Mississippi Water Resources Research Institute (MWRRI)

Final Technical Report – (From) 03/01/10 – (To) 02/28/11

Project Title: A climate-driven model to serve as a predictive tool for management of l groundwater use from the Mississippi Delta shallow alluvial aquifer (fund #331277/831277)

Principal Investigator: Charles L. Wax, PI (co-PI Jonathan Pote)

Institution: Department of geosciences, Mississippi State University
Address: P.O. Box 5448, Mississippi State, MS 39762
Phone/Fax: (662) 325-3915
E-Mail: wax@geosci.msstate.edu

Approximate expenditures during reporting period:

Federal: $13,779 Non-Federal: $60,000 (in-kind) Cost Share: $32,837

Equipment purchased during reporting period: none

Abstract:

The objective of this research was to develop a model that can be used as a management tool to find ways to meet the needs for water use while conserving groundwater. This is the third phase of the project to meet these objectives. In phase one of the project, the growing season precipitation was used to develop a relationship that estimated irrigation use, and this was the driving mechanism of the model that simulated water use to the year 2056. Phase two added the use of surface water when growing season precipitation was 30% or more above normal. In this third phase, a new climatological input was introduced into the model—irrigation demand. Irrigation demand was calculated using daily precipitation, evaporation, and a crop coefficient to estimate daily water needs by crop type. Daily values were summed to one week segments which were added to derive the total growing season irrigation demand. Weekly summations increased temporal resolution, improving model efficiency in accounting for excess daily rainfall, allowing the model to apply excess rainfall in subsequent days.

Research completed:

Figure 1 shows the inputs to the model and the resulting estimate of annual water uses for Sunflower County. This effective rainfall compared to irrigation use provides a much-improved rainfall-irrigation coefficient for use in the model
The model is constructed in an Excel spreadsheet. The interactive model file is sent as a separate file along with this report.

	A	B	C	D	E	F	G	H
1	2008/2055							
2	Total Acres							
3	COTTON	% furrow	% pivot				GS Precip	Seasonal ID
4	60300	0.81	0.19				18.69	0.46804775
5	RICE	% contour	% straight	% MI	% ZG			
6	27600	0.2	0.56	0.12	0.12		18.69	2.9971192
7	CORN	% furrow	% pivot	% Str	% ZG			
8	8910	1	0	0	0		18.69	1.16513959
9	SOYBEANS	%furrow	% straight	% pivot	% contour	% ZG		
10	86350	0.49	0.4	0.03	0.06	0.02	18.69	0.92303002
11	CATFISH	% MF	% 6/3					
12	24300	0.34	0.66					

I	J	K	L	M	N	O
Furrow Use	Pivot Use				Water Used	
0.491450139	0.369757724				**28240.21337**	
Con Use	St Use	MI Use	ZG Use			
3.62651423	3.17694635	2.667436086	1.678386751		**83514.60657**	
Furrow Use	Pivot Use	Str Use	ZG Use			
1.24669936	0.582569794	1.38651611	0.827249108		**11108.0913**	
Furrow Use	St Use	Pivot Use	Con Use	ZG Use		
1.043023924	0.803036119	0.904569421	0.83995732	0.526127112	**79472.50179**	
MF Use	6/3 Use					
3.3525	0.785833333				**40301.55**	**242637**

Figure 1. Model illustration

Methods

In order to assess the change in volume of water in the aquifer, it was necessary to collect climatological data, crop coefficient formulas, crop data, and water use data for the growing season. Growing season was defined as May through August. In this study, all but the evaporation data were collected and analyzed for Sunflower County only. It was assumed that climate and cultural land uses (crops, acreages, irrigation methods) in Sunflower County were representative of the entire Delta region. These data were used in a model that was developed to identify and account for relationships between climatological variability and cultural water use. The model is interactive, allowing the user to change input values and alter the final output, thus allowing for specific scenarios to be simulated. Successive alternative combinations of variables were simulated with the model to determine possible methods and strategies to aid in groundwater conservation and management.

Climatological Data-

The precipitation record from Moorhead, MS (located centrally in Sunflower County) and the evaporation record from Stoneville, MS were used in the analysis. The data were arrayed in an Excel spreadsheet, and missing data were identified. Gaps in the data were filled with data from the next-nearest climate station location. The result was a serially complete and homogeneous daily record of precipitation and evaporation from 1961-2009. The evaporation data were used to represent potential evaporation (PE), or the demand of the atmosphere for water. To include consideration for the physiological demand of different crops at different phenological stages, the PE was modified by crop coefficients.

