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2950 Niles Road, St. Joseph, MI 49085-9659, USA
269.429.0300 fax 269.429.3852 hq@asabe.org www.asabe.org

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Irrigation Research Needs in the USA Mid-South and Southeast, Humid and Sub-Humid Regions

Earl D. Vories

USDA-ARS, P.O. Box 160, Portageville, MO 63873 USA, Earl.Vories@ars.usda.gov

Steven R. Evett

USDA-ARS, P.O. Drawer 10, Bushland, TX 79012 USA, Steve.Evett@ars.usda.gov

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Abstract. *Irrigated area in the Mid-South and Southeast United States continues to increase greatly in response to economic imperatives (risk avoidance) and recurring short- and long-term drought conditions and now totals 4 million ha even though mean annual precipitation in those regions exceeds 1 m. Most new irrigation is supplied from groundwater, meaning that the water is pressurized and possibilities for improved irrigation efficiencies exist, but increased groundwater use has also caused aquifer declines. With irrigation comes a more stable production environment, which encourages increased plant densities and associated fertilizer and pesticide inputs that must be appropriately managed to prevent ground and surface water pollution. Because of commonly low available water holding capacities and root-limiting layers at shallow depths in many soils in these regions, irrigation management is difficult and appropriate methods are not well identified. Water quality and water use efficiency impacts under irrigation are also poorly understood, but comprehension is necessary if conversion from groundwater to surface water supplies is to be justified. At the same time that irrigation has rapidly increased, research and extension personnel in the region focusing on irrigation have declined in number. Furthermore, the ARS irrigation research effort has not sufficiently increased in response to the new challenges for irrigation to provide food and fiber for an expanding population. A combined state and federal response to these challenges is needed to provide appropriate and effective problem solutions that ensure efficient water use and high crop water productivity while protecting water supplies and the environment.*

Keywords. Humid regions irrigation, surface water supply, aquifer depletion, irrigation management, water quality, water quantity, watersheds.

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Introduction

The US Department of Agriculture's National Agricultural Statistics Service (NASS) divides the US into 20 Water Resource Areas (Fig. 1), with the Lower Mississippi (WRA 08) containing 4.6 million ha of farmland in portions of Missouri, Kentucky, Arkansas, Tennessee, Mississippi, and Louisiana (NASS, 2010b). These current and former flood plains of the Mississippi River and its tributaries are characterized by low slopes, fertile silt loam to clay soils, and often poor drainage. Drainage districts were the first formal organizations for farm water management in the region since, at the time, drainage was a bigger concern than irrigation. Irrigation has increased rapidly in the Lower Mississippi, also called the Mid-South, with the irrigated area reaching 3 million ha in 2008 (NASS, 2010b). Only a small amount of that land is in fully functioning formal irrigation districts with surface water distribution systems. The largest increases in the region were in Arkansas, with steady increases in Mississippi and Missouri as well. Unlike other regions, the increase in irrigated area has largely not been tied to the development of irrigation districts, but rather has resulted from individual farm operators installing irrigation wells.

