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An Analysis of Irrigation Policy in the Mississippi Delta

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AN ANALYSIS OF IRRIGATION POLICY IN THE MISSISSIPPI DELTA

By
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ABSTRACT

This thesis aims to provide a sustainable irrigation alternative that could be easily adopted by farmers in the Mississippi Delta in order to improve water resource management. The Mississippi Alluvial Valley Aquifer, the groundwater system that lies under the Mississippi Delta, is being depleted at rapid rates due to industrial farming and unsustainable, outdated irrigation methods. The intent of this research is to evaluate the water scarcity problem in the Mississippi Delta by assessing water extraction rates and the progression of agriculture in the region. Then, various irrigation methods will be evaluated before a final suggestion is made. Through extensive secondary research, I found that the surge valve irrigation method is the most sustainable, effective, and efficient irrigation alternative that could be easily adopted by farmers in the Mississippi Delta. Surge valve irrigation provides a water-conscious method of irrigation that is economical while being proven to yield similar crop quantities as the current irrigation methods yet cutting down on overall costs. With the widespread adoption of surge valve irrigation, the Mississippi Delta could be on a path to sustainable water resource management and proper aquifer maintenance.

LIST OF FIGURES

Table of Contents

Chapter 1: Introduction

When driving through the Mississippi Delta, it's impossible to ignore the vast, seemingly ubiquitous farmland that fills the landscape. In the warmer months, the highway bisects snow-like plains of cotton that stretch for miles, and from inside an air-conditioned vehicle, it can be easy to forget the 90-degree weather that scorches the outdoors. When the air starts to chill in the autumnal months, though, the Delta can appear barren as all that remain in the fields are naked sprigs that once held Mississippi's famous cotton. Loosely populated and heavily cultivated, the Delta seems to be the ideal setting for heavy farming, but the global demand for cash crops like soy, corn, and cotton; the heavily subsidized nature of industrialized farming in the United States; and unsustainable irrigation practices all intersect to create an environmental disaster that could be the demise of the historical Delta.

The Mississippi Delta is a region in northwest Mississippi sandwiched between the Mississippi and Yazoo Rivers, and the area is rich in culture, ecology, and history. Apart of the Mississippi Alluvial Plain (MAP), it wasn't settled until the early nineteenth century, but it quickly boomed into a vital region for the pre-Civil War economy due to the success of cotton in the region (*Visit the Delta,* n.d.). Prior to its settlement, Native Americans lived fruitfully on the land from around 1000 B.C.E. and mostly depended on small-scale farming. Once white settlers occupied the area, Native Americans were essentially forced out of the region due to the Indian Removal Act of 1830, which forcibly removed Native Americans from Mississippi and allowed for European settlement on the previously Indigenous land (Office of the Historian, n.d.). The land was swiftly transformed to support high-volume agriculture by enslaved Black workers taken and forced into labor by white settlers. Relying exclusively on the labor of enslaved Black workers, the region fostered economic prosperity and enormous wealth for white plantation owners who monopolized all of the political and social power in the state. Remnants of these sprawling plantations still exist in the area, and the brutal history of the area can feel like a ghost in the now-vacant mansions (Wilson et. al, 2004).

After the Civil War and Emancipation, freed Black men and women saw the Delta as a "frontier of opportunity," and consistently fought for their right to own land and be political agents (Wilson et. al, 2004). However, due to the heavily engrained institution of slavery that entrenched every facet of American existence, the oppressive, white-dominated Mississippi government continually ensured the complete disenfranchisement of Black Mississippians, which ultimately forced them to be sharecroppers on the same Delta farms even after the political emancipation of all enslaved peoples in the United States. There were new industries introduced to the region after the Civil War, though these industries were still both agriculturally centered and relied heavily on the exploitation of Black workers. Former plantations were turned into operations focused on churning out commodity crops for the global economy. "By 1910, tenants operated ninety-two percent of Delta farms, and ninety-five percent of those tenants were African American" (Wilson et. al, 2004). White affluent farm owners still maintained their "Old South" lifestyles, though, regardless of the modernization of industry in the area and the abolition of slavery. Gross displays of affluence began to form again in the post-Civil War era, and one of the main displays of wealth other than lavish parties and decorum was elite education (Wilson et. al, 2004). This worsened the already impenetrable gap in education between Black and white Americans, which only perpetuated the exploitation of Black tenant labor.

The social fabric of the Mississippi Delta did not always remain as it was pre- and post-Civil War, though. With the increasingly violent living conditions Black Mississippians faced in the Delta during the Jim Crow era, the Delta, like most of the South, was impacted by the Great Migration of Black southerners to the North. “The Illinois Central Railroad became a powerful symbol to African Americans of escape from the Delta and connections to a broader world,” which encouraged mobility north (Wilson et. al, 2004). However, the Great Migration did not consist of the movement of all Black Mississippians in the Delta, and with the tight-knit Black communities remaining in the Delta came the birth of the blues, a pivotal and revered musical genre said to have emerged in the Delta during slavery. Delta blues culture made an artful requiem out of the suffering of Black folks in the Delta (Wilson et. al, 2004).

During the twentieth century, the federal government began to have a role in defining the Delta specifically through flood policy which impacted agribusiness. While there had been multiple catastrophic floods that devastated the Delta, the Great Flood of 1927 was the catalyst that forced the federal government’s hand to enact protective and preventative policies. After the 1927 flood that claimed the lives of 250 to 500 people and destroyed over 16.6 million acres, “Congress appropriated $325 million for an extensive flood control system” (Wilson et. al, 2004). The Mississippi River and Tributaries (MR&T) project was also established after the Great Flood of 1927 in order to prevent overflows on “developed alluvial lands” and floods in various water systems (Mississippi River Commission, 2007, pg. 2). This allocation of funds allowed for the continuation of exploitative tenant labor, but there was an economic shift during World War II, pulling workers out of the Delta and into the military. This forced farms to consolidate lands, diversify crop types, and mechanize farms (Wilson et. al, 2004). The heavy tie the Delta has with slavery and institutionalized racism continues to impact present-day Delta culture, and the farming industry has only grown and become more specialized. Due to the incredibly complex history and culture of the Mississippi Delta, social, economic, and environmental injustices have unfortunately been woven into the fabric of Delta society and perpetually ignored by outsiders. The Delta has suffered from a multitude of injustices, but has maintained its resilience and character.

Like most of the continental U.S., the Mississippi Delta gets its water from an underground aquifer system. The area is "dense with industrial-level agriculture sustained by groundwater-dependent irrigation supplied by the" Mississippi River Valley Alluvial Aquifer (Killian et. Al, 2019). The Mississippi River Valley Alluvial Aquifer (MRVAA) encompasses approximately 33,000 square miles in the southeastern U.S., covering six states including Mississippi, Missouri, Kentucky, Tennessee, Louisiana, and Arkansas (Czarnecki et. al, 2002). It "contains freshwater in an area of 7,000 [square miles] adjacent to the Mississippi River" and is the "highest yielding aquifer in Mississippi" (Dalsin, 1978). As shown in Figure 2, an adaptation from a map made by the U.S. Geological Survey, the aquifer also has a saturated thickness that exceeds 100 feet in most locations (*USGS*, n.d). This means that in most areas, the aquifer's pore spaces are completely filled with water (Buddemeier, 2000). The aquifer is an "unconsolidated sand and gravel aquifer" with intergranular porosity (U.S. Geological Survey, n.d.), meaning that the groundwater gathers by way of porous sand, gravel, soil, and/or "incompletely cemented sedimentary rock" (Georgia Southwester State University, n.d.). In these types of aquifers, hydraulic conductivity, or the ability for water to easily flow through the sediments in the ground, is relatively high compared to other types of aquifers, but it is also dependent on the amount of clay present in the ground (U.S. Geological Survey, n.d.). According to a study reported in the *Journal of Contemporary Water Research and Education*, clay is the limiting factor in aquifer recharge in the MRVAA as there is a "confining clay layer" that overlies the aquifer in many locations (Reba et. al, 2017). However, this does not prevent the aquifer from having overall "favorable hydrologic characteristics" (Czarnecki et. al; 2002). Since the aquifer is one of the largest in the United States and has high hydraulic conductivity, it would be assumed that the aquifer is in a stable condition that is able to support the region it lies under, but as it will be shown, that is not the case.

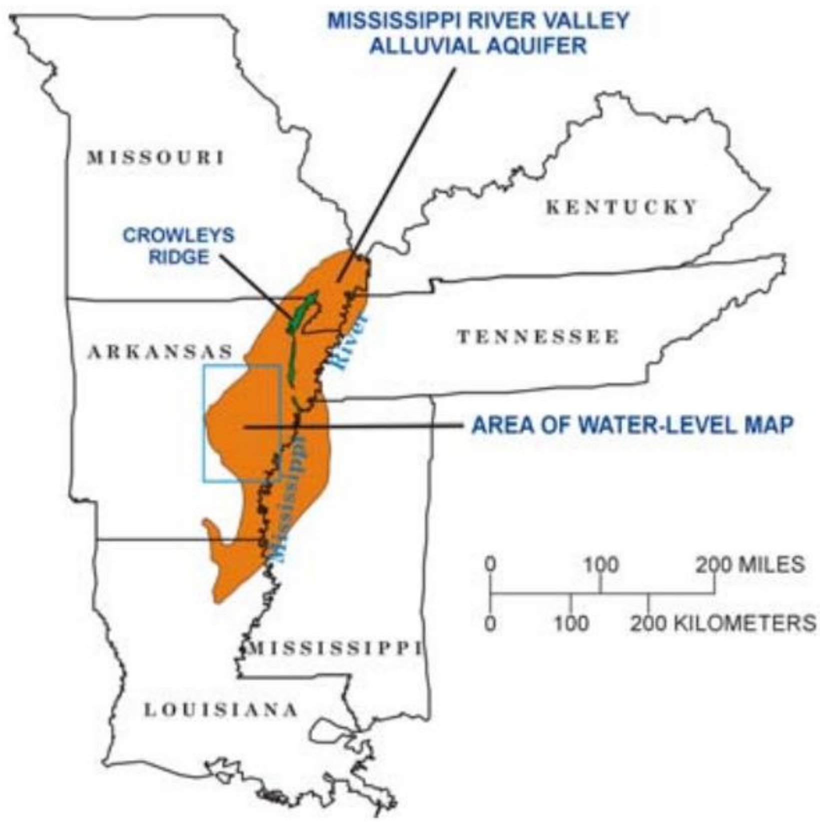

Figure 1 Location of Alluvial Aquifer*, Czarnecki et. al, 2002*

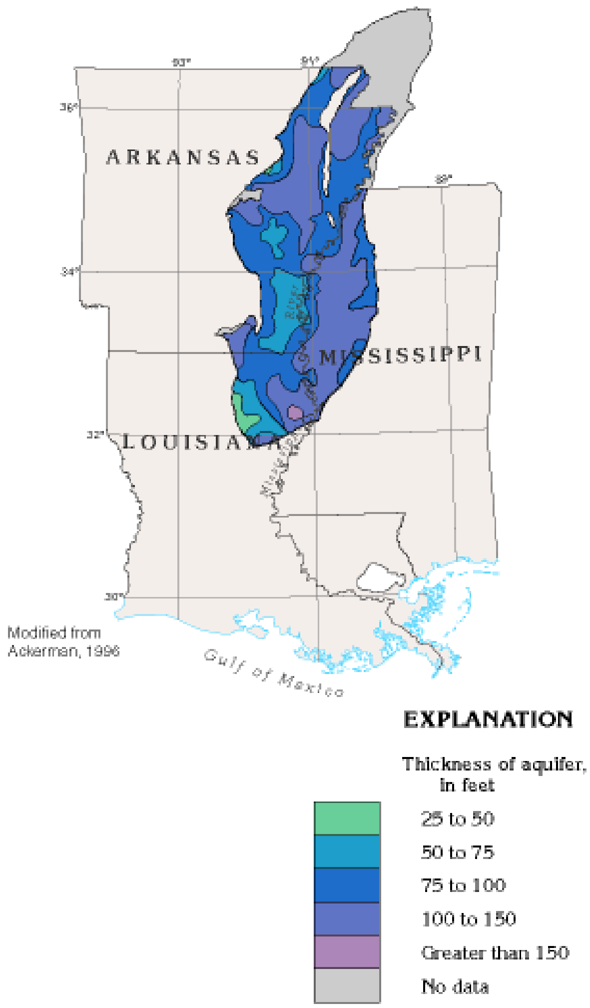

Figure 2 Mississippi River Valley Alluvial Aquifer*, USGS*

Despite the sparse and decreasing population throughout the entire Delta region due to "an increase in [agriculture] and manufacturing technology that has led to fewer jobs" (Gillette, 2019), groundwater depletion remains a staggering problem that is plaguing the area due to heavy irrigation practices and high-impact farming. According to a list created by *Claro*, an organization focused on clean energy and sustainable practices, the Mississippi Delta farmlands are home to the top five "most water intensive crops" (Sharma, n.d.). These five – soybean, cotton, rice, wheat, and corn – are also the world's cash crops, so there is a strong economic dependency on the production of these crops. According to the U.S. Department of Agriculture, gross cash farm income (GCFI),"annual income before expenses", is set to be $431 billion in

2020, a $98 billion increase from the GCFI in 2000 (adjusted for inflation). Further, as shown in Figure 3, of the $196.2 billion in cash crop receipts in 2018, “corn and soybeans accounted for 43.9 percent of the total” (*USDA*, 2020). These numbers show that these cash crops have a large economic impact, and that is the driving force behind their production. However, according to the *Union of Concerned Scientists* (2016), the rate at which farms in the United States operate is environmentally harmful and comes at a massive cost to taxpayers. The increasingly specialized nature of farms in exclusively producing these cash crops has been heavily, if not exclusively, driven by federal subsidies that “encourage farmers to keep growing … even when prices for these crops plummet.” Federal crop insurance premium subsidies create an economic reliance on commodity crops for farms that ensures that farmers will grow these crops despite demand or value drops. Because of this focus on commodity crops, farmers engage in irrigation practices that have adverse effects on the environment and water (*UCS*, 2016).

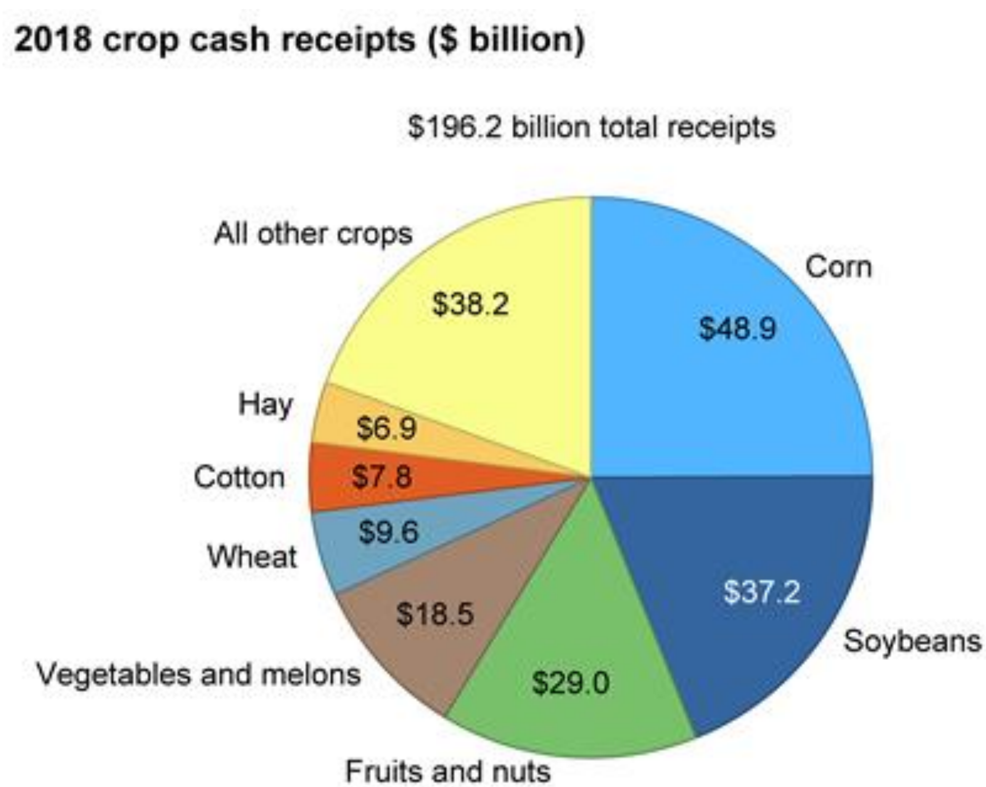

Figure 3 Cash Crop Receipts, USDA 2018

According to the 2013 Farm and Irrigation Survey conducted by the U.S. Department of Agriculture, one of the most heavily irrigated areas in the United States sits directly on the MRVAA (*USDA*, 2013). In the water resource region defined as the Lower Mississippi area, there were 8,013,711 acres irrigated, second only to the Missouri water resource region. On farms in the Lower Mississippi water resource region, there were 81,805 irrigation pumps documented while only 5,174 total acre-feet of reclaimed water were applied on farm acreage in the region. The total "on-farm energy expense for pumping irrigation water" in the region in 2013 also reached approximately $258,708,000, ranking 5th in highest expenses out of the twenty water resource regions in the United States (*USDA*, 2013).