Crop coefficient formulas-

The SCS (1970) established consumptive crop use coefficient curves for a variety of crops. Ranjha and Ferguson (1982) matched these values with curves of best fit and derived the following equations to calculate a crop coefficient for three crops, using crop age in days from emergence as input:

$$CC\ (Soybeans) = 0.21-(2.97)(DAY)10^{-3}+(4.74)(DAY)^{2}10^{-4}-(4.03)(DAY)^{3}10^{-6}$$

$$CC\ (Corn) = 0.12+(0.01)(DAY)+(0.18)(DAY)^{2}10^{-3}-(2.05)(DAY)^{3}10^{-6}$$

$$CC\ (Cotton) = 0.11-(0.011)(DAY)+(0.55)(DAY)^{2}10^{-3}-(3.49)(DAY)^{3}10^{-6}$$

Crop Data

Crop data for cotton, rice, soybeans, corn, and catfish were collected from the U.S. Department of Agriculture’s National Agricultural Statistics Service (NASS). For the five crops, total acres and total irrigated acres were retrieved for the years 2002-2009 (the only years for which measured water use data were available).

Water Use Data

Water use data were supplied by Yazoo-Mississippi Delta Joint Water Management District (YMD) in acre-feet/acre (A-F/A). For 2005 through 2009, these data were divided into the amount of water used by each specific irrigation method for cotton, corn, soybeans, and rice (as determined by a survey of about 140 sites monitored by YMD shown in Figure 4), as well as the total average water use for each of the crops. For 2002-2004, only the total average water use amount for each of the four crops was provided. Therefore, a ratio based on the 2005-2008 specific irrigation methods-to-total average water use from 2002-2004 was formulated to identify relationships between the given average water use and constituent water use amounts associated with each specific irrigation method for each crop for the years 2002-2004 (Merrell, 2008).

Catfish water use is dependent upon whether the producer uses the maintain-full (MF) or the drop-add (6/3) management scheme. Only total average water use by catfish ponds was provided by YMD, also in A-F/A, and only for 2004 and 2006. So, the catfish water use model developed by Pote and Wax (1993) was used with the Moorhead climate data to estimate the amounts of water used by each of the management schemes in Sunflower County for the period 1961-2009. A ratio between the total average water use and the water use associated with the two possible management schemes in catfish ponds was developed, similar to the water use amounts determined for the specific irrigation methods of the row crops and rice. As shown in Table 3, an average of the four years for which measurements were available was calculated to obtain the percentage of water use by each of the management schemes.

These water use data for row crops, rice, and aquaculture were combined with acreage data to calculate the total amount of water used for irrigation for each crop in the county in 2006. This analysis provided an evaluation of water use by crop type which was the basis for developing a static model. The static model was used as a standard against which all other scenarios of climatic variability, land use and management changes were compared.

Irrigation demand-water use relationship

Recognizing that the amount of rainfall during a growing season significantly influences the amount of irrigation needed, a method was developed to account for this climatological variability. Total growing season precipitation was initially used, but problems with timing and distribution of rainfall through the growing season led to a weak relationship in some years. It was therefore decided to increase the resolution of the model and therefore refine effective precipitation estimates by examining moisture deficits and surpluses on a daily basis.

In addition to atmospheric demand (evaporation), crop water demand was introduced into the model by use of a crop coefficient relating crop water use to phenological stage. Evaporation data and the crop coefficient combine the climatic demand and crop demand to estimate the total daily demand for water. Irrigation demand is derived for each day by subtracting the calculated daily total demand for water from daily precipitation.

Daily accounting of water demand resulted in the use of only rainfall needed to satisfy each day's specific irrigation demand, discarding the excess rainfall for that day. In reality, the environment does not "restart" each day; that extra moisture would be saved in the soil and applied to the next few days' water need, reducing the irrigation demand over those few days. In order to more accurately model actual field practices, daily irrigation demand values were summed by weeks through the growing season, capturing the "excess" rainfall on any day and thereby reducing the weekly demand for irrigation. The weekly values were then summed to get a total seasonal irrigation demand. This more realistically calculated irrigation demand was regressed against actual seasonal water use, as measured by YMD, to find the relationship to predict actual water that will be used in any year. Calculated seasonal irrigation demand is now used as the climatological variability input to drive the model.

Table 1 shows how growing season calculated irrigation demand was regressed against measured total average water use for cotton, corn, soybeans, and rice for 2002-2009 to develop the function for estimating the amount of water use by crops based on the amount of irrigation demand. Figure 2 shows a comparison of measured water compared to the water use calculated by this method for the row crops and rice for the period 2002-2009. Figure 3 shows an example of calculated irrigation demand for Corn from1961-2009, and compares the calculated demand against the measured irrigation from 2002-2009. Catfish water use was obtained from model-estimates based on daily rainfall rather than total growing season rainfall. In this manner, water use by all five crops was linked to climatic variability each year.