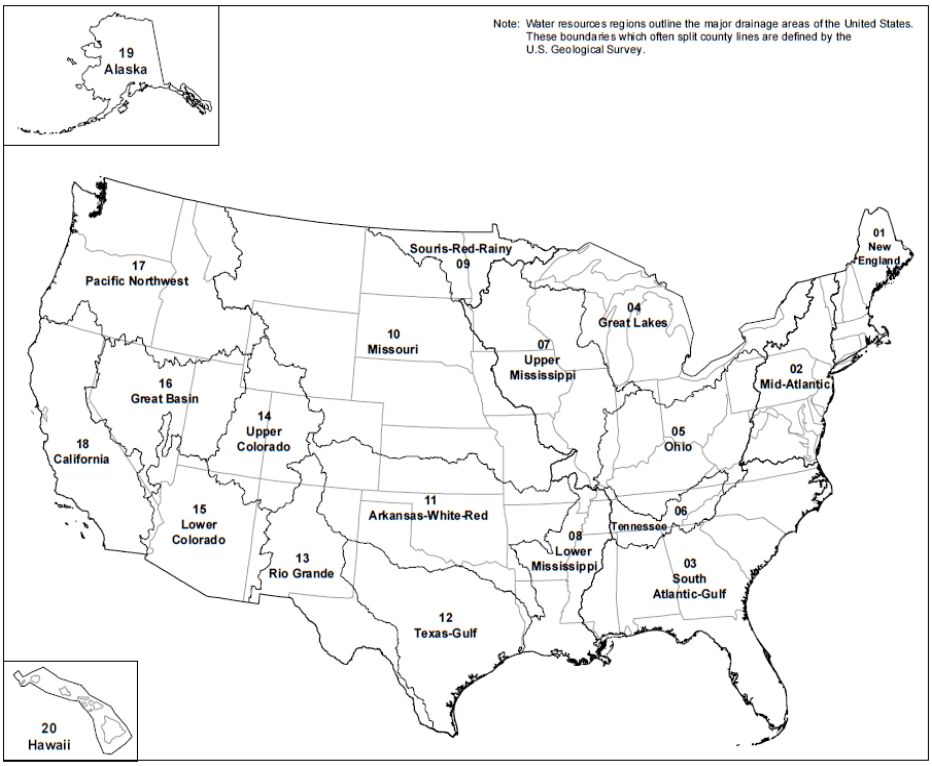

Figure 1. USDA – NASS Water Resource Areas map of the United States (NASS, 2010b).

The South Atlantic – Gulf (WRA 03), also called the Southeast, contains 3 million ha of farmland in portions of Mississippi, Alabama, Georgia, Florida, South Carolina, North Carolina, Virginia, and Tennessee (Fig. 1). Irrigation has also increased rapidly in the Southeast, with the irrigated area reaching 1 million ha in 2008 (NASS, 2010b). Both the Mid-South and Southeast have a sub-humid climate and an average annual rainfall in excess of 1 m (Fig. 2). Even though annual rainfall is generally sufficient for some level of crop production, periods of drought during the growing season make irrigation essential for economically optimum yields of all widely produced summer crops.

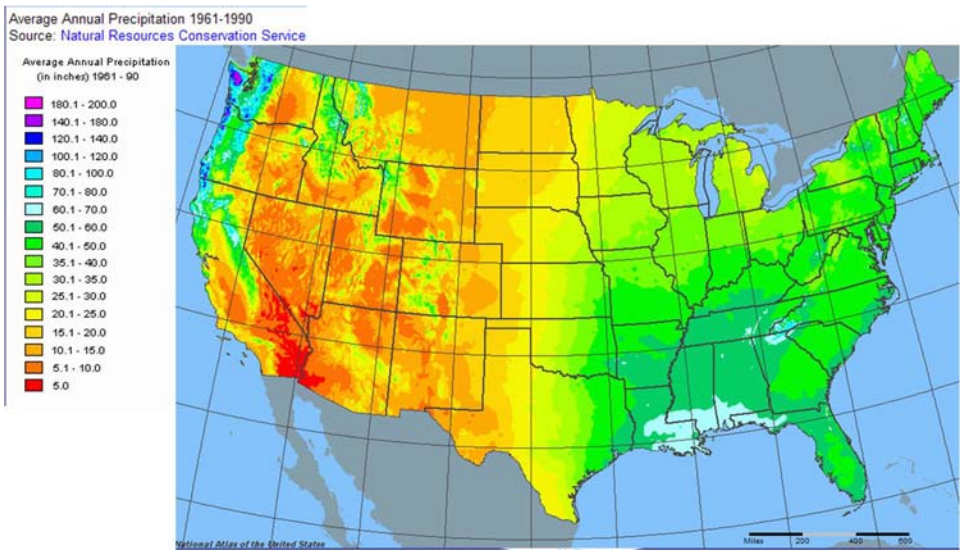

Figure 2. Average annual precipitation for the continental United States (from www.nationalatlas.gov).

