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FINAL PROJECT REPORT

Wax, C.L., J. Pote, J. Massey. 2009. A continuation of climatological and cultural influences on annual groundwater decline in the Mississippi Delta shallow alluvial aquifer: Modeling potential solutions (year two). Project 2008MS72B.

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Mississippi Water Resources Research Institute (MWRRI)

Final Technical Report – (From) 03/01/08 – (To) 02/28/09

Project Title: A continuation of climatological and cultural influences on annual groundwater decline in the Mississippi Delta shallow alluvial aquifer: Modeling potential solutions (year two) (fund #330912/830912)

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

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Approximate expenditures during reporting period:

Federal: $18,304 Non-Federal: $40,000 (in-kind) Cost Share: $16,973

Equipment purchased during reporting period: none

Research completed:

Water use from the delta aquifer, contributed as in-kind contribution to the project by the Yazoo-Mississippi Delta Joint Water Management District, has been quantified by crop, acreage, and irrigation method. A relationship between growing season rainfall and irrigation water use has been developed to link interannual variations in water use to variations in climate (rainfall). Water use coefficients have been developed to link each specific type of irrigation on each crop type with a water use amount in acre feet per acre. A complete prototype water use model has been completed using acreages, irrigation methods, and management strategies in place during 2006 in Sunflower County to predict annual water demand for cotton, rice, soybeans, corn, and catfish. Figure 1 shows the inputs and the resulting estimate of annual water use for Sunflower County. 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	I	J	K	L	M	N	O
1	DELTA MODEL--Sunflower County 1961-2006						GS Precip	AVG Use						Total Use	Yearly Use
2	1961/2008														
3	Total Acres														
4	COTTON	% furrow	% pivot						Furrow Use	Pivot Use					
5	60300	0.81	0.19				16.73	0.4281	0.458067	0.338199				26248.11	
6	RICE	% contour	% straight	% MI	% ZG				Con Use	St Use	MI Use	ZG Use			
7	27600	0.2	0.56	0.12	0.12		16.73	2.8835	3.546705	3.05651	2.53748	1.758935		81048.96	
8	CORN	% furrow	% pivot	% Str	% ZG				Furrow Use	Pivot Use	Str Use	ZG Use			
9	8910	1	0	0	0		16.73	0.7608	0.768408	0.372792	0.654288	0.53256		6846.515	
10	SOYBEANS	%furrow	% straight	% pivot	% contour	% ZG			Furrow Use	St Use	Pivot Use	Con Use	ZG Use		
11	86350	0.49	0.4	0.03	0.06	0.02	16.73	0.6781	0.766253	0.583166	0.759472	0.596728	0.47467	58442.68	
12	CATFISH	% MF	% 6/3						MF Use	6/3 Use					
13	24300	0.37	0.63						3.11	0.78				39907.9	212494.17
14															

Figure 1. Model illustration

The growing season climate data for the last 47-years were used to run the water demand model for a 47-year (2008-2055) period into the future to assess aquifer drawdown and recharge characteristics annually and cumulatively over the long-term period. Changes in acreages of the major crops, specific irrigation methods, and water management strategies were used to create various scenarios, then conduct multiple model runs to assess the effects of the instituted changes on aquifer drawdown and recharge characteristics over the long-term period.

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 2, 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.