Table 1. Predictive equations developed from regressing calculated irrigation demand against measured water use

	Cotton			Corn	
	Calculated	Measured		Calculated	Measured
2002	0.45	0.5		0.90	0.9
2003	0.41	0.5		0.61	0.6
2004	0.42	0.3		0.57	0.4
2005	0.51	0.5		0.79	1
2006	0.60	0.8		1.20	1.2
2007	0.61	0.5		0.67	0.8
2008	0.47	0.6		1.17	1.2
2009	0.52	0.3		0.99	0.8
	Y=0.494867(X)+0.232725			Y=1.180774(X)+0.001839	
	Soybeans			Rice	
	Calculated	Measured		Calculated	Measured
2002	0.65	0.68		3.02	3.2
2003	0.48	0.64		2.62	2.8
2004	0.45	0.37		2.69	2.5
2005	0.71	0.6		3.05	3
2006	0.93	1		3.34	3.4
2007	0.75	0.8		3.09	3
2008	0.93	1		3.00	3.1
2009	0.79	0.6		3.01	2.8
	Y=1.105858(X)+0.026753			Y=1.111286(X)+1.671355	

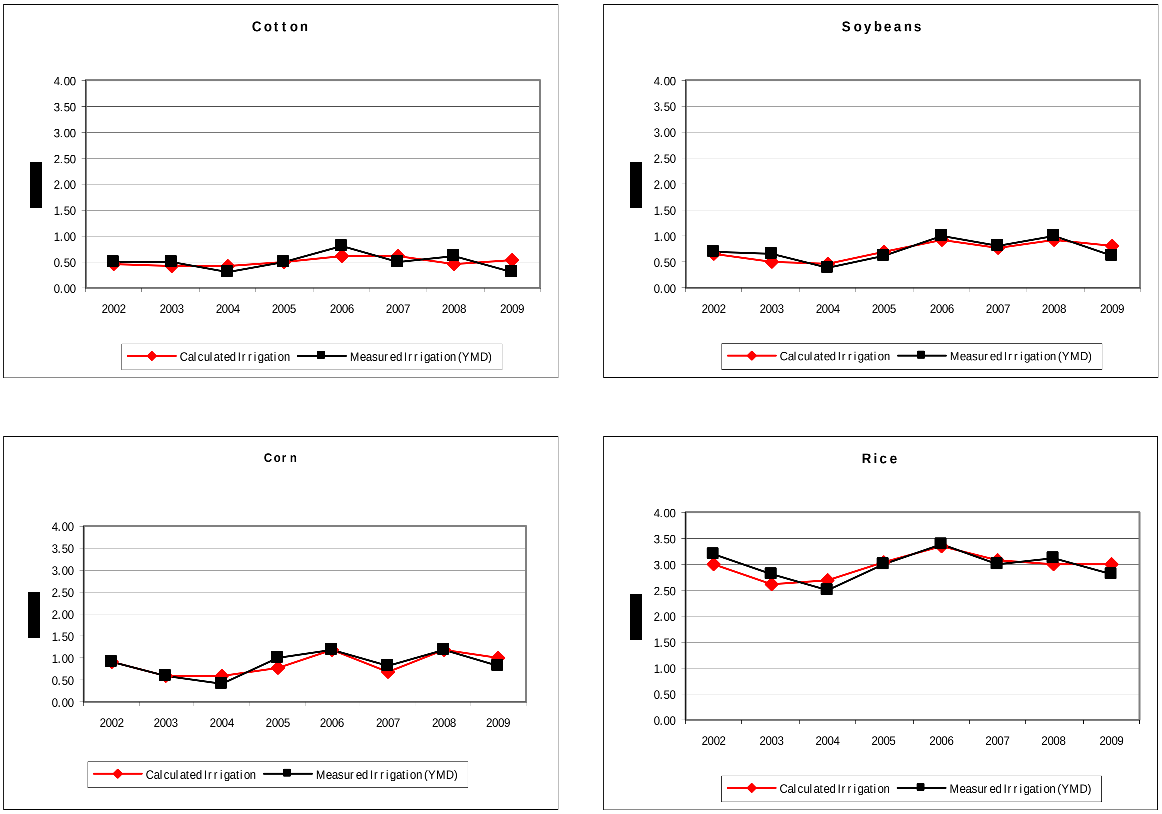

Figure 2. Comparison of calculated and measured water use.