Irrigation Change in the United States

Irrigation was practiced thousands of years ago by the Hohokam people along the Salt River in central Arizona. Small-scale irrigation was also practiced by other indigenous peoples, but the arrival of the Mormons in Utah in the 1860s began a steady expansion of irrigation in the arid western US. Irrigation became a common practice for pioneers in the Yakima Valley of Washington, along the Snake River in Idaho, in the Central Valley of California, and in other states where stream flows were easily captured and diverted into surface water irrigation systems.

The federal government took an interest in irrigation with the Reclamation Act of 1902, which, along with succeeding acts, was designed to provide federal aid for the construction of dams, reservoirs, and irrigation water delivery systems in order to promote settlement of the west. Federal work projects during the Great Depression of the 1930s further promoted construction of large projects. Federal help for the rapid expansion of irrigation in the West continued after World War II, but gradually declined due to budget shortfalls and changing attitudes about the environment and water use.

By 1970, the era of rapid federal development of irrigation had ended (National Research Council, 1996). However, the combination of rapid industrialization during World War II, widespread rural electrification, and the drought of the 1950s led to a rapid increase in the number of irrigation wells in the Great Plains after World War II. Well construction for irrigation in the Mid-South began a steady expansion at about the same time, particularly in Arkansas. In the 1970s, irrigation began a steady growth in Louisiana, Mississippi, and the Missouri Bootheel (i.e., extreme southeast portion) as well, encouraged by low energy costs, shallow alluvial aquifers, and the ready availability of pumps and power plants.

Since 1978, irrigation expansion has occurred without large federal or state projects and has primarily been the responsibility of individual farm operators who obtain water from wells drilled

on their property or water that they divert from adjacent stream or drainage flows. The large federally funded projects in the West were supported historically by strong research and outreach efforts on the part of universities and USDA's Agricultural Research Service (ARS) and Natural Resource Conservation Service (NRCS). With the exception of Nebraska, however, expansion in the last 30 years has largely occurred without strong irrigation-related research and extension efforts in the affected states. This view is supported by the fact that roughly three-quarters of the ARS irrigation research scientists are located in the western states. Of the 38 ARS projects with "irrigation" in the title, only seven (the same number as Office of International Research Programs) from three states were based in the Mid-South or Southeast and only two (MO, GA) were appropriated projects (i.e., funded directly by congress). Another 21 projects had "irrigated" in the title, but only three are from the two regions and only one (GA) was an appropriated project.

Between 1997 and 2007 irrigated area in the US was practically static at just over 22 million ha; however, there were large changes among the states. California had the largest decline at more than 350,000 ha (NASS, 2010b). Texas had a decline of more than 300,000 ha due both to depletion of the Ogallala Aquifer in the Texas Panhandle and to the cessation of considerable rice irrigation along the Gulf Coast (due to price support changes, not water supply). Nebraska reported the largest increase and one of the few increases west of the Mid-South at 600,000 additional ha irrigated, largely due to increased drilling into the Ogallala Aquifer. Except in portions of Nebraska, the Ogallala is essentially a fossil aquifer, receiving recharge at rates of approximately 25 mm per year. Pumping from aquifers for irrigation is clearly not sustainable in much of the Great Plains, and further declines in irrigated area are expected. Declines in irrigated area in states like Arizona, New Mexico, and Nevada are tied to a burgeoning urban population and a scarce water resource that is completely allocated or even over allocated. Throughout the western US, water resources are completely or over allocated.

Irrigation in the Mid-South and Southeast

Until recently, drainage districts were the only formal water management organizations in the Mid-South. The French and Spanish both recognized drainage as an essential water management practice in Louisiana, and the granting of lands to individuals was tied to the establishment of a drainage system. However, federal interest in drainage came much later with the Swamp Land Grants of 1849 and 1850 (Harrison, 1961). Under these federal acts, Arkansas and Louisiana received 3.6 and 4.9 million ha, respectively, to be sold with the proceeds used for land reclamation. Most of the funds were used to build levees along the Mississippi River. In Arkansas, organized drainage enterprises began in 1869 when a state statute provided that special improvement districts could be organized for drainage purposes (Harrison, 1961). Drainage only became practical after 1900, however, when flooding by the Mississippi had been adequately controlled. Hundreds of drainage districts had been formed in the Mid-South and 3.5 million ha were drained by 1960 (Harrison, 1961).

