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Development of an Interactive Model Predicting Climatological and Cultural Influences on Annual Groundwater Volume in the Mississippi Delta Shallow Alluvial Aquifer

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

By

Tia Lení Merrell

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in Partial Fulfillment of the Requirements
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in Geosciences
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DEVELOPMENT OF AN INTERACTIVE MODEL PREDICTING CLIMATOLOGICAL AND CULTURAL INFLUENCES ON ANNUAL GROUNDWATER VOLUME IN THE MISSISSIPPI DELTA SHALLOW ALLUVIAL AQUIFER

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Water volume in the shallow alluvial aquifer in the Mississippi Delta region is subject to seasonal declines and annual fluctuations caused by both climatological variability and crop water use variations from year-to-year. The most recently documented water volume decline in the aquifer is estimated at 500,000 acre-feet. Available climate, crop acreage, irrigation water use, and groundwater decline data from Sunflower County, MS are used to evaluate the climate-groundwater interactions in the Mississippi Delta region. This research produced a model that simulates the effects of climatic variability, crop acreage changes, and specific irrigation methods on consequent variations in the water volume in the aquifer. Climatic variability is accounted for in the model by predicative equations that relate annual measured plant water use (irrigation) to growing season precipitation amounts. This derived relationship allows the application of a long-term climatological record to simulate the cumulative impact of climate on groundwater used for irrigation.

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CHAPTER I

INTRODUCTION

Undoubtedly, water is the world's most precious nonrenewable resource. One fact often overlooked is that water available for human use and consumption is minimal. Approximately 97 percent of the world's water is saline and unusable to humans (Figure 1). The remaining three percent is fresh water, and approximately 69 percent of that is frozen in glaciers and icecaps. Thirty percent is groundwater and when compared to the total, makes up less than one percent (~ 0.76) of the Earth's total water supply (USGS, 2008). Although a minuscule amount, it is responsible for most of the world's irrigation.

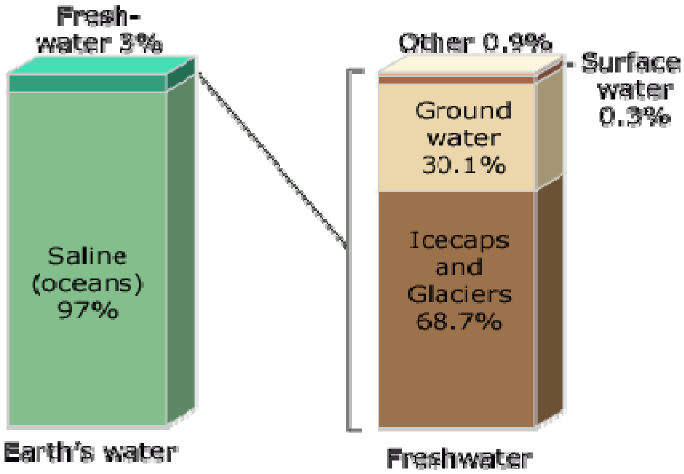


Figure 1

The Earth's water distribution (USGS, 2008)

In 2000 in the United States, an average of 137,000 million gallons per day (Mgal/d) (153,000 acre-feet per year) were used for irrigation. Approximately 99 percent of that came from fresh water underground aquifers. Because so many areas in the United States rely so heavily upon aquifers for irrigation, groundwater depletion has become a problem in recent years, especially in the Mississippi Delta shallow alluvial aquifer in northwestern Mississippi.

Mississippi, predominantly an agriculture and forestry state, is a breadbasket of the Southeastern United States. Mississippi's agricultural economy is dominated by the Delta region in northwestern Mississippi which produces nearly 100 percent of the state's rice, over 95 percent of the catfish and more than 70 percent of soybeans and cotton (Arthur, 2001). Producers in the region, looking for greater insurance against climatic variability, have recently begun to depend heavily upon irrigation to supply water for crops.

The shallow alluvial aquifer is the main source of groundwater developed for irrigation in the Mississippi Delta region. The aquifer is heavily used for irrigation of corn, soybeans, and cotton, as well as for rice flooding and for supplying water for aquaculture ponds in the prominent catfish industry. Water levels in the aquifer are subject to seasonal declines and annual fluctuations caused by both climatological and crop water use variations from year-to-year. Declines in the water level of the aquifer can be dramatic and are most notable during the period April-October of each year, particularly in years when normal crop water demands are accentuated by concurrent abnormally dry climatic conditions. Recharge during the remainder of the year has recently been insufficient to restore water levels, and the aquifer is now being depleted at the approximate rate of 300,000 acre-feet per year (Pennington, personal comm., 2006b).

Data from the Yazoo Mississippi Delta Joint Water Management District (YMD) confirm that since 1990 the aquifer has been on a consistent decline. Twice yearly, YMD staff measure water levels in a network of 550 wells which are then compared to previous years to show patterns and trends in the aquifer (Pennington, 2006a). The ‘sawtooth’ pattern shown in Figure 2 delineates a seasonal pattern of drawdown in the fall and recharge in the spring, with the recharge being consistently less than the drawdown, resulting in a trend of overall decline in the aquifer through time. On the basis of the demonstrable and continued decline in the aquifer, there is an acute need to determine the most water-efficient ways to irrigate crops in the Delta. In collaboration with the YMD, data were collected to determine acreage of crops irrigated, irrigation method used, and water use in acre-feet. The data were then implemented into a simulation model in an effort to identify strategies to enhance water conservation without prejudicing crop production and economic stability of the region.

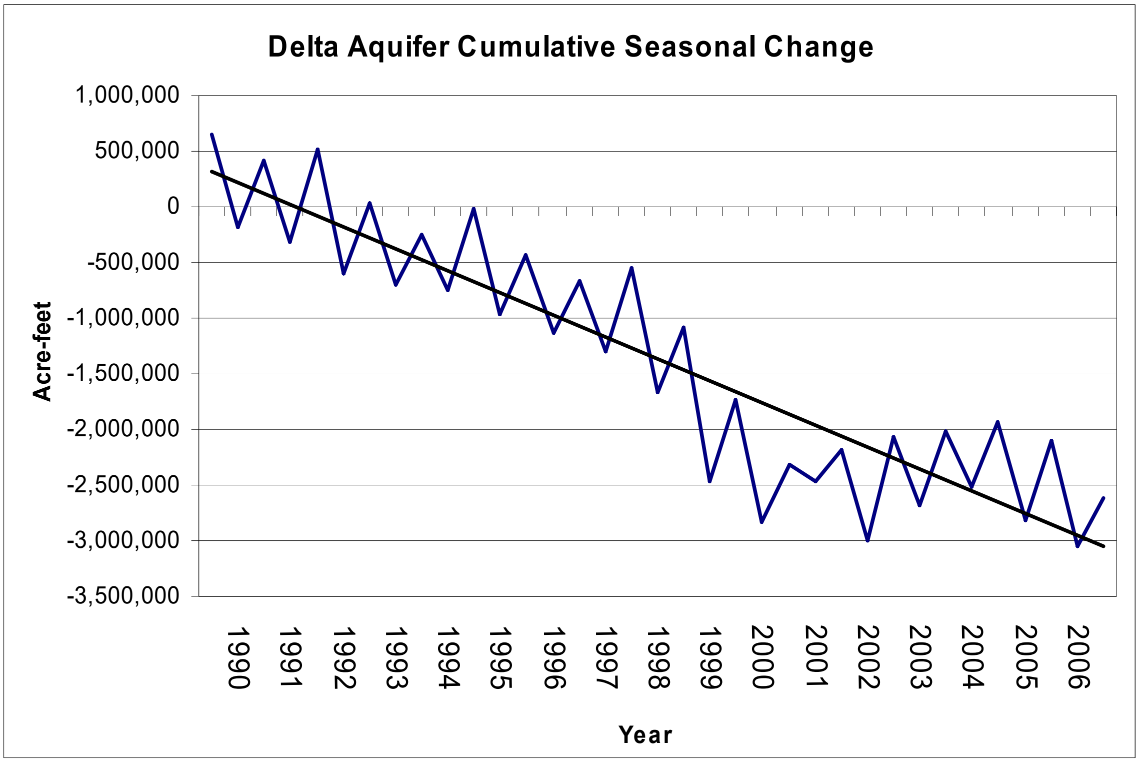


Figure 2

Decline in the shallow alluvial aquifer

To underscore the critical nature of this water problem, the most recent water level decline measured in the aquifer (October 2005- 2007) is estimated at 500,000 acre-feet (Pennington, 2006b). The recent large declines may, however, represent a worst-case situation in which continuous drought has resulted in consequent increased demand for irrigation. It is estimated that water use for row crops doubled during this period (Pennington, 2006b).

It is of paramount importance to understand how climatological variability and cultural uses of the water interact to cause the groundwater level in the aquifer to vary. It is also critical to discover and implement management strategies for potentially using precipitation and other surface water sources as substitutes for aquifer withdrawals, thereby reducing the use of groundwater in the region. Finding ways to reduce the consistent drop in water level in the aquifer will require a curtailment of about 300,000 acre-feet of groundwater use each year, and this is the highest priority of this research project. Mitigation of the continuous groundwater decline is essential to agricultural producers in the region, managers in the YMD, and planners and policy makers in Mississippi Department of Environmental Quality (MDEQ) who must design sustainable water use scenarios that will allow continuation of the productivity of the region.

The objectives of the research are to a) quantify both natural climatological variation and cultural water use and b) utilize that information to construct a simulation model that can be used to recommend strategies to retard the rate of drawdown in the aquifer. The hypothesis is that the combination of climatological variability and cultural factors such as crop acreages and specific irrigation methods result in annual groundwater use and consequent aquifer decline. To test the hypothesis, the constructed model will be used to identify relationships between climatological variability and cultural water use. The model will be interactive allowing the user to change input values and alter the final output, thus allowing for specific scenarios to be tested. Subsequent alternative combinations of variables will be simulated with the model to determine the best methods and strategies to aid in groundwater conservation and management.

CHAPTER II

BACKGROUND

The Mississippi Alluvial Plain

In describing the Mississippi Delta, author David L. Cohn (1948) said that it “begins in the lobby of the Peabody Hotel in Memphis and ends on Catfish Row in Vicksburg.” Fisk (1944) describes the alluvial plain in Mississippi as a ‘valley-within-valley’ that was formed during the final cycle of world-wide glaciation. Geographically, the area of the Mississippi Alluvial Plain (hereafter referred to as the Delta) located in northwestern Mississippi encompasses all or part of 19 counties spanning an area of approximately 7,000 square miles (4,480,000 acres) (Arthur, 2001). As shown in Figure 3, the Delta’s “core” counties of Bolivar, Coahoma, Humphreys, Issaquena, Leflore, Quitman, Sharkey, Sunflower, Tunica, and Washington lie entirely within the floodplain. In addition, varying amounts of land in Carroll, DeSoto, Grenada, Holmes, Panola, Tallahatchie, Tate, Warren, and Yazoo counties are also included in the Delta (Saikku, 2005).

The Delta extends from the Mississippi-Tennessee border at Memphis, Tennessee, about 200 miles southward to Vicksburg, Mississippi. Approximately midway between Memphis and Vicksburg, the Delta reaches its widest point of about 70 miles (Arthur, 2001). The Mississippi River forms the western boundary of the Delta while the eastern boundary is defined by the Bluff Hills that begin just below Memphis and run south to Greenwood and then southwesterly along the Yazoo River. The land surface has little relief, sloping gently from one-quarter to one-half foot per mile (Saikku, 2005).

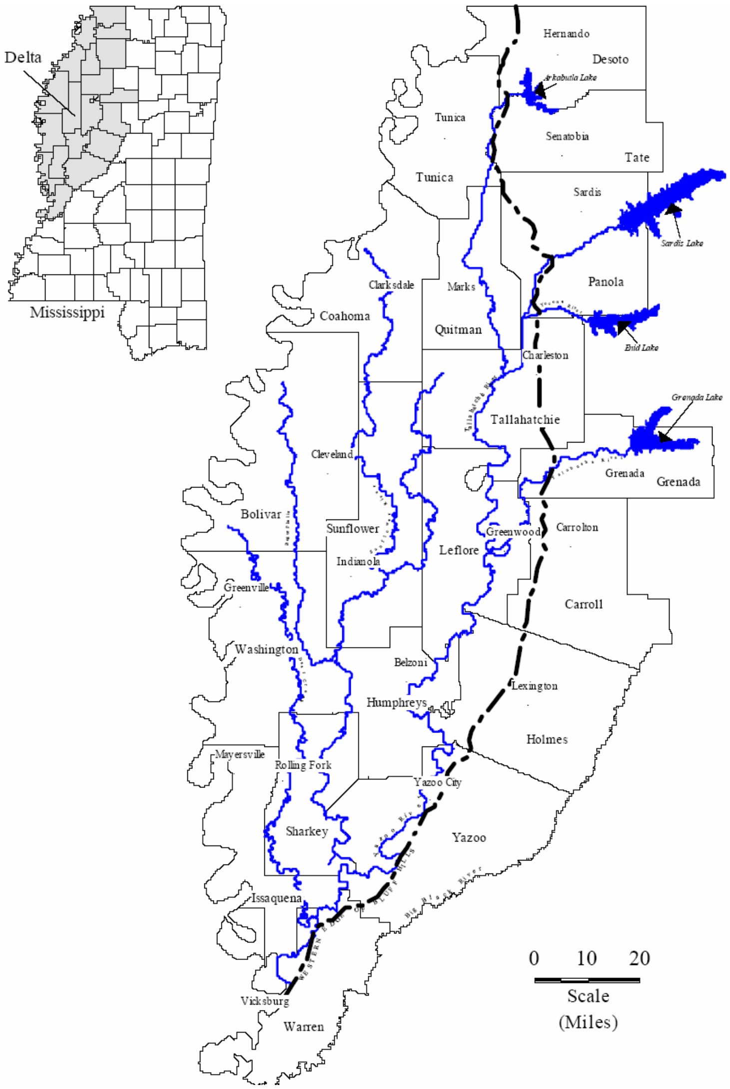


Figure 3

Counties of the Mississippi Delta (YMD, 2006)

The Mississippi Delta Shallow Alluvial Aquifer

Aquifer Characteristics

The Mississippi shallow alluvial aquifer (hereafter referred to as the alluvial aquifer) is part of a larger aquifer system formed by the Mississippi River and its tributaries underlying the Mississippi River alluvial plain (Arthur, 2001). The alluvium in the aquifer was deposited on an erosional Tertiary-age surface having a system of north-south valleys (Fisk, 1944), and consists of sand and gravel from the Quaternary age (Arthur, 2001). The average thickness of the Mississippi River alluvium in northwestern Mississippi is approximately 120-160 feet (Arthur, 2001) with a general range from 80-240 feet (Sumner and Wasson, 1990). Borings in the alluvium show that there is a general gradiation upward from coarse gravel and sand to the finer deposits of gravel and sand, and then near the surface of silt and clay (Harrison, 1961) (Figure 4).