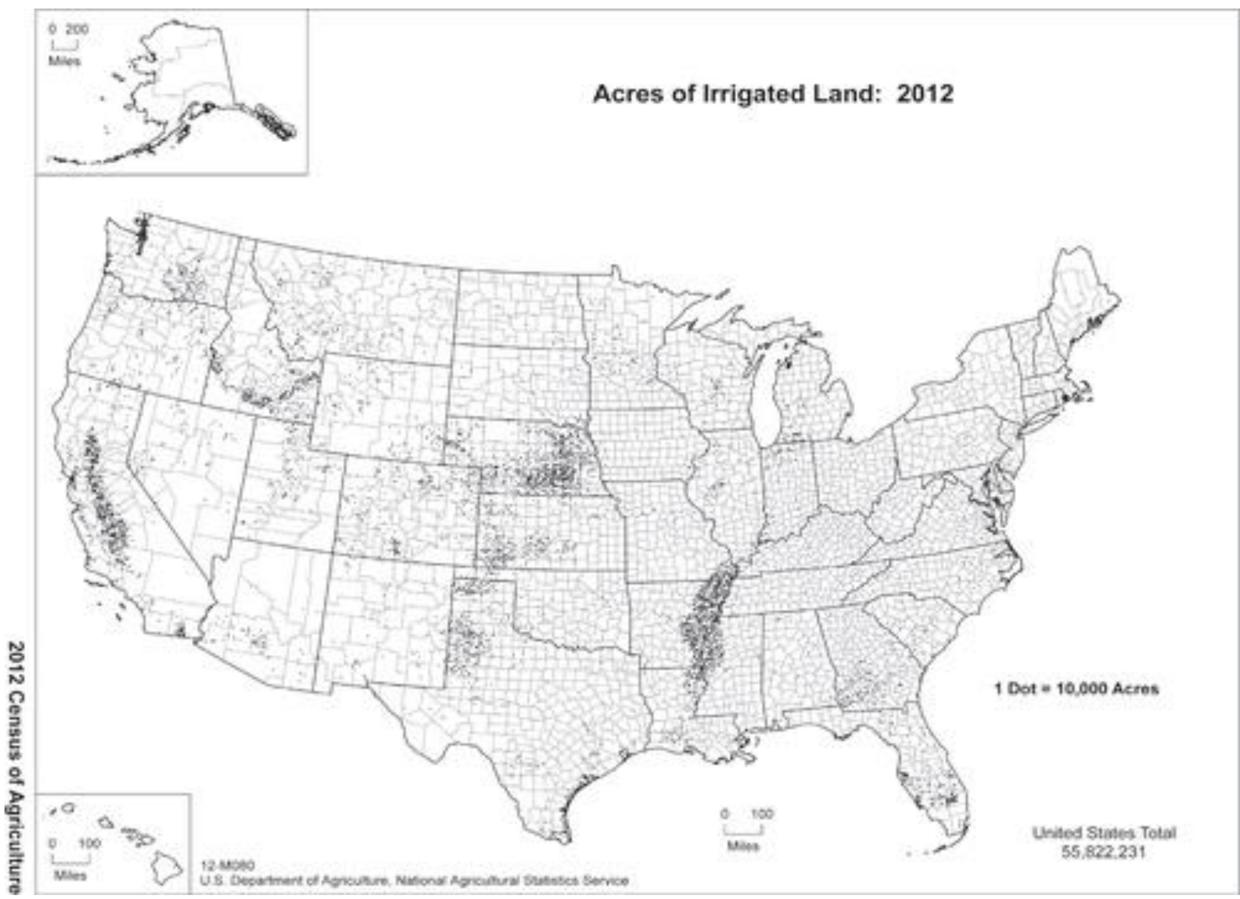

Figure 4 Acres of Irrigated Land: 2012, USDA 2013

While the MAP has always been heavily cultivated and relied on agribusiness, there has been an increase in the area irrigated due to both “economic imperatives” known as “risk avoidance” and irregular droughts that occur despite the fact that the “mean annual precipitation” in the area “exceeds [one meter]” (Vories et. al, 2010). To support this increase in irrigation, most irrigation systems rely on groundwater. In order to access groundwater for purposes of irrigation, water must be pressurized to reach the surface and be used (Vories et. al, 2010). Groundwater sources are deteriorating, though, and the increasing demand in groundwater for purposes of irrigation has led to aquifer declines. The demand is not unwarranted, though, due to the “commonly low available water holding capacities and root-limiting layers at shallow depths in many soils” in the area (Vories et. al, 2010). All of this contributes to a “non-sustainable trend in irrigation” that “makes it difficult for water resource managers to make sound decisions for future water sustainability” (Dyer, Mercer, Rigby, & Grimes, 2015). Further, as noted above, a geological limitation that contributes to insufficient aquifer rates is a dense, impermeable layer of clay in certain areas that decreases water’s ability to re-enter the groundwater system. This “limits rates of aquifer recharge” in the areas where the clay is at its thickest (Reba et. al, 2017).

In regards to agricultural management and irrigation, the alluvial aquifer is the “third most used aquifer in the United States” which has created a depletion cycle that is unsustainable for the MRVAA (Kenny et. Al, 2005). According to a study done on groundwater depletion by the *USGS*, the area known as the Mississippi embayment, marked as “12” on Figure 5, is a region that encompasses the MRVAA, but is not limited to the alluvial aquifer, and the area is now home to one of the most depleted groundwater systems in the United States (Konikow, 2013). According to Figure 5, the alluvial aquifer can be seen as one of the few aquifer regions highlighted in red that has groundwater depletion in a range of 150-400 cubic centimeters, a rate of depletion that is much greater than the rate of recharge (Diep, 2013). The Mississippi embayment area has seen a "total net volumetric groundwater depletion" of 182.0 km^3 from 1900-2008 with an "average volumetric rate of groundwater depletion" increasing from 1.176 km^3/yr in 1900-2000 to 8.048 km^3/yr in 2001-2008 (Konikow, 2013). The rate of depletion was studied using the "flow model" which uses "calculations of changes in volume of stored water made using a deterministic groundwater-flow model calibrated to long-term observations of heads and parameter estimates for the system" (Konikow, 2013). This increasing rate of depletion in the area that encompasses the MRVAA shows an apparent issue in aquifer use and depletion rates, and according a report done in the *New York Times,* this continued depletion of water resources can cause the land to "no longer support irrigation" because "when the groundwater runs out, it is gone for good" (Wines, 2013).

There is a prevalent "non-sustainable trend in irrigation" that "makes it difficult for water resource managers to make sound decisions for future water sustainability" according to a report done in the *Journal of Hydrology* (Dyer, Mercer, Rigby, & Grimes, 2015). This trend must come to an end in order to preserve regions like the Delta and ensure a sustainable path towards prosperity.

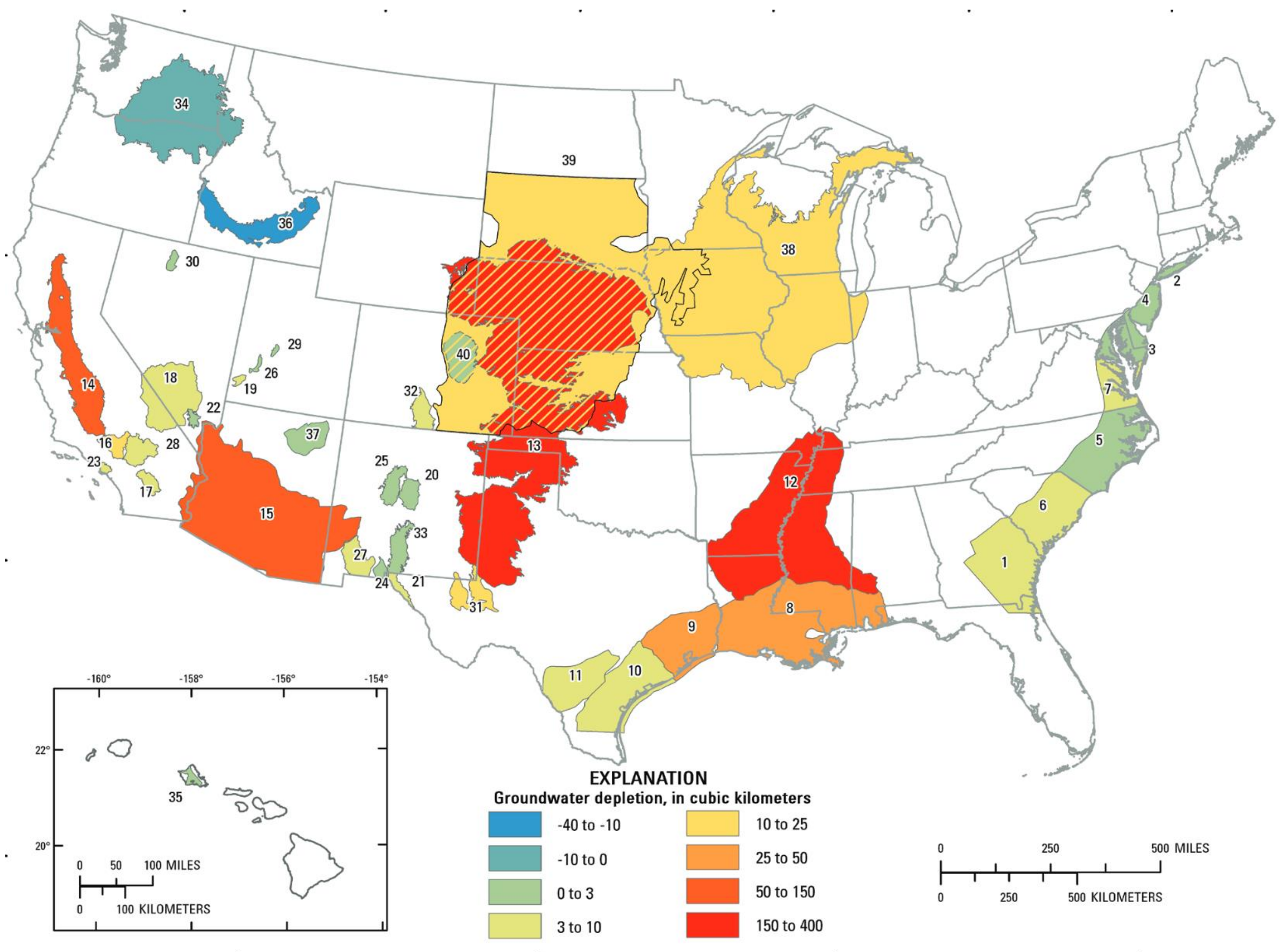

Figure 5 Groundwater Depletion in the U.S., Diep 2013

Purpose and Research Question

The water crisis in the Mississippi Delta is an issue that demands fast action and mobilization because the groundwater is swiftly being depleted and the soil is reaping the consequences. After decades of poor irrigation practices, the Delta is almost to a state of irreversibility. The excessive extraction from the Mississippi River Valley Alluvial Aquifer has made water levels drop dramatically to a point of scarcity.

The intent of this thesis is to examine irrigation alternatives that can provide sustainable outcomes for the agricultural production and water resource management in the Mississippi

Delta. This thesis aims to evaluate the groundwater status of the MRVAA and analyze the current irrigation methods used on commodity farms in the Mississippi Delta which have been shown to directly cause the depletion of the MRVAA. The increasing depletion rates in the region have led to a water resource scarcity crisis that must be assessed. The long-term impact these irrigation practices have on the aquifer system will also be researched and projected to offer a no-action scenario that will be juxtaposed with the outcomes of water-focused environmental policy alternatives. This leads to a vital question that will be at the crux of this paper: What are sustainable irrigation alternatives for the Mississippi Delta? To answer this question this thesis will first examine the history of irrigation and agribusiness in the United States followed by an outline of the methodology used for the research. Next, findings will be presented regarding alternative irrigation and water resource management practices. Then irrigation policy alternatives will be offered. Finally, policy recommendations will be made based on the findings. The final recommendations aim to be ones that will yield the highest water conservation while still maintaining prosperous economic profit. These will then be revealed as the path that needs to be taken by farmers, Delta municipalities, and the Mississippi state government.

Chapter 2: Background

This section will highlight necessary background information needed to understand the issue of water security in the Mississippi Delta. First, I will offer the evolution of agriculture in the United States by closely examining the nature of commodity crops, global demand, and farming subsidies. Next, the evolution of irrigation will be mapped out in order to offer a clear view on the history of irrigation and how modern irrigation methods were developed. Finally, I will connect the two by showing how agriculture is a driving force for irrigation.

Evolution of Agriculture

Roughly 12,000 years ago, there was a massive paradigm shift in how humans functioned within the environment in order to survive. Communities began to abandon the hunter-gather lifestyle, and they started to permanently settle lands for farming. This is known as the Neolithic Revolution, or the Agricultural Revolution (*History.Com*, 2018). "Then came the Middle Ages, a period marked by selective cross-breeding of plants and animals for optimal quality and a technique known as ridge and furrow farming, a plowing technique employing oxen (and later, horses) that inspired similar methods used today" (*Bayer US*, 2018). Following the Middle Ages, crop rotation methods were developed which allowed for different crops to be grown and harvested at varying times throughout the seasons in order to produce a more sustainable output year-round (*Bayer US*, 2018). In regards to North America, "mass agricultural practices were not particularly present … until the arrival of the European colonists" (Mason, n.d.). While most Native American societies practiced agriculture prior to the arrival of settlers, it was not as widespread and uniform throughout the tribes (Mason, n.d.). However, it did not take long after the first European settlements in North America were established for land allocation and agriculture to be a symbol of status. By as early as the 17th century, land was being granted to rich and prominent settlers, and in 1619, enslaved African people were forcefully brought to the America for the specific purpose of providing free labor for the growing farms. While “tobacco was the chief cash crop of the South” in the 18th century, the invention of the cotton gin in 1793 allowed for larger outputs while decreasing labor inputs (Bellis, 2020). Following the Industrial Revolution in the 1700s, “more people could work in urban industries as a result of agricultural productivity” since “crops … required fewer workers” and there was “better soil replenishment and improved livestock care” (*Bayer US*, 2018).

The United States government did not begin playing a role in the functions of agriculture until the establishment of the Agriculture Committee in the House of Representatives in 1820 and the Senate in 1825 (USDA, 2000). In May of 1862, the U.S. government expanded their involvement in agribusiness by establishing the United States Department of Agriculture (USDA, n.d.) and the Homestead Act which “encouraged Western migration by providing settlers 160 acres of public land” (Library of Congress, n.d.). Shortly after, the end of the Civil War marked the end of the enslavement of African Americans, and large farming plantations could no longer profit from the forced labor of enslaved people. However, the end of slavery did not mark the end of the exploitation of Black people in the country, as plantations quickly switched from relying on slave labor to relying on the sharecropping system (USDA, 2000). Under sharecropping, the landlord would allow a “tenant to use the land in exchange for a share of the crop,” which “encouraged tenants to work to produce the biggest harvest they could, and ensured they would remain tied to the land” (PBS, n.d.).

There was a massive and steady increase in the number of farms from 1850 to 1910 (USDA, 2020), and this is most likely due to the spike in prairie settlements that began to arise in the 1860s following the Homestead Act. There was an increase in migration to the prairies in the

1880s due to heavy rainfall and fertile lands, but unfortunately for the new settlers, the rain did not last and dry weather led to the demise of most crops. This ignited social movements for farmers who established the Granges and Farmers' Alliance "to address the problems faced by farmers," and farmers founded their own political party called the People's Party – or the Populists – who even ran their own candidate, James B. Weaver, for the 1892 presidential election (Library of Congress, n.d.). With the number of farms continuing to rise in the early 1900s, innovations in agriculture were being rapidly introduced, and there was a "widespread use of machinery, fertilizer, and pesticide technology" (*Bayer US*, 2018). This allowed for the continued diversification of farms in the 20th century, but "after peaking at 6.8 million farms in 1935, the number of U.S. farms fell sharply until leveling off in the early 1970s" (USDA, 2020). This decrease in the number of farms was marked by "growing productivity in agriculture and increased nonfarm employment opportunities" (USDA, 2020). Prior to this decline, though, "most U.S. farms were diversified, meaning they produced a variety of crops and animal species together on the same farm, in complementary ways" (Johns Hopkins, 2016). During the early 1900s, most of the labor on the farm was performed manually or by domesticated livestock. All of this rapidly changed in the early-mid 1900s due to the specialization of farms which allowed farmers to "focus all their knowledge, skills and equipment on one or two enterprises" (Johns Hopkins, 2016).

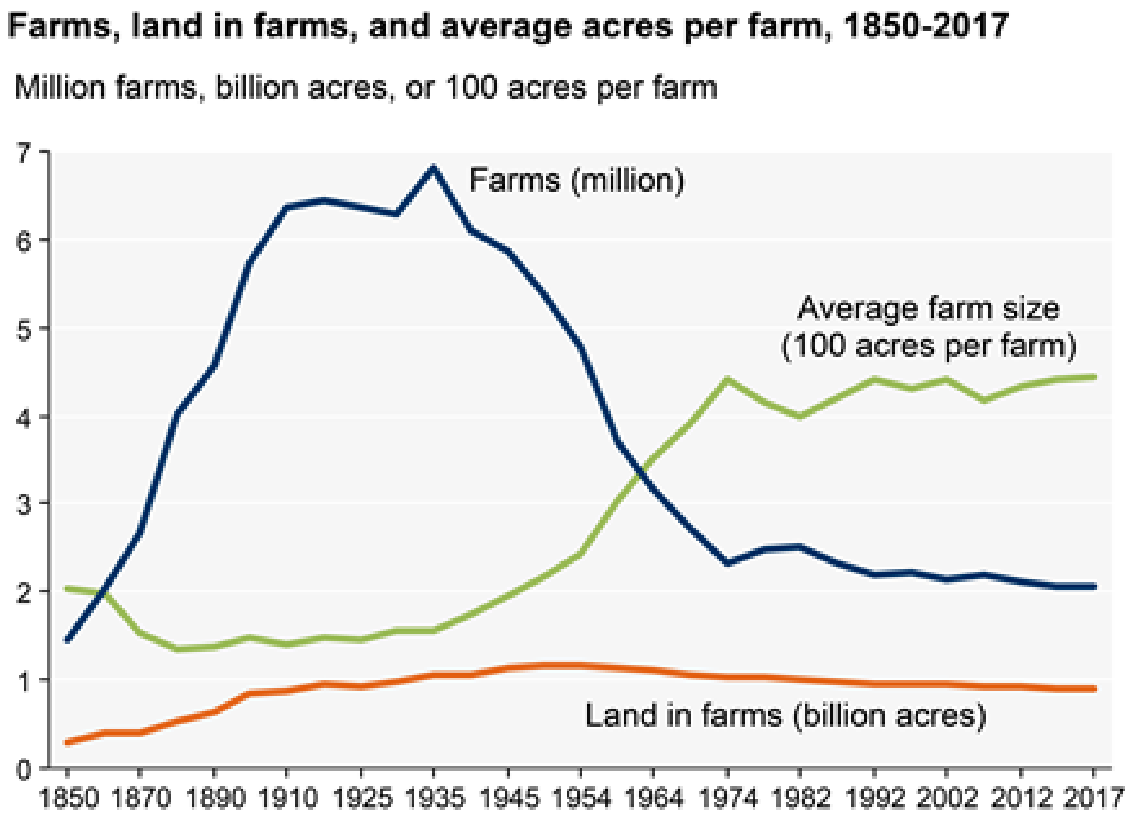

Figure 6 Farms, Land in Farms, and Average Acres per Farm, 1850-2017, USDA 2020

As shown in Figure 6, there is an observable inverse correlation between the number of farms in the United States and the average farm size. As there were fewer and fewer farms, the remaining farms became larger. As a result, "the remaining farms have more acreage, on average – about 444 acres in 2017 versus 155 acres in 1935" (USDA, 2020).