The drainage districts allowed farming to flourish and irrigation began increasing rapidly after World War II due to the major drought of the 1950s, the increasing mechanization of agriculture, and the frequent occurrence of summer drought periods. By 2008, 3 million ha of land were irrigated in the Mid-South using 13 billion m^3 of water yearly, 84% of which was obtained from groundwater. Similarly, 1 million ha of land were irrigated in the Southeast using over 3 billion m^3 of water yearly, with 60% from groundwater. The major irrigation types were surface irrigation (79% in Mid-South, 21% in Southeast) and sprinkler (22% in Mid-South and 56% in Southeast) (NASS, 2010b).

While western states experienced declines in irrigated area between 1997 and 2007, most Mid-South and Southeast states saw increases. After Nebraska, the four largest increases were in

Arkansas (273,000 ha), Missouri (113,000 ha), Mississippi (105,000 ha) and Georgia (99,000 ha). The only states in either the Mid-South or Southeast to experience decreases were Kentucky (500 ha) and Virginia (1,700 ha), both of which have relatively small irrigated areas, Louisiana (2,600 ha), and Florida (130,200 ha) (NASS, 2010b).

Even with the reductions in Florida and Louisiana, six of the top 17 states in 2008, in terms of irrigated area, were in the Mid-South or Southeast (NASS, 2010b):

- Arkansas, 1.8 million ha (4th);
- Mississippi, 590,000 ha (12th);
- Missouri, 500,000 ha (13th);
- Florida, 490,000 ha (14th);
- Georgia, 410,000 (16th); and
- Louisiana, 380,000 ha (17th).

With the exception of Florida (53%), in each of those states more than 75% of the irrigation water is from groundwater wells, with the portions in Missouri and Mississippi being 97% and 95%, respectively.

According to Harper (1956), irrigation began in Arkansas in 1904 when 28 ha of rice were planted near Lonoke. By 1915, there were 40,000 ha of rice, and by 1949, 142,000 ha of rice plus 34,000 ha of other crops irrigated in eastern Arkansas (Harper, 1956). The adoption of irrigation was motivated by risk aversion on the part of lenders and farmers. Although Arkansas receives >1 m of rainfall annually, drought periods in the summer frequently cause large yield losses. Even short droughts are problematic due to the shallow root zones and thus small water holding capacities of the many soils affected by root-limiting fragipans and tillage pans. Similar factors have driven adoption of irrigation in the Southeast. Rice is entirely irrigated and was produced on an average of 600,000 ha between 2000 and 2009 in Arkansas (NASS, 2010a). In addition to crop irrigation, Arkansas produced half of the nation's baitfish and ranked third in catfish production (NASS, 2009).

The US Army Corps of Engineers (USACE, 2000) reported that by 1915 the Alluvial Aquifer, the principal water source for agriculture in eastern Arkansas and surrounding areas, was already being tapped at a rate that exceeded its ability to recharge in the Grand Prairie region of Arkansas. Groundwater overdraft problems were officially recognized as early as 1939 (State Planning Board, 1939), but active planning for irrigation improvements began in the 1980s in response to the rapid increase in irrigated areas and resulting rapid groundwater declines. Planning and action have involved cooperation by multiple agencies including the Arkansas Natural Resources Commission (ANRC), NRCS, USACE, and US Geological Survey (USGS). In 1987, the Eastern Arkansas Water Conservation Project quantified existing irrigation efficiency problems (USDA-SCS, 1987). Irrigation application efficiency measured on farmers' fields averaged 65% for paddy rice and 83% for sprinkler irrigation, with furrow irrigation somewhere between those values. The 1987 report was followed by a series of reports on the Eastern Arkansas Region Comprehensive Study beginning in 1990 (USACE, 1990), which established the feasibility of surface water development to replace pumping groundwater for irrigation. The second Arkansas Water Plan assumed that demand for water would increase greatly, largely due to increases in irrigated cropland (ASWCC, 1990). It also recommended that surface water diversions be used to meet the increased demands and to reduce groundwater depletion and that regional irrigation districts be formed to manage those resources. Diversions were envisioned from the Arkansas, White, Black, Bayou de View, and L'Anguille Rivers. Irrigation water conservation improvements were also recommended.