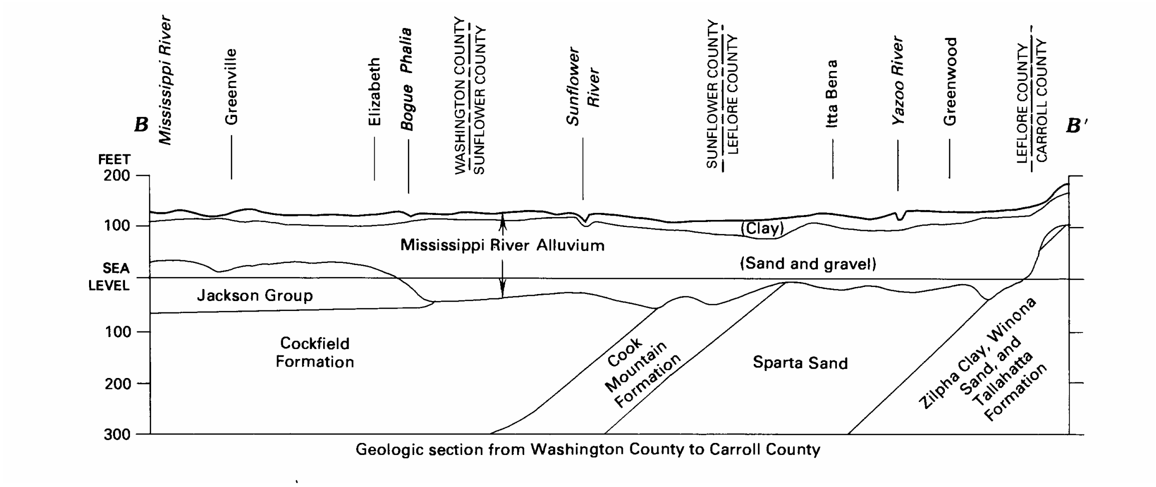


Figure 4

Geologic cross-section east-west in the Mississippi Delta (Sumner and Wasson, 1990)

Recharge of the alluvial aquifer is dependent upon climatic conditions as well as cultural conditions. Natural fluctuations in the hydrologic cycle can lead to either recharge or discharge, and conditions may vary greatly. The aquifer is recharged by water from the Mississippi River and rivers within the Delta during periods of high river stages. The aquifer is also recharged by aquifers and sediments abutting the eastern edge of the alluvial plain, and by rainfall that does not runoff, evaporate, or transpire (Arthur, 2001). Along the eastern edge of the Delta, along the Bluff Hills, the clay cap is lacking and recharge occurs through permeable alluvial fans (Mallory, 1990). Recently, water demand for the aquifer has been so substantial that the aquifer has shown a consistent downward trend in overall water volume.

Aquifer Volume Measurements

To obtain a better understanding of the total water volume in the aquifer, personnel from the United States Geological Survey (USGS), Office of Land and Water Resources (OLWR), MDEQ, and the YMD have made water-level measurements from over 300 observation wells in the alluvial aquifer during the fall and spring of each year since fall 1980 (Arthur, 2001). Each year the water levels in the wells are compared with that well’s previous measurements to determine fluctuations in the total volume. It has been noted that the water levels in the aquifer fluctuate seasonally, with the highest levels occurring during the spring after winter recharge and the lowest levels occurring during the fall following heavy withdrawal in the growing season (Pennington, personal comm., 2006b).

Permitting

The use of wells in the alluvial aquifer for irrigation began to increase markedly in the 1970s. By the end of the decade, water level declines were detected leading to the installation of the previously mentioned network of monitoring wells in 1980. Water use permitting began in 1985 and was originally carried out by the OLWR in MDEQ. In 1994, YMD began receiving, processing, and reviewing agricultural water use permits for the Delta. Over 80 percent of all water permits for Mississippi are located in the Delta (Figure 5) with about 14, 750 groundwater use permits for the aquifer and 2250 surface water permits for agriculture in the Delta (YMD, 2006).

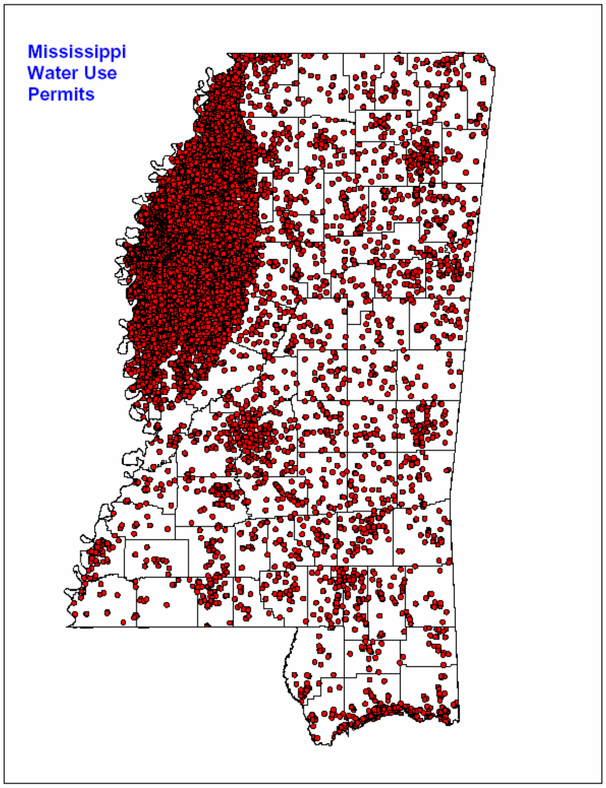


Figure 5

Water use permits (Pennington, 2005)

Climatology of the Delta

Mississippi is classified as a Humid Subtropical climate characterized by mostly mild winters and long, hot summers with no routinely recurring wet or dry season (Wax, 2006). Annual precipitation ranges from 45 inches in the northern Delta to 60 inches in the southern Delta (Snipes, et al., 2005) with rainfall ranging from 23-25 inches during the freeze-free season (Wax, 2006). Even though rainfall in the Delta is plentiful, the majority is received in months when it is least needed. Data collected from the Delta Research and Extension Center in Stoneville, MS indicated that over a 30-year period, only 28 percent of rainfall occurred during the growing season months of May, June, July, and August. Even though the previous is true, it is important to note that it is the high variability in interannual growing season precipitation which drives the need for irrigation in the Delta. With 220-260 frost-free days per year and an average soil temperature greater than 59° F at a depth of 20 inches (Snipes, et al., 2005), the Mississippi Delta is a prime region for agriculture as well as aquaculture.

Warm season patterns in the Delta are largely controlled by the Bermuda High, a semi-permanent tropical high-pressure area in the Atlantic. Cold season weather is typically controlled by cold-fronts originating in the northwestern and north-central parts of the United States and Canada (Saikku, 2005). The climate of Mississippi can also be influenced by global teleconnections such as El Niño and La Niña which can alter normal weather patterns in the state. With all of these factors controlling the climate of Mississippi, the state is often characterized by a ‘feast or famine’ situation (Wax, 2006). The consequent unreliability of growing season precipitation has led to an increased reliance on irrigation to ensure crop productivity.

Cultural Influences on the Delta

History of the Landscape

Originally a hardwood forest, the Delta is now the largest contiguous agricultural landscape in the Unites States. The region is thought to have been deforested during the period from 1865 to the early 1930s. In 1932 the Southern Forest Experiment Station reported that at least 60 percent of the Delta had been deforested. Between 1945 and 1959 over 300,000 acres were cleared, and by the early 1960s less than 32 percent of the hardwood forest remained (Saikku, 2005). Originally, cotton was the cash crop supplying most of the Delta's revenue, but other row crops began to be introduced as well. Soybean acreage increased from one million to 71 million between 1930 and 1985 (Saikku, 2005), and 1950 brought about a favorable rice market in which rice acreage increased substantially. However, the drought period of 1951-1954 made farmers realize that surface water and precipitation was not enough to sustain their crops, and by the end of 1955 over 900 wells had been constructed in the alluvial aquifer (Harvey, 1956).

Between 1950 and 1982 the amount of irrigated land in Mississippi rose from 5,056 to 430,901 acres with the concentration of those acres being in the Delta (Saikku, 2005). In the mid-1970s aquaculture production expanded rapidly in the Delta and continued to gain acreage over the next ten years (Pote et al., 1988). Presently, there are approximately 1.5 million acres of irrigated land in the Delta (NASS, 2006) with over 98 percent of withdrawal from the aquifer being used for irrigation of cotton, soybeans, corn, rice, and catfish, especially in the central Delta (Arthur, 2001).

Irrigation Methods and Management Schemes

There are six main irrigation methods that were used in this study: furrow, contour-levee, straight-levee, zero-grade, center-pivot, and multiple inlet. Each method will be further explained along with their advantages and disadvantages. The two water management schemes, maintain-full (MF) and 6/3, used in aquaculture for catfish production will also be defined and discussed.

Furrow Irrigation

Furrow irrigation consists of shallow, evenly-spaced channels that run parallel to the row direction (Snipes, et al., 2005) (Figure 6). The field must have a positive, continuous row grade. The row grade should be a minimum of 0.1 percent with a maximum of no more than 0.5 percent. Row length is also a factor for consideration. Row lengths of ¼ mile or less are generally the most effective (CES UofA, 2006a). Furrow irrigation is the least expensive irrigation method; however, it is highly water consumptive and varies widely in its efficiency, between 30-90 percent (Snipes, et al., 2005).

Figure 6

Furrow irrigation

Contour-Levee Irrigation

Contour-levee irrigation is implemented by constructing earthen levees perpendicular to the primary slope in a field (Figure 7). The levees must follow the natural slope of the field to maintain water depth. The number and spacing of the levees depends of the size and slope(s) of the field. The steeper the slopes, the closer together and more ‘wavy’ the contours will appear. Gates or spills are built into the levees to allow for the flow of water from one levee to another. Because water must flow from one levee to another, water control is difficult and more consumptive than other methods (Massey, personal comm., 2008).

Figure 7

Contour-levee irrigation

Straight-Levee Irrigation

Straight-levee irrigation requires the use of equipment to level the field using the cut and filled method (Figure 8). Soil is moved so that the earth has a uniform slope, typically approximately 0.1 percent across the field. Once the slope of the field is uniform, levees can be installed at regular intervals. Because the levees can be placed at regular intervals, unlike the contour-levee method, fewer levees are needed. Usually the straight-levee system yields a 25 percent water use savings over the contour-levee system (Massey, personal comm., 2008).

Figure 8

Straight-levee irrigation

Zero-Grade Irrigation

The zero-grade system is similar to the straight levee system with the exception that no slope is present across the field; and therefore, no levees are needed (Figure 9). Flood depths of two to three inches are common, and water savings compared to straight levee are approximately 20 percent. The average field size for this irrigation method is about 40 acres (Massey, personal comm., 2008).

Figure 9

Zero-grade irrigation

Center Pivot Irrigation

Center pivot irrigation systems consist of a main pipeline suspended above the crop by towers (Figure 10). The pipe itself has sprinklers along its length and rotates around the pivot location in a circle (McVey and Williams, 1980). The ¼ mile system is the most common center pivot system, and it covers approximately 130 acres of a 160 acre field (CES UofA, 2006a). Advantages of center pivots include low labor requirements, uniform applications, and the ability to control irrigation amount through light, frequent applications (McVey and Williams, 1980). The biggest disadvantage with center pivot systems is that there is a high initial cost due to mechanical equipment and system set-up.

Figure 10

Center pivot irrigation

Multiple Inlet Irrigation

Multiple inlet irrigation systems irrigate individual levees simultaneously through the use of tubing placed alongside the field or throughout the field (Figure 11). Holes or gates in the tubing allow for the release of water, and the flow of each of the inlets can be altered based upon differing amounts of water need throughout the field. Several advantages of multiple inlet irrigation include increased fertilizer and herbicide efficiency, a reduction in runoff from the field, reductions in labor costs, and a reduction in pumping costs. Disadvantages include the initial cost of installation of the tubing and the initial adjustment of the inlets, movement of the tubing, and difficulty in working around or over the tubing (CES UofA, 2006b).

Figure 11

Multiple-inlet irrigation

Table 1 summarizes the advantages and disadvantages of each specific irrigation method. For example, it can be seen that while the furrow irrigation method is the least expensive method to implement, it is also the most consumptive. As another example, the multiple-inlet method has many advantages, but is also expensive to initially install. These advantages and disadvantages will be considered when making alterations in the model leading to recommendations for water conservation.

Table 1

Advantages and disadvantages of irrigation methods

Specific Irrigation Methods: Advantages & Disadvantages		
Method	**Advantages**	**Disadvantages**
Furrow	--least expensive method	--water-consumptive --wide variation in efficiency
Contour-levee	--follows natural slope of land	--water control is difficult --water-consumptive
Straight-levee	--requires fewer levees than CL --typically 25% savings compared to CL	--requires mechanical equipment to cut and fill field
Zero-grade	--no levees are needed --typically 20% savings compared to SL	--limited to small fields
Center pivot	--low labor requirements --uniform application of water --ability to control application	--high initial cost requiring mechanical equipment and system set-up
Multiple Inlet	--increased fertilizer and herbicide efficiency --reduction in runoff --low labor costs --reduction in pumping costs	--initial cost of installation of tubing --movement of tubing --working around or over tubing

Aquaculture Management Schemes

Maintain-full (MF) is a management scheme for aquaculture ponds in which water levels are maintained daily at the level of the overflow structure by rainfall or water pumped from the aquifer. The main disadvantage of MF is that it allows for no fluctuation over a period of time, therefore, providing no storage space in the pond, so almost all precipitation is lost as overflow.

The 6/3 management scheme for aquaculture ponds allows the water level in the pond to drop six inches below the overflow structure before water is added, creating storage space for precipitation. The amount of water then added is only enough to raise the level of the pond three inches, thereby, managing variations in pond level to capture any rainfall and to reduce overflow, allowing rainfall, in place of groundwater, to compensate for several days of evaporative losses (Pote et al., 1988; Pote and Wax, 1993). This management method has been shown to reduce groundwater use in aquaculture in the southern region by up to 75 percent in some locations (Cathcart, et al., 2007).

Previous Studies

In 1984 a two-dimensional finite-difference computer model of the alluvial aquifer was constructed, calibrated, and verified using water levels observed for five dates from April 1981 to September 1983 (Sumner and Wasson, 1990). The model showed that the aquifer had a net loss in storage of about 360 million gallons per day (Mgal/day) (400, 000 acre-feet per year) from April 1981 to April 1983. During this period, pumpage was about 1,100 Mgal/day (1,270,000 acre-feet per year). The effects of pumpage by wells at 0, 670, 1,100, 1,900, and 4,000 Mgal/day were projected 20 years into the future. By 2003, the static 1,100 Mgal/day (average for the early 1980s) was projected to account for 46 percent of the water withdrawn from aquifer storage, water levels were projected to be lowered more than 20 feet in a large area of the central Delta, and groundwater levels were projected to continue to decline in the future (Sumner and Wasson, 1990).

Mallory (1990) used the groundwater flow model developed by Sumner and Wasson (1984) to simulate the effects of groundwater withdrawals consistent with three scenarios of ground and surface water withdrawals. The first scenario reflected current trends (in 1990) in the aquifer to serve as a baseline for the second and third scenarios. It projected that some locations in the Delta would be completely dewatered by 2007 and that by 2030 more than 800,000 acres would be dewatered. The second scenario proposed to replace groundwater withdrawals used for irrigation of row crops and rice with surface water. Aquaculture users would continue to use groundwater, as would industrial, livestock, fish and wildlife, and thermoelectric power users. Results of this scenario showed a decrease in the rate of decline, projecting that by 2030, three-fourths of the Delta would have a saturated thickness of greater than 100 feet. The third scenario was similar to the second in that all irrigation for row crops and rice were replaced by surface water; however, it also assumes that aquaculture users would practice groundwater conservation. Results of this scenario projected that saturated thickness in the aquifer would be approximately 10-20 feet greater than in scenario two.

The two previous studies built models that focused on the mechanical and technical aspects of the alluvial aquifer, such as transmissivity, hydraulic conductivity, specific yield, and storage coefficient to simulate groundwater conservation. Although this model has the same objective, it is more heavily focused on climatological variability and cultural aspects of the Delta.

CHAPTER III

DATA COLLECTION AND METHODS OF ANALYSIS

Data Collection

To accurately assess the change in water volume in the aquifer, climatological data, crop data, and water use data were collected. For this study these data were collected and analyzed for Sunflower County only. Sunflower County is located centrally in the area of greatest drawdown in the aquifer, and it is also the center of the well-monitoring study area defined by YMD (Figure 12). It was assumed that climate and cultural land uses (crops, acreages, irrigation methods) in Sunflower County were representative of the entire Delta region.