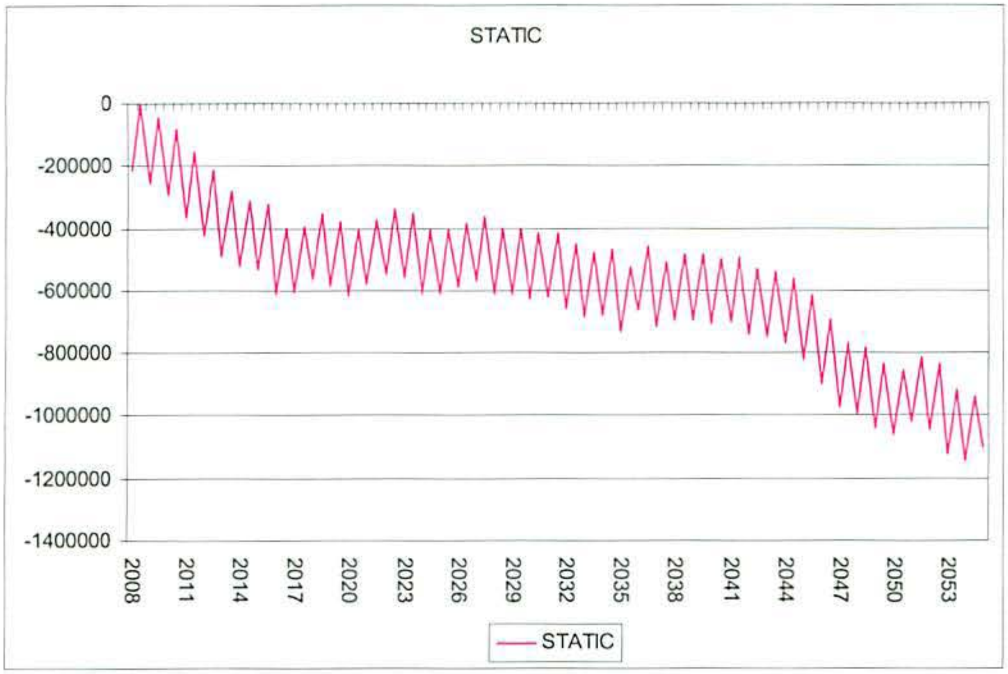


Figure 2. Static 2006 model simulation

Most Conservative Irrigation Methods Implemented Scenario

The most conservative irrigation method for each crop was used to determine the effects water conservation efforts could have on the aquifer for the 47 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 1. Figure 3 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 1. 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