In Arkansas, primarily the eastern portion of the state, irrigation now covers nearly 2 million ha, making it the fourth-ranking irrigated state. Irrigation from wells on individual farm tracts used

over 8 billion m^3 of water in 2008 (NASS, 2010b) and increased pumping has resulted in serious aquifer depletion in some areas. Large areas of eastern Arkansas are now designated as "Critical Ground Water Areas" and others are under study (Fig. 3). The "critical area" designation is based on significant groundwater declines and/or water quality degradation. Stream flows in the region are more than adequate to replace groundwater with surface diversions; however, the formation of irrigation districts is required to manage water distribution and there is usually considerable opposition that must be overcome. As of 2002, ten irrigation project areas had been identified and some planning had been completed (Fig. 4). Two of those projects (Plum Bayou and Point Remove) have been completed and others are in some stage of completion through cooperative actions of local, state, and federal agencies. However, lack of scientific data is a major impediment to project design and public acceptance, not only in Arkansas but in other Mid-South and Southeast states.

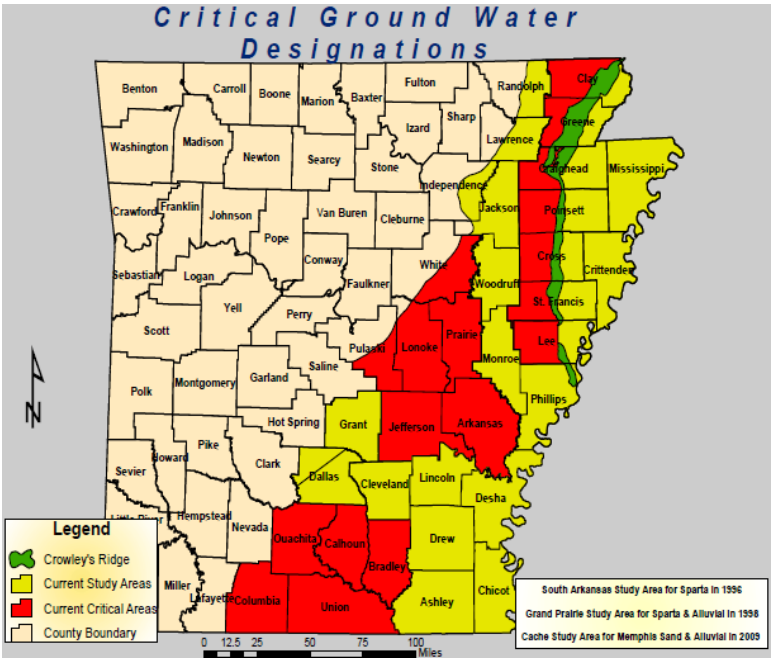

Figure 3. Critical groundwater areas (shown in red; study areas in yellow) in Arkansas (from www.anrc.arkansas.gov).

Water pumped from the Alluvial Aquifer in Mississippi increased from 2.8 million m^3 per day in 1975 to approximately 7.6 million m^3 per day in 1994 and is expected to continue to increase rapidly for irrigation of rice and row crops, catfish production, and industrial use (Arthur and Strom, 1996). There is concern that Mississippi will experience the aquifer declines already evident in Arkansas and the Alluvial Aquifer is being monitored cooperatively by USGS and the Yazoo Mississippi Delta Joint Water Management District (YMD), which was formed in 1989. As of 2002, irrigation pumping in Mississippi had not explored the deeper-lying Sparta Aquifer, the main source of drinking water in the region, to any great extent.