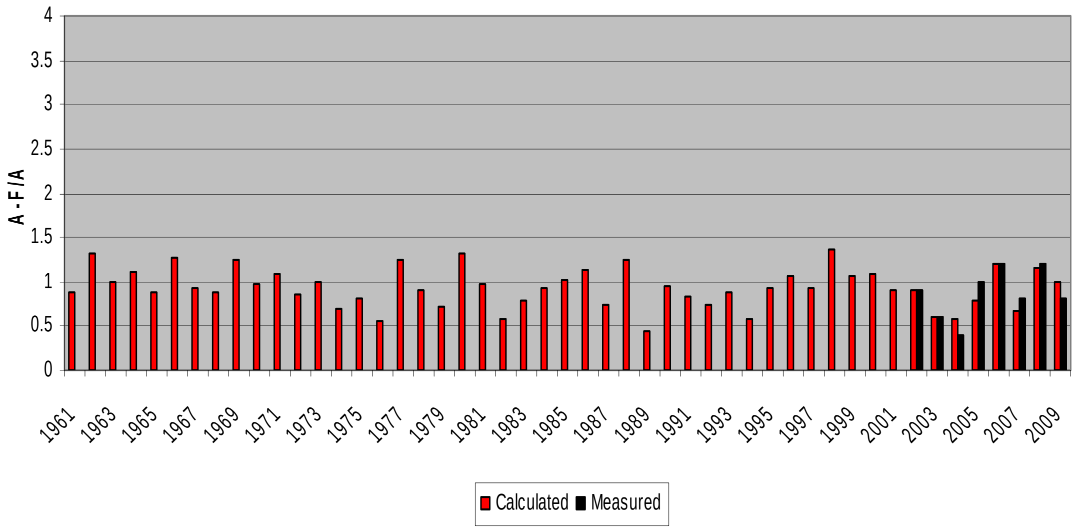

Figure 3: Calculated (1961-2009) vs. Measured (2002-2009) Corn Irrigation

(Y=1.180774(x) + 0.001839; R^2=0.77)

Model Results

The climate data, crop data, water use data, and irrigation demand - water use relationships were used to develop a model that could assess water volume declines in the aquifer over a growing season. The model calculated amounts of water taken from the aquifer by each specific irrigation method and management method for each of the five crops. The model then summed the specific water uses for each year, resulting in a total annual reduction in the volume of water in the aquifer.

Using the Sunflower County 2006 land use and crop water use relationships with irrigation demand-water use relationships developed for each crop, calculated irrigation demand from the past 48 years (1961-2009) was used as a variable in the model to estimate the total water use for each year 48 years into the future (2008-2056). The average of the annual recharge volumes measured in the aquifer between 1989-2009 was then used with the modeled water volume declines each year to characterize the cumulative water volume changes over the 48-year period. The model was subsequently used to simulate different scenarios of water use by changing crop acreages or irrigation methods from the static 2006 data.

Four scenarios were simulated with the model. The simulations and results are as follows:

<u>The static 2006 scenario</u>

The Static 2006 scenario reflected what the state of aquifer would be if no changes were made in the climate or cultural land uses or practices throughout the period. All crop acreages, irrigation methods, and percentages of irrigation methods remained the same as documented in 2006. As shown in Figure 4, during the first ten years, water volumes in the aquifer slowly declined. This occurred because growing season precipitation was below normal during these years causing the demand for irrigation to rise; therefore, in those years, withdrawals exceeded recharge. For the next approximately 30 years, the volume of the aquifer reached a stationary level. This can be attributed to two factors. First, there are a number of years during this period that growing season precipitation far exceeds the average, allowing for greater recharge to occur. Secondly, managers at YMD began to make conservation efforts, and believe that the results of those efforts are evident in the rebounding water levels. In the last seven years, there is again a marked decline. This could be attributed to the fact that there were a number of drought years during the period, and the amount of precipitation received was not sufficient to sustain levels due to withdrawals for irrigation.