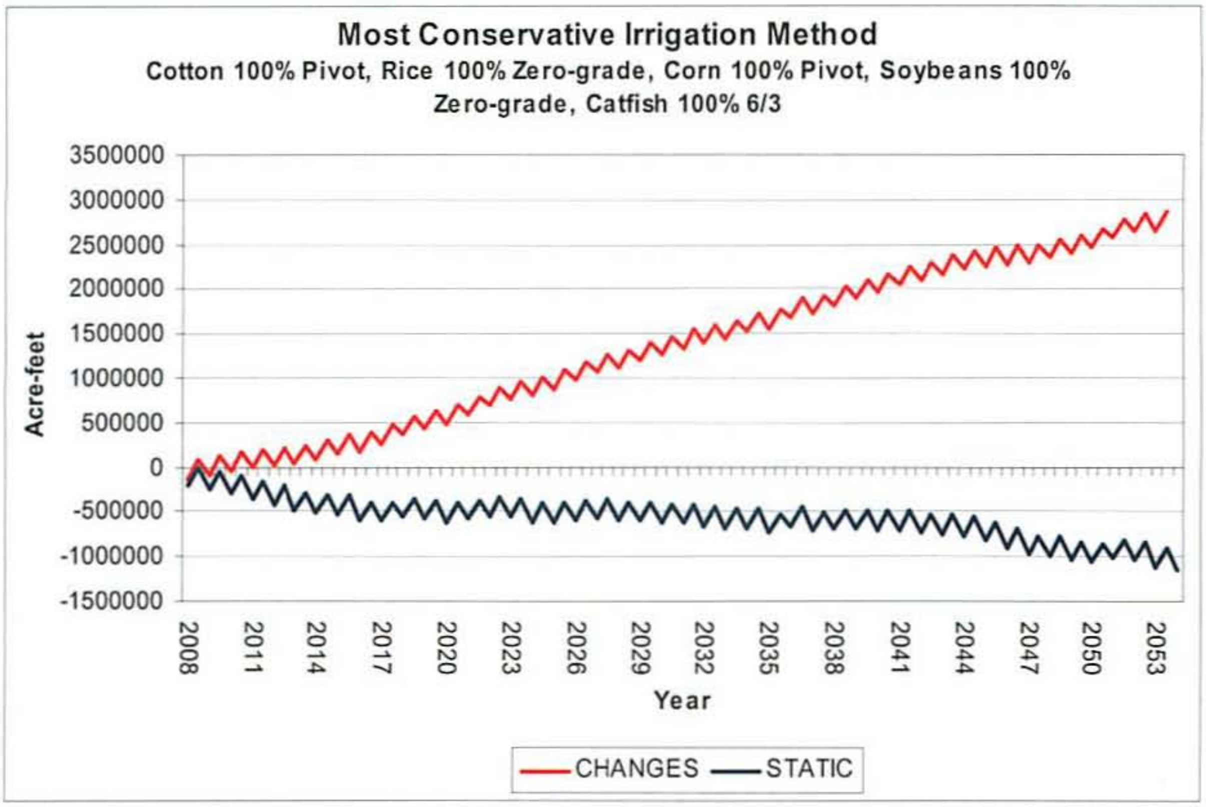


Figure 3. Most conservative irrigation method implemented

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 4, 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 47-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.