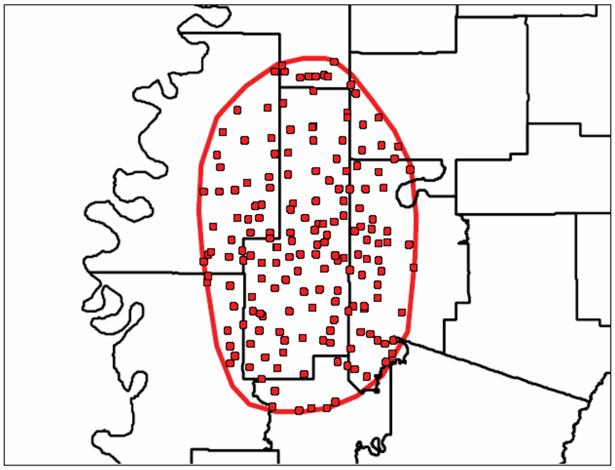


Figure 12

Study area defined by YMD with Sunflower County located centrally (Pennington, 2006a)

Climatological Data

The daily precipitation record for Moorhead, MS (located centrally in Sunflower County) was used in this analysis. Data were collected from the United States Historical Climatology Network (USHCN) and inspected for missing data. Any missing data were supplemented with data from the next nearest station, Greenwood, MS. The result was a serially complete and homogeneous daily record of precipitation from 1949—2007. The data were then organized into growing season totals for each year with the growing season defined as May through August.

Crop Data

Crop data for cotton, rice, soybeans, and catfish were collected from the United States Department of Agriculture National Agricultural Statistics Service (NASS). For each of the four crops, total acreages and total irrigated acres were collected for the years 2002—2007 (the only years for which water use data were available). Similar data for corn, which was not reported in NASS, were obtained through the county agent for Sunflower County (Baird, 2007). Irrigated acres and the percentages of each type of irrigation or management method used for each of the five crop types in 2006 are shown in Table 2.

Water Use Data

Water use data were supplied by YMD in acre-feet per acre (A-F/A). For the years 2005—2007, 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 141 sites monitored by YMD shown in Figure 13. Total average water use for each crop was provided for the period 2002—2007.

Table 2

Irrigated acres and type of irrigation or management method used for each crop type in Sunflower County, 2006

Crop	Acres Irrigated	Percent Furrow	Percent Straight	Percent Pivot	Percent Contour	Percent Zero Grade	Percent Multiple Inlet	Percent MF	Percent 6/3
Cotton	60,300	81		19					
Rice	27,600		56		20	12	12		
Corn	8,910	100							
Soybeans	86,350	49	40	3	6	2			
Catfish	24,300							37	63

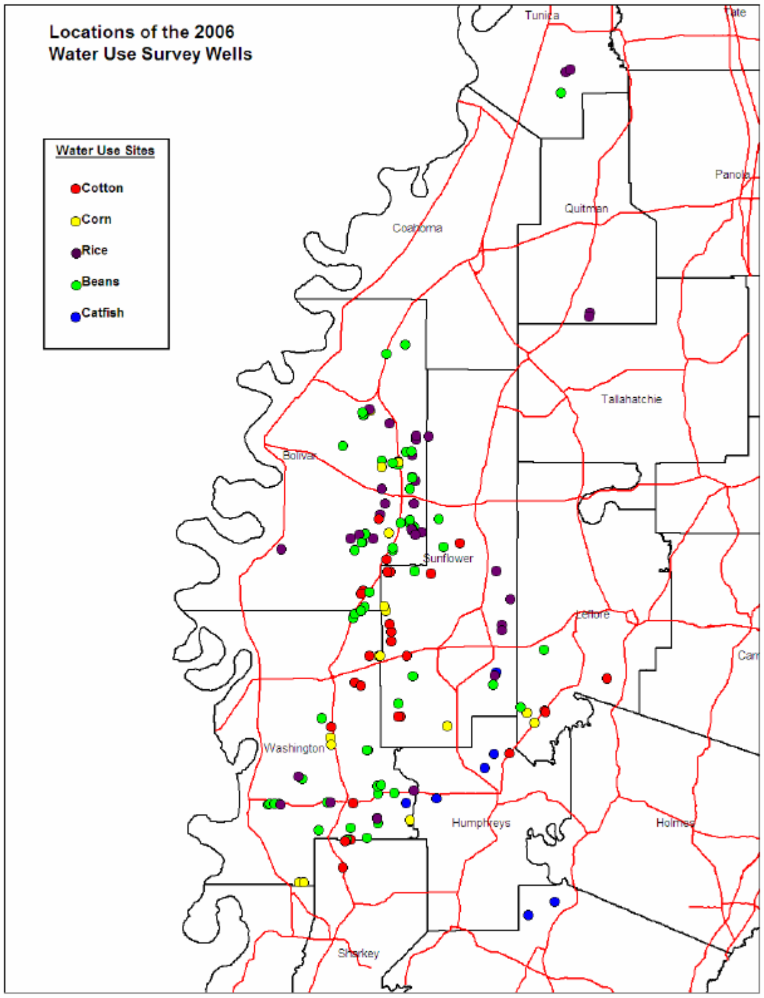


Figure 13

Locations of 2006 water use survey wells (Pennington, 2006a)

Catfish water use is dependent upon whether the producer uses the MF or 6/3 management scheme. YMD only provided total average water use data for 2004, 2006, and 2007, also given in A-F/A. To supplement the missing data, the catfish water use model developed by Pote and Wax (1993) was used along with the Moorhead climate data to estimate the amounts of water used by each management scheme in Sunflower County for the period 1961—2007. In an effort to determine the percentage of water use by each of the management schemes, a ratio was developed between the total average water use and the water use associated with the two management schemes.

As shown in Table 3, a basic algebraic equation was used to determine the percentage of water use by each of the management schemes. The MF and 6/3 water use numbers (in A-F/A) were provided by the Pote and Wax catfish model, and the total water use (also in A-F/A) was provided by YMD. The three numbers were then used in the equation respectively to obtain *x* (% MF) and 1-*x* (% 6/3). An average of the three years for which measurements were available was then calculated to obtain the percentage of water use by each of the management schemes.

Table 3

Explanation of catfish management scheme water use

Equation: *MFx + 6/3 (1-x) = Total Water Use (A-F/A)*					
	MF	6/3	Total	X	1-X
2004	3.16	0.53	1.45	0.35	0.65
2006	3.52	1.56	2.4	0.43	0.57
2007	3.65	1.03	1.9	0.33	0.67
			Average	**0.37**	**0.63**

Development of Rain-Irrigation Relationship

The amount of rainfall during a growing season (May—August) significantly influences the amount of irrigation needed. To account for this climatic variability, a relationship was developed between growing season precipitation and total average water use for cotton, corn, soybeans, and rice (Table 4). The Data Analysis ToolPak in Excel was used to regress growing season precipitation (*x*) against total average water use (*y*) for each of the four crops. The regression yielded an equation for each crop that could be used in the model to account for climatic variability. Since the amount of growing season precipitation directly affects the amount of groundwater used for irrigation, this relationship is the cornerstone of interannual variability in the model.

Catfish water use numbers were obtained from model-based estimates based on daily rainfall (Pote and Wax catfish model) rather than total growing season rainfall. In this manner, natural and cultural processes were integrated into the model.

Table 4

Explanation of rain-irrigation relationship

Regression Input: Precipitation (*x*) vs. Total Average Water Use (*y*)					
Year	Precip (growing)	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

Development of Irrigation Coefficients

For 2002—2004 only total average water use amounts for each of the four crops were provided by YMD. To assess water use by each specific irrigation method for each crop, a ratio was developed using the 2005—2007 specific irrigation methods-to-total average water use. This derived ratio was then used to identify relationships between the given total average water use and constituent water use amounts of that total associated with each specific irrigation method for the years 2002—2004.

The ratio is given as the A-F/A water use for a specific irrigation method for a crop, divided by the total average water use for the same crop. Using cotton as an example, Table 5 shows that furrow irrigation water use in 2007 was 0.53 A-F/A. The total average water use for furrow irrigation in 2007 was 0.50 A-F/A. Furrow water use was then divided by the total average water use (0.53 A-F/A / 0.50 A-F/A) to get the furrow-to-average water use of 1.06. The same procedure was used for the pivot irrigation method. The ratio was calculated for the years 2005—2007, and the average of those three years is used as the specific irrigation coefficient in the model, depicted in bold in Table 5.

Table 5

Development of specific 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**

Development of the Model

The climate data, crop data, water use data, rain-irrigation relationship, and irrigation coefficients were used to develop a model that could assess water volume decline in the aquifer over a growing season. Understanding that there are limitations to the model, two major assumptions have been made regarding its development. First, the model is climate-driven, meaning that it is sensitive to changes in growing season precipitation. Therefore, it has been assumed that the climate of the past 47 years (1961—2007) will mirror the climate of the next 47 years (2008—2054). As an example, growing season precipitation that was received in 1961 will be used as the same amount for 2008 and so on. Second, due to continual changes in cultural land use, it was assumed that the cultural landscape would remain as it is for Sunflower County in 2006. The irrigated acreages as well as the percentages of each specific irrigation method would remain static throughout the 47-year simulation of the model. The equations derived from the rain-irrigation relationship and the irrigation coefficients would also remain static.

Model Description

The model was built in a Microsoft Excel spreadsheet in 'blocks' with each block representing one year (Figure 14). A total of 47 blocks represents simulation 47 years into the future for the period 2008—2054. There are two main sections of the model. The Interactive section allows the user to make changes that are then projected over the 47 year period. The Formulated section consists of formulas that compute changes made in the Interactive section of the model.

Interactive Section

The Interactive section (A—G in the spreadsheet, refer to Figure 14) includes crop acreages, specific crop irrigation methods and management schemes, and growing season precipitation. Crop acreages represent only those acres that were irrigated in Sunflower County in 2006. Next to each crop's irrigated acreages are the specific irrigation methods and their percentages followed by the growing season precipitation received that year. These are the model inputs that can be altered to assess various future outcomes from changes in cultural or natural processes.

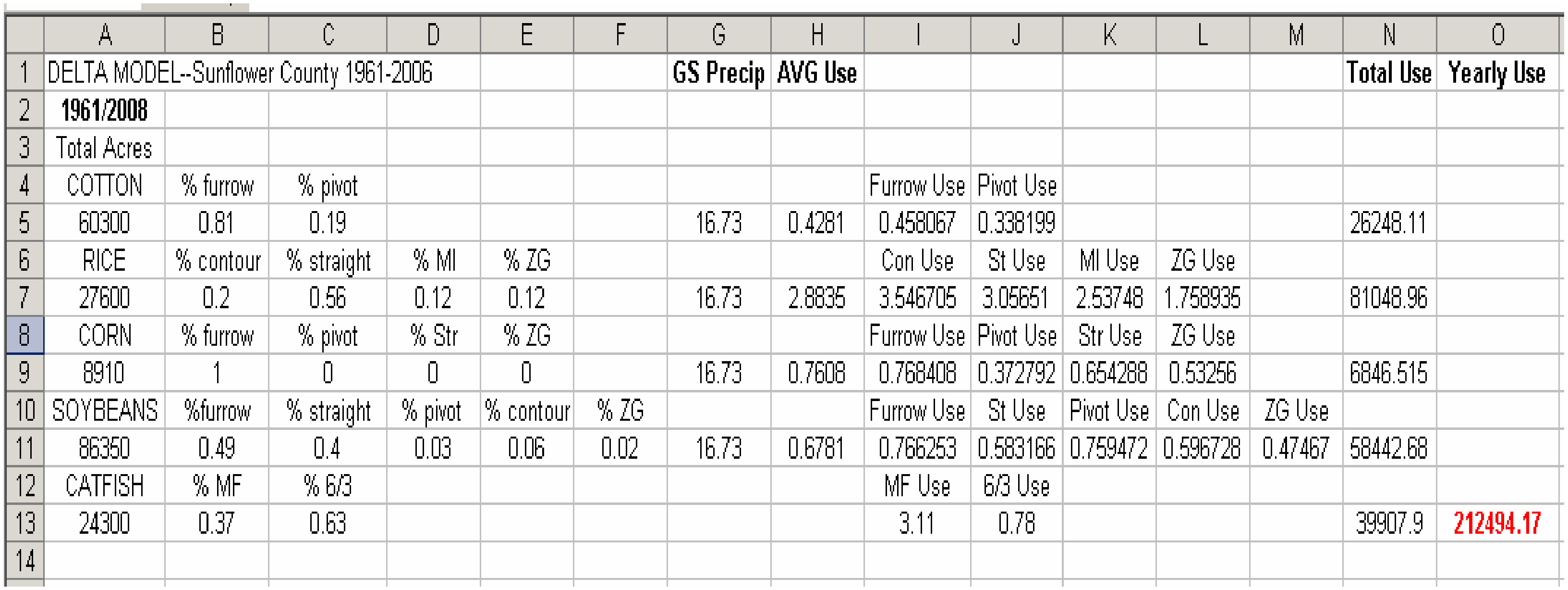
Formulated Section

The Formulated section (H—O in the spreadsheet, refer to Figure 14) uses all of the previously derived relationships. The growing season precipitation numbers and catfish water use numbers are retrieved from worksheets adjacent to the model worksheet. Column H: Average Use accounts for climatic variability in the model by using the equations derived from the rain-irrigation relationships coupled with the growing season rainfall for cotton, rice, corn, and soybeans (Figure 15). Columns I—M use resultant water use from column H and are multiplied by the irrigation coefficients to account for total water use for each specific irrigation method. Column N: Total Use reflects the total additive water use by each specific irrigation method (Figure 16).

Column O: Yearly Use is the result of the five total use water numbers for each of the five crops. By building the model in this fashion, climatic variability was taken into account as well as the water use by each specific irrigation method.

Making the Model Interactive

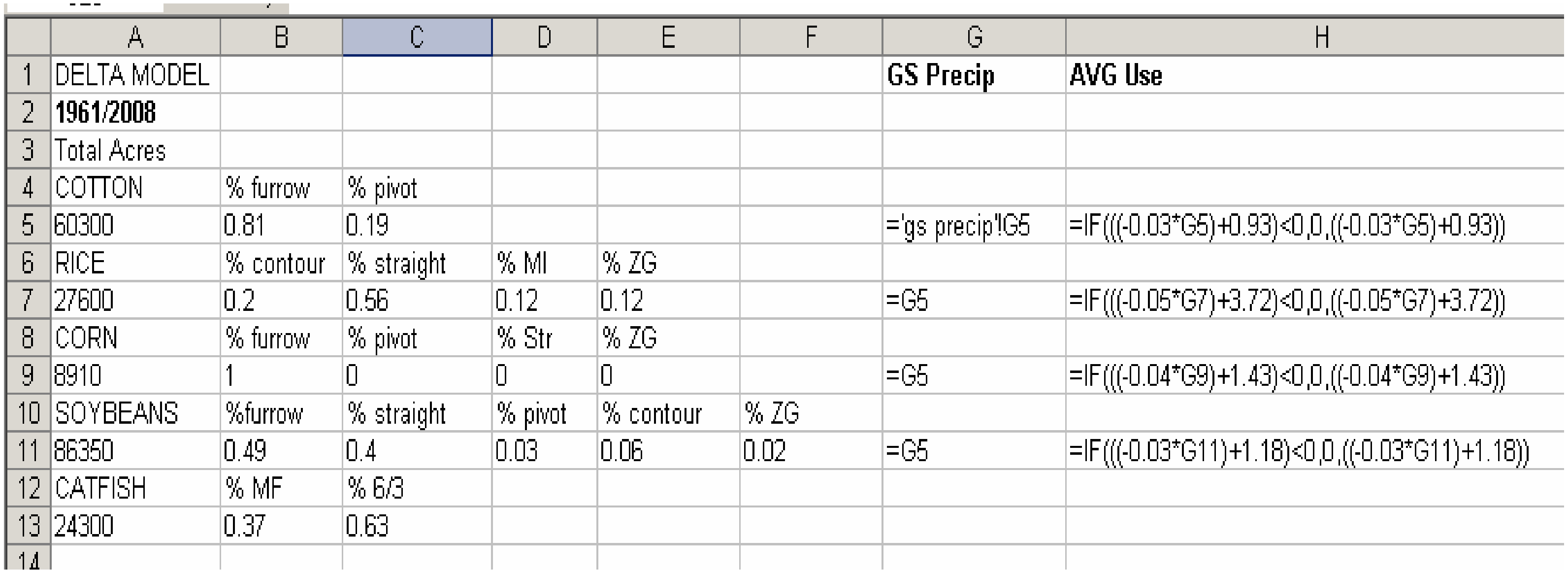
As previously stated, the model would operate under static conditions in Sunflower County in 2006. In an effort to make the model as user-friendly as possible, it was made to be completely interactive. The first block (year) of the model was used as the base for all other years, and then cell reference formulas were applied to all other blocks to make a change in the first block simultaneously change throughout the entire 47 year period. For example, if a user wanted to change the corn acreage from 8,910 acres to 65,000 acres (which actually occurred in Sunflower County in 2007), he would simply make the change in cell A9 and all subsequent years would reflect the change.