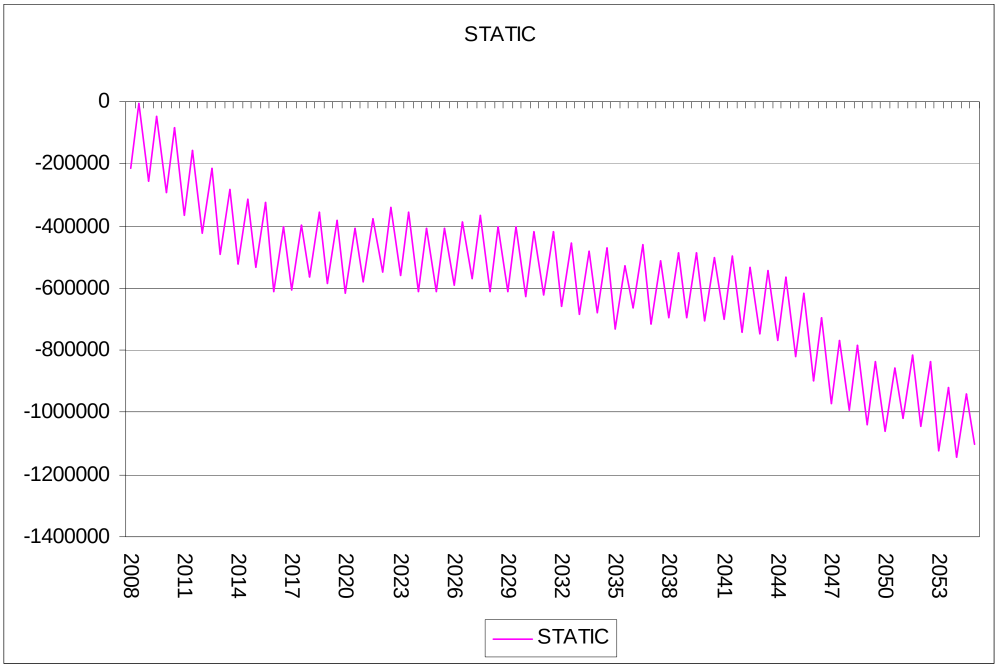

Figure 4. Static 2006 model simulation

<u>Most Conservative Irrigation Methods Implemented Scenario</u>

The most conservative irrigation method for each crop was used to determine the effects water conservation efforts could have on the aquifer for the 48 year period. In this scenario, the most conservative method for each crop was the only method used for irrigation. For example, 100% of cotton irrigation was assigned to center-pivot irrigation, and all other methods of irrigation of cotton were assigned a value of 0. All other irrigation methods for the conservative and consumptive scenarios are shown in Table 2. Figure 5 shows the difference between the static 2006 “base” model (blue) and the state of the aquifer after the conservation changes were made (red). The result is an increase of approximately 3,000,000 acre-feet of water in the aquifer over the entire period, with a consistent increase in water volume throughout time as recharge overcame withdrawal year after year.

Table 2. Irrigation methods used in conservative and consumptive scenarios

	Irrigation Method	
Crop	**Conservative**	**Consumptive**
Cotton	pivot	furrow
Rice	zero-grade	contour
Corn	pivot	straight
Soybeans	zero-grade	pivot
Catfish	6/3	MF