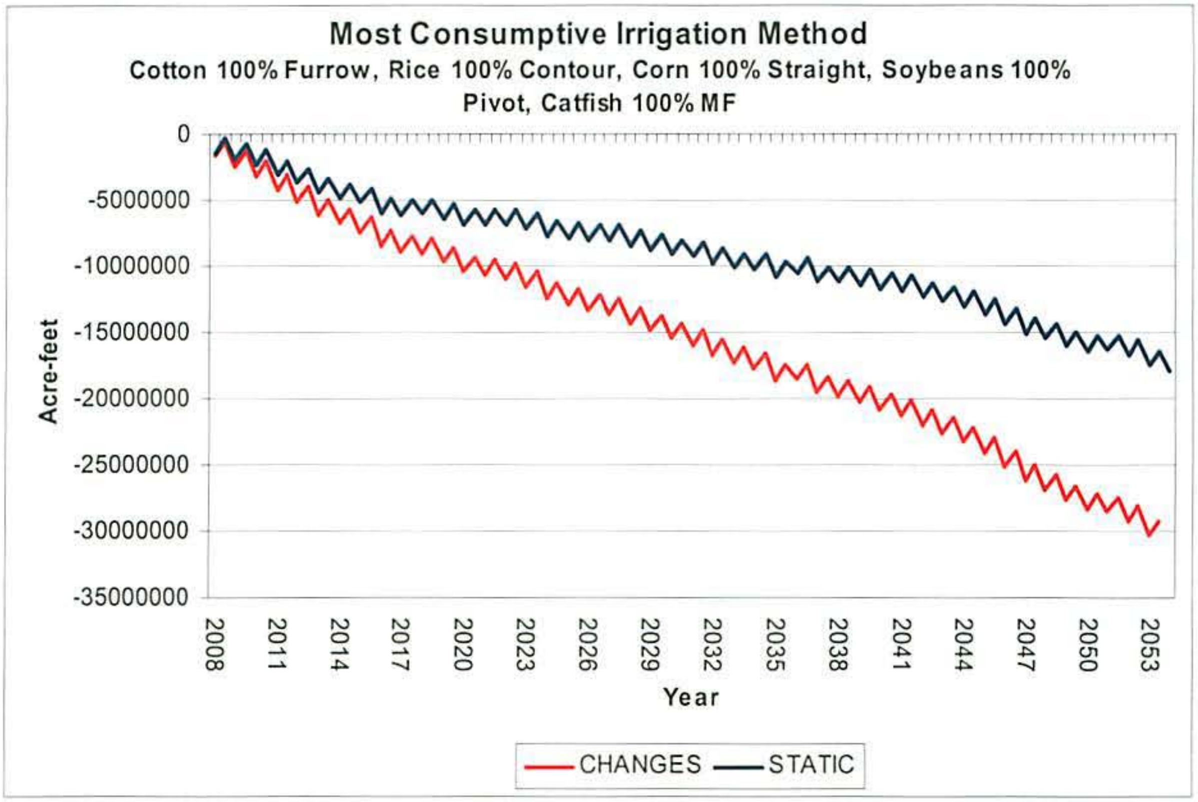


Figure 4. Most consumptive irrigation methods implemented

Use of surface water scenario

A GIS analysis was performed to determine the number of acres within one-quarter mile of all streams in the Delta. The technique was used to map all streams in the Delta, then place a quarter mile buffer around each stream, then calculate the total number of acres in the buffer zones. The number found was about 25% of the total acres in the Delta, so it was assumed that about 25% of irrigated acres could potentially be irrigated with surface water when it was available. It was then assumed that surface water would be available in the streams when growing season precipitation was 30% or more above average. The model was then set to allow for 25% of total irrigation from surface water in place of groundwater in those years.

The model then calculated savings in groundwater use by assuming surface water was used for irrigation on 25% of the acres when available through the 54-year period (Figure 5).

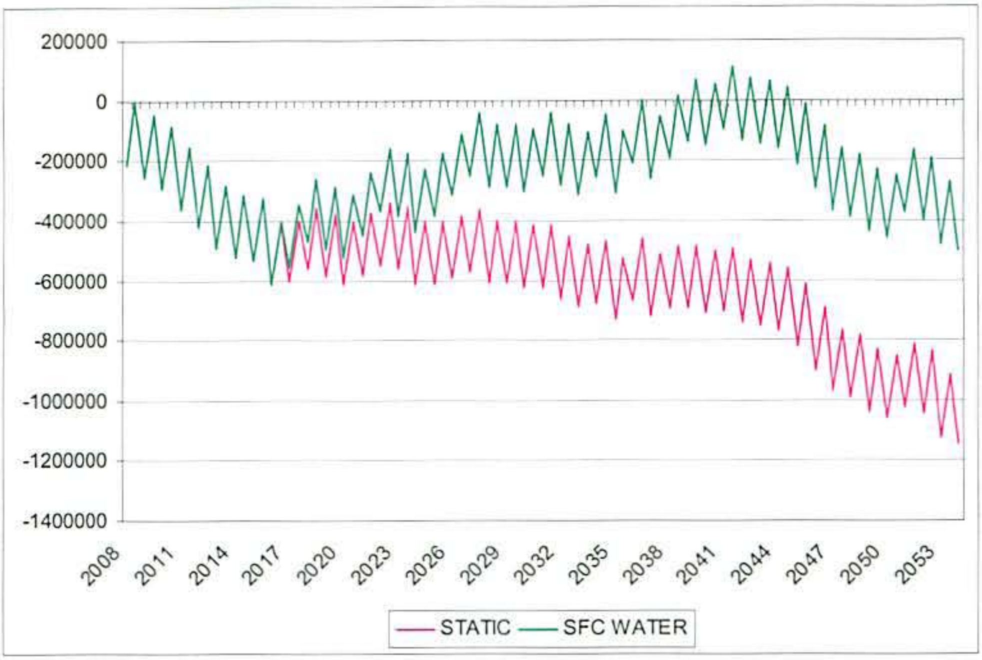


Figure 5: Surface water irrigation implemented

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 successful. All acreages of the five crop types were collected, but 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 Department of Environmental Quality, June 2008.

2. Presentation of preliminary results to Yazoo-Mississippi Delta Joint Water Management District, DEQ, and USGS special committee on delta groundwater modeling, Stoneville, February 2009. (Power Point slides sent as separate file along with this report)

3. Tia L. Merrell, 2008. Development of an Interactive Model Predicting Climatological and Cultural Influences on Annual Groundwater Volume in the Mississippi Delta Shallow Alluvial Aquifer. A thesis submitted to the faculty of the department of geosciences, Mississippi State University. (Word file sent as a separate attachment with this report)

Student Training:

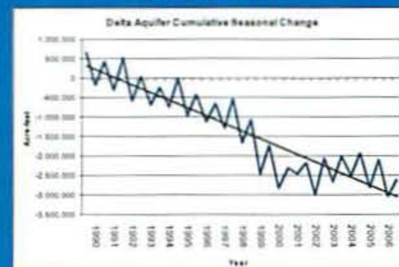
Name	Level	Thesis	Major	Graduation
Tia L. Merrell	M.S.	Yes	Geosciences	May 2009
Victoria Lemmermann	B.S.	No	Geosciences	May 2010

Report submitted by:
Charles L. Wax

March 2, 2009

DEVELOPMENT OF AN INTERACTIVE MODEL PREDICTING CLIMATOLOGICAL AND CULTURAL INFLUENCES ON ANNUAL GROUNDWATER VOLUME IN THE MISSISSIPPI DELTA SHALLOW ALLUVIAL AQUIFER

Problem

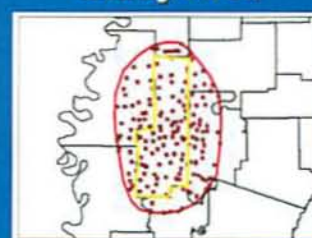


- Alluvial aquifer experiencing approximately 300,000 acre-feet per year decline due to the continuous drought and subsequent demand for irrigation

Objectives

- Quantify both natural climatological variation and cultural water use
- Utilize that information to construct a simulation model that can be used to recommend strategies to retard the rate of drawdown in the aquifer

Study Area



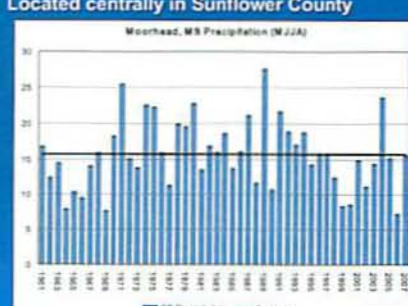
- Study area of well-monitoring system as defined by Yazoo Mississippi Delta Joint Water Management District (YMD)
- Sunflower County at center of greatest drawdown

Model Variables

- Climatological
  - Growing season precipitation
    - May—August
- Cultural
  - Crop type
    - Cotton, corn, rice, soybeans, catfish
  - Irrigation methods
    - Furrow, straight-levee, contour-levee, zero-grade, multiple-inlet, center pivot, maintain full, 6/3
  - Water Use
    - Supplied by YMD in acre-feet per acre (A-F/A)

Growing Season Precipitation

- Moorhead, MS
  - Located centrally in Sunflower County



Average = 15.64

Specific Irrigation Methods

- Six irrigation methods used in this study
  - Row crop and rice
- Two aquaculture management methods
- Yellow—advantage
- Red—disadvantage

Furrow Irrigation

- Least expensive method
- Water-consumptive

Contour-Levee (CL) Irrigation

- Follows natural slope of field
- Water-consumptive

Straight-Levee (SL) Irrigation

- Requires fewer levees than CL
- Typically 25% savings over CL
- Requires mechanical equipment

Zero-Grade (ZG) Irrigation

- No levees needed
- Typically 20% savings over SL
- Limited to small fields

Center Pivot (CP) Irrigation

- Low labor requirements
- Uniform application of water
- High initial cost

Multiple Inlet (MI) Irrigation

- Reduction in runoff and pumping costs
- Low labor costs
- Initial cost of installation
- Working around tubing

Catfish Management Methods

Aquaculture Management Schemes	
Maintain -Full (MF)	Water levels are maintained daily at level of overflow structure by rainfall or water pumped from aquifer. Allows for no fluctuation over time providing no storage space so all precipitation is lost as overflow
6/3	Allows water level in ponds to drop six inches below overflow structure before water is added creating storage space for any precipitation. If water is added, only three inches, still allowing space for precipitation and reducing overflow

Development of Rain-Irrigation Relationship

- Variables
  - Growing season precipitation (X)
  - Groundwater used for irrigation (Y)

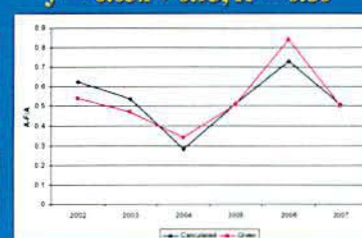
Regression Input: Precipitation (x) vs. Total Average Water Use (y)