	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 14

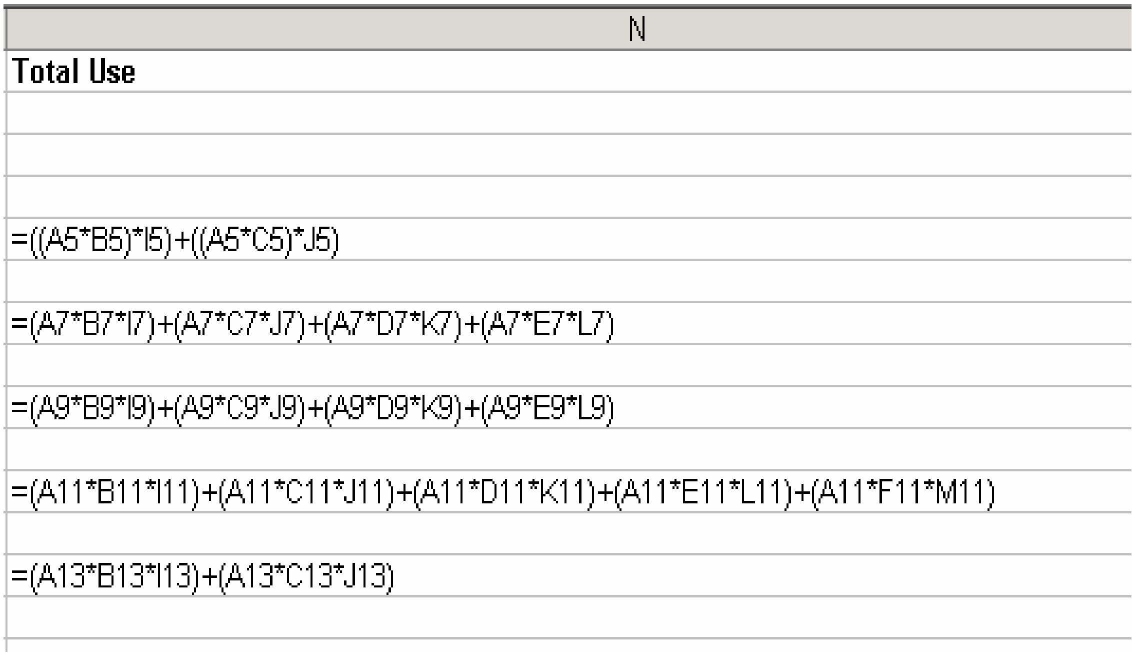
Model illustration



	A	B	C	D	E	F	G	H
1	DELTA MODEL						**GS Precip**	**AVG Use**
2	**1961/2008**							
3	Total Acres							
4	COTTON	% furrow	% pivot					
5	60300	0.81	0.19				='gs precip'!G5	=IF(((-0.03*G5)+0.93)<0,0,((-0.03*G5)+0.93))
6	RICE	% contour	% straight	% MI	% ZG			
7	27600	0.2	0.56	0.12	0.12		=G5	=IF(((-0.05*G7)+3.72)<0,0,((-0.05*G7)+3.72))
8	CORN	% furrow	% pivot	% Str	% ZG			
9	8910	1	0	0	0		=G5	=IF(((-0.04*G9)+1.43)<0,0,((-0.04*G9)+1.43))
10	SOYBEANS	%furrow	% straight	% pivot	% contour	% ZG		
11	86350	0.49	0.4	0.03	0.06	0.02	=G5	=IF(((-0.03*G11)+1.18)<0,0,((-0.03*G11)+1.18))
12	CATFISH	% MF	% 6/3					
13	24300	0.37	0.63					
14								

Figure 15

Model illustration showing formulas for growing season precipitation and rain-irrigation relationship



N
Total Use
=((A5*B5)*I5)+((A5*C5)*J5)
=(A7*B7*I7)+(A7*C7*J7)+(A7*D7*K7)+(A7*E7*L7)
=(A9*B9*I9)+(A9*C9*J9)+(A9*D9*K9)+(A9*E9*L9)
=(A11*B11*I11)+(A11*C11*J11)+(A11*D11*K11)+(A11*E11*L11)+(A11*F11*M11)
=(A13*B13*I13)+(A13*C13*J13)

Figure 16

Total water use: (crop acreage*specific irrigation method*water use by specific irrigation method) for all specific irrigation methods for cotton, rice, corn, soybeans, and catfish respectively.

Representing Changes Graphically

The primary output of the model is a graph that will project the change in water volume of the aquifer over the 47 year period. The cumulative change is found by combining the withdrawal and recharge each year. The model supplies the withdrawal each year as the total water use. Recharge, however, is not given by the model and had to be derived from another source.

Derivation of Recharge

Recharge of the alluvial aquifer is a complex process. It has been assumed that lateral recharge of the aquifer occurred from the west and the east by various rivers, lakes, and other catchment basins, and that high river stages or high amounts of precipitation would lead to more recharge in the aquifer. Therefore, water stages on the Mississippi River at Greenville and at Grenada Lake were compiled in an attempt to determine recharge. River stages at Greenville on the western edge of the aquifer were correlated with the fall-to-spring recharge numbers provided by YMD. A high correlation value would suggest that the river was a source of recharge for the aquifer. However, almost no correlation existed (Table 6). The water stages at Grenada Lake on the eastern edge of the aquifer were correlated using the same procedure as the Greenville river stages, and yielded a similar result.

Table 6

Correlation between recharge and water stages

Recharge Oct-April (A-F)	**Greenville Stage Change (Ft)**	**Grenada Stage Change (Ft)**
485,594	16.80	9.20
726,554	21.10	6.30
897,964	23.90	14.50
620,829	11.00	-0.70
556,739	18.46	1.49
703,510	-2.89	4.12
408,310	17.80	-0.08
Correlation	**0.06**	**0.63**

YMD calculated fall-to-spring recharge values for 1989—2007 at the annual water level monitoring sites, compiling an annual recharge for the study area. The average of those 19 years (Table 7) was assumed to be the annual recharge for the study. Since Sunflower County is approximately one-third of the study area (refer to Figure 12), the average for the entire study area was divided by three to obtain an average recharge value for Sunflower County. That number was then used in the model output as the recharge value for each year.

Table 7

Fall to spring recharge values

Year	**Fall to Spring Change (Ac/Ft)**
1989	663,214
1990	587,570
1991	816,297
1992	609,810
1993	419,184
1994	700,685
1995	508,550
1996	453,113
1997	718,946
1998	561,372
1999	685,795
2000	485,594
2001	726,554
2002	897,964
2003	620,829
2004	556,739
2005	703,510
2006	408,310
2007	481,975
Average	610,843
Avg/3	**203,614**

Simulation Scenarios

One of the main purposes of the model is to serve as a tool for water management and conservation. Several scenarios were conducted by using the model to determine the various affects changes would have on overall water use as well as the sensitivity of the model to changes in specific crops through a period of years.

Static 2006 Scenario

The static 2006 scenario serves as a base for all other subsequent scenarios computed by the model. It reflects what the condition of the aquifer would be if no changes were made to crop acreages or irrigation methods over the 47 year period with only the climate (precipitation) varying each year. The graphical representation of the static 2006 scenario is shown in all other scenarios to serve as a baseline to aid in comparison.

Most Conservative Irrigation Methods Implemented Scenario

This scenario used only the most conservative irrigation method for each of the five crops and represents what would be a "best case scenario." The most conservative method was determined from information given in A-F/A for each irrigation method in the 2007 YMD Annual Report (Pennington, 2007). Table 8 is a comparison of the most conservative and most consumptive irrigation methods used in the comparative scenarios.

Table 8

Most conservative versus most consumptive irrigation method

	Most Conservative		Most Consumptive	
	Method	A-F/A	Method	A-F/A
Cotton	pivot	0.40	furrow	0.53
Rice	ZG	2.17	contour	4.47
Corn	pivot	0.40	straight	1.30
Soybeans	ZG	0.65	pivot	1.19
Catfish	6/3	1.03	MF	3.65

Most Consumptive Irrigation Methods Implemented Scenario

This scenario used only the most consumptive irrigation method for each of the five crops and represents a “worst case scenario.” As shown in Table 8, the most consumptive method often uses twice the amount of water as the most conservative method.

Addition of Surface Water Scenario

This purpose of this scenario was to determine how much, if any, the use of surface water for irrigation would have on overall aquifer water levels throughout time. Using the GIS software ArcMap, a shapefile of all streams in the Delta was compiled (Figure 17). A buffer of one-quarter mile was then placed around each of the streams. The area of that buffer was calculated in square meters (m^2) and was converted into acres.

The resultant number was the total number of acres that could potentially be irrigated with surface water when it was available.

As stated in Chapter II, the Delta spans approximately 4,480,000 acres. The buffer area around the streams was 1,102,647 acres, or approximately one-fourth of the total area of the Delta. Assuming that this would also be true for Sunflower County, the scenario stated that in years when growing season precipitation was 30 percent above normal, the total water use would be one-fourth less since surface water would be available to use in lieu of groundwater from the aquifer over ¼ of the irrigated acres.

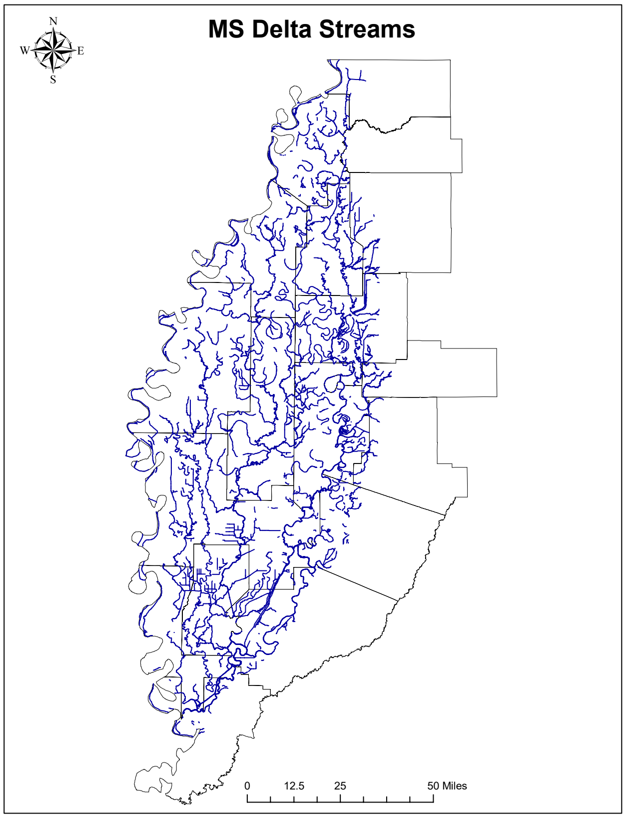


Figure 17

Streams in the Mississippi Delta

Realistic Scenario: Rice Example

This scenario was considered a realistic possibility for implementation because it utilized a water conservation practice that is already in effect in some parts of the Delta. It has been discovered that rice producers in the Delta can reduce their water use by as much as half by using the multiple inlet rice irrigation (MIRI) method (MRPB, 2006). The MIRI method uses polypipe to irrigate each rice paddy simultaneously in contrast to the flood irrigation method in which each rice paddy receives overflow from a higher paddy. The MIRI method of irrigation prevents over-pumping and reduces the amount of water leaving the field. It has been estimated that more than 25 percent of rice producers in the Delta have already adopted the MIRI method with more producers adopting the method each year (MRPB, 2006).

Since the model simulates water use over a 47 year period, this scenario assumed that 60 percent of producers adopted the MIRI method over this time period. Joe Massey, an associate professor in Mississippi State University's Department of Plant and Soil Sciences, has also stated that more than 60 percent of rice producers in the Delta have leveled their fields for straight-levee irrigation (personal comm., 2008). However, if MIRI irrigation adoption rates continue as expected, that number will decrease. Therefore, 30 percent of the irrigation in the scenario was set to be straight-levee irrigation. The remaining 10 percent was set to be contour-levee irrigation since many irrigated soybean fields are often planted in rotation with rice, and those fields often utilize levee irrigation (Snipes et. al, 2005). Irrigation methods for the four remaining crops in the model remained static as set in 2006 for the purpose of this scenario.

CHAPTER IV

RESULTS AND DISCUSSION

Results

Data Collection

Climatological Data

Growing season totals for the period 1961—2007 were used in the model to account for climatic variability. The average growing season precipitation was 15.64 inches with the minimum occurring in 2006 at 7.28 inches and the maximum in 1989 at 27.64 inches. Figure 18 was used as a reference in conjunction with Figure 2 (seesaw graph) when attempting to determine the effect growing season precipitation had on overall water use.

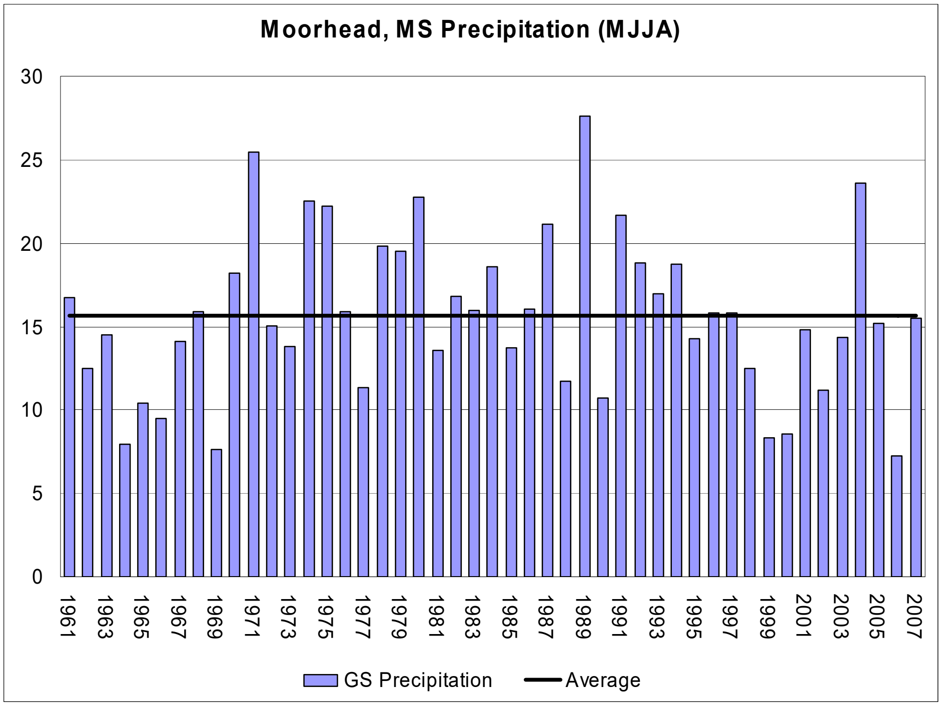


Figure 18

Growing season precipitation in Moorhead, MS in Sunflower County

Crop Data and Water Use Data

Crop data and water use data were combined to estimate water use by crop type by irrigation method per year. The data were compiled in an Excel spreadsheet, and were used as a reference when building the model. Table 9 is an excerpt from that spreadsheet showing cotton as the example. As shown in Table 9 there are two sources of irrigated acres for Sunflower County. As mentioned in Chapter III, acreages were acquired from NASS and YMD, respectively.