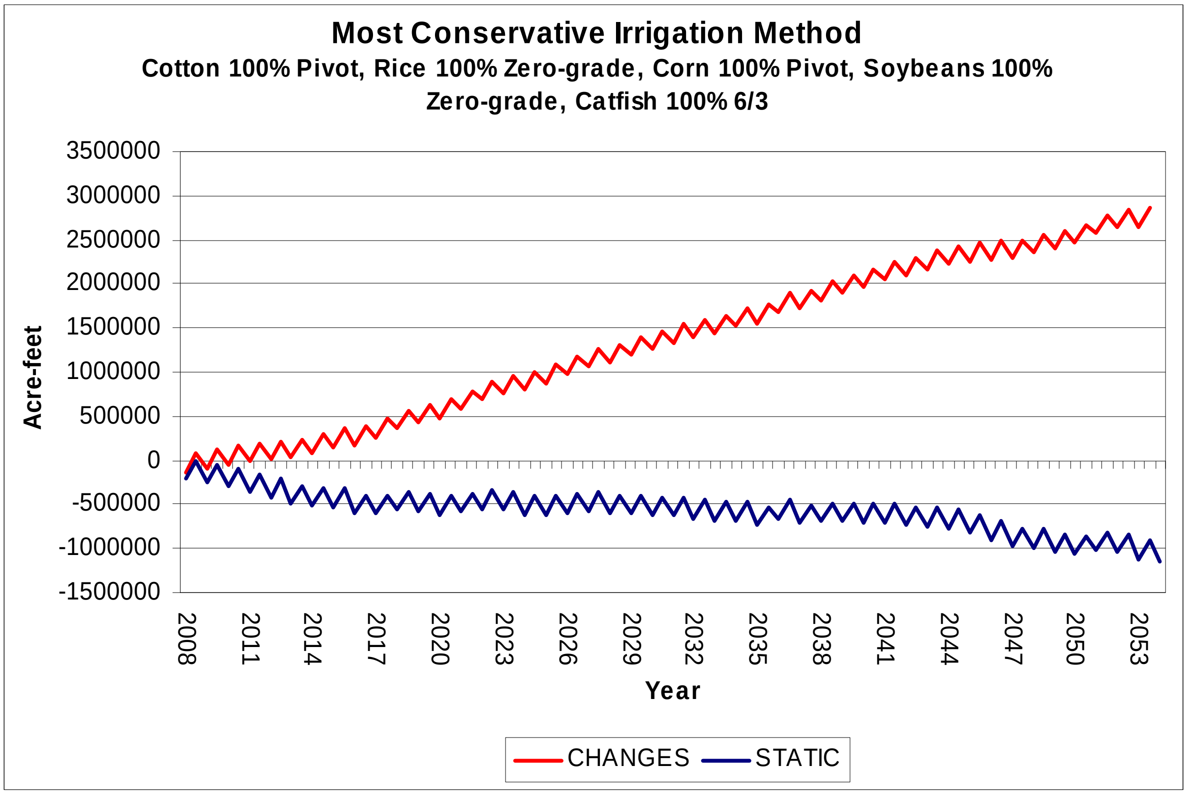

Figure 5. Most conservative irrigation method implemented

Most Consumptive Irrigation Methods Implemented Scenario

This scenario is the opposite of the previous scenario and represents a situation in which the most consumptive irrigation method is implemented. This particular scenario and its resulting output would be a good example to use when conveying to farmers, producers, other water consumers, and planners the need for conservation practices. As shown in Figure 6, if the most consumptive irrigation method was used for each crop, the aquifer would lose approximately 30,000,000 acre-feet of water over the 48-year period by experiencing a consistent annual loss of water volume as more water was withdrawn than recharge could replace. It is not known at what point the aquifer would be completely de-watered.

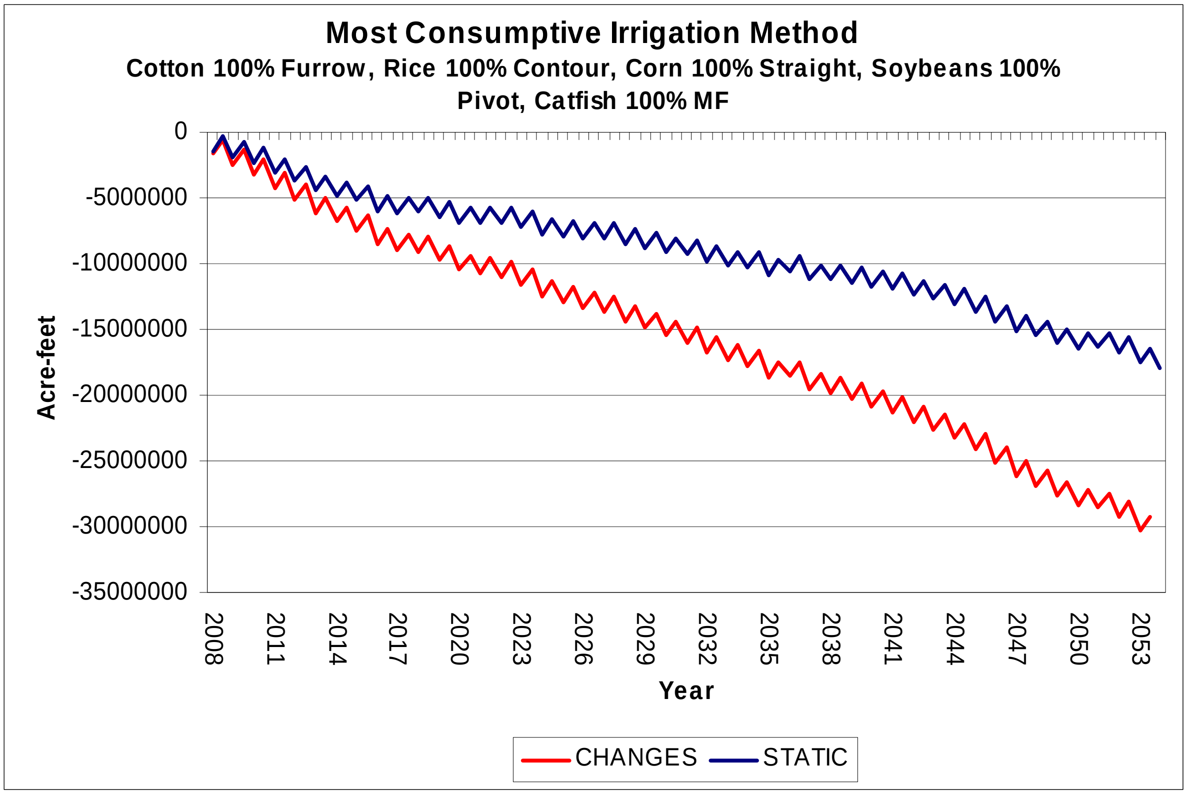

Figure 6. Most consumptive irrigation methods implemented

Use of surface water scenario

Figure 7 shows results of using surface water in lieu of groundwater in combination with the use of the new irrigation demand as the climatological driver for the model for the 48-year period 2008-2056 (and incorporating the wet year 2009). Using surface water for 25% of irrigation demand when growing season rainfall was 30% or more above average resulted in consistent declines in water volume from the beginning of the period until about 2017. During this 10-year period there were no years in which growing season precipitation met the 30% above normal threshold. From about 2017 to 2044 water volumes in the aquifer increased or stayed level, well above what the volume would have been each year if no surface water had been used. Beginning in 2044 another group of years occurred when the precipitation did not meet the 30% threshold and water volumes declined accordingly until the end of the period, but still ended about positive 1,000,000 A-F above the static scenario.

