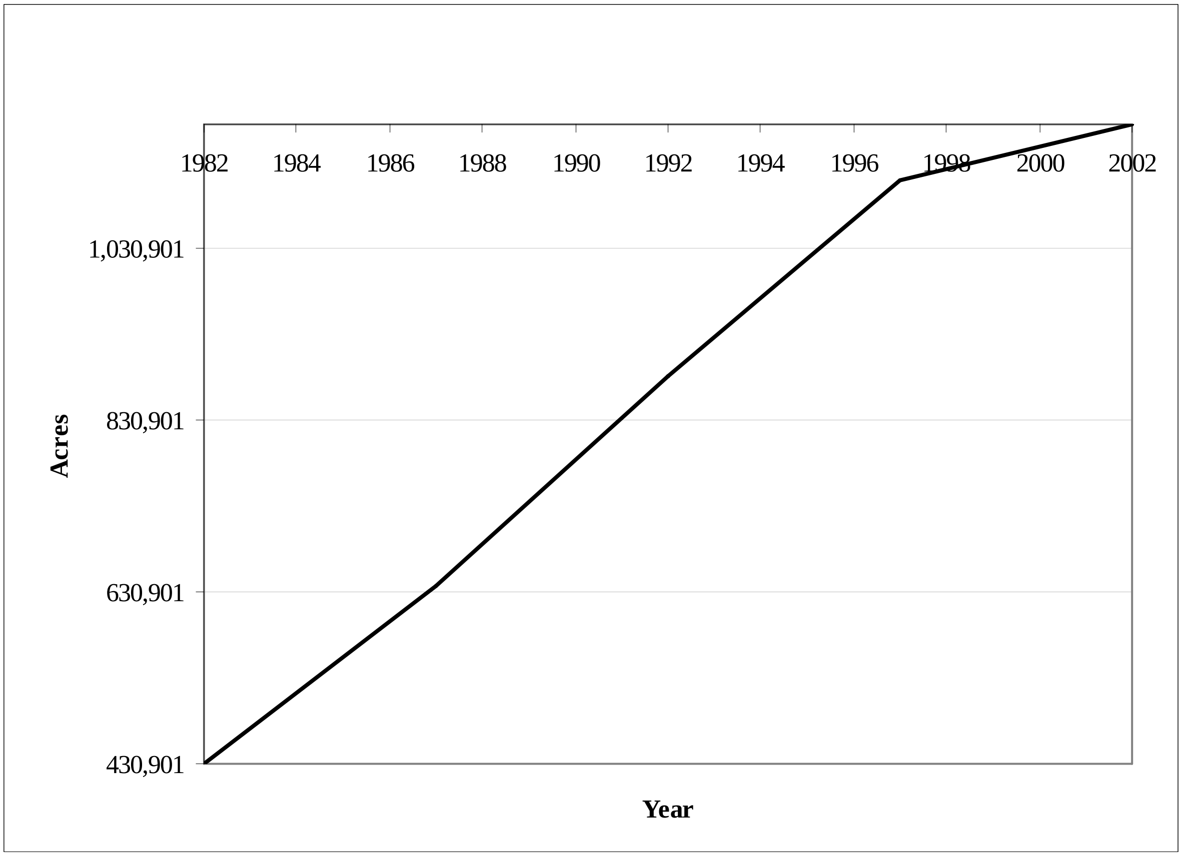
Source: *Yazoo Mississippi Delta Joint Water Management District*'s Water Use and Aquifer Trends in the Mississippi Delta 2006 Report