To obtain the water use by crop type by irrigation method, data collected from the YMD Water Use Survey (refer to Figure 13) sites were used. As an example, in 2005 YMD sampled 24 cotton sites: 18 furrow, 6 pivot. To determine the percent of each irrigation method (***B*** and ***F***), the number of specific irrigation method sites was divided by the total number of sites. To determine the number of acres for each specific irrigation method (***C*** and ***G***), the total number of irrigated acres (***A***) was multiplied by the percent of each irrigation method (***B*** and ***F***). To determine water use in A-F/A for each irrigation method (***D*** and ***H***), the sum of water use by each irrigation method as reported by YMD was divided by the total number of sites for that specific irrigation method. However, two of the 18 furrow sites reported zero water use. Therefore, those sites were excluded and the number obtained for furrow water use in A-F/A reflects only 16 sites. Acre-feet of water for each specific irrigation method (***E*** and ***I***) was found by multiplying the number of acres for each specific irrigation method (***C*** and ***G***) by the water use in A-F/A for each specific irrigation method (***D*** and ***H***). Finally, the total water use in A-F (***J***) was the sum of the total water use in A-F by each specific irrigation method (***E*** and ***I***).

Table 9

Water use in Sunflower County by crop type by irrigation method per year, example highlighted in yellow

Water Use Sunflower County by Crop Type by Irrigation Method per Year

	A	*B*	*C*	*D*	*E*
Cotton	**Irrigated Acres**	**% Furrow**	**Acres Furrow**	**A-F/A Furrow**	**A-F Furrow**
2007	29171	0.95	27712.45	0.53	14687.6
2006	60300	0.81	48843	0.89	43470.27
2005	61700	0.75	46275	0.55	25451.25
	F	*G*	*H*	*I*	*J*
	% Pivot	**Acres Pivot**	**A-F/A Pivot**	**A-F Pivot**	**Total A-F**
	0.05	1458.55	0.4	583.42	**15271**
	0.19	11457	0.62	7103.34	**50574**
	0.25	15425	0.42	6478.5	**31930**
	K	*L*	*M*		
YMD	**Irrigated Acres**	**A-F/A**	**Total A-F**		
2007	29171	0.5	**14586**		
2006	60300	0.84	**50652**		
2005	61700	0.51	**31467**		
2004	45500	0.34	**15470**		
2003	44000	0.47	**20680**		
2002	50700	0.54	**27378**		
2001	79200				
2000	57100				

Development of Rain-Irrigation Relationships

As previously stated in Chapter III, the rain-irrigation relationships were developed by performing a regression on growing season precipitation and water use in A-F/A for cotton, corn, rice, and soybeans. The output of the regression of each of the four crops resulted in a linear equation and an R^2 value as shown in Table 10. The R^2 values ranged from 0.75 for corn to 0.89 for rice. The linear equation produced by the regression was used to compute the amount of water use by each crop. Those numbers were then compared with the water use numbers provided by YMD. Figure 19 shows the resulting graphs of the Given (YMD) water use and the Calculated (linear equation) water use.

Table 10

Equations resulting from rain-irrigation regression

Regression Output		
Crop	**Equation**	**R^2**
Cotton	$y = -0.03x + 0.93$	0.80
Rice	$y = -0.05x + 3.72$	0.89
Corn	$y = -0.04x + 1.43$	0.75
Soybeans	$y = -0.03x + 1.18$	0.79

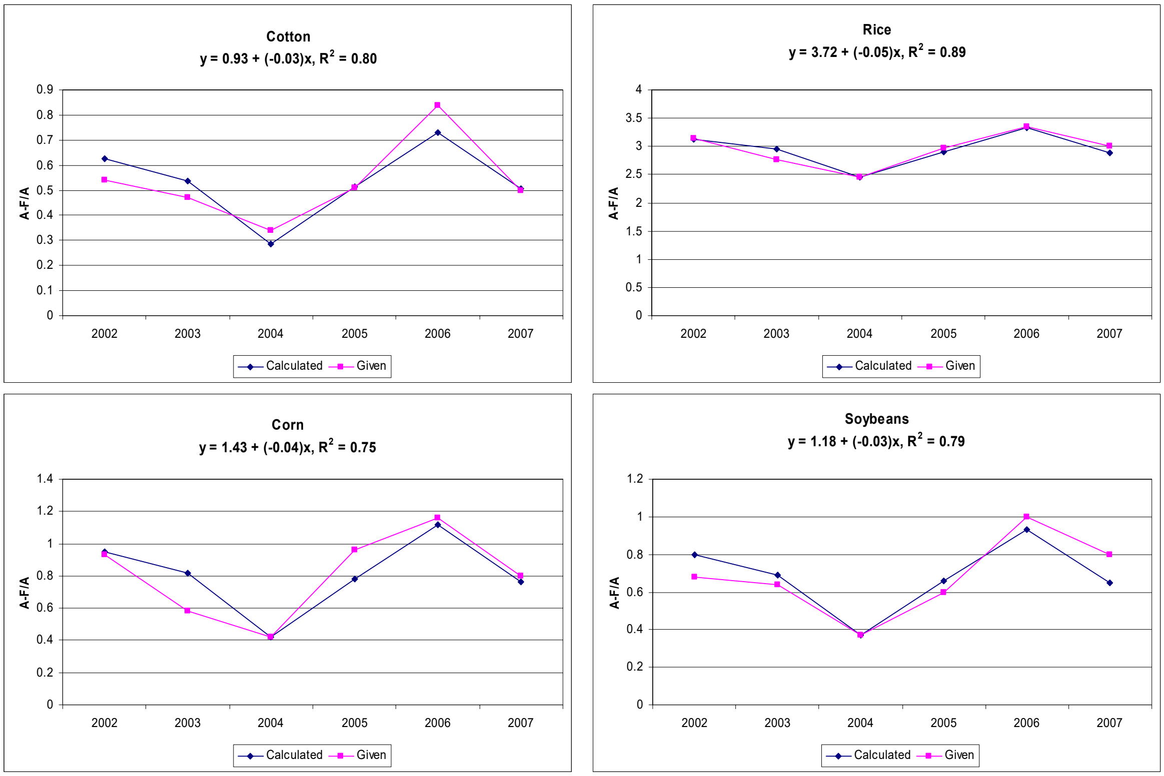


Figure 19

Graphs comparing calculated water use to the given water use

Model Simulation Scenarios

The model simulation scenarios result in graphs that show water volume changes in the aquifer over the 47 year period. Users can choose to make minor or major changes, and both cultural and climatological inputs can be varied. For each scenario, the static 2006 line will represent the "base" and reflect no change in climate or cultural use over the period.

Static 2006

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 20, during the first ten years, water volumes in the aquifer slowly declined. This occurred because growing season precipitation was below normal (refer to Figure 18) 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 (Pennington, personal comm., 2006). From about 2047—2054, 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.

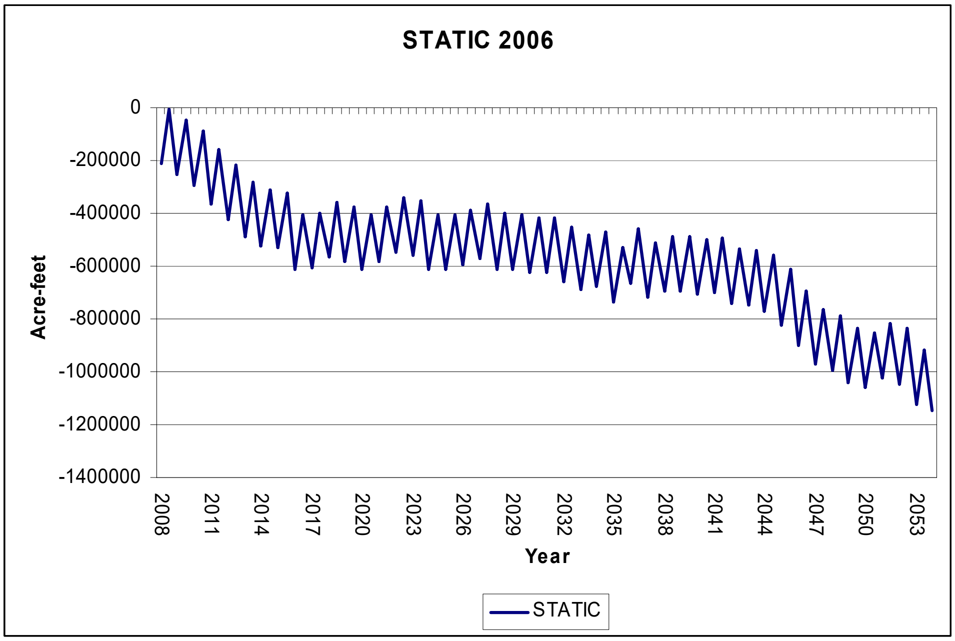


Figure 20

Static 2006 model simulation

Most Conservative Irrigation Methods Implemented

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 11. Figure 21 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 11

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

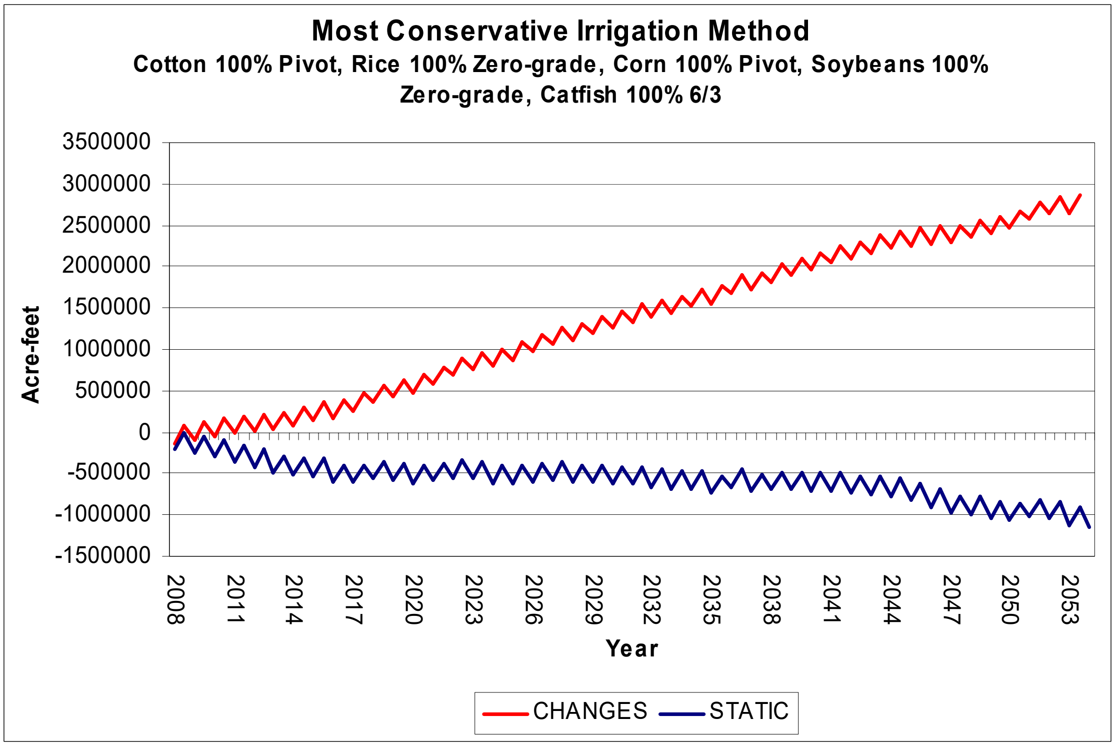


Figure 21

Most conservative irrigation methods implemented

Most Consumptive Irrigation Methods Implemented

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 22, if the most conservative 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.

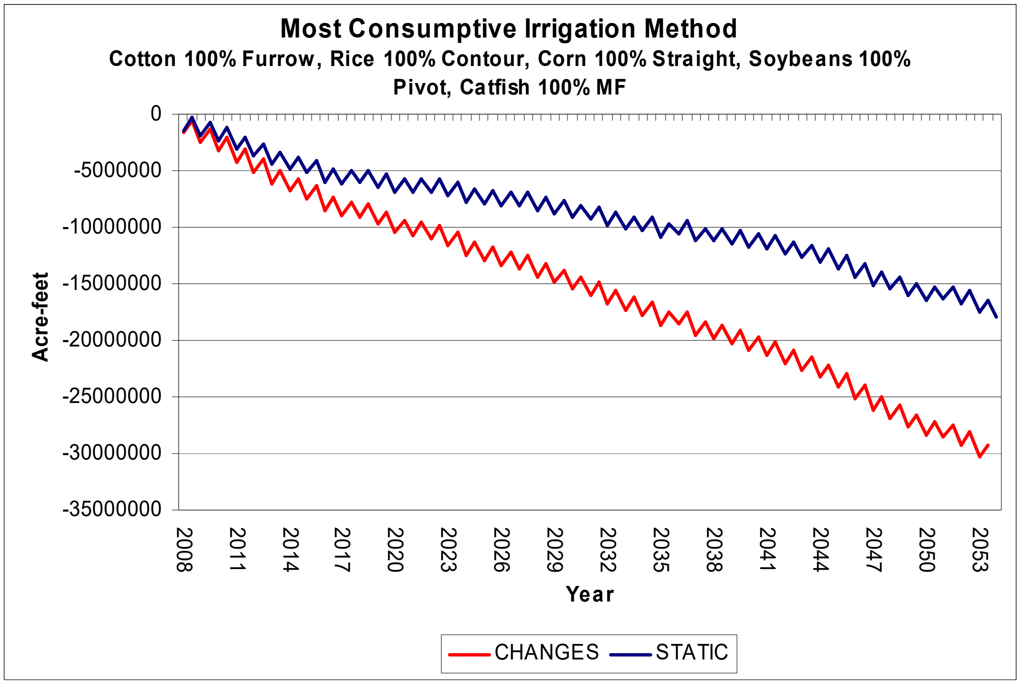


Figure 22

Most consumptive irrigation methods implemented

Addition of Surface Water

This scenario projected the amount of water that could be conserved if producers used surface water to irrigate when it was available. It was assumed that when growing season precipitation is at least 30% above normal, surface water from streams within the Delta would have sufficient water to allow for adequate irrigation of about ¼ of the row crop acreages, and proportionally decrease the amount of water withdrawn from the aquifer. Figure 23 shows an estimated 650,000 acre-feet of water could be conserved over the 47 year period by using surface water as supplemental irrigation when it is available.

During the first ten years of the simulation, there is no indication of water conservation. This occurs because during those years, precipitation amounts were not 30% above normal, so surface water could not be used as a supplement for groundwater. Table 12 shows only those years when precipitation amounts met the requirement to allow for surface water use. Only in 14 of the 47 years, about 30 percent of the time, were streams able to reliably provide enough surface water, however, when applied to the period as a whole, conservation of groundwater through use of surface water for irrigation was estimated to be approximately 13,700 acre-feet per year. Table 12 shows an implied conservation of about 25 percent of groundwater when surface water irrigation is practiced.