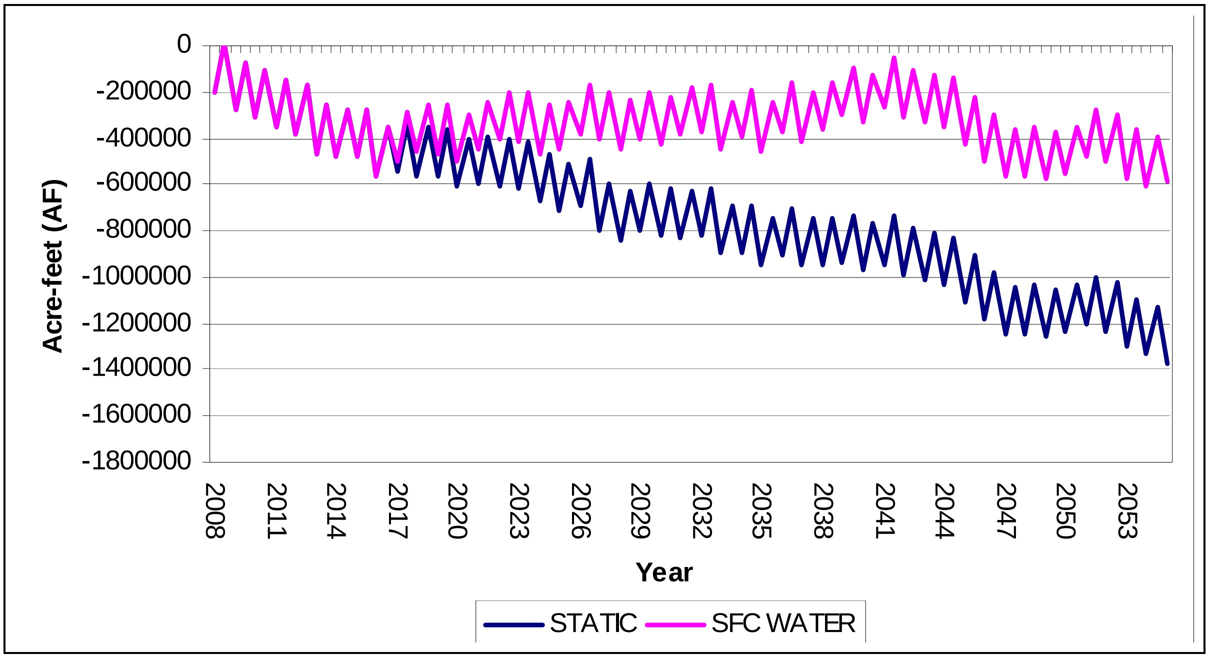

Figure 7. Model results 2008-2056 when surface water irrigation is implemented and irrigation demand is used as the climatological driver

Significant Findings

1. The amount of water withdrawn from the aquifer each year for irrigation is directly related to climate inputs--specifically precipitation, evaporation, and resulting plant water demand.

2. The aquifer volume responds positively and quickly to changes in management strategies and land use changes.

3. Use of surface water in lieu of groundwater for irrigation in years when growing season precipitation is 30% or more above average can significantly reduce aquifer drawdown in that year, resulting in a faster recovery of volume in the aquifer during the recharge period. Figure 8 shows how often precipitation could supply crop water needs for each of the row crops and rice through the 49-year period by comparing calculated irrigation demand and total growing season precipitation. The bars above the mid-line represent years when the climate delivers “extra” water, more than the crops can use. These are years when the extra, or surplus, water could be stored. The bars below the mid-line represent years when rainfall is not sufficient to meet the needs of the crops. In these years, 100% of the water delivered by the climate is used and the crop needs must be supplemented with additional groundwater irrigation.

The analysis concludes that climate could provide the entire water need of the plants in 70% of the years for corn, 65% of the years for soybeans and cotton, and even 5% of the years for rice. Even though the distribution of the extra water through the growing season may rule out total dependence of producers on this source of water, this analysis does demonstrate that extra water delivered by the climate could be a source of water that could be used often in place of pumped groundwater. Instituting this practice could save energy, save producers money, and enhance the sustainability of the aquifer.