Changes in midpoint acreage for cropland, by State, 1982-2007

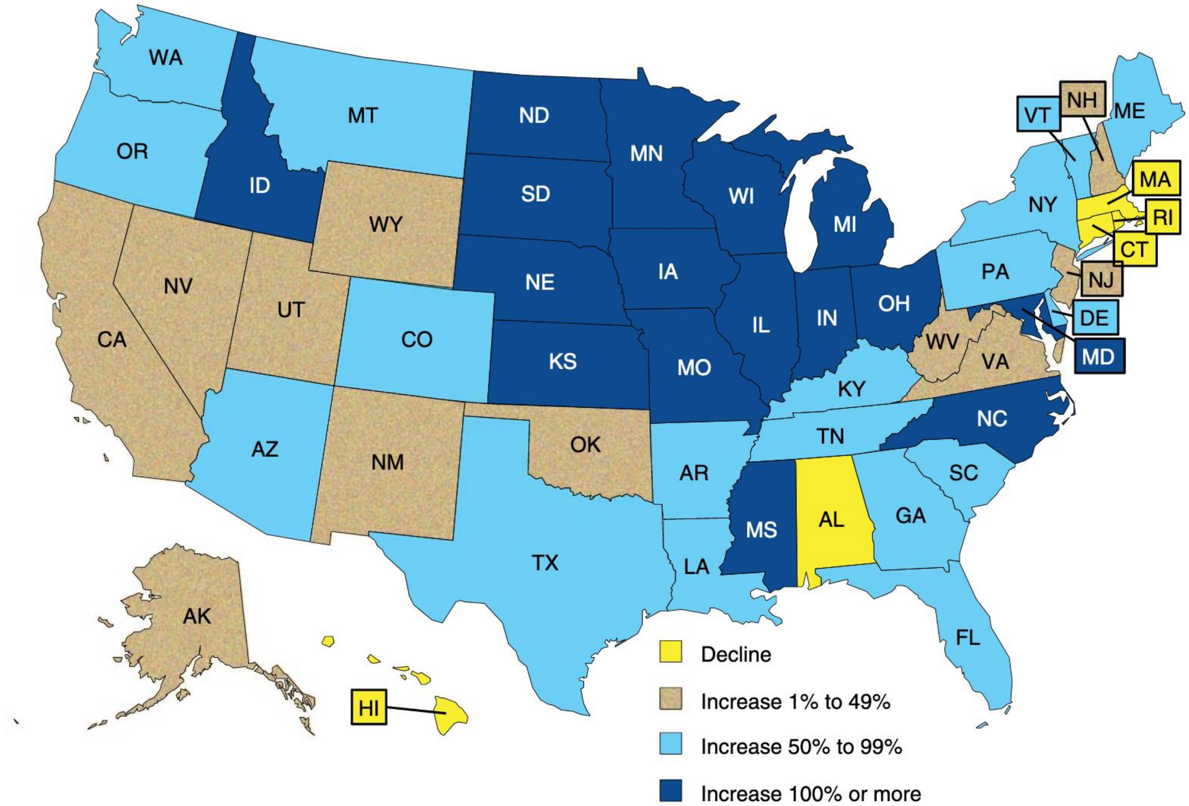

Figure 7 Changes in midpoint acreage for cropland by state 1982-2007, USDA 2013

In regards to the diversification of farms, the United States Department of Agriculture (USDA) issued a report in 2013 on the organization of crop farming in the U.S. The report used the "measure of midpoint acreage in which half of all cropland acres are on farms with more cropland than the midpoint, and half are on farms with less." It noted that the midpoint acreage "nearly doubled between 1982 to 2007, from 589 acres to 1,105." This occurred in the five major commodity crops: corn, cotton, rice, soybeans, and wheat. As shown in Figure 7, Mississippi can be seen as one of 16 states that saw a midpoint acreage increase of 100% or more due to the high volume of cropland in the state. The report also recorded the "shifts in agricultural specialization" as noted in Figure 8, and the "regional shifts in cropland" as noted in Figure 9.

Both of these figures (8 and 9) show the shifts that occur between 1950 and the early 2000s. (Macdonald, Corb, & Hopp, 2013).

(Note: the "Southern 6" includes the states Alabama, Arkansas, Georgia, Mississippi, North Carolina, and South Carolina.)

Shifts in agricultural specialization in selected States, 1950-2010

Item	1950	1980	2010
		Percent	
Crop share of region cash receipts			
Corn Belt 4	29	61	68
Corn and soybean share of crop receipts	63	89	93
Southern 6	72	51	40
Cotton and tobacco share of crop receipts	71	32	18
Share of U.S. livestock cash receipts			
Corn Belt 4	26	16	13
Southern 6	5	10	17
Share of U.S. crop cash receipts			
Corn Belt 4	13	23	22
Southern 6	18	10	9

Figure 8 Shifts in agricultural specialization in selected States, 1950-2010, USDA 2013

Regional shifts in cropland, 1950-2007

Item	1950	1982	2007
Total acres (millions)	383.2	382.8	334.9
	Percent of U.S. cropland used for crops		
Region:			
Northeast	5.5	3.6	3.3
Appalachian	6.8	5.0	5.1
Southeast	6.2	3.8	2.8
Delta	4.8	5.0	4.5
Lake States	10.6	10.4	10.8
Corn Belt	21.0	22.6	24.7
Northern Plains	22.2	24.5	25.2
Southern Plains	11.4	9.6	9.2
Mountain	7.0	9.8	9.2
Pacific	4.5	5.7	5.2
All	100.0	100.0	100.0

Figure 9 Regional shifts in cropland, 1950-2007, USDA 2013

According to Figure 9, "states in the Northeast, Appalachian, and Southeast regions held 18.5 percent of all cropland used for crops in 1950, and 11.2 percent in 2007, a 7.3 percentage point decline that in part reflected declines in cotton and tobacco acreage" (Macdonald, Corb, & Hopp, 2013). The shifts in cropland from 1950 to 2007 indicate the increasingly specialized nature of farming that occurred during that time as commodity crops became more and more prevalent. In the Southern 6 states, "crops accounted for 72 percent of cash receipts in 1950, and most of that reflected just two crops—cotton and tobacco. By 2010, crops fell to 40 percent of cash receipts as cotton and tobacco declined and poultry and hog production expanded" (Macdonald, Corb, & Hopp, 2013). This is due to the rise of monoculture, or the perpetual growing and harvesting of a singular type of crop every year, and industrial agriculture relies heavily on the outputs produced by monoculture farming as it allows for the boom of commodity crops (McKenzie, 2007). Monoculture and the specialization of farms led to a massive boom in agriculture output, and between 1948 and 2015 "total agricultural output nearly tripled" despite the fact that "the amount of labor and land (two major inputs) used in farming declined by about 75 percent and 24 percent, respectively." Further, the total "U.S. farm output grew by 170 percent" during this time with an average annual growth rate of 1.48 percent (Wang, Nehring, & Mosheim, 2018). As shown in Figure 10 below, total agricultural output continued to steadily increase from 1948 to 2017 due to "innovations in animal and crop genetics, chemicals, equipment, and farm organization." This occurred without a substantial increase in inputs which resulted in a decline in the "amount of land and labor used in farming" with a coinciding tripling of total farm output (USDA, 2020).

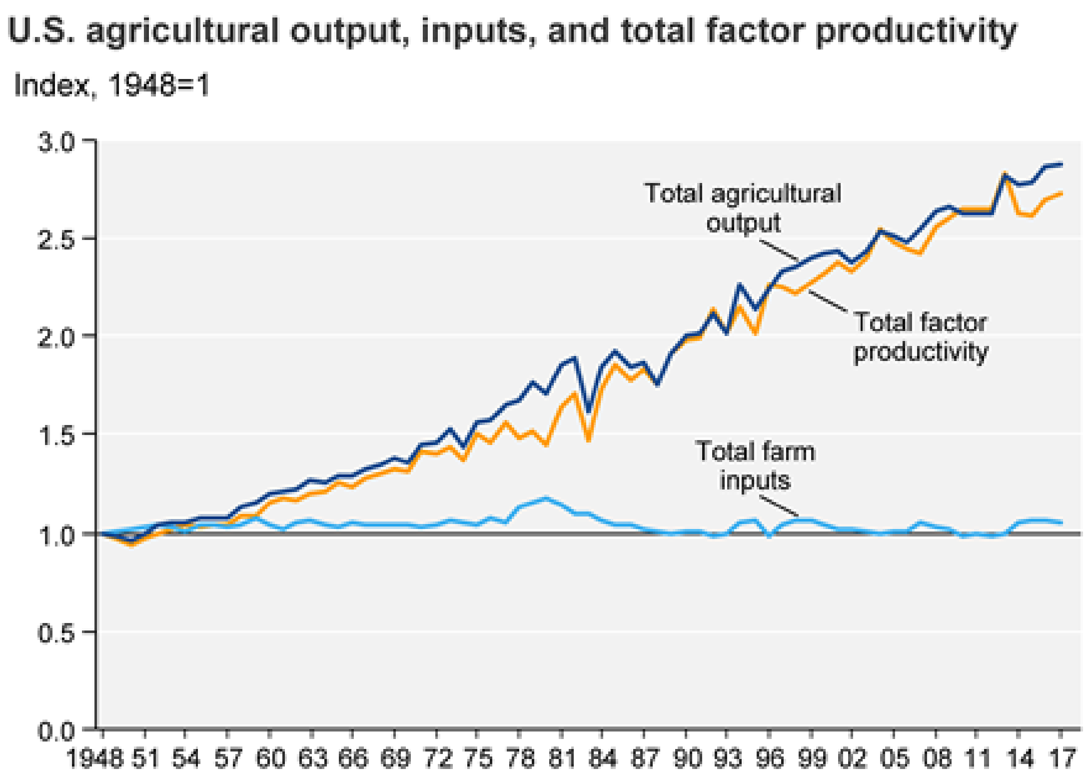

Figure 10 U.S. agricultural output, input, and total factor productivity, USDA 2020

Another major shift in the function of agriculture in the 20th century was the shift in farming inputs. As shown in Figure 11, labor and land inputs have greatly declined since 1948. In fact, from 1948 to 2015 there was a 75% decline in labor inputs as well as a 24% decline in land inputs. In contrast, “intermediate and capital inputs (excluding land) grew by 134 percent and 78 percent respectively” which “offset the negative impacts from reductions of labor and land.” Intermediate goods include “feed and seed, energy use, fertilizer and lime, pesticides, purchased services and other materials used.” This allowed for the “overall contribution of input growth to output growth to remain slightly positive” (Wang, Nehring, & Mosheim, 2018). As noted prior, the advent of various technological enhancements such as machinery and chemicals allowed for an increase in access to these resources by farmers, and the cost of these resources has declined over time in comparison to wages.

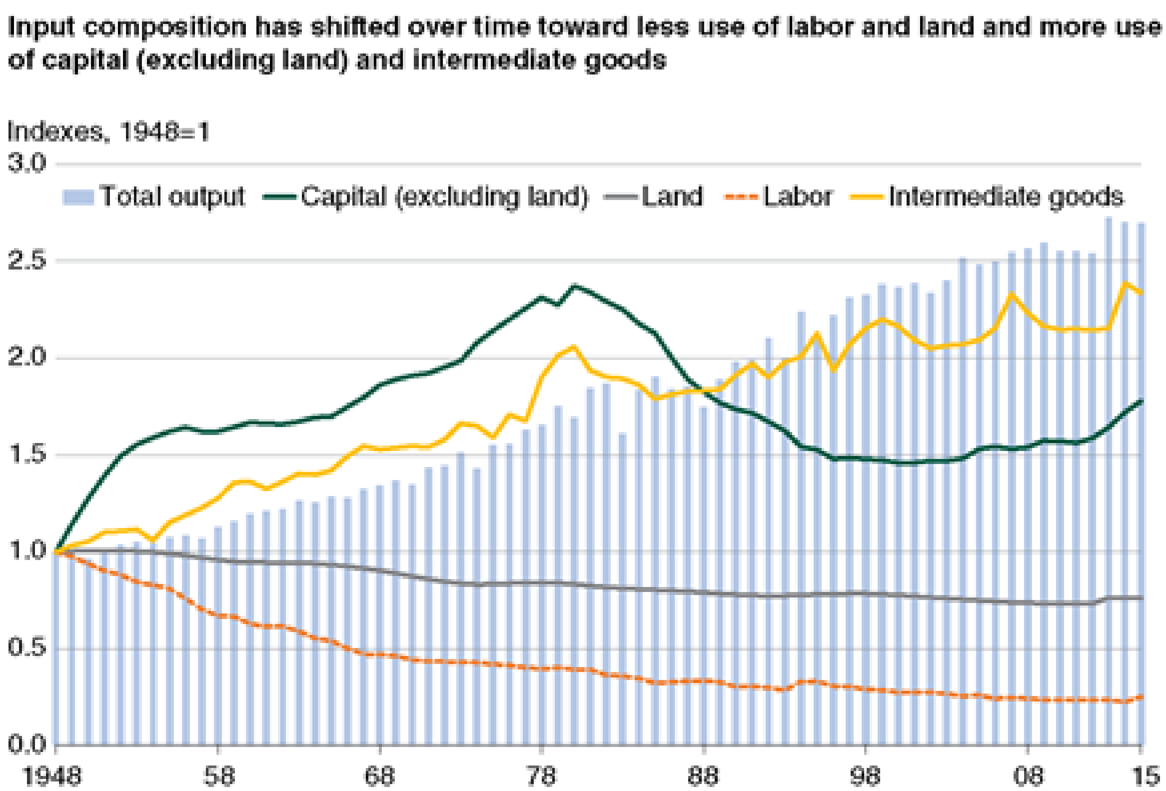

Figure 11 Input composition, USDA 2018

Concerning the income of farms, there has been a gradual increase in the gross cash farm income (GCFI) since 2000, and "since 2016, GCFI has been relatively stable. As shown in Figure 12, there was an observable increase in GCFI from 2000 to 2014 followed by a substantial drop from 2014 to 2016. In 2020, the GCFI is projected to be at $431 billion which is a $98 billion dollar increase from the GCFI of $333 billion in 2000 (adjusted for inflation) (USDA, 2020). This trend in GCFI impacts the value of production on farms by Economic Research Service (ERS) farm type. Namely, GCFI shows the massive discrepancy between large-scale family farms and small family farms. Family farms are defined as farms "where the majority of business is owned by the operator and individuals related to the operator," and non-family farms are defined as farms "where the principal operator and their relatives do not own a majority of the business" (USDA, 2020). According to Figure 13, family farms "of various types together accounted for nearly 98 percent of all U.S. farms in 2018." Small family farms, those with a GCFI less than $350,000, made up almost 90% of all farms in the United States while large-scale family farms, those with a GCFI of $1 million or more, made up almost 3% of all farms. Although the majority of farms in the U.S. are small family farms, they only accounted for about 21% of the value of production while large family farms accounted for nearly 46% of the value of production. (USDA, 2020). This is because agriculture in the U.S. is "dominated by the 3% of farms that are large or very large" with a large farm being described again as a farm yielding an income of $1 million or more. Currently there are approximately 2 million farms that are 97% family-owned (Amadeo, 2019).