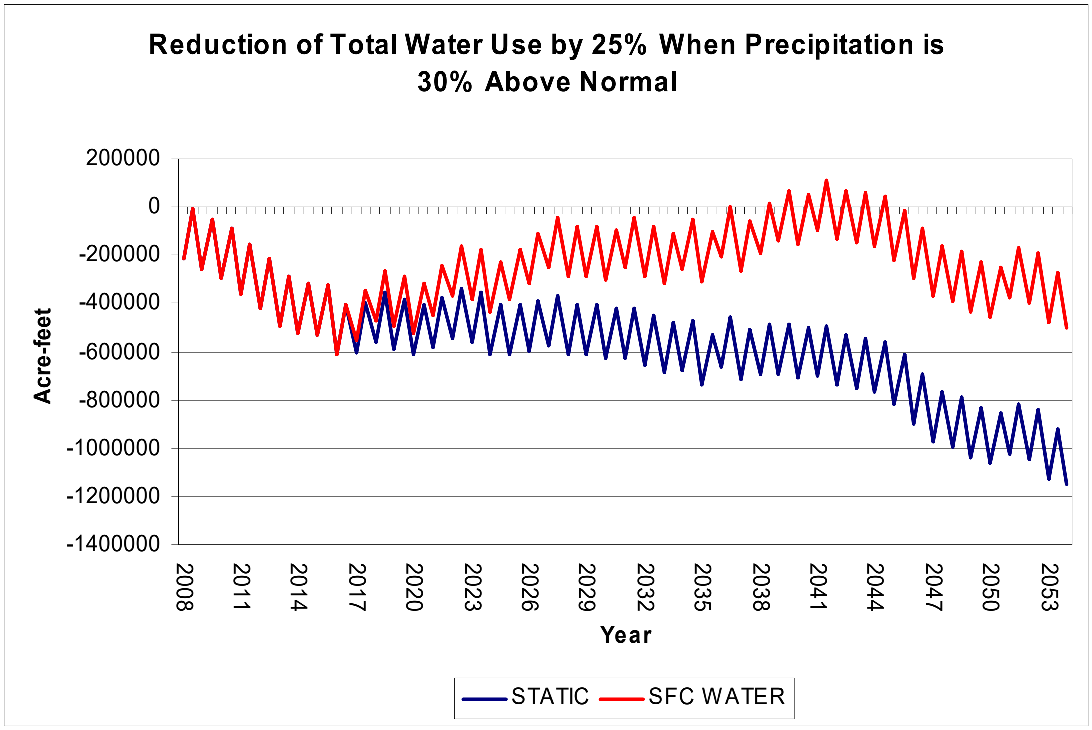


Figure 23

Changes in water volume when surface water is used to supplement irrigation

Table 12

Years when surface water irrigation was available to supplement groundwater

Year	Projected Year	Initial Total Groundwater Use (A-F)	Groundwater Use with Surface Water Added (A-F)	Implied Groundwater Conservation (A-F)
1970	2017	199,952.79	149,964.59	49,988.20
1971	2018	163,981.82	122,986.36	40,995.45
1974	2021	172,233.53	129,175.14	43,058.38
1975	2022	173,393.96	130,045.47	43,348.49
1978	2025	205,067.84	153,800.88	51,266.96
1979	2026	186,843.62	140,132.72	46,710.91
1980	2027	185,269.21	138,951.90	46,317.30
1984	2031	203,262.24	152,446.68	50,815.56
1987	2034	198,262.67	148,697.01	49,565.67
1989	2036	137,722.23	103,291.67	34,430.56
1991	2038	182,435.73	136,826.80	45,608.93
1992	2039	206,430.24	154,822.68	51,607.56
1994	2041	201,810.46	151,357.85	50,452.62
2004	2051	166,330.51	124,747.88	41,582.63
Period Total		**2,582,996.82**	**1,937,247.62**	**645749.21 (25%)**

Realistic Scenario: Rice Example

Changes in this scenario are meant to reflect changes that could realistically or likely occur in the Delta over the next 47 years as described in Chapter III. Figure 24 shows that approximately 200,000 acre-feet of water could be conserved if MIRI irrigation continues to be adopted and becomes the main method of irrigation preferred by rice producers in the Delta.

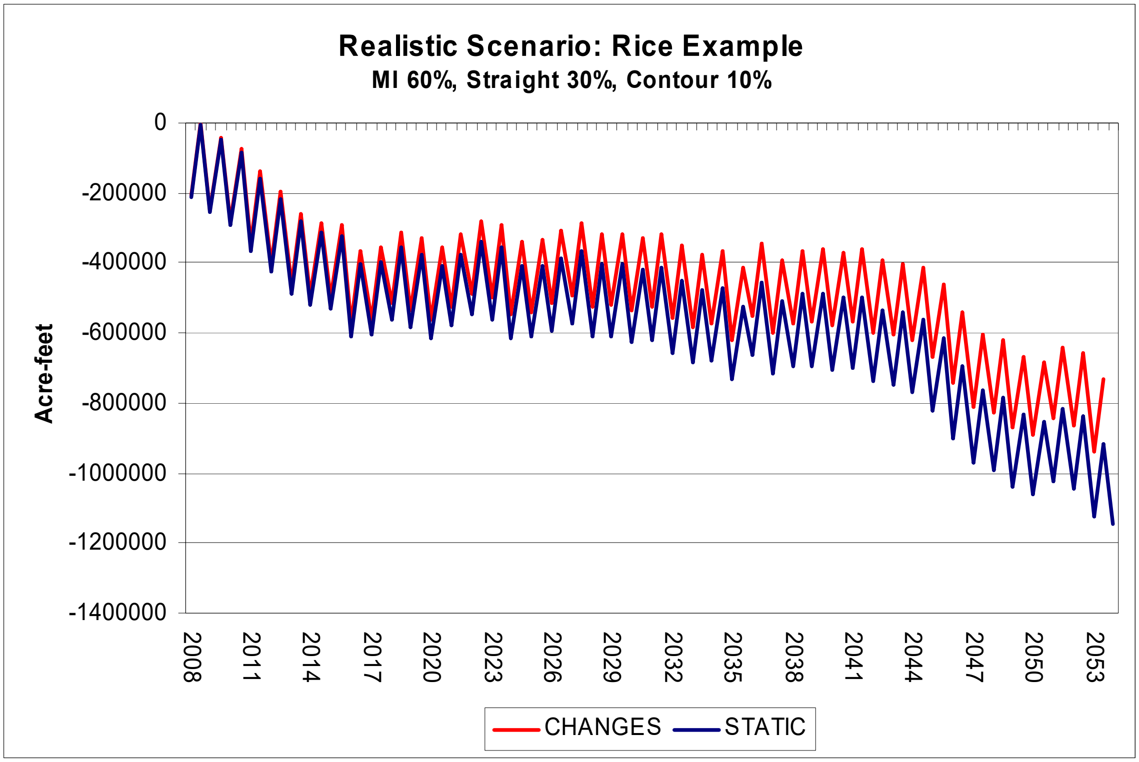


Figure 24

Realistic Scenario: Rice Example

Discussion

Practical Applications

Permitting

As previously stated in Chapter II, there are approximately 15,000 wells currently in operation in the Delta. YMD oversees the permitting process of new and replacement wells. The model has the potential to be integrated into this process because personnel at

YMD are seeking ways to enhance adoption of alternative conservation methods. When this project began, it was likely that within the next ten years a person seeking a permit to dig a well and pump water from the alluvial aquifer would have to agree to certain conditions of water conservation. For example, it has been found that the MIRI method for rice irrigation is very effective as well as water-conservative. The model simulations presented to the YMD Board of Directors has convinced them to authorize new permitting procedures beginning in 2009.

The new permitting procedure (Appendix B) states that if a permit applicant is currently using an efficient irrigation method as defined by the Board (e.g. sprinkler, precision land forming, tail-water recovery), that applicant could be issued a standard ten year permit. However, if the applicant is using a less conservative irrigation method (furrow), that applicant would receive a three year permit with continuation contingent upon proposing a plan to adopt a more conservative irrigation method (Pennington, personal comm., 2008). The YMD Board felt confident enough in the reliability of the results of the model simulations to encourage producers to move toward more conservative irrigation methods.

Climatological Scenarios

The model would also be useful when projecting various climatological scenarios. Growing season precipitation is one of the main driving components in the model and model results have shown great sensitivity to changes in this variable. Scenarios could be run to determine how water use in the aquifer would change if the Delta received 20% more rainfall or 30% less rainfall, or other such changes in precipitation in the future. The model could also be used to determine change in the aquifer if the Delta experienced a number of drought years followed by one or two rainy years. In these ways, the model could be valuable in assessing the impacts of climate change to water availability in the aquifer.

Senate Bill 2860: AN ACT TO CREATE THE MISSISSIPPI GLOBAL CLIMATE STUDY COMMISSION FOR THE PURPOSE OF STUDYING THE IMPACTS THAT GLOBAL CLIMATE CHANGE WILL HAVE ON THE STATE OF MISSISSIPPI AND FOR THE PURPOSE OF RECOMMENDING APPROPRIATE STATE RESPONSES TO ADDRESS GLOBAL CLIMATE CHANGE AND PROBLEMS LIKELY TO BE ASSOCIATED WITH IT; AND FOR RELATED PURPOSES was introduced to the Mississippi State Legislature in the 2008 Regular Session. If passed, an eleven member committee will be responsible for studying the potential impacts that global climate change will have on Mississippi. Of those eleven members, two must be from MDEQ. MDEQ staff who will be chosen for this project have requested and received training on the use of the model with an intent to run scenarios using different precipitation regimes in the state.

Limitations

Although the model appears to be a useful tool, it is also important to make note of its many limitations. First, it has been assumed that seasonal growing season precipitation totals are efficient when accounting for climatic variability. It could be that monthly, weekly, or even daily precipitation totals would be far more accurate and provide a better model output.

Secondly, the water use survey sites used by YMD are not entirely representative of the irrigation methods used throughout the Delta. YMD acknowledged this when they stated in their 2007 annual report "…one should note the small sample size of pivots in the row crop classifications, flood irrigation in corn, and zero grade sites in corn and beans. While these sites give us a glimpse of each particular method's water efficiency the small sample size should be considered before drawing any broad conclusions" (Pennington, 2007). More specifically, 21 cotton sites were used in the water use survey. Of those 21 sites, only one site represented pivot irrigation while the rest were furrow irrigation. It is understood that data based upon one site will not be a true representation of all other sites of that same method. However, these measurements are the only data available, and so they are used with an acknowledgement of the inherent limitations imposed.

Lastly, the finite water volume of the aquifer is not known. It is unknown exactly how many acre-feet of water can be withdrawn from the aquifer before it is de-watered. Also, the layers of alluvium at the bottom of the aquifer must be taken into consideration. YMD, along with other agencies, are trying to determine a water level that could be accepted as the lowest point in the aquifer, and water could not be withdrawn below that level.

CHAPTER V

CONCLUSIONS

The model is a sensitive tool that is useful for various forms of analysis. It is user-friendly and completely interactive, allowing for single or multiple changes simultaneously. Growing season precipitation can be used to simulate inter-annual climatological variability through time. Crop acreages and irrigation methods can be used to account for cultural influences on water use through time. This combination of climatological and cultural drivers of groundwater demand can be used in the model to determine best and worst case scenarios in overall groundwater use in the aquifer.

The model also has the potential to be used to recommend water use management techniques. Results indicate that the aquifer responds to small changes in water use methods, and that the aquifer water volume is apparently very strongly related to changes in water use methods associated with climatological variability. YMD and the Mississippi Department of Environmental Quality (MDEQ) have shown an interest in using the model as a tool to propose conservation practices to producers across the Delta, and to assess the efforts of various climate change situations.

The model currently reflects the area of greatest drawdown in the aquifer. However, research will continue with an effort to expand the model to reflect the entire Delta instead of only Sunflower County.

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APPENDIX A

2006 STATIC SCENARIO MODEL SIMULATION

This appendix shows the results of the 2006 static model simulation. It reflects what would happen if there were no changes to land use or specific irrigation methods over the 47 year period. Table 13 shows crop acreages and specific irrigation methods for each crop as they existed in Sunflower County in 2006. Although it is shown only once, these values remain constant throughout each year of the simulation. Directly below Table 13 is the actual year-by-year simulation, beginning with the formulated section of the model starting with growing season precipitation (Table 14). Every year the growing season precipitation is different, as well as the irrigation coefficients in the AVG Use column. The number in bold in the Yearly Use column is the total water use by all five crops for that year.

Table 13

Static 2006 scenario acreages and specific irrigation methods

Static 2006 Scenario Crop Acreages and Specific Irrigation Methods (in %)									
	Acres	Furrow	Pivot	Contour	Straight	MI	ZG	MF	6/3
Cotton	60,300	0.81	0.19						
Rice	27,600			0.20	0.56	0.12	0.12		
Corn	8,910	1.00							
Soybeans	86,350	0.49	0.03	0.06	0.40		0.02		
Catfish	24,300							0.37	0.63

Table 14

Static 2006 model simulation

	GS Prp	**AVG Use**	**Specific Irrigation Method Water Use**					**Total Use**	**Yearly Use**
2008									
			Furrow Use	Pivot Use					
Cotton	16.73	0.4281	0.4581	0.3382				26,248	
			Con Use	St Use	MI Use	ZG Use			
Rice	16.73	2.8835	3.5467	3.0565	2.5375	1.7589		81,049	
			Furrow Use	Pivot Use	Str Use	ZG Use			
Corn	16.73	0.7608	0.7684	0.3728	0.6543	0.5326		6,847	
			Furrow Use	St Use	Pivot Use	Con Use	ZG Use		
Soybeans	16.73	0.6781	0.7663	0.5832	0.7595	0.5967	0.4747	58,443	
			MF Use	6/3 Use					
Catfish			3.1093	0.7807				39,908	**212,494**
2009									
			Furrow Use	Pivot Use					
Cotton	12.51	0.5547	0.5935	0.4382				34,010	
			Con Use	St Use	MI Use	ZG Use			
Rice	12.51	3.0945	3.8062	3.2802	2.7232	1.8876		86,980	
			Furrow Use	Pivot Use	Str Use	ZG Use			
Corn	12.51	0.9296	0.9389	0.4555	0.7995	0.6507		8,366	
			Furrow Use	St Use	Pivot Use	Con Use	ZG Use		
Soybeans	12.51	0.8047	0.9093	0.6920	0.9013	0.7081	0.5633	69,354	
			MF Use	6/3 Use					
Catfish			3.3723	1.3152				50,455	**249,164**

Table 14 (continued)

2010									
			Furrow Use	Pivot Use					
Cotton	14.51	0.4947	0.5293	0.3908				30,332	
			Con Use	St Use	MI Use	ZG Use			
Rice	14.51	2.9945	3.6832	3.1742	2.6352	1.8266		84,169	
			Furrow Use	Pivot Use	Str Use	ZG Use			
Corn	14.51	0.8496	0.8581	0.4163	0.7307	0.5947		7,646	
			Furrow Use	St Use	Pivot Use	Con Use	ZG Use		
Soybeans	14.51	0.7447	0.8415	0.6404	0.8341	0.6553	0.5213	64,183	
			MF Use	6/3 Use					
Catfish			3.6722	1.5470				56,699	**243,028**
2011									
			Furrow Use	Pivot Use					
Cotton	7.95	0.6915	0.7399	0.5463				42,398	
			Con Use	St Use	MI Use	ZG Use			
Rice	7.95	3.3225	4.0867	3.5219	2.9238	2.0267		93,388	
			Furrow Use	Pivot Use	Str Use	ZG Use			
Corn	7.95	1.112	1.1231	0.5449	0.9563	0.7784		10,007	
			Furrow Use	St Use	Pivot Use	Con Use	ZG Use		
Soybeans	7.95	0.9415	1.0639	0.8097	1.0545	0.8285	0.6591	81,144	
			MF Use	6/3 Use					
Catfish			3.4135	1.2925				50,478	**277,415**
2012									
			Furrow Use	Pivot Use					
Cotton	10.4	0.618	0.6613	0.4882				37,891	
			Con Use	St Use	MI Use	ZG Use			

Table 14 (continued)