Figure 2. Water Level Change, 2005-2006



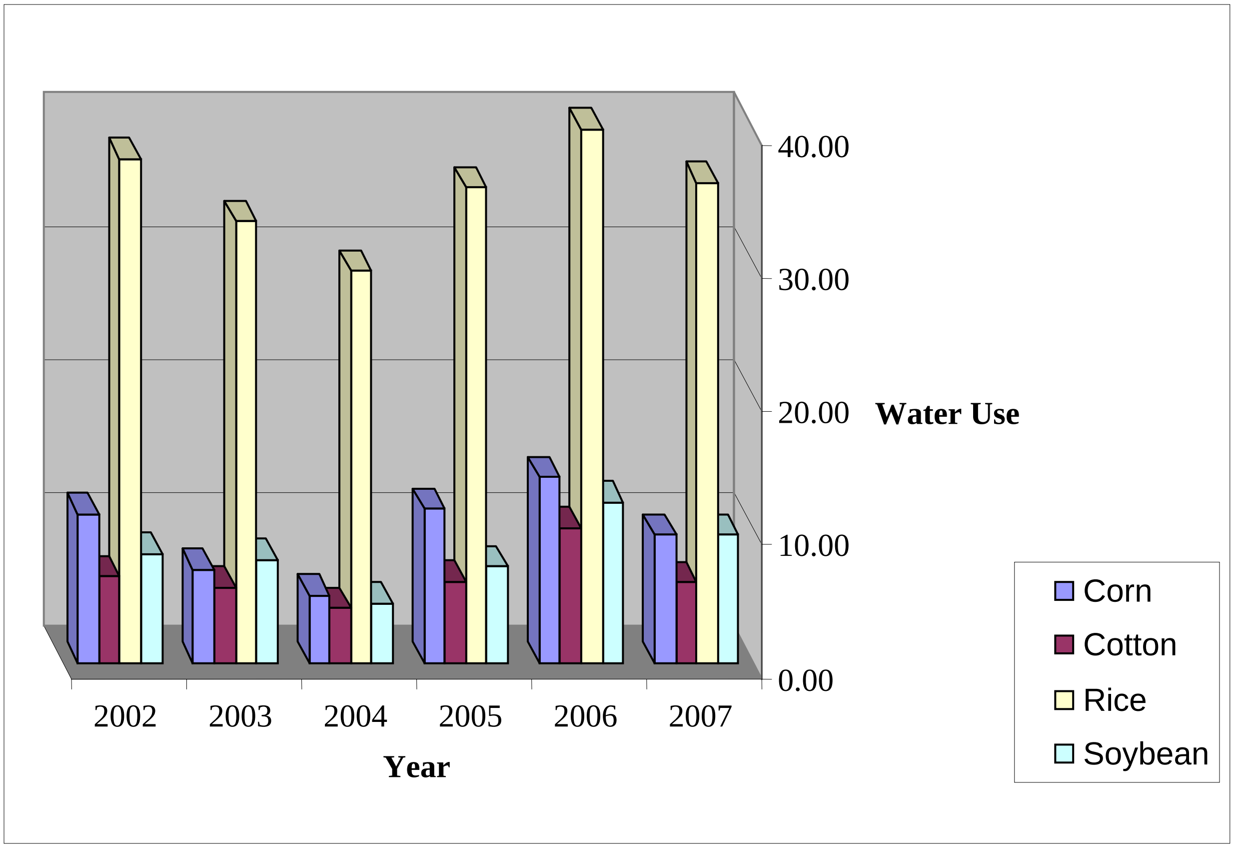
Source: *Yazoo Mississippi Delta Joint Water Management District*'s Water Use and Aquifer Trends in the Mississippi Delta 2007 Report

Figure 3. Water Level Change, 1997-2007



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

Figure 4. Total Irrigated Acres, Census Years, MS, 1982-2002



Source: http://www.ymd.org/pdfs/wateruse/Water%20Use%20Report%202007.pdf

Figure 5. Water Use, Acre-Inches, MS Delta, 2002-2007 Annual Average

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	9.70	-33,012	118,116[d]
Cotton	6.40	-112,188	-27,104
Rice	35.34	-289,225	-485,154
Soybeans	8.18	-170,825	-361,668
Total		-605,250	-755,810
Slippage[e]			-0.2488[f]

[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 2002-2007 annual average (YMD, 2008).

[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 2002-2007 (YMD, 2008).

[d] A positive (negative) change indicates an increase (decrease) in water demand.

[e] Slippage = 1 – (econometric change in water demand / physical change in water demand).

[f] Slippage using FAPRI 2016 price projections ($2.99/bushel for corn, $0.60/lb for cotton, $8.87/cwt for rice, and $6.37/bushel for soybeans) turned out be a very close 0.2483.