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.
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:

The static 2006 scenario

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.
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

<table>
<thead>
<tr>
<th>Irrigation Method</th>
<th>Crop</th>
<th>Conservative</th>
<th>Consumptive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotton</td>
<td>pivot</td>
<td>furrow</td>
<td></td>
</tr>
<tr>
<td>Rice</td>
<td>zero-grade</td>
<td>contour</td>
<td></td>
</tr>
<tr>
<td>Corn</td>
<td>pivot</td>
<td>straight</td>
<td></td>
</tr>
<tr>
<td>Soybeans</td>
<td>zero-grade</td>
<td>pivot</td>
<td></td>
</tr>
<tr>
<td>Catfish</td>
<td>6/3</td>
<td>MF</td>
<td></td>
</tr>
</tbody>
</table>
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.
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).
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:**

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<th>Level</th>
<th>Thesis</th>
<th>Major</th>
<th>Graduation</th>
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<tr>
<td>Tia L. Merrell</td>
<td>M.S.</td>
<td>Yes</td>
<td>Geosciences</td>
<td>May 2009</td>
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<tr>
<td>Victoria Lemmermann</td>
<td>B.S.</td>
<td>No</td>
<td>Geosciences</td>
<td>May 2010</td>
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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, com, rice, soybeans, catfish
  - Irrigation methods
    Furrow, straight-levee, contour-levee, zero-grade, multiple-inlet, center pivot, maintain full, 8/3
  - Water Use
    Supplied by YMD in acre-feet per acre (A-F/A)

Growing Season Precipitation
- Moorhead, MS
  - Located centrally in Sunflower County

Moorhead, MS Precipitation (W/A)

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

Development of Rain-Irrigation Relationship

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

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

<table>
<thead>
<tr>
<th>Year</th>
<th>GSP (in)</th>
<th>Cotton (A-F/A)</th>
<th>Rice (A-F/A)</th>
<th>Corn (A-F/A)</th>
<th>Soybeans (A-F/A)</th>
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<td>2002</td>
<td>11.19</td>
<td>0.54</td>
<td>3.15</td>
<td>0.93</td>
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<td>2003</td>
<td>14.34</td>
<td>0.47</td>
<td>2.76</td>
<td>0.58</td>
<td>0.64</td>
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<tr>
<td>2004</td>
<td>23.63</td>
<td>0.34</td>
<td>2.45</td>
<td>0.42</td>
<td>0.37</td>
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<tr>
<td>2005</td>
<td>15.22</td>
<td>0.51</td>
<td>2.97</td>
<td>0.96</td>
<td>0.60</td>
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<tr>
<td>2006</td>
<td>7.28</td>
<td>0.84</td>
<td>3.34</td>
<td>1.16</td>
<td>1.00</td>
</tr>
<tr>
<td>2007</td>
<td>15.53</td>
<td>0.50</td>
<td>3.00</td>
<td>0.80</td>
<td>0.80</td>
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</table>

Development of Rain-Irrigation Relationship

Cotton Example

\[
y = -0.03x + 0.93, R^2 = 0.80
\]

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)

<table>
<thead>
<tr>
<th>Year</th>
<th>Total Avg. Furan (A-F/A)</th>
<th>Pivot (A-F/A)</th>
<th>Furan to Avg (A-F/A)</th>
<th>Pivot to Avg (A-F/A)</th>
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<td>2007</td>
<td>0.50</td>
<td>0.53</td>
<td>0.55</td>
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<tr>
<td>2006</td>
<td>0.84</td>
<td>0.89</td>
<td>0.62</td>
<td>0.60</td>
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<tr>
<td>2005</td>
<td>0.51</td>
<td>0.55</td>
<td>0.42</td>
<td>0.38</td>
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</table>

\[
\begin{align*}
0.53 \text{ A-F/A} & = 1.06 \\
0.50 \text{ A-F/A} & = 0.80 \\
(1.06 + 1.06 + 1.08)/3 & = 1.07 \\
(0.80 + 0.74 + 0.82)/3 & = 0.80 \\
\end{align*}
\]
Development of the Model

<p>| | | | | | | |</p>
<table>
<thead>
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<tr>
<td>1</td>
<td>DELTA MODEL - Sunflower County 1961-2006</td>
<td>GS Precip</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>2</td>
<td>1961-2006</td>
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<td></td>
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<tr>
<td>3</td>
<td>Total Acres</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>COTTON</td>
<td>% furrow</td>
<td>% pivot</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>5</td>
<td>40300</td>
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<td>0.19</td>
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<tr>
<td>6</td>
<td>RICE</td>
<td>% contour</td>
<td>% straight</td>
<td>% MF</td>
<td>% ZG</td>
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<td>7</td>
<td>27600</td>
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<td>0.56</td>
<td>0.12</td>
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<tr>
<td>8</td>
<td>CORN</td>
<td>% furrow</td>
<td>% pivot</td>
<td>% Str</td>
<td>% ZG</td>
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</tr>
<tr>
<td>9</td>
<td>8910</td>
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<td>0.0</td>
<td></td>
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<tr>
<td>10</td>
<td>SOYBEANS</td>
<td>% furrow</td>
<td>% straight</td>
<td>% pivot</td>
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<tr>
<td>11</td>
<td>96350</td>
<td>0.48</td>
<td>0.4</td>
<td>0.03</td>
<td>0.06</td>
<td>0.02</td>
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<td>12</td>
<td>CATFISH</td>
<td>% MF</td>
<td>% ZG</td>
<td></td>
<td></td>
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<tr>
<td>13</td>
<td>24000</td>
<td>0.37</td>
<td>0.63</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

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
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

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 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

Reduction of Total Water Use by 25% When Precipitation is 30% Above Normal

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

Senate Bill 2860

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