Rice	10.4	3.2	3.9360	3.3920	2.8160	1.9520		89,945	
			Furrow Use	Pivot Use	Str Use	ZG Use			
Corn	10.4	1.014	1.0241	0.4969	0.8720	0.7098		9,125	
			Furrow Use	St Use	Pivot Use	Con Use	ZG Use		
Soybeans	10.4	0.868	0.9808	0.7465	0.9722	0.7638	0.6076	74,809	
			MF Use	6/3 Use					
Catfish			3.3688	1.5283				53,686	**265,457**
2013									
			Furrow Use	Pivot Use					
Cotton	9.46	0.6462	0.6914	0.5105				39,620	
			Con Use	St Use	MI Use	ZG Use			
Rice	9.46	3.247	3.9938	3.4418	2.8574	1.9807		91,266	
			Furrow Use	Pivot Use	Str Use	ZG Use			
Corn	9.46	1.0516	1.0621	0.5153	0.9044	0.7361		9,463	
			Furrow Use	St Use	Pivot Use	Con Use	ZG Use		
Soybeans	9.46	0.8962	1.0127	0.7707	1.0037	0.7887	0.6273	77,240	
			MF Use	6/3 Use					
Catfish			3.5417	1.5415				55,442	**273,032**
2014									
			Furrow Use	Pivot Use					
Cotton	14.08	0.5076	0.5431	0.4010				31,122	
			Con Use	St Use	MI Use	ZG Use			
Rice	14.08	3.016	3.7097	3.1970	2.6541	1.8398		84,773	
			Furrow Use	Pivot Use	Str Use	ZG Use			
Corn	14.08	0.8668	0.8755	0.4247	0.7454	0.6068		7,800	
			Furrow Use	St Use	Pivot Use	Con Use	ZG Use		

Table 14 (continued)

Soybeans	14.08	0.7576	0.8561	0.6515	0.8485	0.6667	0.5303	65,294	
			MF Use	6/3 Use					
Catfish			3.2430	1.2685				48,577	**237,568**
2015									
			Furrow Use	Pivot Use					
Cotton	15.89	0.4533	0.4850	0.3581				27,793	
			Con Use	St Use	MI Use	ZG Use			
Rice	15.89	2.9255	3.5984	3.1010	2.5744	1.7846		82,229	
			Furrow Use	Pivot Use	Str Use	ZG Use			
Corn	15.89	0.7944	0.8023	0.3893	0.6832	0.5561		7,149	
			Furrow Use	St Use	Pivot Use	Con Use	ZG Use		
Soybeans	15.89	0.7033	0.7947	0.6048	0.7877	0.6189	0.4923	60,615	
			MF Use	6/3 Use					
Catfish			3.0817	0.7793				39,638	**217,424**
2016									
			Furrow Use	Pivot Use					
Cotton	7.61	0.7017	0.7508	0.5543				43,023	
			Con Use	St Use	MI Use	ZG Use			
Rice	7.61	3.3395	4.1076	3.5399	2.9388	2.0371		93,866	
			Furrow Use	Pivot Use	Str Use	ZG Use			
Corn	7.61	1.1256	1.1369	0.5515	0.9680	0.7879		10,129	
			Furrow Use	St Use	Pivot Use	Con Use	ZG Use		
Soybeans	7.61	0.9517	1.0754	0.8185	1.0659	0.8375	0.6662	82,023	
			MF Use	6/3 Use					
Catfish			3.5055	1.5902				55,862	**284,904**

Table 14 (continued)

2017									
			Furrow Use	Pivot Use					
Cotton	18.19	0.3843	0.4112	0.3036				23,563	
			Con Use	St Use	MI Use	ZG Use			
Rice	18.19	2.8105	3.4569	2.9791	2.4732	1.7144		78,997	
			Furrow Use	Pivot Use	Str Use	ZG Use			
Corn	18.19	0.7024	0.7094	0.3442	0.6041	0.4917		6,321	
			Furrow Use	St Use	Pivot Use	Con Use	ZG Use		
Soybeans	18.19	0.6343	0.7168	0.5455	0.7104	0.5582	0.4440	54,668	
			MF Use	6/3 Use					
Catfish			3.1783	0.5113				36,404	**199,953**
2018									
			Furrow Use	Pivot Use					
Cotton	25.45	0.1665	0.1782	0.1315				10,209	
			Con Use	St Use	MI Use	ZG Use			
Rice	25.45	2.4475	3.0104	2.5944	2.1538	1.4930		68,794	
			Furrow Use	Pivot Use	Str Use	ZG Use			
Corn	25.45	0.412	0.4161	0.2019	0.3543	0.2884		3,708	
			Furrow Use	St Use	Pivot Use	Con Use	ZG Use		
Soybeans	25.45	0.4165	0.4706	0.3582	0.4665	0.3665	0.2916	35,896	
			MF Use	6/3 Use					
Catfish			3.2717	1.0425				45,375	**163,982**
2019									
			Furrow Use	Pivot Use					
Cotton	15.04	0.4788	0.5123	0.3783				29,357	

Table 14 (continued)

			Con Use	St Use	MI Use	ZG Use			
Rice	15.04	2.968	3.6506	3.1461	2.6118	1.8105		83,424	
			Furrow Use	Pivot Use	Str Use	ZG Use			
Corn	15.04	0.8284	0.8367	0.4059	0.7124	0.5799		7,455	
			Furrow Use	St Use	Pivot Use	Con Use	ZG Use		
Soybeans	15.04	0.7288	0.8235	0.6268	0.8163	0.6413	0.5102	62,812	
			MF Use	6/3 Use					
Catfish			3.3853	1.0292				46,193	**229,241**
2020									
			Furrow Use	Pivot Use					
Cotton	13.83	0.5151	0.5512	0.4069				31,582	
			Con Use	St Use	MI Use	ZG Use			
Rice	13.83	3.0285	3.7251	3.2102	2.6651	1.8474		85,125	
			Furrow Use	Pivot Use	Str Use	ZG Use			
Corn	13.83	0.8768	0.8856	0.4296	0.7540	0.6138		7,890	
			Furrow Use	St Use	Pivot Use	Con Use	ZG Use		
Soybeans	13.83	0.7651	0.8646	0.6580	0.8569	0.6733	0.5356	65,941	
			MF Use	6/3 Use					
Catfish			3.2313	1.0277				44,785	**235,324**
2021									
			Furrow Use	Pivot Use					
Cotton	22.55	0.2535	0.2712	0.2003				15,543	
			Con Use	St Use	MI Use	ZG Use			
Rice	22.55	2.5925	3.1888	2.7481	2.2814	1.5814		72,870	
			Furrow Use	Pivot Use	Str Use	ZG Use			
Corn	22.55	0.528	0.5333	0.2587	0.4541	0.3696		4,752	

Table 14 (continued)

			Furrow Use	St Use	Pivot Use	Con Use	ZG Use		
Soybeans	22.55	0.5035	0.5690	0.4330	0.5639	0.4431	0.3525	43,395	
			MF Use	6/3 Use					
Catfish			3.1060	0.5062				35,675	**172,234**
2022									
			Furrow Use	Pivot Use					
Cotton	22.18	0.2646	0.2831	0.2090				16,223	
			Con Use	St Use	MI Use	ZG Use			
Rice	22.18	2.611	3.2115	2.7677	2.2977	1.5927		73,390	
			Furrow Use	Pivot Use	Str Use	ZG Use			
Corn	22.18	0.5428	0.5482	0.2660	0.4668	0.3800		4,885	
			Furrow Use	St Use	Pivot Use	Con Use	ZG Use		
Soybeans	22.18	0.5146	0.5815	0.4426	0.5764	0.4528	0.3602	44,351	
			MF Use	6/3 Use					
Catfish			2.9678	0.5135				34,545	**173,394**
2023									
			Furrow Use	Pivot Use					
Cotton	15.88	0.4536	0.4854	0.3583				27,812	
			Con Use	St Use	MI Use	ZG Use			
Rice	15.88	2.926	3.5990	3.1016	2.5749	1.7849		82,244	
			Furrow Use	Pivot Use	Str Use	ZG Use			
Corn	15.88	0.7948	0.8027	0.3895	0.6835	0.5564		7,152	
			Furrow Use	St Use	Pivot Use	Con Use	ZG Use		
Soybeans	15.88	0.7036	0.7951	0.6051	0.7880	0.6192	0.4925	60,640	
			MF Use	6/3 Use					

Table 14 (continued)

Catfish			3.2835	0.7738				41,369	**219,217**
2024									
			Furrow Use	Pivot Use					
Cotton	11.36	0.5892	0.6304	0.4655				36,126	
			Con Use	St Use	MI Use	ZG Use			
Rice	11.36	3.152	3.8770	3.3411	2.7738	1.9227		88,596	
			Furrow Use	Pivot Use	Str Use	ZG Use			
Corn	11.36	0.9756	0.9854	0.4780	0.8390	0.6829		8,780	
			Furrow Use	St Use	Pivot Use	Con Use	ZG Use		
Soybeans	11.36	0.8392	0.9483	0.7217	0.9399	0.7385	0.5874	72,327	
			MF Use	6/3 Use					
Catfish			3.6633	1.3193				53,134	**258,963**
2025									
			Furrow Use	Pivot Use					
Cotton	19.8	0.336	0.3595	0.2654				20,601	
			Con Use	St Use	MI Use	ZG Use			
Rice	19.8	2.73	3.3579	2.8938	2.4024	1.6653		76,734	
			Furrow Use	Pivot Use	Str Use	ZG Use			
Corn	19.8	0.638	0.6444	0.3126	0.5487	0.4466		5,741	
			Furrow Use	St Use	Pivot Use	Con Use	ZG Use		
Soybeans	19.8	0.586	0.6622	0.5040	0.6563	0.5157	0.4102	50,505	
			MF Use	6/3 Use					
Catfish			3.5307	1.2895				51,486	**205,068**
2026									

Table 14 (continued)

			Furrow Use	Pivot Use					
Cotton	19.54	0.3438	0.3679	0.2716				21,079	
			Con Use	St Use	MI Use	ZG Use			
Rice	19.54	2.743	3.3739	2.9076	2.4138	1.6732		77,100	
			Furrow Use	Pivot Use	Str Use	ZG Use			
Corn	19.54	0.6484	0.6549	0.3177	0.5576	0.4539		5,835	
			Furrow Use	St Use	Pivot Use	Con Use	ZG Use		
Soybeans	19.54	0.5938	0.6710	0.5107	0.6651	0.5225	0.4157	51,177	
			MF Use	6/3 Use					
Catfish			3.0677	0.2659				31,652	**186,844**
2027									
			Furrow Use	Pivot Use					
Cotton	22.72	0.2484	0.2658	0.1962				15,230	
			Con Use	St Use	MI Use	ZG Use			
Rice	22.72	2.584	3.1783	2.7390	2.2739	1.5762		72,631	
			Furrow Use	Pivot Use	Str Use	ZG Use			
Corn	22.72	0.5212	0.5264	0.2554	0.4482	0.3648		4,690	
			Furrow Use	St Use	Pivot Use	Con Use	ZG Use		
Soybeans	22.72	0.4984	0.5632	0.4286	0.5582	0.4386	0.3489	42,955	
			MF Use	6/3 Use					
Catfish			3.7398	1.0542				49,763	**185,269**
2028									
			Furrow Use	Pivot Use					
Cotton	13.57	0.5229	0.5595	0.4131				32,061	
			Con Use	St Use	MI Use	ZG Use			
Rice	13.57	3.0415	3.7410	3.2240	2.6765	1.8553		85,490	

Table 14 (continued)

			Furrow Use	Pivot Use	Str Use	ZG Use			
Corn	13.57	0.8872	0.8961	0.4347	0.7630	0.6210		7,984	
			Furrow Use	St Use	Pivot Use	Con Use	ZG Use		
Soybeans	13.57	0.7729	0.8734	0.6647	0.8656	0.6802	0.5410	66,613	
			MF Use	6/3 Use					
Catfish			3.4999	1.2915				51,240	**243,387**
2029									
			Furrow Use	Pivot Use					
Cotton	16.79	0.4263	0.4561	0.3368				26,138	
			Con Use	St Use	MI Use	ZG Use			
Rice	16.79	2.8805	3.5430	3.0533	2.5348	1.7571		80,965	
			Furrow Use	Pivot Use	Str Use	ZG Use			
Corn	16.79	0.7584	0.7660	0.3716	0.6522	0.5309		6,825	
			Furrow Use	St Use	Pivot Use	Con Use	ZG Use		
Soybeans	16.79	0.6763	0.7642	0.5816	0.7575	0.5951	0.4734	58,288	
			MF Use	6/3 Use					
Catfish			3.0204	0.5100				34,964	**207,178**
2030									
			Furrow Use	Pivot Use					
Cotton	15.93	0.4521	0.4837	0.3572				27,720	
			Con Use	St Use	MI Use	ZG Use			
Rice	15.93	2.9235	3.5959	3.0989	2.5727	1.7833		82,173	
			Furrow Use	Pivot Use	Str Use	ZG Use			
Corn	15.93	0.7928	0.8007	0.3885	0.6818	0.5550		7,134	
			Furrow Use	St Use	Pivot Use	Con Use	ZG Use		

Table 14 (continued)

Soybeans	15.93	0.7021	0.7934	0.6038	0.7864	0.6178	0.4915	60,511	
			MF Use	6/3 Use					
Catfish			3.1299	1.0355				43,994	**221,532**
2031									
			Furrow Use	Pivot Use					
Cotton	18.55	0.3735	0.3996	0.2951				22,900	
			Con Use	St Use	MI Use	ZG Use			
Rice	18.55	2.7925	3.4348	2.9601	2.4574	1.7034		78,491	
			Furrow Use	Pivot Use	Str Use	ZG Use			
Corn	18.55	0.688	0.6949	0.3371	0.5917	0.4816		6,191	
			Furrow Use	St Use	Pivot Use	Con Use	ZG Use		
Soybeans	18.55	0.6235	0.7046	0.5362	0.6983	0.5487	0.4365	53,737	
			MF Use	6/3 Use					
Catfish			3.3337	0.7818				41,942	**203,262**
2032									
			Furrow Use	Pivot Use					
Cotton	13.69	0.5193	0.5557	0.4102				31,840	
			Con Use	St Use	MI Use	ZG Use			
Rice	13.69	3.0355	3.7337	3.2176	2.6712	1.8517		85,321	
			Furrow Use	Pivot Use	Str Use	ZG Use			
Corn	13.69	0.8824	0.8912	0.4324	0.7589	0.6177		7,941	
			Furrow Use	St Use	Pivot Use	Con Use	ZG Use		
Soybeans	13.69	0.7693	0.8693	0.6616	0.8616	0.6770	0.5385	66,303	
			MF Use	6/3 Use					
Catfish			3.4665	1.3039				51,130	**242,535**

Table 14 (continued)

2033									
			Furrow Use	Pivot Use					
Cotton	16.06	0.4482	0.4796	0.3541				27,481	
			Con Use	St Use	MI Use	ZG Use			
Rice	16.06	2.917	3.5879	3.0920	2.5670	1.7794		81,991	
			Furrow Use	Pivot Use	Str Use	ZG Use			
Corn	16.06	0.7876	0.7955	0.3859	0.6773	0.5513		7,088	
			Furrow Use	St Use	Pivot Use	Con Use	ZG Use		
Soybeans	16.06	0.6982	0.7890	0.6005	0.7820	0.6144	0.4887	60,175	
			MF Use	6/3 Use					
Catfish			3.5884	1.5810				56,468	**233,201**
2034									
			Furrow Use	Pivot Use					
Cotton	21.12	0.2964	0.3171	0.2342				18,173	
			Con Use	St Use	MI Use	ZG Use			
Rice	21.12	2.664	3.2767	2.8238	2.3443	1.6250		74,879	
			Furrow Use	Pivot Use	Str Use	ZG Use			
Corn	21.12	0.5852	0.5911	0.2867	0.5033	0.4096		5,266	
			Furrow Use	St Use	Pivot Use	Con Use	ZG Use		
Soybeans	21.12	0.5464	0.6174	0.4699	0.6120	0.4808	0.3825	47,092	
			MF Use	6/3 Use					
Catfish			3.6856	1.2878				52,852	**198,263**
2035									
			Furrow Use	Pivot Use					
Cotton	11.72	0.5784	0.6189	0.4569				35,463	

Table 14 (continued)