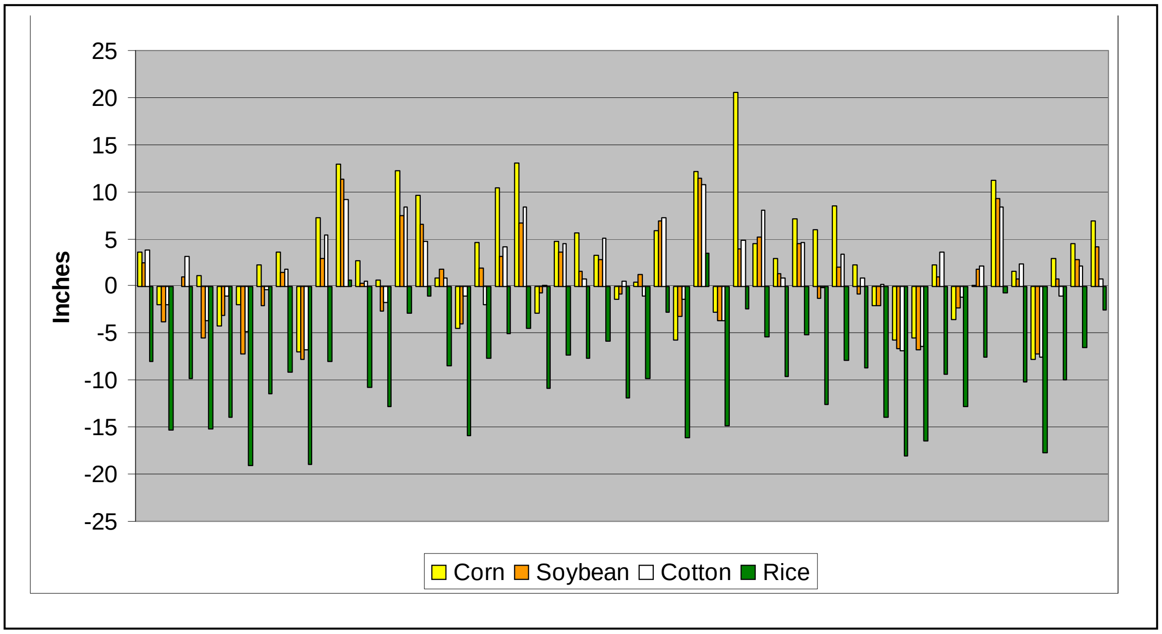

Figure 8. Effective precipitation—years in which climate delivers a surplus or a deficit of precipitation to meet crop water needs.

References

Merrell, Tia L., 2008. "Development of an Interactive Model Predicting Climatological and Cultural Influences on Annual Groundwater Volume in the Mississippi Delta Shallow Alluvial Aquifer." MS Thesis, Mississippi State University.

Pote, J.W. and C.L. Wax, 1993. "Modeling the Climatological Potential for Water Conservation in Aquaculture." Transactions of the American Society of Agricultural Engineers, Volume 36 (5), 1343-1348.

Ramkja, A.V. and K.A. Ferguson. 1982. On-farm irrigation scheduling by computer simulation in Arkansas. Presentation, ASAE Southwest Region Meeting, April, 1982, Shreveport, LA.

Soil Conservation Service, 1970. Irrigation water requirements, Technical Release No. 21, U.S. Department of Agriculture, Washington, DC.

Problems Encountered:

Identifying controls of aquifer recharge rates has not been successful. Attempts to relate recharge to Mississippi River stage on the west, to Grenada Lake stage on the east, and to non-growing season precipitation totals on both east and west sides of the delta have not been successful. Annual recharge used in the model scenarios was the average of the 19 years of measured recharge supplied by YMD. Changes in cultural practices adopted for the various model run scenarios are not known to be practical or economically feasible—these need to be confirmed as valid possibilities before rigid recommendations are developed. An attempt to make the model represent total water use across the entire delta region (not just Sunflower County) was not completed because irrigated acreages were not available for all the counties. Using the percentages of irrigated to non-irrigated acres measured for Sunflower County was not considered accurate after several unsuccessful attempts to estimate total delta-wide water use.

Publications/Presentations

1. Presentation of preliminary results to Mississippi Water Resources Research Institute External Advisory Board, November 2010.

2. Presentation of preliminary results to U.S. Army Corps of Engineers Climate Symposium, Vicksburg, MS, September 2010.

3. "Refining effective precipitation estimates for a model simulating conservation of groundwater in the Mississippi Delta Shallow Alluvial Aquifer". Presentation at Mississippi Water Resources Conference, Bay St. Louis, MS, November 2010. (Power Point slides sent as separate file along with this report)

Student Training:

Name	Level	Thesis	Major	Graduation
Robert Thornton	Ph.D.	Yes	Earth and Atmospheric Science	May 2012
Jason Sydjeko	M.S.	No	Geosciences	May 2011
Chas Swindoll	B.S.	No	Geosciences	May 2011

Report submitted by:
Charles L. Wax February 23, 2011