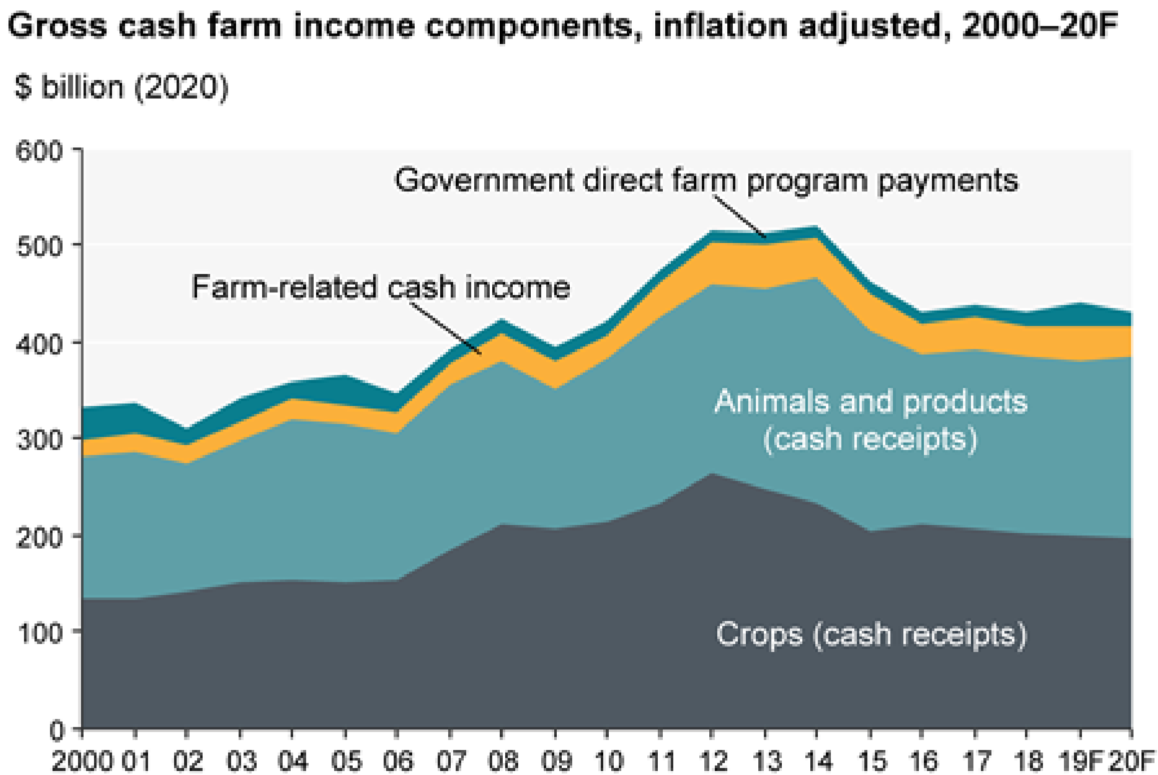

Figure 12 Gross cash farm income components, inflation adjusted, 2000-20F, USDA 2020

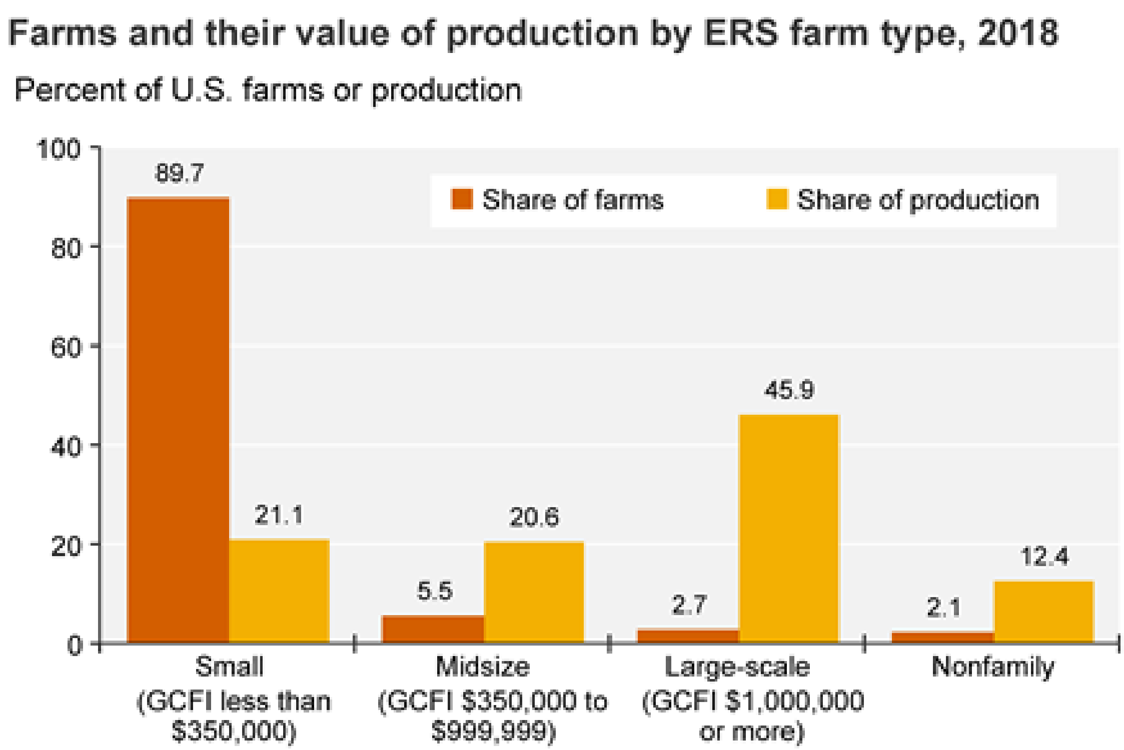

Figure 13 Farms and their value of production, 2018, USDA 2020

The evolution of agriculture in the United States has hinged on a massive economic dependency on agricultural production. This has impacted the personal income farmers and their families receive due to the increasingly commodity-based nature of modern day farming. According to the U.S. Department of Agriculture (USDA), the median household income for farming households exceeds the median household income for all households by $9,301. This is obviously impacted by the farm size as the income from farming increases as the size of the farm increases. The USDA also notes that "most households earn some income from off-farm employment" since over half of the farms in the country receive less than $10,000 in farm sales. This is significantly less than the amount earned by "typical household operating large-scale farms," which was $348,811 in 2018. It is noted that most of that recorded income on large-scale farms comes directly from farming (USDA, 2020).

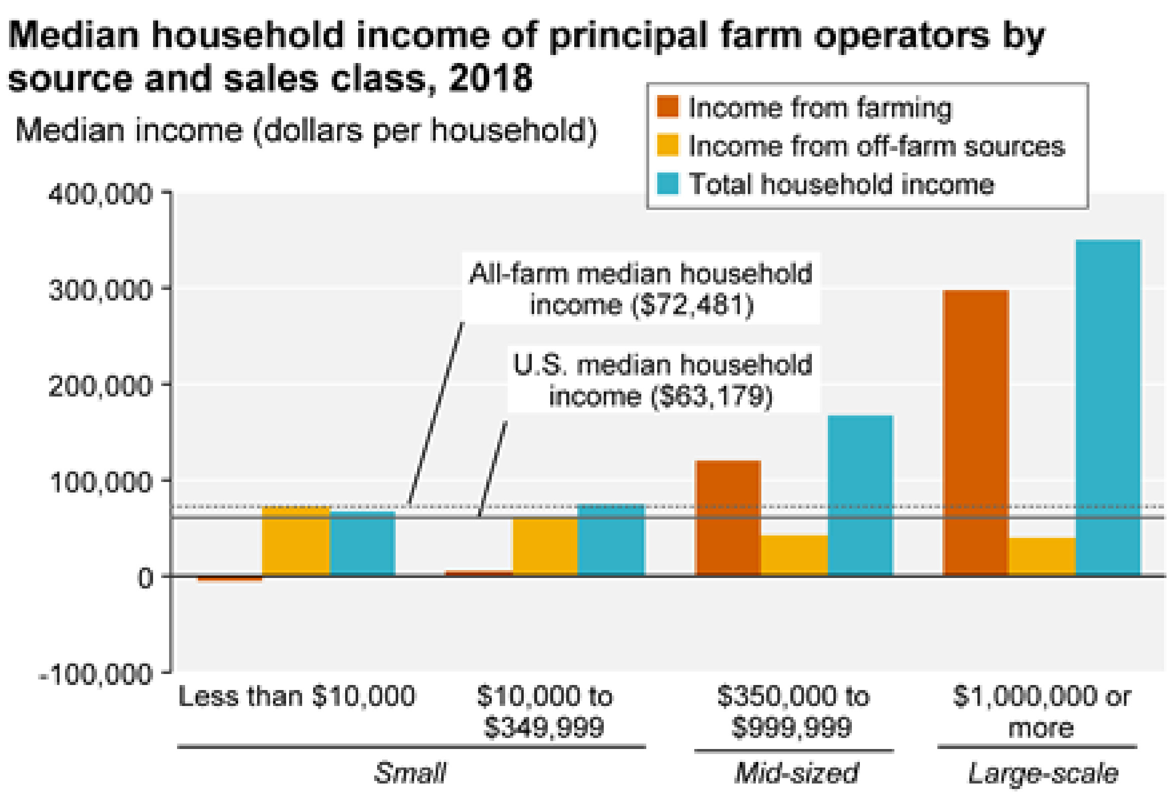

Figure 14 Median household income, 2018, USDA 2020

These large-scale farms are mostly, if not exclusively, dependent on the production of commodity crops, and the governmental protections in place allow for them to be “better equipped with volatile food prices” (Amadeo, 2019). The large-scale farming corporations are able to track the commodities market, which is an “auction where commodity traders bid on a price of hard assets.” This directly impacts food prices as the traders determine the prices through an open exchange, and the USDA supports the agricultural industry with “subsidies, loans, and technical assistance” (Amadeo, 2019). According to the Environmental Working Group (EWG), these federal subsidies account for a sizable allocation of funds. In 2017, “commodity subsidies in the United States totaled $7.2 billion.” The $7.2 billion was distributed among the states, and Mississippi ranked 18th out of the 50 states in receiving the highest percentage of that budget. In 2017, Mississippi received $162,310,416 in farming subsidies which was about 2.3% of the total farming subsidies. A timeline of the commodity subsidies received by Mississippi can be viewed below (Figure 15), and the total amount of subsidies received by Mississippi from 1995-2019 was about $7.1 billion (Amadeo, 2019).

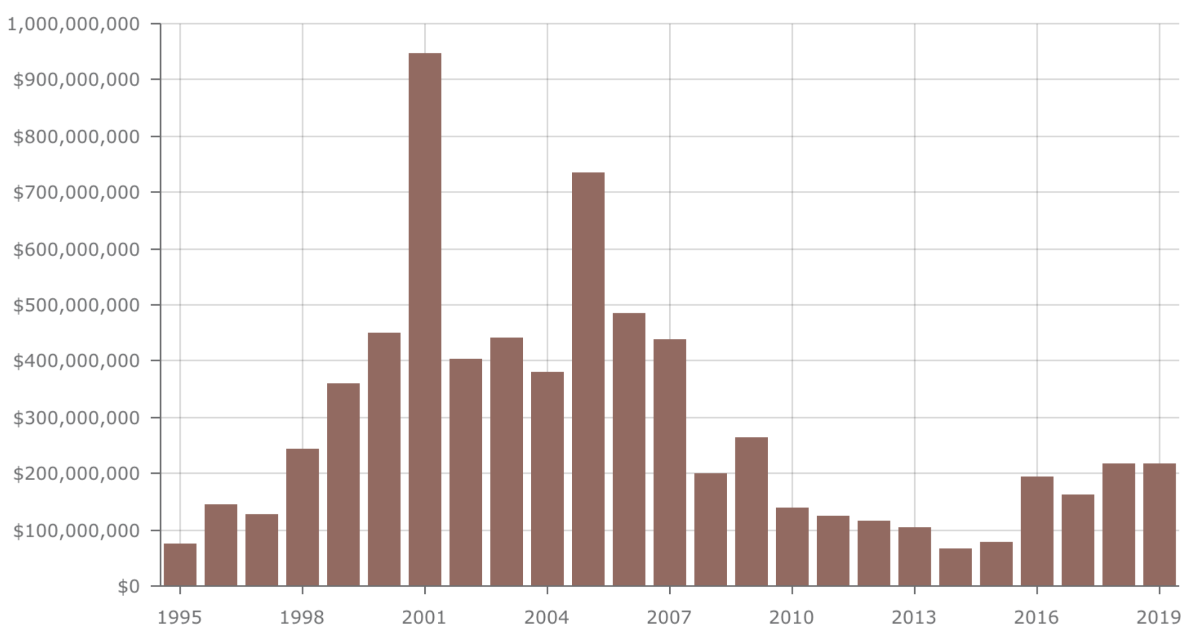

Figure 15 Commodity Subsidies Received by MS, 1995-2019, Amadeo 2019

Mississippi is an important agricultural producer in the United States and ranks in the top 20 for its production of 15 different commodities. There are about 42,400 farms that cover approximately 11.2 million acres in the state. Of the almost 50,000 farms, “broilers, chickens raised for meat, are the top commodity in the state” (Patterson, Tancey, & Fuller, 2016, para. 1).

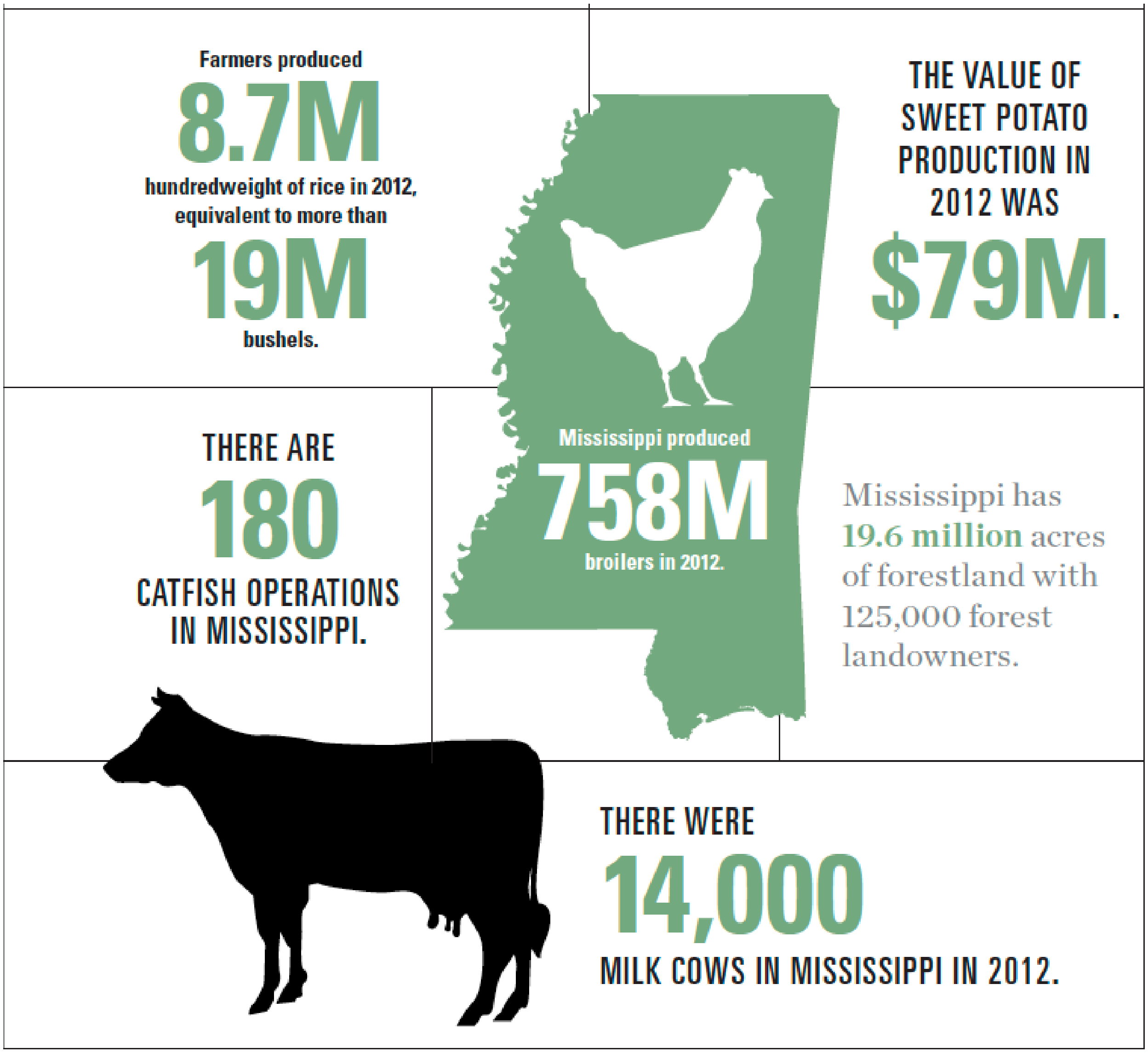

Figure 16 Mississippi Agricultural Production in 2012, Farm Flavor 2016

In regards to the Mississippi Delta region, it was not cultivated by European settlers until the nineteenth century due the swamp lands that inhabited the area. North-eastern and eastern farmers began to move to the Delta in the early 1800s to escape the overworked farm lands they previously worked on. It was within the nineteenth century that agriculture began to grow into a booming, “labor-intensive plantation-system based on African slave labor” (Snipes et. al, 2005, pg. 3). Cotton was the primary cash crop in the region until the Civil War, which dismantled slavery in the United States, but agriculture production continued in the Delta with the sharecropping and tenant labor systems.

One factor that stymied the full development of Delta lands for agriculture was the “annual flooding of the Mississippi River,” which “hindered access to its fertile soils” (Snipes et. al, 2005, pg. 3). “Intensive development of…agricultural lands was not possible until the early 20th century, when systems of levees were constructed to control flooding from the Mississippi River” (Snipes et. al, 2005, pg. 3). Following the Great Flood of 1927, the Mississippi River and Tributaries Project was created in 1928 in order to establish advanced and preventative flood control methods in the lower Mississippi region. The project was created to “provide enhanced protection from floods, while maintaining a mutually compatible and efficient Mississippi River channel for navigation” (Mississippi River Commission, 2007, pg. 2). The projected included the establishment of levee systems which block flooding in alluvial land, floodways to “divert excess flows,” reservoirs, and pumping stations (Mississippi River Commission, 2007, pg. 2). There was a request for a reassessment of the project in 1954-1955 by the Senate Committee on Public Works, and the request was met by a “cooperative effort by the Weather Bureau, the U.S. Army Corp of Engineers, and the Mississippi River Commission” (Mississippi River Commission, 2007, pg. 3). This new project design accounted for and included data on the “sequence, severity, and distribution of past major storms,” and it also studied “35 different hypothetical combinations of actual storms that produced significant amounts of precipitation and runoff” (Mississippi River Commission, 2007, pg. 3). As shown in Figure 17, this improved project design account for water flow, movement, and characteristics during storm surges with the new flood control systems in place.