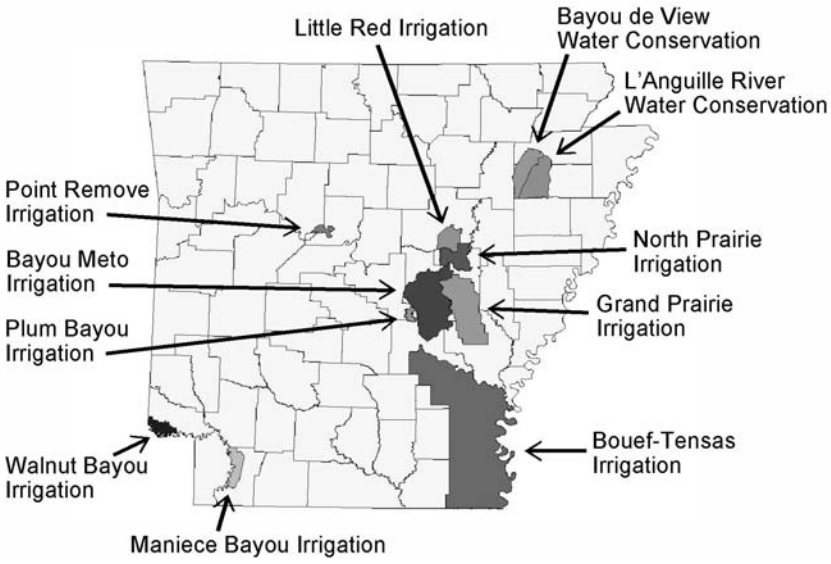

Figure 4. Irrigation project areas as of 2002. The two water conservation districts are subunits of the Northeast Arkansas irrigation area under study (Source: NRCS).

Land owners in Arkansas have riparian water rights and rights to groundwater based on common law (Harper, 1956). Historically, the situation was much the same in the other Mid-South and Southeast states. However, in Mississippi, recent state law has reserved surface water rights for the state. Consequently, surface water distribution and irrigation projects in Mississippi will be organized at the state level by YMD (YMD, 2002). Irrigation districts for the distribution of surface water were virtually unknown in the region until recently. However, the recent formation of irrigation districts, particularly in Arkansas, is occurring largely in areas already heavily irrigated by individual farm operators and represents an attempt to address groundwater decline problems by a combination of two approaches: (i) water conservation; and (ii) replacement of groundwater sources with surface water sources.

Water conservation practices most commonly used are on-farm storage reservoirs, tail-water recovery systems, and pump and pipe systems to (i) transfer water from tail-water pits back to reservoirs, (ii) distribute water to fields, and (iii) re-lift water from drainage canals and bayous into reservoirs and fields. With these practices, much of the runoff from rainfall is captured for irrigation use. This is particularly important for storage of off-season rainfall and prevention of nutrient movement to larger streams, lakes and the ocean. The existing drainage canals are implicitly included in these systems, serving as they do to capture diffuse runoff and re-distribute it for capture by downstream farmers. This re-use of drainage and runoff waters undoubtedly increases system-wide water use efficiency, but to an extent that is currently unknown. Drainage waters that are re-used typically deposit sediment in farmers' fields; but the improvement in water quality engendered by this practice is also not quantified. Finally, extensive re-use of drainage waters, while increasing system-wide water use efficiency, may result in less water in bayous and wetlands, the effects of which also need study.

Water quality issues gained importance in the 1990s. The Arkansas Governor's Water Resources Task Force report recommended development of a water quality research plan and the identification of gaps in existing research infrastructure, along with providing support to leverage federal research funds and federal/state research partnerships (Rockefeller, 2001). Also recommended was the provision of resources to improve Arkansas' water quality

monitoring program, including development of Total Maximum Daily Loads (TMDLs) and implementation of non-point source reduction programs. The USGS monitors stream gaging and water quality stations in Arkansas and in 2000 reported on 81 surface-water gaging stations and 62 surface-water quality stations. However, funding cuts had reduced water quality stations by 136 and stream gaging stations by 43 prior to the 2000 report, leaving large areas of Arkansas with sparse data on stream flows and water quality (Porter et al., 2000).