			Con Use	St Use	MI Use	ZG Use			
Rice	11.72	3.134	3.8548	3.3220	2.7579	1.9117		88,090	
			Furrow Use	Pivot Use	Str Use	ZG Use			
Corn	11.72	0.9612	0.9708	0.4710	0.8266	0.6728		8,650	
			Furrow Use	St Use	Pivot Use	Con Use	ZG Use		
Soybeans	11.72	0.8284	0.9361	0.7124	0.9278	0.7290	0.5799	71,396	
			MF Use	6/3 Use					
Catfish			3.7487	1.5690				57,725	**261,325**
2036									
			Furrow Use	Pivot Use					
Cotton	27.64	0.1008	0.1079	0.0796				6,180	
			Con Use	St Use	MI Use	ZG Use			
Rice	27.64	2.338	2.8757	2.4783	2.0574	1.4262		65,716	
			Furrow Use	Pivot Use	Str Use	ZG Use			
Corn	27.64	0.3244	0.3276	0.1590	0.2790	0.2271		2,919	
			Furrow Use	St Use	Pivot Use	Con Use	ZG Use		
Soybeans	27.64	0.3508	0.3964	0.3017	0.3929	0.3087	0.2456	30,234	
			MF Use	6/3 Use					
Catfish			3.1895	0.2610				32,672	**137,722**
2037									
			Furrow Use	Pivot Use					
Cotton	10.69	0.6093	0.6520	0.4813				37,358	
			Con Use	St Use	MI Use	ZG Use			
Rice	10.69	3.1855	3.9182	3.3766	2.8032	1.9432		89,538	
			Furrow Use	Pivot Use	Str Use	ZG Use			
Corn	10.69	1.0024	1.0124	0.4912	0.8621	0.7017		9,021	

Table 14 (continued)

			Furrow Use	St Use	Pivot Use	Con Use	ZG Use		
Soybeans	10.69	0.8593	0.9710	0.7390	0.9624	0.7562	0.6015	74,060	
			MF Use	6/3 Use					
Catfish			3.3103	1.2889				49,495	**259,471**
2038									
			Furrow Use	Pivot Use					
Cotton	21.67	0.2799	0.2995	0.2211				17,162	
			Con Use	St Use	MI Use	ZG Use			
Rice	21.67	2.6365	3.2429	2.7947	2.3201	1.6083		74,106	
			Furrow Use	Pivot Use	Str Use	ZG Use			
Corn	21.67	0.5632	0.5688	0.2760	0.4844	0.3942		5,068	
			Furrow Use	St Use	Pivot Use	Con Use	ZG Use		
Soybeans	21.67	0.5299	0.5988	0.4557	0.5935	0.4663	0.3709	45,670	
			MF Use	6/3 Use					
Catfish			3.1606	0.7847				40,430	**182,436**
2039									
			Furrow Use	Pivot Use					
Cotton	18.81	0.3657	0.3913	0.2889				22,422	
			Con Use	St Use	MI Use	ZG Use			
Rice	18.81	2.7795	3.4188	2.9463	2.4460	1.6955		78,126	
			Furrow Use	Pivot Use	Str Use	ZG Use			
Corn	18.81	0.6776	0.6844	0.3320	0.5827	0.4743		6,098	
			Furrow Use	St Use	Pivot Use	Con Use	ZG Use		
Soybeans	18.81	0.6157	0.6957	0.5295	0.6896	0.5418	0.4310	53,065	
			MF Use	6/3 Use					

Table 14 (continued)

Catfish			3.4601	1.0197				46,720	**206,430**
2040									
			Furrow Use	Pivot Use					
Cotton	16.98	0.4206	0.4500	0.3323				25,788	
			Con Use	St Use	MI Use	ZG Use			
Rice	16.98	2.871	3.5313	3.0433	2.5265	1.7513		80,698	
			Furrow Use	Pivot Use	Str Use	ZG Use			
Corn	16.98	0.7508	0.7583	0.3679	0.6457	0.5256		6,757	
			Furrow Use	St Use	Pivot Use	Con Use	ZG Use		
Soybeans	16.98	0.6706	0.7578	0.5767	0.7511	0.5901	0.4694	57,796	
			MF Use	6/3 Use					
Catfish			3.5621	1.0255				47,726	**218,764**
2041									
			Furrow Use	Pivot Use					
Cotton	18.73	0.3681	0.3939	0.2908				22,569	
			Con Use	St Use	MI Use	ZG Use			
Rice	18.73	2.7835	3.4237	2.9505	2.4495	1.6979		78,238	
			Furrow Use	Pivot Use	Str Use	ZG Use			
Corn	18.73	0.6808	0.6876	0.3336	0.5855	0.4766		6,127	
			Furrow Use	St Use	Pivot Use	Con Use	ZG Use		
Soybeans	18.73	0.6181	0.6985	0.5316	0.6923	0.5439	0.4327	53,272	
			MF Use	6/3 Use					
Catfish			3.2848	0.7885				41,605	**201,810**
2042									

Table 14 (continued)

			Furrow Use	Pivot Use					
Cotton	14.3	0.501	0.5361	0.3958				30,718	
			Con Use	St Use	MI Use	ZG Use			
Rice	14.3	3.005	3.6962	3.1853	2.6444	1.8331		84,464	
			Furrow Use	Pivot Use	Str Use	ZG Use			
Corn	14.3	0.858	0.8666	0.4204	0.7379	0.6006		7,721	
			Furrow Use	St Use	Pivot Use	Con Use	ZG Use		
Soybeans	14.3	0.751	0.8486	0.6459	0.8411	0.6609	0.5257	64,726	
			MF Use	6/3 Use					
Catfish			3.6022	1.5406				55,973	**243,602**
2043									
			Furrow Use	Pivot Use					
Cotton	15.84	0.4548	0.4866	0.3593				27,885	
			Con Use	St Use	MI Use	ZG Use			
Rice	15.84	2.928	3.6014	3.1037	2.5766	1.7861		82,300	
			Furrow Use	Pivot Use	Str Use	ZG Use			
Corn	15.84	0.7964	0.8044	0.3902	0.6849	0.5575		7,167	
			Furrow Use	St Use	Pivot Use	Con Use	ZG Use		
Soybeans	15.84	0.7048	0.7964	0.6061	0.7894	0.6202	0.4934	60,744	
			MF Use	6/3 Use					
Catfish			3.3217	0.5113				37,694	**215,789**
2044									
			Furrow Use	Pivot Use					
Cotton	15.79	0.4563	0.4882	0.3605				27,977	
			Con Use	St Use	MI Use	ZG Use			
Rice	15.79	2.9305	3.6045	3.1063	2.5788	1.7876		82,370	

Table 14 (continued)

			Furrow Use	Pivot Use	Str Use	ZG Use			
Corn	15.79	0.7984	0.8064	0.3912	0.6866	0.5589		7,185	
			Furrow Use	St Use	Pivot Use	Con Use	ZG Use		
Soybeans	15.79	0.7063	0.7981	0.6074	0.7911	0.6215	0.4944	60,873	
			MF Use	6/3 Use					
Catfish			3.4215	1.0282				46,503	**224,908**
2045									
			Furrow Use	Pivot Use					
Cotton	12.5	0.555	0.5939	0.4385				34,029	
			Con Use	St Use	MI Use	ZG Use			
Rice	12.5	3.095	3.8069	3.2807	2.7236	1.8880		86,994	
			Furrow Use	Pivot Use	Str Use	ZG Use			
Corn	12.5	0.93	0.9393	0.4557	0.7998	0.6510		8,369	
			Furrow Use	St Use	Pivot Use	Con Use	ZG Use		
Soybeans	12.5	0.805	0.9097	0.6923	0.9016	0.7084	0.5635	69,380	
			MF Use	6/3 Use					
Catfish			3.6303	1.8164				60,447	**259,218**
2046									
			Furrow Use	Pivot Use					
Cotton	8.35	0.6795	0.7271	0.5368				41,662	
			Con Use	St Use	MI Use	ZG Use			
Rice	8.35	3.3025	4.0621	3.5007	2.9062	2.0145		92,826	
			Furrow Use	Pivot Use	Str Use	ZG Use			
Corn	8.35	1.096	1.1070	0.5370	0.9426	0.7672		9,863	
			Furrow Use	St Use	Pivot Use	Con Use	ZG Use		

Table 14 (continued)

Soybeans	8.35	0.9295	1.0503	0.7994	1.0410	0.8180	0.6507	80,110	
			MF Use	6/3 Use					
Catfish			3.6960	1.8018				60,814	**285,275**
2047									
			Furrow Use	Pivot Use					
Cotton	8.59	0.6723	0.7194	0.5311				41,221	
			Con Use	St Use	MI Use	ZG Use			
Rice	8.59	3.2905	4.0473	3.4879	2.8956	2.0072		92,489	
			Furrow Use	Pivot Use	Str Use	ZG Use			
Corn	8.59	1.0864	1.0973	0.5323	0.9343	0.7605		9,777	
			Furrow Use	St Use	Pivot Use	Con Use	ZG Use		
Soybeans	8.59	0.9223	1.0422	0.7932	1.0330	0.8116	0.6456	79,489	
			MF Use	6/3 Use					
Catfish			3.5244	1.5483				55,392	**278,367**
2048									
			Furrow Use	Pivot Use					
Cotton	14.82	0.4854	0.5194	0.3835				29,761	
			Con Use	St Use	MI Use	ZG Use			
Rice	14.82	2.979	3.6642	3.1577	2.6215	1.8172		83,733	
			Furrow Use	Pivot Use	Str Use	ZG Use			
Corn	14.82	0.8372	0.8456	0.4102	0.7200	0.5860		7,534	
			Furrow Use	St Use	Pivot Use	Con Use	ZG Use		
Soybeans	14.82	0.7354	0.8310	0.6324	0.8236	0.6472	0.5148	63,381	
			MF Use	6/3 Use					
Catfish			3.2960	0.7663				41,366	**225,776**

Table 14 (continued)

2049									
			Furrow Use	Pivot Use					
Cotton	11.19	0.5943	0.6359	0.4695				36,438	
			Con Use	St Use	MI Use	ZG Use			
Rice	11.19	3.1605	3.8874	3.3501	2.7812	1.9279		88,835	
			Furrow Use	Pivot Use	Str Use	ZG Use			
Corn	11.19	0.9824	0.9922	0.4814	0.8449	0.6877		8,841	
			Furrow Use	St Use	Pivot Use	Con Use	ZG Use		
Soybeans	11.19	0.8443	0.9541	0.7261	0.9456	0.7430	0.5910	72,767	
			MF Use	6/3 Use					
Catfish			3.1320	1.2762				47,698	**254,578**
2050									
			Furrow Use	Pivot Use					
Cotton	14.34	0.4998	0.5348	0.3948				30,644	
			Con Use	St Use	MI Use	ZG Use			
Rice	14.34	3.003	3.6937	3.1832	2.6426	1.8318		84,408	
			Furrow Use	Pivot Use	Str Use	ZG Use			
Corn	14.34	0.8564	0.8650	0.4196	0.7365	0.5995		7,707	
			Furrow Use	St Use	Pivot Use	Con Use	ZG Use		
Soybeans	14.34	0.7498	0.8473	0.6448	0.8398	0.6598	0.5249	64,622	
			MF Use	6/3 Use					
Catfish			3.1039	0.7912				40,019	**227,400**
2051									
			Furrow Use	Pivot Use					
Cotton	23.63	0.2211	0.2366	0.1747				13,556	

Table 14 (continued)

			Con Use	St Use	MI Use	ZG Use			
Rice	23.63	2.5385	3.1224	2.6908	2.2339	1.5485		71,352	
			Furrow Use	Pivot Use	Str Use	ZG Use			
Corn	23.63	0.4848	0.4896	0.2376	0.4169	0.3394		4,363	
			Furrow Use	St Use	Pivot Use	Con Use	ZG Use		
Soybeans	23.63	0.4711	0.5323	0.4051	0.5276	0.4146	0.3298	40,602	
			MF Use	6/3 Use					
Catfish			3.1604	0.5253				36,457	**166,331**
2052									
			Furrow Use	Pivot Use					
Cotton	15.22	0.4734	0.5065	0.3740				29,026	
			Con Use	St Use	MI Use	ZG Use			
Rice	15.22	2.959	3.6396	3.1365	2.6039	1.8050		83,171	
			Furrow Use	Pivot Use	Str Use	ZG Use			
Corn	15.22	0.8212	0.8294	0.4024	0.7062	0.5748		7,390	
			Furrow Use	St Use	Pivot Use	Con Use	ZG Use		
Soybeans	15.22	0.7234	0.8174	0.6221	0.8102	0.6366	0.5064	62,347	
			MF Use	6/3 Use					
Catfish			3.4919	1.0312				47,182	**229,116**
2053									
			Furrow Use	Pivot Use					
Cotton	7.28	0.7116	0.7614	0.5622				43,630	
			Con Use	St Use	MI Use	ZG Use			
Rice	7.28	3.356	4.1279	3.5574	2.9533	2.0472		94,330	
			Furrow Use	Pivot Use	Str Use	ZG Use			
Corn	7.28	1.1388	1.1502	0.5580	0.9794	0.7972		10,248	

Table 14 (continued)

			Furrow Use	St Use	Pivot Use	Con Use	ZG Use		
Soybeans	7.28	0.9616	1.0866	0.8270	1.0770	0.8462	0.6731	82,876	
			MF Use	6/3 Use					
Catfish			3.4902	1.5500				55,109	**286,194**
2054									
			Furrow Use	Pivot Use					
Cotton	15.53	0.4641	0.4966	0.3666				28,455	
			Con Use	St Use	MI Use	ZG Use			
Rice	15.53	2.9435	3.6205	3.1201	2.5903	1.7955		82,735	
			Furrow Use	Pivot Use	Str Use	ZG Use			
Corn	15.53	0.8088	0.8169	0.3963	0.6956	0.5662		7,278	
			Furrow Use	St Use	Pivot Use	Con Use	ZG Use		
Soybeans	15.53	0.7141	0.8069	0.6141	0.7998	0.6284	0.4999	61,545	
			MF Use	6/3 Use					
Catfish			3.6467	1.0283				48,530	**228,545**

APPENDIX B

PROPOSED GROUNDWATER PERMIT REVISIONS

Conservation Practices for Groundwater Permits

Row crop or Rice

1. Is irrigation runoff from this well captured and reused by you? (Tail water recovery system) (If yes, SW permit number)
2. Is water from this well applied through a sprinkler irrigation system?
3. Is the entire (>90%) water application area precision leveled with straight levees?
4. Is the entire (>90%) water application area zero grade leveled?
5. Can water from an existing SW permit be applied to at least 75% of the irrigated area?
6. The well has a flow meter with water use reported annually.
7. Are you in a drainage district or watershed with an approved water conservation plan?

If you say yes to any of the above, you will receive a 10 year Class 1 permit.

Tail water recovery system may apply water to this or any other permitted land area owned and or managed by the same individual.
In some cases the water application area may include more than one field. In this case, the condition must apply to the entire area.

Catfish

1. Are the outlet pipe elevations set equal to or higher than the pond levee height all summer on all ponds receiving water from this well?
2. Is there a device on the well to automatically or remotely shut off the well?
3. Do you have a water level indicating device that supports management of pond water levels reducing over-filling and allowing significant rainfall capture (6/3 method)?

You must respond yes to two options to receive a 10 year Class 1 permit.

Wildlife

1. Do you have a plan of operation that takes advantage of surface water and rain when available? Please attach a copy of the plan for review.

A surface water use plan is the only option to receive a 10 year Class 1 permit.

If you do not have sufficient conservation practices to obtain Class 1 permit, based on the above criteria, you will receive a 3 year Class 2 permit. When a 3 year Class 2 permit expires, the land must have sufficient conservation practices to obtain a Class 1 standing, or an approved accumulating flow metering device must be installed on the well, and an annual report of water use must be submitted by December 31st of each year.

Standby wells are permitted for 10 years.