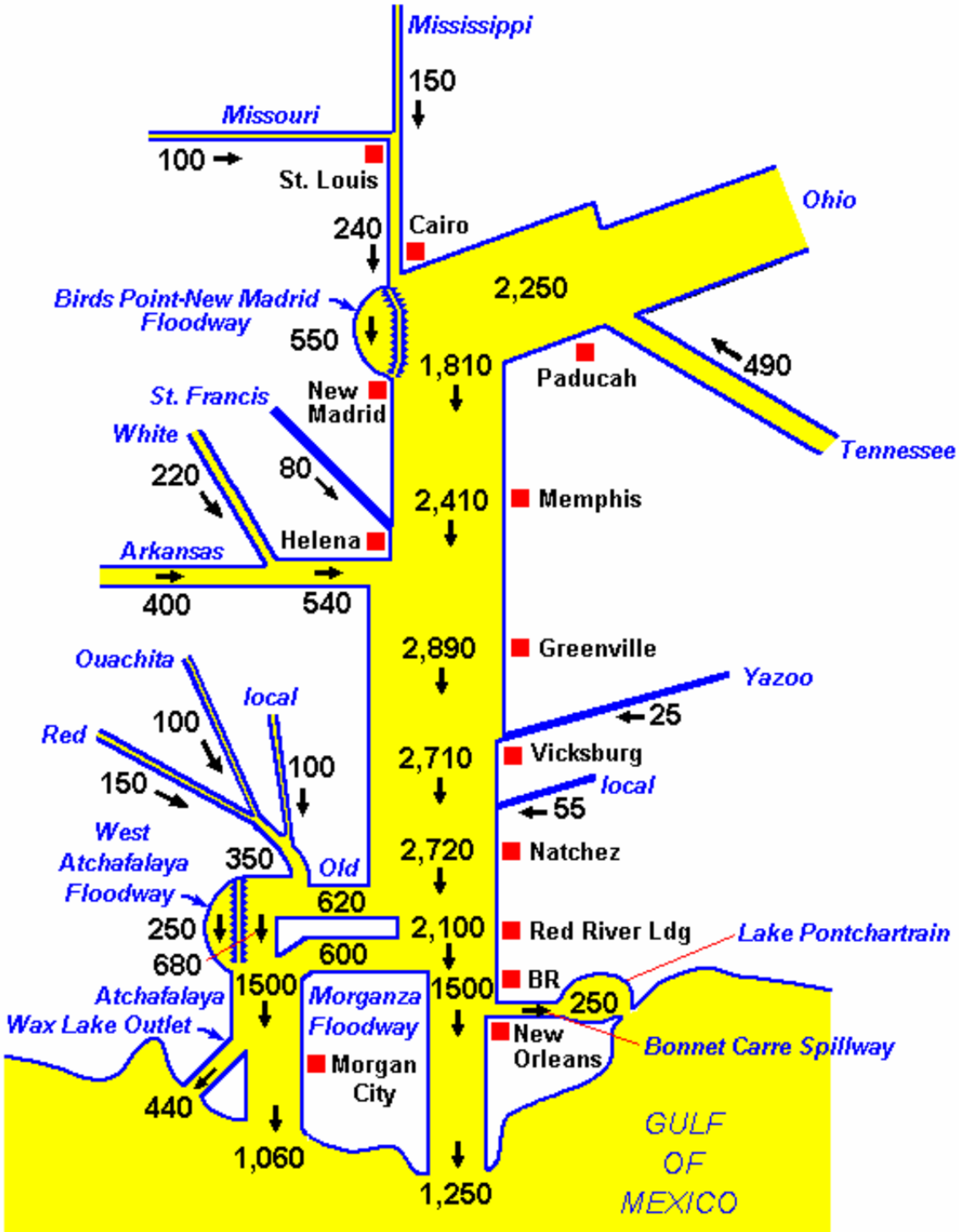

Figure 17 The Project Design Flood, Mississippi River Commission 2007

The 1954-1955 project design remains the current system in place after a flood in 1973 proved the project design flood to be adequate and successful. The flood peak discharges remain the same, and the current project design flood, which is regulated by reservoirs, “is about 25 percent greater than the devastating 1927 flood" (Mississippi River Commission, 2007, pg. 5). This project allowed for the expansion and evolution of agriculture in the Mississippi Delta. As new farming technologies and innovations arose, agriculture in the Delta "evolved into large, mechanized, low-labor, and capital intensive farms" with an "increase in diversification of commodities from cotton to … catfish, rice, corn, and soybean" (Snipes et. al, 2005, pg. 3). The total value of all the harvested commodity crops in the Mississippi Delta (cotton, catfish, soybeans, rice, and corn) equaled $1,070,635,000 in 2002, with cotton yielding the most value (Snipes et. al, 2005).

Evolution of Irrigation

Old ruins of Native irrigation systems discovered in the Southwestern United States date irrigation to as far back as 1200 B.C.E. There have been canals and systems found that indicated rather large-scale irrigation methods, and "a network of canals [that] filtered into … fields" spanning over 100 acres has been discovered (Voss Land & Tree, 2019, para. 5). Other complex irrigation canals were discovered in the Southwest, specifically those of the Hohokam community. This community dated to "as late as the mid-1400s" and "developed an extensive grid of canals to feed water from the river sources into their fields" (Voss Land & Tree, 2019, para. 9). However, there was not much documented evidence of irrigation until the Spanish exploration. One of the first European expeditions in what is presently known as the United States of America was Spanish explorer Coronado who traveled alongside an army of "Spanish horsemen and native footmen" (Hess, 1912, pg. 808). While there is no specific mention of irrigation systems in Coronado's writings, he does write of Native American communities who had access to great harvests and an abundance of crops. These notations by Coronado account for the "earliest documentary evidence of the practice of irrigation within the … United States"

(Hess, 1912, pg. 809). Nearly four centuries later, the first irrigation ditch was created to use Californian stream waters by the "Mission fathers of the Jesuit and Franciscan orders" (Hess, 1912, pg. 810). Other Spanish uses of irrigation in the West included only small and elementary practices, and the real boom of irrigation did not come until the establishment of Anglo-Saxon settlers in the West.

Modern irrigation in the United States began in Salt Lake City, Utah in 1849 when Anglo-Saxon settlers irrigated the land to allow for the waters of City Creek to water their potato farms (Mead, 1899). Irrigation and irrigated land stayed rather stagnant throughout the late 1800s and early 1900s, but it began to rapidly expand in the 1940s due to new technologies which increased "ground and surface water availability" (Edwards & Smith, 2018, para. 3). Especially in regions defined as "humid" – referring to all land east of the 98th meridian – irrigation did not even develop until the mid-twentieth century because of the regular precipitation in the region. Those regions were prone to short-term droughts, though, which made the soil unsuitable for crops. Irrigation systems were therefore created in these humid regions to combat the periods of drought and to increase crop quality. Within the decade of 1940-1950, total irrigated lands in the United States nearly tripled due to a culmination of factors such as the droughts in the 1930s, increased farming prices created during World War II, "improved transportation, … improved irrigation equipment, … and greater availability of electricity in rural areas" (Clyde, 1952, pg. 25). Namely, the large shift in irrigation began when the company Rainbird released its first impact sprinkler in 1933, "ushering in the era of efficient modern irrigation" (*Rainbird.com,* n.d.).

While the main goal of irrigation – to divert and/or withdraw water from "natural stream flow, aquifers, and springs" – has remained the same, the methods by which this is done have evolved. Modern irrigation, according to the U.S. Geological Survey, involved the storing of withdrawn water in “open reservoirs that also serve other uses” including “recreation, flood protection, flow regulation, and hydropower generation” (USGS, n.d, para. 4). Groundwater irrigation developed to provide access to better quality water when surface water is unavailable either economically or physically. However, the “costs associated with locating aquifers, drilling wells, and pumping” have the possibility to make groundwater more expensive. (USGS, n.d, para. 4). A diagram of irrigation water use can be seen in Figure 18.

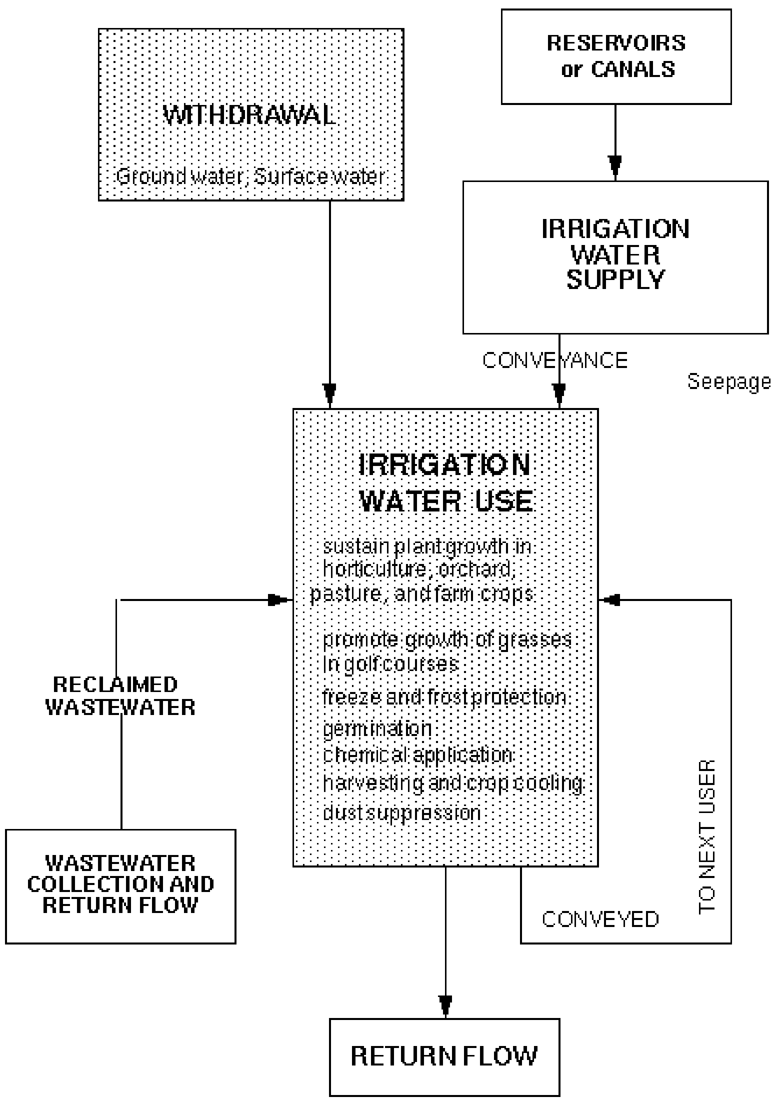

Figure 18 Irrigation Water Use, USGS

In regards to present day irrigation use, the 2012 Farm and Ranch Irrigation Survey a survey released every five years since 2003 by the USDA – noted that there are 55,822,231 acres of irrigation land in the United States with 1,651,978 of those being in Mississippi. (USDA, 2013). There was an observed 53% increase in irrigated acres in Mississippi, as shown by Figure 19. There was also an observable change in irrigated acreage in the Mississippi Delta region specifically. From 2002 to 2013, there was a continual increase in irrigated acres, as shown in Figures 20 and 21.

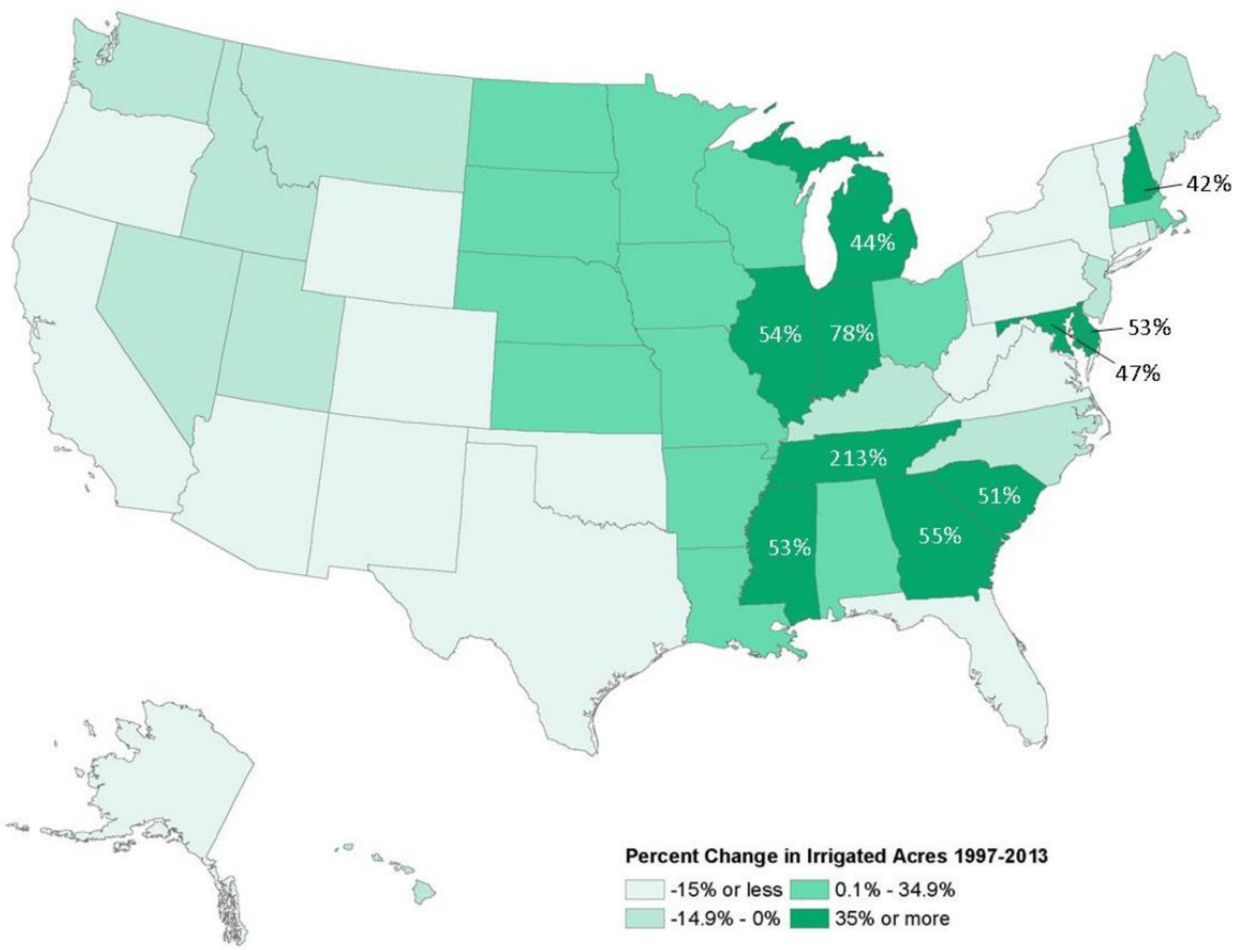

Figure 19 Change in Irrigated Acres, USDA 2013

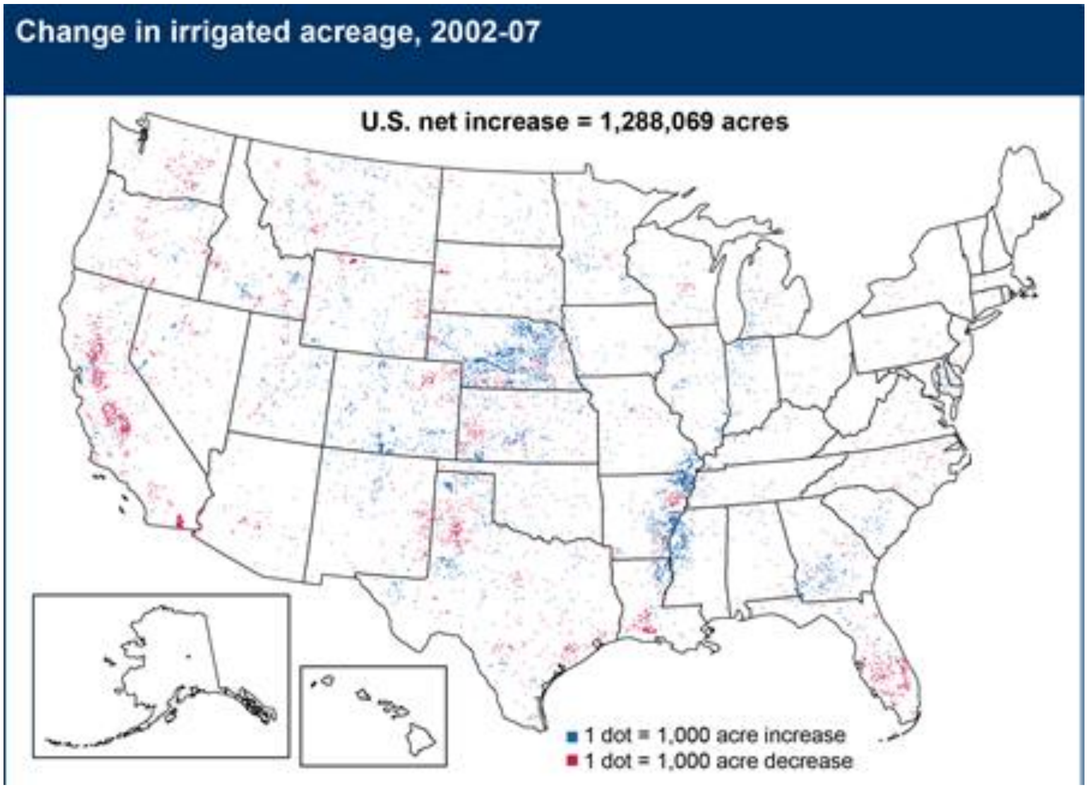

Figure 20 Change in Irrigated Acreage, 2002-2007, USDA 2013

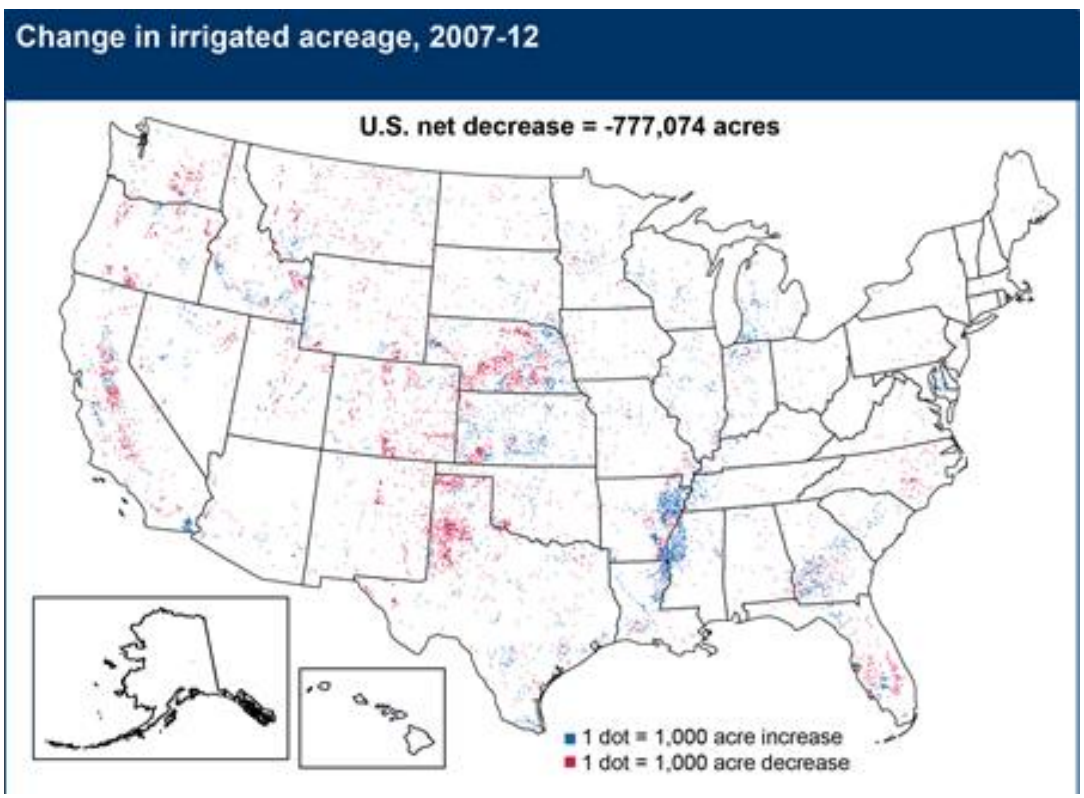

Figure 21 Change in Irrigated Acreage, 2007-2012, USDA 2013

Mississippi is one of the most irrigated states in the United States, and is leading in the top states with the most irrigated lands. The USDA notes in their 2012 survey on irrigation and water use that "while irrigated production is largely concentrated in the arid Western states," Mississippi is one of the three Eastern states in the top thirteen most irrigated states. It is joined by Florida and Arkansas (USDA, 2012). Of all of the irrigated land in the U.S., the thirteen "leading irrigation States in 2012 accounted for 78.8 percent of all irrigated acres" (USDA, 2012). Figure 22 is a graph of these thirteen irrigated states. As of 2012, Mississippi accounts for 3% of the irrigated acres in the country.