IRRIGATION RESEARCH NEEDS

Irrigated area in the Mid-South and Southeast US continues to increase greatly in response to economic imperatives (risk avoidance) and recurring short- and long-term drought conditions. Most new irrigation is supplied from wells, meaning that the water is pressurized and possibilities for improved irrigation efficiencies exist. Also, with irrigation comes a more stable production environment, which encourages increased plant densities and associated fertilizer and pesticide inputs that require appropriate management to prevent ground and surface water pollution. Because of commonly low available water holding capacities and root-limiting layers at shallow depths in many soils in these regions, irrigation management is difficult and appropriate methods are not well identified. Water quality and water use efficiency impacts under irrigation are also poorly understood.

In contrast with the rapid growth of irrigation, there is relatively little irrigation research occurring in the Mid-South and Southeast. Evett et al. (2003) reported low numbers of research and extension workers involved in irrigation and the numbers have declined further since their study was conducted. Retirements and other factors have caused many people to leave the area while budget cuts and refocusing of priorities have led to most of them not being replaced. Similar reductions have impacted NRCS.

There also are impediments to multi-state cooperation addressing irrigation research needs. USDA's National Institute of Food and Agriculture (NIFA) Project S1018, Irrigation Management for Humid and Sub-Humid Areas, was formed in 2004 with the overall goal "to coordinate research and extension programs that are associated with irrigation management in the sub-humid and humid regions of the United States." Such coordination is needed; however, with the relatively small number of research and extension workers spread over a large area, participation in the project was quite limited even before the budget cuts observed in recent years. At the time of this report it is unknown whether the project will continue.

Although there is insufficient humid and sub-humid area irrigation research being conducted, there is fairly unanimous recognition of needs for additional irrigation research to solve problems faced by farmers, natural resource managers, and policy makers. Some of the key areas of need are:

Irrigation Efficiency

- How much of current irrigation water demand could be met by on-farm conservation, including the use of tailwater pits, storage reservoirs, and replacement of earthen ditches with piping?
- What inexpensive equipment can be developed/adapted for automation and remote control of irrigation and drainage pumps?
- What are the effects of irrigation storage reservoirs and tailwater systems on overall farm-level irrigation efficiency and water quality?
- If farm- and project-level efficiencies are increased, what are the impacts on the riparian environment and wetlands?

Irrigation Methods/Management

- What changes can be made to make rice irrigation more efficient? How likely is it that rice irrigation methods will change from continuous flood to more efficient methods? Will other practices such as center pivot sprinklers, level basins, etc., economically increase efficiencies?
- What is the best way to schedule irrigation when water logging is as likely and harmful as water deficits? Guidelines must be developed to maximize soil water storage so as to reduce runoff and nutrient loss in the frequent case of rainfall after irrigation. Crop water use values must be determined for varieties and climate of the region.
- Are weather forecasting and remote precipitation measurement (radar based systems) reliable enough to improve irrigation scheduling?
- Is subsurface drip irrigation a viable method in the region? How can the emitter plugging/water quality problems be overcome?
- Are moving irrigation systems (center pivot and linear move) appropriate and effective on the soils of the region? Can soil variability problems be addressed with variable rate irrigation systems integrated into moving irrigation systems?

Water Quality/TMDL Issues

- What is the quality of runoff water leaving agricultural fields in terms of sediments, nutrients, and chemicals?
- What are the water quality impacts of irrigation methods, management, system design (including tail-water pits, reservoirs and pipe networks), choice of crop, and tillage practices?
- What are appropriate minimum stream flows to meet environmental concerns? There is a lack of understanding of minimum biological stream flow requirements.
- What are appropriate TMDLs for irrigated lands, including effects on sediment and nutrient contaminants of agricultural ditches and wetlands, vegetation effects, and aquatic indicator animals?
- Can water be conjunctively used for irrigation and aquaculture? Are there bio-accumulation issues? Can irrigation improve quality of fishpond effluent?