Year	GSP	Cotton	Rice	Corn	Soybeans
2002	11.19	0.54	3.15	0.93	0.68
2003	14.34	0.47	2.76	0.58	0.64
2004	23.63	0.34	2.45	0.42	0.37
2005	15.22	0.51	2.97	0.96	0.60
2006	7.28	0.84	3.34	1.16	1.00
2007	15.53	0.50	3.00	0.80	0.80

Cotton Example

$y = -0.03x + 0.93, R^2 = 0.80$

Year	GSP (X)	Cotton (Y)
2002	11.19	0.54
2003	14.34	0.47
2004	23.63	0.34
2005	15.22	0.51
2006	7.28	0.84
2007	15.53	0.50



This relationship accounts for climatic variability and is the driving force of the model!!

Rainfall-irrigation relationship gives average water use for each crop

Model then calculates water used by each specific irrigation method for each crop (irrigation coefficient)

Development of Irrigation Coefficients (Cotton Example)

	Total Avg (A-F/A)	Furrow (A-F/A)	Pivot (A-F/A)	Furrow to Avg	Pivot to Avg
2007	0.50	0.53	0.40	1.06	0.80
2006	0.84	0.89	0.62	1.06	0.74
2005	0.51	0.55	0.42	1.08	0.82
				1.07	0.79

$$\frac{0.53\ \text{A-F/A}}{0.50\text{A-F/A}} = 1.06 \qquad \frac{0.40\ \text{A-F/A}}{0.50\ \text{A-F/A}} = 0.80$$

$(1.06 + 1.06 + 1.08)/3 = 1.07$ $(0.80 + 0.74 + 0.82)/3 = 0.79$

Development of the Model

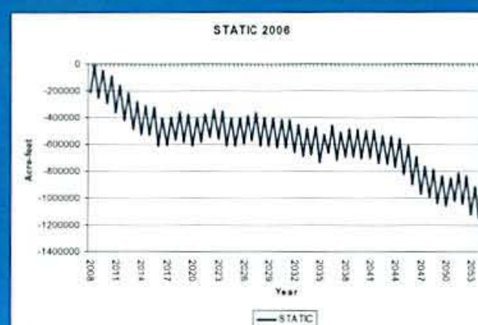
	A	B	C	D	E	F	G
1	DELTA MODEL--Sunflower County 1961-2006						GS Precip
2	1961/2008						
3	Total Acres						
4	COTTON	% furrow	% pivot				
5	60300	0.81	0.19				16.73
6	RICE	% contour	% straight	% MI	% ZG		
7	27600	0.2	0.56	0.12	0.12		16.73
8	CORN	% furrow	% pivot	% Str	% ZG		
9	8910	1	0	0	0		16.73
10	SOYBEANS	%furrow	% straight	% pivot	% contour	% ZG	
11	86350	0.49	0.4	0.03	0.06	0.02	16.73
12	CATFISH	% MF	% 6/3				
13	24300	0.37	0.63				
14							

H	I	J	K	L	M	N	O
AVG Use						Total Use	Yearly Use
	Furrow Use	Pivot Use					
0.4281	0.458067	0.338199				26248.11	
	Con Use	St Use	MI Use	ZG Use			
2.8835	3.546705	3.05651	2.53748	1.758935		81048.96	
	Furrow Use	Pivot Use	Str Use	ZG Use			
0.7608	0.768408	0.372792	0.654288	0.53256		6846.515	
	Furrow Use	St Use	Pivot Use	Con Use	ZG Use		
0.6781	0.766253	0.583166	0.759472	0.596728	0.47467	58442.68	
	MF Use	6/3 Use					
	3.11	0.78				39907.9	212494.17