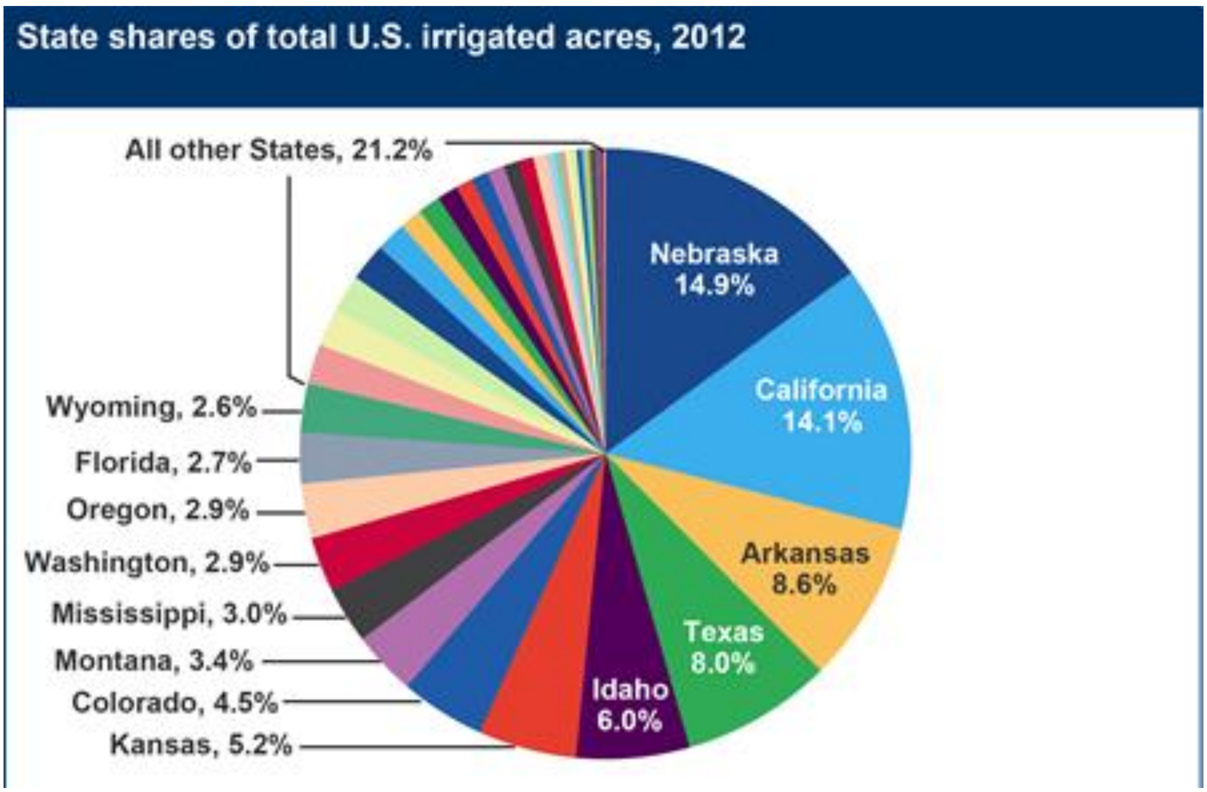

Figure 22 State shares of total U.S. irrigated acres, USDA 2012

In the Eastern states, soybeans are the most prominent irrigated crop representing about 30% of the irrigated acres. They are closely followed by corn (for grain) at 24.3%. The following three most prominent irrigated crops are vegetables, rice, and cotton, respectively. A modified graph of the distribution of irrigated acres by crop has been provided as Figure 23, and it has been modified to include only the 31 Eastern States (USDA, 2012). While Mississippi is not leading in vegetable production, it is a leading producer in corn, soybean, rice, and cotton, all of which are in the top 5.

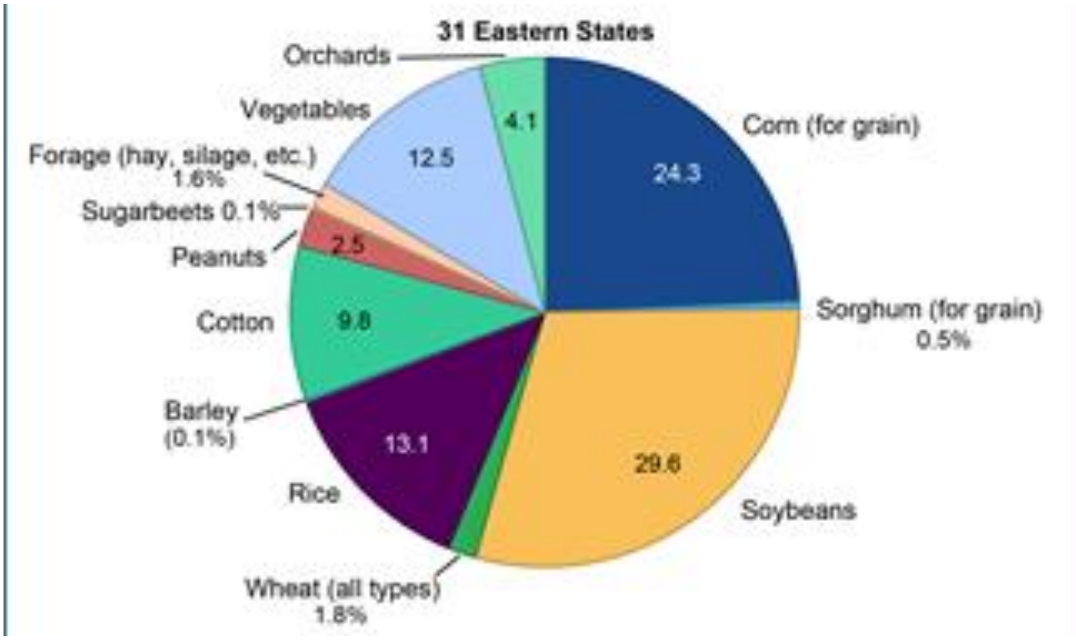

Figure 23 Distribution of irrigated acres by crop, 2012, USDA 2012

Agriculture as a Driving Force for Irrigation

Since the advent of North American irrigation with the Hohokam community in around the 1400s, irrigation has served a clear purpose: agriculture. Even to the present day, agriculture remains the primary driving force for irrigation, and is the "largest consumer of Earth's available freshwater," as about "70% of 'blue water' withdrawals from watercourses and groundwater are for agricultural usage" (Global Agriculture, n.d., para. 3). This is three times more water usage than 50 years ago, and it is estimated that "by 2020, the global water demand of agriculture is estimated to increase by a further 19% due to irrigation needs" (Global Agriculture, n.d., para. 3).

According to *Global Agriculture*, “blue water” is defined as freshwater from rivers, lakes, groundwater, and glaciers, and it is noted that only “part of the rainfall feeds this freshwater supply” (Global Agriculture, n.d., para. 2). This is because the majority of rainfall is either directly reevaporated or absorbed by plants. Rainfall that does make it to the groundwater and freshwater systems is called “green water,” and it accounts for around 55% to 80% of the freshwater “depending on the region of world” and “local wood density” (Global Agriculture, n.d., para. 2). Figure 24 explains the distinction between “green water” and “blue water” while also noting water use. This figure shows that globally, over 5% of freshwater, mainly green water, is used in agriculture alone, not accounting for grazing lands for livestock (Global Agriculture, n.d.).

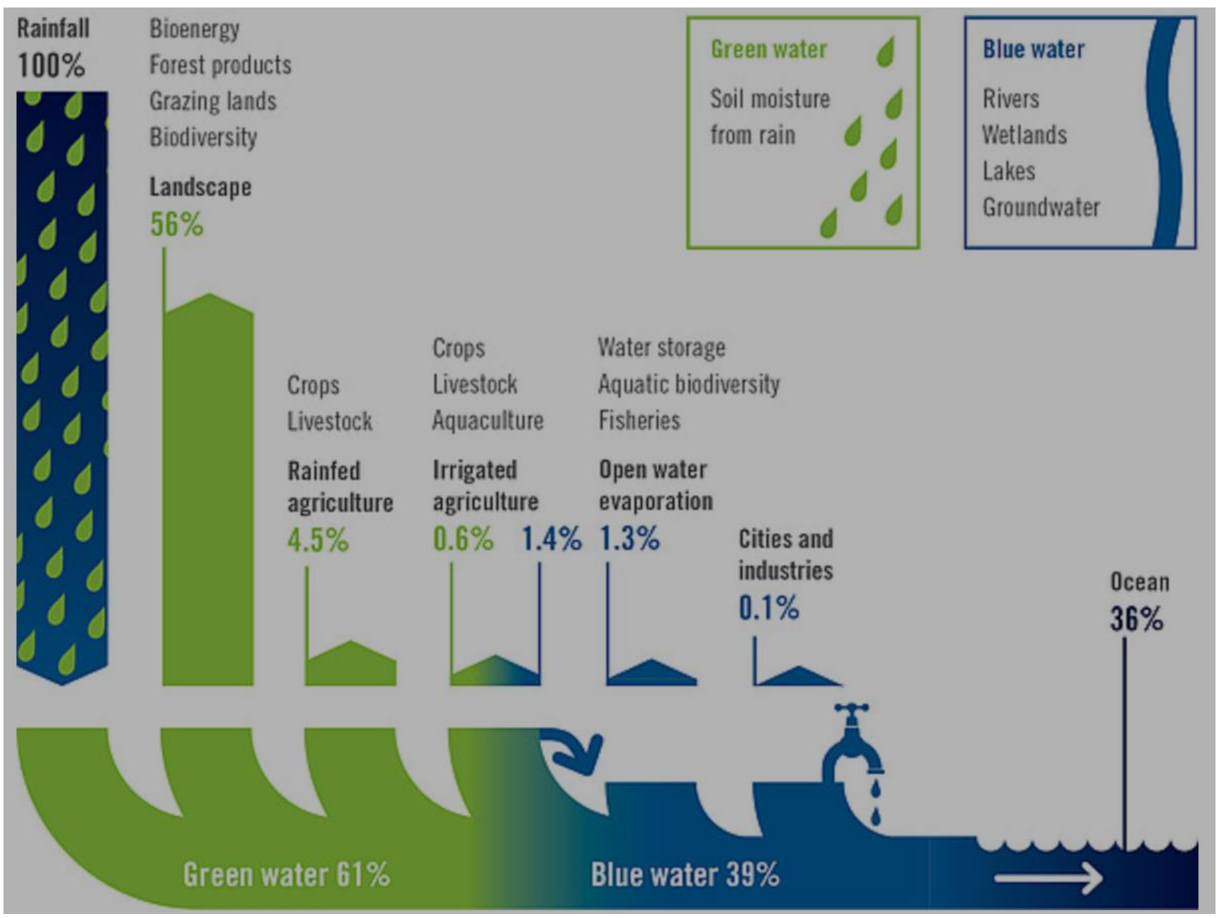

Figure 24 Green and Blue Water, Global Agriculture

In terms of global competition for water used for agriculture, it is estimated that "approximately 40% of the world's food is currently cultivated in artificially irrigated areas" that have been mainly fueled by "huge investments in additional irrigation systems between the 1960s and 1980s" (Global Agriculture, n.d., para. 3). Figure 25 shows the global water use for agricultural, industrial, and municipal purposes. North America is shown to use about 40% of its water sources for agricultural purposes.

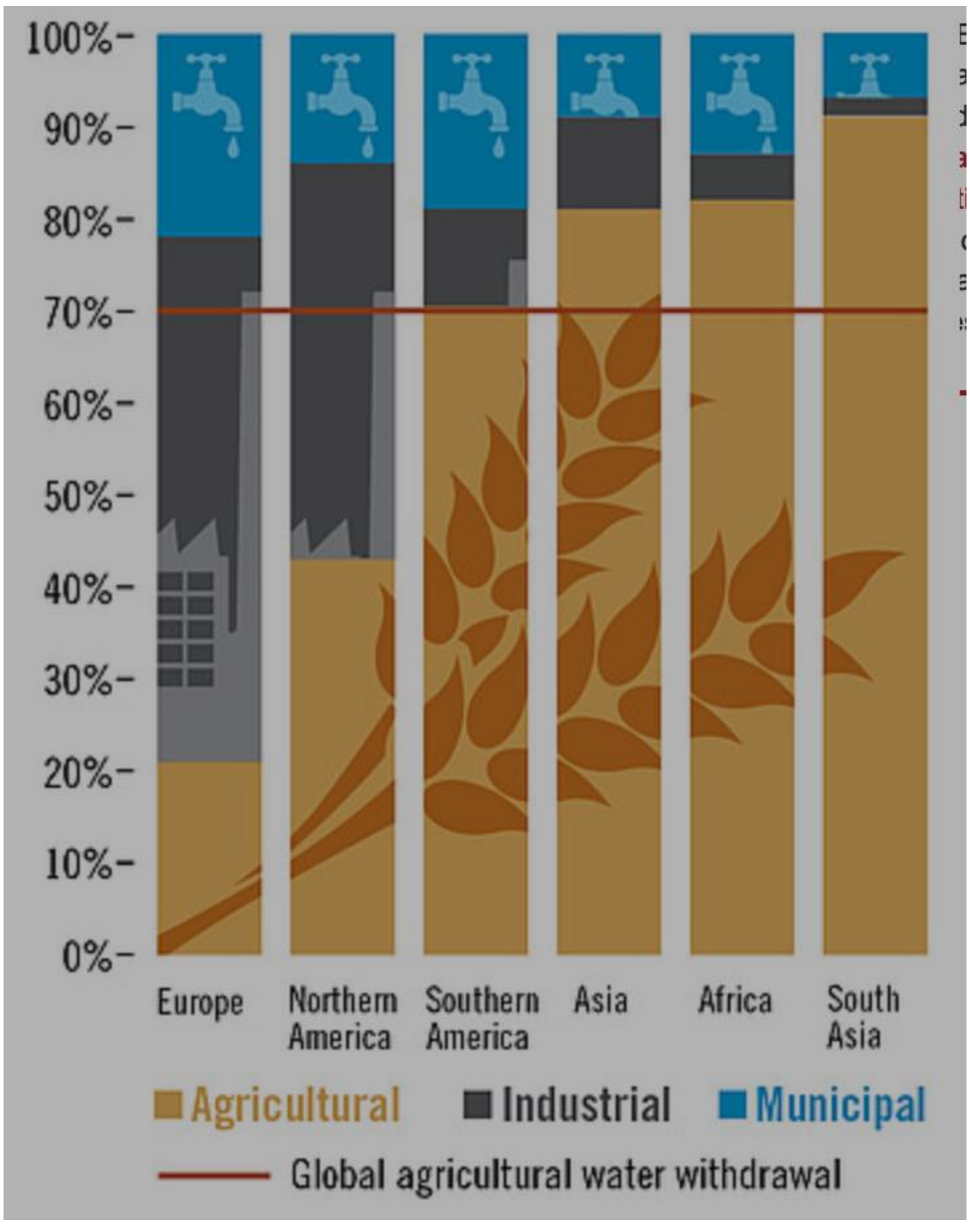

Figure 25 Global Water Use, Global Agriculture

Specifically in the United States, crops from irrigated farms show to have a high market value. Of the top 13 states with the most irrigated acres, 10 of those states had a 60% or above percent of their market value come from crops sold from irrigated farms. Mississippi was in the second bracket, with anywhere from 60% to 85.9% of its market value coming from crops from irrigated farms (USDA, 2012). Figure 26 provides a map for this. With irrigation, though, the U.S. Geological Survey notes that "water used for irrigation" is "only about one-half reusable" because the "rest is lost by evaporation into the air, evapotranspiration from plants, or is lost in transit" (USGS, n.d., para. 5).