Social Issues

- How will competing interests of agricultural, industrial, and municipal users be resolved? What are the competing entities and their water requirements now and in the future?
- What is the federal government's interest in water resource development, and what should the goals be?
- What are the costs associated with a reduction in irrigated area (reduced yields and reduced farmland valuation)?
- Arkansas generates approximately 100 billion m^3 of runoff yearly. There is a need to develop 10% of this. How should it be done?
- As irrigated area decreases in the semi-arid Great Plains and arid West, what pressures will occur to change irrigation (crops, efficiencies, methods) in the Mid-South and Southeast?

- What is the role of irrigation in biofuel production and food production?

Soil - Irrigation Interactions

- What are pertinent soil properties that will influence possibilities, opportunities and outcomes for irrigated agriculture?
- Hydraulic conductivities are low in typical soils of the Mid-South, which are extremely low in organic matter and have massive structure. Which irrigation methods are favored in these soils?
- Fragipans and tillage pans are common in Mid-South and Southeast soils. How do they affect irrigation efficiencies and yields and what remediative measures are appropriate?

Irrigation Project Design and Management

- How are the hydrology and water balance of irrigated areas affected by design alternatives such as on-farm storage reservoirs, tail-water pits, and re-lift pumps?
- What is the life of storage reservoirs and tailwater pits being built today? What is the rate of sedimentation?
- What can be done to control embankment erosion, which is a serious problem in the un-cohesive silt loam soils common in the region? Are there chemical soil treatments such as polyacrylamide (PAM) that can control erosion? Are there more efficient and cost-effective seeding options?

Production Practices/Agronomics

- What are the effects of row spacing and plant density on irrigation efficiency and the economics of production?
- What are the effects of PAM on soil erosion and infiltration in irrigated systems?
- To what extent can irrigation scheduling improve water and nutrient management in a system where water is captured in tail-water pits and recycled?
- Will no-till rice production improve soil organic matter and thus structure and related properties?
- How do tillage practices affect crop water use?

These are just a few of the questions that agricultural producers, landowners, environmentalists, sportsmen, government agencies, and everyone else who uses the water resources in the Mid-South and Southeast are asking. Ignoring the problems assures that they will worsen; however, there has been little interest in redirecting resources from the regions with diminishing irrigated areas to those areas experiencing increases. Even in better economic environments, few new irrigation-related research and extension positions were created and often existing positions were not filled or were redirected if they were vacated. Lawsuits over sharing water between states, declining wells, and worsening water quality will continue in the humid and sub-humid regions unless a focused effort can be encouraged and the necessary human and intellectual capital can be found to address the problems.

Conclusion

Irrigated area in the Mid-South and Southeast United States continues to increase greatly in response to economic imperatives (risk avoidance) and recurring short- and long-term drought

conditions even though mean annual precipitation in those regions exceeds 1 m. Most new irrigation is supplied from wells, meaning that the water is pressurized and possibilities for improved irrigation efficiencies exist. Also, with irrigation comes a more stable production environment, which encourages increased plant densities and associated fertilizer and pesticide inputs that must be managed appropriately to prevent ground and surface water pollution. Because of commonly low available water holding capacities and root-limiting layers at shallow depths in many soils in these regions, irrigation management is difficult and appropriate methods are not well identified. Water quality and water use efficiency impacts under irrigation are also poorly understood. At the same time that irrigation has rapidly increased, research and extension personnel focusing on irrigation have declined in number in the region and multi-state cooperation has not increased. Furthermore, the ARS irrigation research effort has not sufficiently increased in the region in response to the new challenges for irrigation to provide food and fiber for an expanding population. A combined state and federal response to these challenges is required to provide appropriate and effective problem solutions while ensuring efficient water use, high crop water productivity, and protection of water supplies and the environment.

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