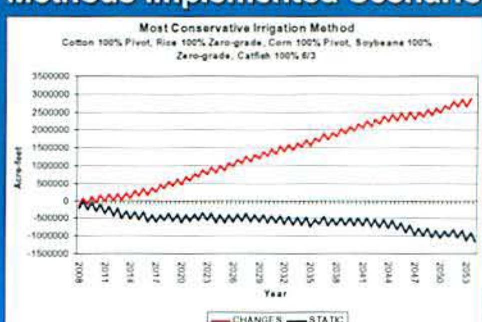
Model Simulation Scenarios

- Several scenarios conducted to determine:
  - Various effects changes would have on overall water use
  - Sensitivity to changes in specific crop acreages and irrigation methods

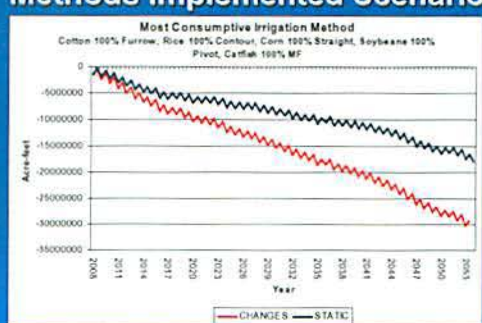
Static 2006 Scenario



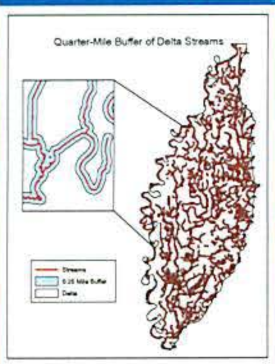
Most Conservative Irrigation Methods Implemented Scenario



Most Consumptive Irrigation Methods Implemented Scenario



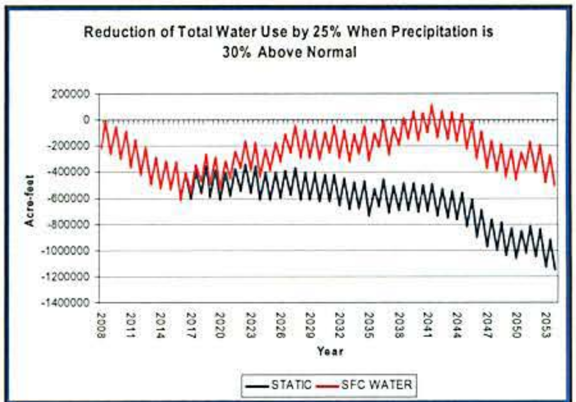
Addition of Surface Water Scenario



Total Area of Delta: 4,480,000 acres

Total Area of Streams Buffer: 1,102,647 acres

~25% of Total Delta Area

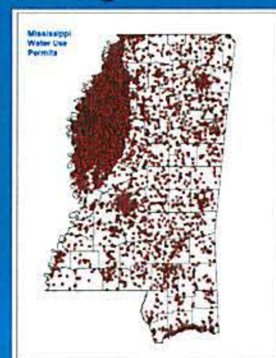


Practical Applications

- Permitting
- Climatological Scenarios

Permitting

- ~15,000 wells currently in operation in the Delta
- Over 80% of all water use permits for MS are in the Delta



Adoption of New Permitting Procedures

- Adopted as a result of confidence in model simulations (!!!)
- New Changes
  - Applicant must meet specified water conservation requirements to receive 10 year Class 1 permit
  - If requirements not met, will receive 3 year, Class 2 permit
    - At end of 3 years, subject to investigation

Climatological Scenarios

- Climate variability
  - If Delta received 20-30% more/less rainfall
  - Number of drought years followed by rainy years
- Senate Bill 2860
  - MS Global Climate Study Commission
  - Use model in this study

Limitations

- Assumption that growing season precipitation totals are sufficient
- Water use survey sites not entirely representative of irrigation methods used throughout Delta
- Finite water volume of aquifer is unknown

Conclusions

- Model is a sensitive tool useful for various forms of analysis
  - User-friendly and completely interactive
- Can be used to recommend water use management techniques
- Can be used to simulate various scenarios including climate change

Further Research

- Expand model to reflect entire Delta region
- Continued updates and improvements to model as more measured water use data become available