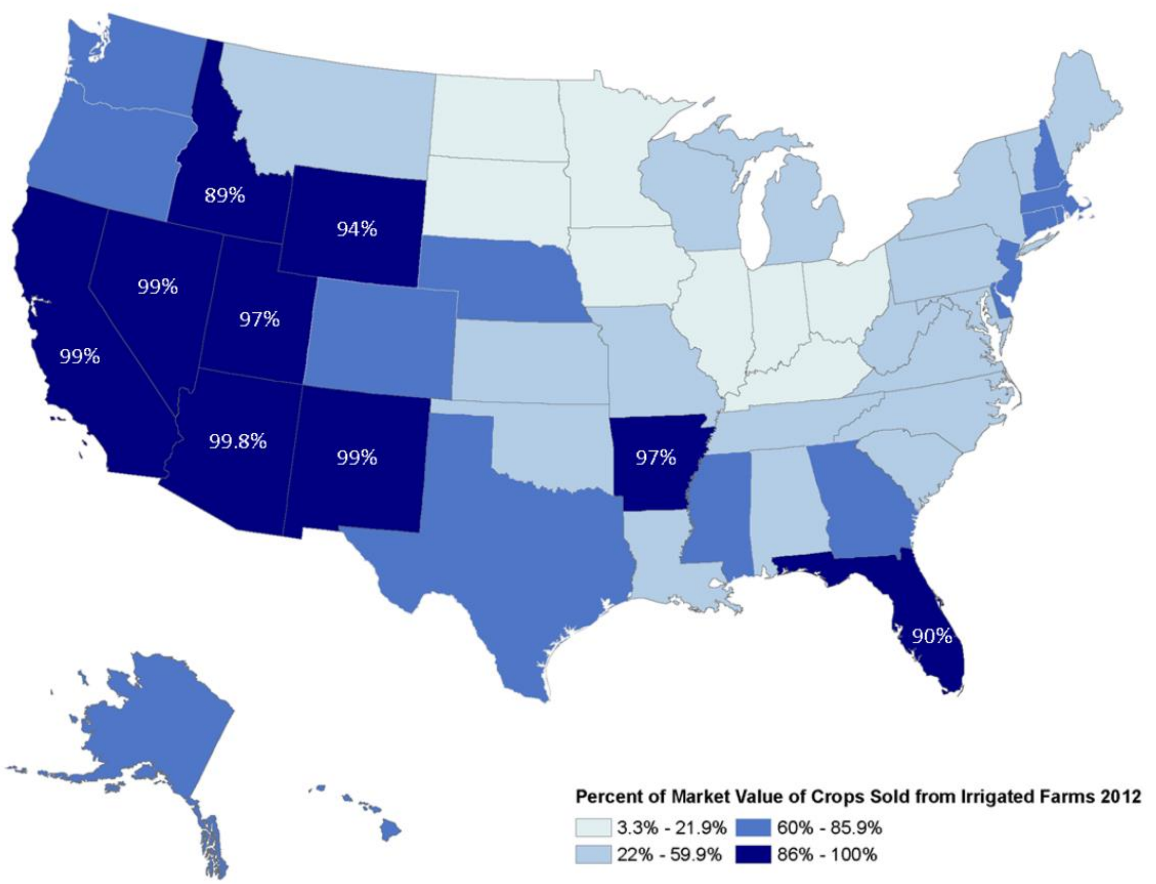

Figure 26 Percent of Market Value of Crops Sold from Irrigated Farms 2012, USDA 2012

Chapter 3: Methodology

In order to understand and examine the irrigation practices used in the Mississippi Delta and the adverse impacts those practices have that lead to a water crisis, literature review was a vital tool necessary to a holistic understanding of the issue. In order to access this literature, University of Mississippi Library's OneSearch and Google Scholar were used to access scholarly research on the topic. Reports from accredited sources such as governmental organizations, esteemed magazine publications, and local reports were also employed. The focus of these sources was as follows: irrigation practices in the Mississippi Delta, farming demands, agricultural policy and processes, groundwater systems and treatment, water policy, groundwater depletion, the environmental impact of improper irrigation, and water scarcity in the Mississippi Delta. Literature review was the necessary research approach due to the interdisciplinary, encapsulating, complex, and systematic nature of the water crisis plaguing the Mississippi Delta. A comprehensive understanding of the issue and all of its facets must be had in order to properly critically analyze the issue.

The systematic approach to reviewing the relevant and available sources on the subject occurred in the following way: First, I used the "advanced search" feature on the University of Mississippi Library's OneSearch database in order to establish precise indicator words which were "irrigation, methods, practices, sustainable, water, large, scale, farming, and current." Then I filtered the results to include only peer-reviewed and "full article available online" results. I then established a time frame of within the past five years (2015-2020) so that only publications released since could be viewed. When my results were narrowed to 50 results, I evaluated the titles and abstracts of each in order to discern which publications were relevant to my thesis. Once I established which resources would be most pertinent to my research, I compiled the sources in an annotated bibliography where I summarized, quoted, and cited each relevant source. Within the annotated bibliography I also documented relevant graphs and tables that would be necessary to illustrate the components of my thesis throughout.

This research employed a mixed methods approach that consisted of secondary quantitative data and secondary qualitative data. The secondary quantitative data contained data collections from governmental agencies, scientific organizations and unions, university research, and water resource agencies. This data was condensed and analyzed in order to better understand the success of progressive irrigation measures in terms of water preserved, money saved, and excess crops yielded. The quantitative data provided the necessary and relevant data needed to establish and assess the Mississippi Delta water crisis. It also helped better analyze the economic feasibility and gain acquired from adopting alternative irrigation methods

The secondary qualitative data gathered consisted of testimonies from farmers, residents, researchers, and specialists regarding not only the operative state of farms concerning irrigation systems and water usage, but also the success of certain programs. This data was gathered from local solution efforts, university research, and other relevant sources. This secondary qualitative data was gathered in order to better assess the social feasibility of alternative irrigation methods used to alleviate the Mississippi Delta water crisis. It is also imperative in showing the political, social, and economic feasibility of sustainability programs, which is a key indicator of program success.

This mixed methods approach consisting of secondary quantitative and qualitative data was necessary in not only understanding the complexity of the Delta water crisis, but also necessary in properly assessing and discerning potential solutions to the crisis that are the most adaptable and feasible.

Chapter 4: Findings

Through comprehensive literature review, three broad types of irrigation were found to be the most common and feasible irrigation alternatives that could be used to decrease the negative impact excessive and uncontrolled irrigation has on the Mississippi Delta. The main types are: spray/sprinkler method, microirrigation, and surface irrigation.

Spray/Sprinkler Method

The spray/sprinkler irrigation method is the most common irrigation method used in the United States, with about 34,700,000 of the total 63,500,000 acres irrigated in 2015 using the method (USGS, 2018, para. 3). It consists of the controlled application of water that resembles rainfall through a network of "pumps, valves, pipes [and/or] sprinklers" (USGS, 2018, para. 1). This method requires machinery, and is one of the least efficient methods due to the fact that a large amount of water is lost due to evaporation. Because water is shot in the air to then fall on the crops, there is no direct method of water application resulting in great water loss. "Although still widely in used today, high-pressure spray irrigation systems can be quite inefficient" because "up to 35 percent" of water is lost due to winds and evaporation (USGS, 2018, para. 4).

Center-Pivot System

The center-pivot system is a type of spray/sprinkler irrigation and is widely used on large scale farms. It "traverses a circle in the fields" through the use of electric motors. It uses "a number of metal frames (on rolling wheels) that hold the water tube," which is "fixed at the water source at the center of the circle," out into the fields (USGS, 2018, para. 2). There are varying depths of water that are applied which is determined primarily by the ability for the system to travel at a certain rate. For example, just single units are around "1,250 to 1,300 feet long and irrigate about a 130-acre circular area" (USGS, 2018, para. 2). There are also high pressure systems which have a large water gun type feature along the center pivot tube.

Figure 27 A typical center-pivot system, USGS 2018

Microirrigation

A less common irrigation method used is the drip or microirrigation method. While extremely efficient, it is only primarily for fruit and vegetable farming, but there are a few recent incidences of it being used on row crops such as cotton and corn. It accounted for about 5,490,000 of the 63,500,000 irrigated acre-feet in the US as of 2015. In this method, pipes with holes in them are buried shallowly below the ground or are placed slightly above ground next to crops. Water is then run through the pipes creating a slow drip onto "crop roots and stems" (USGS, 2018, para. 1). Because of this, drip irrigation is a very efficient method because it allows for an extremely low evaporation rate. It is considered "one of the more advanced techniques being used today" because it is "much more efficient than traditional spray irrigation" for certain crops (USGS, 2018, para. 1).

Microirrigation as a whole has gained positive attention throughout the years due to its ability to decrease water and fertilizer use as well as decrease the need for manual labor. It also has successful yield rates for the crops it is used on. Because microirrigaton allows only for the direct application of water and fertilizer to the individual plants or trees, the total wetted area is reduced and there is very little water lost to evaporation. The root systems receive the bulk of the water, meaning there is less waste. There is a "high application efficient" and "high water distribution uniformity" because water in microirrigation is applied primary to plant roots creating a "low pressure, low volume irrigation system suitable for high-return value crops such as fruit and vegetable crops" (USGS, 2018, para. 4). Another advantage of microirrigation is that is can be used to "irrigate sloping or irregularly-shaped land areas that cannot be flood irrigated" (USGS, 2018, para. 4).

Surface Irrigation

The oldest form of irrigation is the bucket method, a labor intensive system that requires individual workers to retrieve buckets of water and physically bring them to crops to water them. While this method is entirely dated and never used on large-scale farms anymore, it did give rise to modern day surface irrigation. Surface irrigation, also known as flood or furrow irrigation, is one of the oldest irrigation practices in history. In this method, water is stored and flows down small trenches dug through fields in order to water crops. Surface irrigation is "still used today throughout the world, especially in less-developed areas where mechanical techniques are not available," and it is still one of the most popular irrigation methods in the United States. In the year 2000 it even beat out the spray/sprinkler irrigation method as the most used irrigation method in the United States. Even as of 2015, of the 63,500,000 acres irrigated in the US, 23,300,000 of them were irrigated using the flood or furrow method. This continued use is because “flood irrigation is not the efficient irrigation method, but it is cheap and low-tech” (USGS, 2018, para. 2).

Figure 28 Flood irrigation of corn crops in Mississippi, USGS, 2018

While less water is lost to evaporation in the flood or furrow method than the spray method, water is still lost in high volumes due to runoff. However, many farms are taking steps to make the method more efficient. Because “flood irrigation uses gravity to transport water, and, because water flows downhill, it will miss a part of the field that is on a hill, even a small hill” (USGS, 2018, para. 3). To combat this, farmers are using leveling equipment to flatten a field before planting, which allows an even flow of water throughout the field. Alternatively, farmers have also created ponds at the bottom of their fields to collect the runoff water, which they then pump back up to the top of the field in order to reuse the water.

Surge Flooding Irrigation

Another method used to make flood or furrow irrigation more efficient is surge flooding which releases water at planned and calculated intervals and reduces the amount of runoff

(USGS, 2018, para. 3). More specifically, “surge irrigation is the intermittent application of water used to improve distribution uniformity along a furrow” (Krutz & Henry, 2017, pg. 1). Because wet soil seals at the surface, surge irrigation works off of principle that “dry soil infiltrates water faster than wet soil” (Krutz & Henry, 2017, pg. 1). This means that in a furrow that has already gotten wet, water will move quickly to the dry soil when water is re-introduced. “This phenomenon allows for a faster advance through the field with less deep percolation and better application uniformity” (Krutz & Henry, 2017, pg. 1). This allows for the root zone to have an even distribution of water from the “poly-tubing to the tail ditch” as well as “reduced nutrient loss from deep percolation near the poly-tubing” (Krutz & Henry, 2017, pg. 1).

Flat lying irrigation pipes are commonly used with surge irrigation in agriculture in the south. These type of pipes require Computerized Hole Selection (CPS) to be fully effective. This is because “CHS allows for hydraulic iteration of pressure, row length, and elevation so that each furrow receives the proportional amount of water for the row length.” (Krutz & Henry, 2017, pg. 2). Further, CHS allows for a uniform and stable distribution of water along the pipe which creates a better distribution from the start of the field to the end. To achieve this, fields are divided into equal or similar parts in order to be strategically combined for surge irrigation, and “each set is combined for the total irrigation set time” (Krutz & Henry, 2017, pg. 2). While 24 hours total irrigation set time is preferred, it is recommended to never exceed 40 hours. These suggestions allows for a more efficient control of the irrigated area and aim to decrease water waste.

Chapter 5: Recommendation

After evaluating the different types of irrigation systems reasonably available, my recommendation is surge flooding irrigation due to its efficiency and effectiveness. To further illustrate why surge flooding irrigation is recommended, I will evaluate it using an evaluation framework that will detail out each individual criterion needed in order to adopt an effective and efficient policy proposal.

Efficiency

Surge flooding, a modernized branch of flood and furrow irrigation, is the best form of irrigation alternative to be adopted for agriculture in the Mississippi Delta. According to a 2014 report on sustainable irrigation in the Mississippi Delta by Mississippi State University, around 70% of the Delta is irrigated via the furrow method already, but most are using the dated version of the method that is not water conscious. Since the surge valve irrigation method is a more sustainable, water-conscious method of furrow irrigation, it would be the most efficient method to adopt in the Delta as most farmers are already familiar with furrow irrigation. The difference is that "in surge irrigation, water is applied to an irrigation furrow intermittently, whereas in continuous-flow (or conventional) irrigation, water is applied to the furrow during the entire irrigation set" (Shock, Saunders, English, Mittlestadt, & Shock, 1994, pg. 1). This creates a "reduced intake rate" that allows for water to "advance down the furrow faster" (Nishihara & Shock, 2001, para. 2). When there is a uniform application of water on a field or field set, less water is needed in order to ensure adequate irrigation.

Not only is the surge valve method more efficient because it decreases the amount of water used while maintaining the integrity of the crop yield, it also "can reduce irrigation costs" due to its low water use and reduced need for manual labor (Nishihara & Shock, 2001, para. 1).

Further, there are recommendations set by irrigation specialists for the total time to irrigate each set. This is to ensure proper water use. The recommendations are as follows: irrigation time should never exceed 40 hours and it is suggested to be at or around 24 hours. In regards to energy use, surge valves operate on both solar power and battery. (Krutz & Henry, 2017).

Effectiveness

Surge irrigation is effective with silt loam, sandy soil, and cracking clay soil, all of which are found in the Mississippi Delta. making it adaptable and feasible. The method has four different phases: the "advance cycle" where the "dry furrow is wetted," "out time" which is the "time required for water to reach the end of the furrow," the "soaking cycle" where the "required application depth is infiltrated," and the "soaking time" which is the "time it takes the required application depth to infiltrate" (Krutz & Roach, 2016, para. 4).

When compared to conventional furrow irrigation in a trial in 1990, the surge irrigated furrows only had a 16% fail rate for reaching the end of the furrow while the conventionally irrigated furrows had a 39% fail rate. (Miller, Shock, Stieber, & Saunders, 1992). Another trial in 1991 further proved the effectiveness of surge irrigation by showing that surge irrigation had a 21% better rate of water soaking into the soil (Miller & Shock, 1992). As shown in Figure 29, a table compiled by Oregon State University in 1994, "surge irrigation is an efficient way to conserve water while sustaining yields" (Shock et. al, 1994, pg. 2). Further, in the same study it was found that the average grain yield with the conventional irrigation method was 95 bundles per acre compared to 98.7 bundles per acre with the surge system. While this yield difference is not substantial, the conventional method used 26.5 acre-inches per acre of water while the surge method only used 13.7 acre-inches per acre of water. The runoff rate was .8 acre-inch per acre and .5 acre-inch per acre, respectively (Shock et. al, 1994).

	By irrigation				
	1	2	3	4	Total
Conventional irrigation	------------ ac-in/ac ------------				
Water applied	9. 0	4.8	8.3	4.4	26.5
Runoff	0. 0	0.5	0.2	0.1	0.8
Infiltration	9. 0	4.3	8.1	4.3	25.7
Surge irrigation					
Water applied	4. 7	2.5	4.1	2.4	13.7
Runoff	0. 0	0.5	0.1	0.1	0.7
Infiltration	4. 7	2. 0	4. 0	2.3	13. 0
Comparison					
Water applied	0. 7	0.5	0.6	0.4	0.7
Runoff	1.5	ns	ns	ns	ns
Infiltration	0.7	0.5	0.7	0.4	2.1

Figure 29 "Total water applied, runoff, and infiltration during four furrow irrigations of winter wheat using surge and conventional systems," Oregon State University, 1994

With success even in the 1990s, surge irrigation has only improved in water conservation and as of 2001 “only required 57 percent of the water volume needed using conventional furrow irrigation for the entire irrigation season” (Nishihara & Shock, 2001, para. 6). This is due to the “wetting-drying cycle of surge irrigation” that “reduces water loss to deep percolation” (Shock & Jensen, 2015, pg. 3). Irrigation specialist Jason Krutz notes that there has been a “25% increase in efficiency” as well as “yield improved by 15 bushels” in some cases (Krutz as cited in Beeson & Coblentz, 2014, para. 12).

Equity

Recommending the surge valve irrigation system is an equitable policy suggestion due to accessibility and adaptability. As noted above, it can be used on various types of soil, and is relatively easy to install. If fields already have a gated pipe system in place, switching the “system to surge could be relatively easy and low cost with many benefits,” according to a 2001 cost and benefit analysis of the system done by Oregon State University. Further, fields without much side fall can easily adopt surge irrigation by getting a surge control valve and adding pipe to connect the valve. "Fields with substantial side fall can be adapted to surge irrigation by placing the valve at the corner of the field where water enters and have a transmissions pipe parallel the gated pipe down the first half of the field" (Nishihara & Shock, 2001, para. 9). The accessibility and adaptability of surge irrigation makes it an equitable option for farmers.

Social acceptability

The surge irrigation method should have a high social acceptability due to its efficiency and effectiveness. It also is an economical decision as "costs are relatively low, considering the savings in labor and water, and the reductions in the volume of water runoff achievable" with the method. "The main costs are the surge valve and any extra distribution pipe required to and from the surge valve" (Nishihara & Shock, 2001, para. 10).

The estimated costs of adoption are as follows: valves (8 inch to 10 inch) range from $755 to $895 and controllers range from $545 to $1015 based on the capabilities and features (Nishihara & Shock, 2001). It is estimated that the "initial investment is $2800 with a life expectancy of 20 years and battery replacement required every three years." The valves are versatile, though, as they can be "disconnected and applied to other irrigation sets to help distribute capital cost over more acres" (Beeson & Coblentz, 2014, para. 11).

Technical feasibility

The surge method is very technically feasible due to its versatility and adaptability. There are varying valves for different types of fields, and proper valves will need to be selected "based on the output of the well or riser" (Krutz & Roach, 2016, para. 2). As shown in Figure 30, there are a variety of different valve sizes that have varying capacities from about 700 gallons per minute (GPM) to 2600 GPM. (Text included in original figure reads: "Always math the 'surge valve size to your well output'").

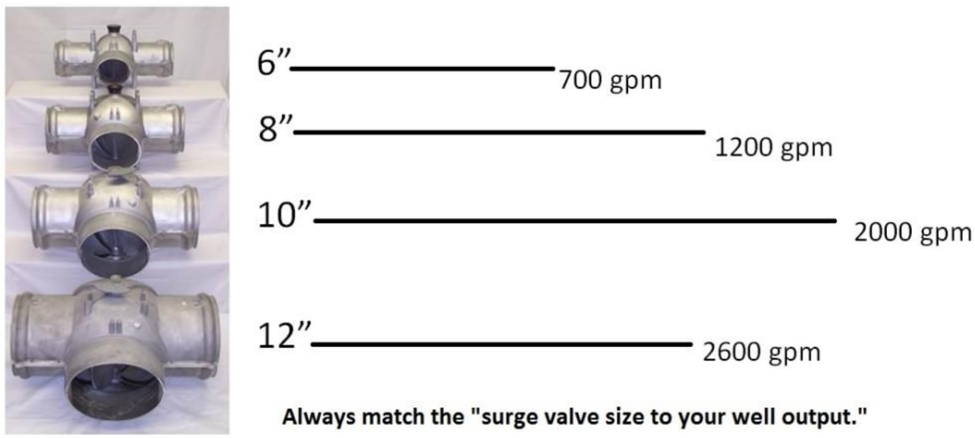

Figure 30 Surge Valve Sizes, Mississippi State University, 2016

There are also two different types of valve controllers. There is the "Star controller" which is "totally digital and much more flexible in programming." There is also the "Jr. III," a "more economic controller" that does not have as many features as the Star controller (Krutz & Roach, 2016, para. 3). Most importantly, and necessarily, there is Computerized Hole Selection (CHS) which "allows for hydraulic iteration of pressure, row length, and elevation so that each furrow receives the proportional amount of water for the row length" (Krutz & Henry, 2017, pg. 2).

Conclusion

This research had two main goals: first, to establish and analyze the water crisis in the Mississippi Delta, and second, to analyze various irrigation methods available in the United States in order to effectively offer one method as the most sustainable policy alternative for the agriculture in the Mississippi Delta. The question that I aimed to answer throughout this process was as follows: What are sustainable irrigation alternatives for the Mississippi Delta? Throughout this thesis, the research question was answered by analyzing secondary qualitative and quantitative data. A reasonable and adequate framework was established for this literature review in order to best accomplish the goals laid out in this thesis.

First, by examining the history of irrigation and agribusiness in the Mississippi Delta followed by an analysis of the various irrigation policy alternatives, a problem was established. Establishing the state of the groundwater in the MRVAA was imperative in order to establish a purpose and need for finding a solution for the Delta water crisis. The intersection of economic, social, environmental, and governmental needs had to be both acknowledged and assessed in order to adequately offer an effective and feasible policy alternative. Once this was done, various findings on different types of irrigation methods were offered and assessed. Only irrigation methods that are capable of supporting large-scale farming and accessible in the United States were offered in the findings in order to maintain feasibility. After all was considered, it is my contention that the surge valve irrigation method is the most effective, feasible, sustainable, and efficient irrigation alternative.

This thesis did not aim to enforce any mandatory regulation to be imposed on farmers in the Mississippi Delta, but instead to offer a feasible policy suggestion that could be effectively and reasonably adopted in order to ensure the success of both farmers and the Mississippi River Valley Alluvial Aquifer.

References

Amadeo, K. (2019, November 13). How the U.S. Agriculture Industry Works. Retrieved from https://www.thebalance.com/us-agriculture-stats-facts-history-4776144

Barlow, J. R. B. & Clark, B. R. (2011). "Simulation of Water-Use Conservation Scenarios for the Mississippi Delta Using an Existing Regional Groundwater Flow Model." *USGS*. Retrieved from: https://pubs.usgs.gov/sir/2011/5019/pdf/2011-5019.pdf

Bayer U.S. (2018, August 27). The Evolution Of Agriculture. Retrieved from https://thebeakerlife.com/the-evolution-of-agriculture-ebc10bf664ae

Beeson, V., & Coblentz, B. (2014). *MAFES Discovers: Irrigation Innovation*. Retrieved from https://www.mafes.msstate.edu/discovers/article.asp?id=4

Bellis, Mary. (2020, February 11). History of American Agriculture. Retrieved from https://www.thoughtco.com/history-of-american-agriculture-farm-machinery-4074385

Buddemeier, R. W. (2000). Saturated Thickness -- Concepts and Measurement. Retrieved from http://www.kgs.ku.edu/HighPlains/atlas/apst.htm

Clyde, G. D. (1952). *History of irrigation in the United States*. Logan, UT: Division of Irrigation Engineering and Water Conservation, Soil Conservation Service, USDA.

Coblentz, B. A. (2013). Irrigation, water conservation issues are high MSU priorities. Retrieved from http://extension.msstate.edu/news/feature-story/2013/irrigation-water-conservation-issues-are-high-msu-priorities

Czarnecki, J. B., Hays, P. D., & Mckee, P. W. (2002). The Mississippi River Valley Alluvial Aquifer in Arkansas: A Sustainable Water Resource? *Fact Sheet*. doi: 10.3133/fs04102

Dalsin, G. J. (1978). The Mississippi River Valley alluvial aquifer in Mississippi. *USGS*. doi: 10.3133/wri78106

Delta History. (n.d.). Retrieved from https://www.visitthedelta.com/delta-history

Diep, F. (2013). "U.S. Has Depleted Two Lake Eries' Worth Of Groundwater Since 1900." *Popular Science*. Retrieved from: https://www.popsci.com/environment/article/2013-05/us-depleted-two-lake-eries-worth-underground-water-1900-study-finds

Dyer, J., Mercer, A., Rigby, J. R., & Grimes, A. (2015). Identification of recharge zones in the Lower Mississippi River Alluvial Aquifer Using High-Resolution Precipitation Estimates." *Journal of Hydrology*, 531, 360-369.

Edwards, E. C., & Smith, S. M. (2018). The Role of Irrigation in the Development of Agriculture in the United States. *The Journal of Economic History*, *78*(4), 1103–1141. doi: 10.1017/s0022050718000608

Farming and Farm Income. (2020, February 5). Retrieved from https://www.ers.usda.gov/data-products/ag-and-food-statistics-charting-the-essentials/farming-and-farm-income/

Gillette, B. (2019). Population Decline in the Mississippi Delta. Retrieved from https://deltabusinessjournal.com/tag/population-decline-in-the-mississippi-delta/

Global Agriculture. (n.d.). Water: Agriculture at a Crossroads. Retrieved from https://www.globalagriculture.org/report-topics/water.html

Hess, R. H. (1912). The Beginnings of Irrigation in the United States. *Journal of Political Economy*, *20*(8), 807–833. doi: 10.1086/252096

History.com Editors. (2018, January 12). Neolithic Revolution. Retrieved from https://www.history.com/topics/pre-history/neolithic-revolution

JH Bloomberg School of Public Health. (2016, August 5). Industrialization of Agriculture. Retrieved from http://www.foodsystemprimer.org/food-production/industrialization-of-agriculture/

Kenny, J. F., Barber, N. L. Hutson, S. S., Linsey, K. S., Lovelace, J. K., & Maupin, M. A. (2005). "Estimated Use of Water in the United States in 2005." *USGS.* Retrieved from: https://pubs.usgs.gov/circ/1344/pdf/c1344.pdf

Killian, C. D., Asquith, W. H., Barlow, J. R. B., Bent, G. C., Kress, W. H., Barlow, P. M., & Schmitz, D. W. (2019). Characterizing groundwater and surface-water interaction using hydrograph-separation techniques and groundwater-level data throughout the Mississippi Delta, USA. *Hydrogeology Journal*, *27*(6), 2167–2179. doi: 10.1007/s10040-019-01981-6

Konikow, L. F. (2013). Groundwater depletion in the United States (1900−2008). *Scientific Investigations Report*. doi: 10.3133/sir20135079

Krutz, L. J., & Henry, C. G. (2017). *Surge Irrigation Information* (publication). *Surge Irrigation Information* (pp. 1–5).

Krutz, J., & Roach, D. (2016, May 26). Surge Valves Increase Application Efficiency. Retrieved from https://www.mississippi-crops.com/2016/05/26/surge-valves-increase-application-efficiency/

Library of Congress. (n.d.). Primary Documents in American History: Homestead Act. Retrieved from https://www.loc.gov/rr/program/bib/ourdocs/homestead.html

Library of Congress. (n.d.). Rural Life in the United States - American Memory Timeline- Classroom Presentation: Teacher Resources - Library of Congress. Retrieved from https://www.loc.gov/teachers/classroommaterials/presentationsandactivities/presentations

Mason, Mason G. (n.d.). History of Agriculture. Retrieved from https://www.environmentalscience.org/history-agriculture

McKenzie, S. (2007). Johns Hopkins Bloomberg School of Public Health. Retrieved from https://resources.saylor.org/wwwresources/archived/site/wp-content/uploads/2015/07/ENVS203-7.3.1-ShawnMackenzie-ABriefHistoryOfAgricultureandFoodProduction-CCBYNCSA.pdf

Mead, E. Yearbook, Department of Agriculture, 1899, Yearbook, Department of Agriculture, 1899591–612 (1900). Washington: United States Government Printing Office. Retrieved from https://naldc.nal.usda.gov/download/IND43620786/PDF

Miller, J. G., & Shock, C. C. (1992). *The Effect of Surge Irrigation on Onion Yield and Quality, Irrigation Efficiency, and Soil Nitrogen Losses*. OR: Oregon State University. doi: https://agsci.oregonstate.edu/sites/agscid7/files/malheur/attachments/ar/surgeOnionEffects.pdf

Miller, J. G., Shock, C. C., Stieber, T. S., & Saunders, L. D. (1992). *Surge irrigation of 'Bliss' spring wheat, 1991* (Rep. No. 899). OR: Oregon State University. doi:http://www.cropinfo.net/AnnualReports/Old/surgeirriwheat1991.html

Mississippi River Commission. (2007). *The Mississippi River & Tributaries Project: Controlling the Project Flood*. Retrieved from https://www.mvd.usace.army.mil/Portals/52/docs/Controlling the Project Flood info paper.pdf

Nishihara, A., & Shock, C. (2001). Cost and Benefits of Surge Irrigation. Retrieved from https://agsci.oregonstate.edu/mes/irrigation/cost-and-benefits-surge-irrigation

Office of the Historian. (n.d.). Indian Treaties and the Removal Act of 1830. Retrieved from https://history.state.gov/milestones/1830-1860/indian-treaties

Patterson, H., Yancey, J., & Fuller, J. (2016, April 23). Mississippi Agriculture. Retrieved from https://www.farmflavor.com/mississippi/mississippi-agribusiness/mississippi-agriculture/

PBS. (n.d.). Sharecropping. Retrieved from https://www.pbs.org/tpt/slavery-by-another-name/themes/sharecropping/

Porosity and Permeability . (n.d.). Retrieved from http://itc.gsw.edu/faculty/bcarter/physgeol/gw/pores.htm

Rainbird. (n.d.). Impact Sprinklers: Rain Bird. Retrieved from https://www.rainbird.com/agriculture/products/impact-sprinklers

Reba, M., Massey, J., Adviento-Borbe, M., Leslie, D., Yaeger, M., Anders, M., & Farris, J. (2017). Aquifer Depletion in the Lower Mississippi River Basin: Challenges and Solutions. *Journal of Contemporary Water Research & Education*, *162*(1), 128–139. doi: 10.1111/j.1936-704x.2017.03264.x

Renken, R.A. (1998) Ground Water Atlas of the United States Arkansas, Louisiana, Mississippi HA 730-F. (n.d.). Retrieved from https://pubs.usgs.gov/ha/ha730/ch_f/F-text2.html#missRV.

Sharma, P. (2017, July 27). 5 Most Water Intensive Crops. Retrieved from https://claroenergy.in/5-most-water-intensive-crops/.

Shock, C. C., & Jenson, L. B. (n2015). *Dealing with Drought: Conserving Irrigation Water* (pp. 1-4, Rep. No. 155). OR: Oregon State University. doi:https://agsci.oregonstate.edu/sites/agscid7/files/malheur/dealingwithdrought.pdf

Shock, C. C., Saunders, L. D., English, M. J., Mittlestadt, R. W., & Shock, B. M. (1994). *Water savings through surge irrigation, 1994* (Rep. No. 947). OR: Oregon State University. doi:http://www.cropinfo.net/AnnualReports/Old/surgesavings1994.html

Snipes, C. E., Nichols, S. P., Poston, D. H., Walker, T. W., Evans, L. P., & Robinson, H. H. (2005). *Current Agricultural Practices of the Mississippi Delta*. Office of Agricultural Communications. Retrieved from https://www.mafes.msstate.edu/publications/bulletins/b1143.pdf#[{"num":72,"gen":0},{"name":"FitH"},796]

Union of Concerned Scientists. (2016). “Subsidizing Waste.” *Union of Concerned Scientists*, , www.ucsusa.org/resources/subsidizing-waste#ucs-report-downloads.

USDA. (n.d.). About the U.S. Department of Agriculture. Retrieved from https://www.usda.gov/our-agency/about-usda

USDA. (2000). Retrieved from https://www.usda.gov/sites/default/files/documents/history-american-agriculture.pdf

USDA. (2012). Census of Agriculture. Retrieved from http://www.agcensus.usda.gov/Publications/2012/Full_Report/Volume_1,_Chapter_1_US/usv1.pdf.

USDA. (2012). Irrigation & Water Use. Retrieved from https://www.ers.usda.gov/topics/farm-practices-management/irrigation-water-use/

USDA. (2013). Census of Agriculture. Retrieved from https://www.nass.usda.gov/Publications/AgCensus/2012/Full_Report/Volume_1,_Chapter_2_US_State_Level/

USDA. (2020). Farming and Farm Income. Retrieved from https://www.ers.usda.gov/data-products/ag-and-food-statistics-charting-the-essentials/farming-and-farm-income/

USGS - U.S. Geological Survey Office of Groundwater. (n.d.). Retrieved from https://water.usgs.gov/ogw/aquiferbasics/uncon.html

USGS . (n.d.). Irrigation Water Use. Retrieved from https://www.usgs.gov/special-topic/water-science-school/science/irrigation

USGS. (2018). *Irrigation: Spray or Sprinkler Irrigation.* (n.d.). Retrieved from https://www.usgs.gov/special-topic/water-science-school/science/irrigation-spray-or-sprinkler-irrigation?qt-science_center_objects=0

USGS. (2018). *Irrigation: Drip or Microirrigation*. Irrigation: Drip or Microirrigation. https://www.usgs.gov/special-topic/water-science-school/science/irrigation-drip-or-microirrigation?qt-science_center_objects=0.

USGS. (2018). *Irrigation Methods: Furrow or Flood Irrigation*. Irrigation Methods: Furrow or Flood Irrigation. https://www.usgs.gov/special-topic/water-science-school/science/irrigation-methods-furrow-or-flood-irrigation?qt-science_center_objects=0.

Vories, E. D., & Evett, S. R. (2010). Irrigation Research Needs in the USA Mid-South and Southeast, Humid and Sub-Humid Regions. *5th National Decennial Irrigation Conference Proceedings, 5-8 December 2010, Phoenix Convention Center, Phoenix, Arizona USA*. doi: 10.13031/2013.35852

Voss Land & Tree. (2019, July 1). The History of Irrigation in the United States. Retrieved from https://www.vosslandscape.com/blog/the-history-of-irrigation-in-the-united-states/ -water-use?qt-science_center_objects=0#qt- science_center_objects

Wang, S. L., Nehring, R., & Mosheim, R. (2018, March 5). Agricultural Productivity Growth in the United States: 1948-2015. Retrieved from https://www.ers.usda.gov/amber-waves/2018/march/agricultural-productivity-growth-in-the-united-states-1948-2015/

Wilson, C. R., Saunt, C., Matthews, S. L., Saikku, M., Crespino, J., … University of Mississippi. (n.d.). Mississippi Delta. Retrieved from https://southernspaces.org/2004/mississippi-delta/.

Wines, M. (2013). "Wells Dry, Fertile Plains Turn to Dust." *The New York Times*. Retrieved from: http://www.nytimes.com/2013/05/20/us/high-plains-aquifer-dwindles-hurting-farmers.html?pagewanted=1&ref=science

2013 Farm and Irrigation Survey. (2013). *USDA*. Retrieved from https://www.nass.usda.gov/Publications/AgCensus/2012/Online_Resources/Farm_and_Ranch_Irrigation_Survey/