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FEATURE

A statewide network for monitoring agricultural water quality and water quantity in Arkansas

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The world population reached seven billion in 2011, and global population of nine billion is expected by 2050. To sustain agricultural production of food, fiber, feed, and fuel for the world population, agriculture requires water and nutrient inputs, which can impair water resources by decreasing water quality and availability. Both are concerns in the agricultural region of the Lower Mississippi River Basin (LMRB) and specifically in the state of Arkansas, where production of rice, cotton, soybean, and poultry are critical to the state's economy. Water quality issues are related to excess nutrients running off of fields that subsequently influence local and regional water bodies (Carpenter et al. 1998). Water quantity issues are related to declines in groundwater caused by withdrawal rates that are greater than recharge rates. Conservation practices targeted at improving water resources and promoted through the Mississippi River Basin Healthy Watersheds Initiative (MRBI) are supported by USDA Natural Resources Conservation Service (USDA NRCS) and include a component dedicated to monitoring the water resources impact of these practices. A statewide monitoring network designed to collect water quality and water quantity data was established in 2010 in Arkansas.

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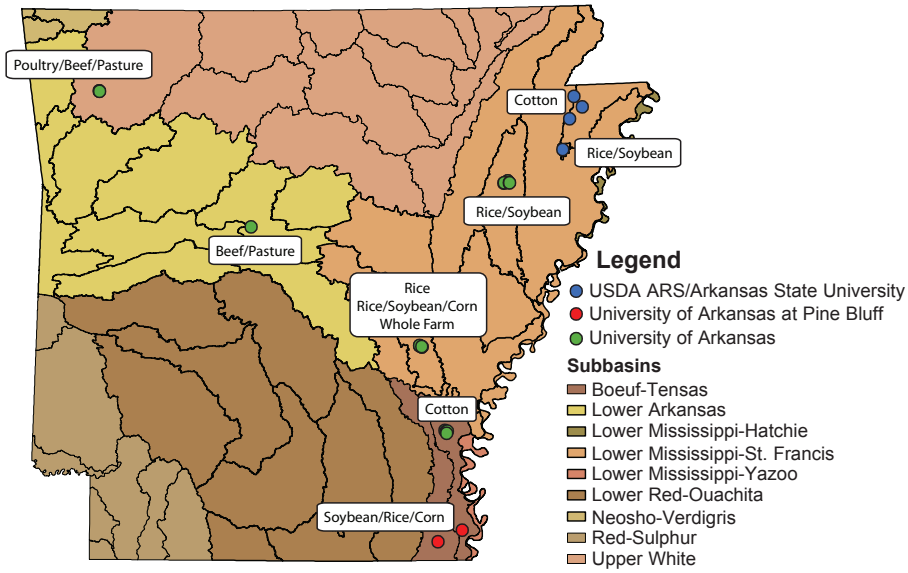
Figure 1

Statewide network station locations with crop rotation and subbasins delineated.



The network is made up of approximately 30 monitoring sites on 12 separate farms where rice, soybean, cotton, corn, poultry, and beef are produced (figure 1). The network is described in this article in detail along with targeted conservation practices. Programs and entities that supported the establishment and ongoing infrastructure of the statewide network are also described.

AGRICULTURE

Agriculture in the LMRB is important to the growth, economy, and culture of the area. The agricultural sector in Arkansas accounts for the largest percent of gross domestic product of any state in the United States. For the 2010 calendar year, cash receipts for Arkansas from all commodities totaled US$8.14 billion. The LMRB accounts for approximately 70% of US rice and Arkansas accounts for 46% of US rice, which contributes largely to the United States being the fourth largest exporter of rice worldwide. Sustainable production of these commodities depends on meeting current agricultural water resources challenges in terms of both water quality and water quantity.

WATER QUALITY

Agriculture is the leading source contributing to impaired surface waters, and sediments are the leading contaminant. Reports indicate that impairment of 41% of lakes and 48% of rivers and streams in the United States is attributed to agricultural activities (USEPA 2002). Concurrent with sediment associated with agricultural activities, nutrients (i.e., nitrogen [N] and phosphorus [P]) also contribute to water quality impairment (Arkansas Department of Environmental Quality 2008). Water quality in the southeastern Arkansas portion of the alluvial aquifer is impaired from elevated chloride levels (Kresse and Clark 2008). Since farmland comprises 65% of the land use in the Mississippi River Basin (Turner and Rabalais 2003), water quality in the LMRB can be considered a local and regional concern.

A hypoxic zone is an area with less than 2 ppm of dissolved oxygen and results from the process of eutrophication and inadequate mixing of oxygenated surface waters. Enrichment with excess N and P inputs to a lake, estuary, or coastal area stimulates plant growth such as phytoplankton, causing algal blooms. When algae die and sink to the bot-

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tom, their decomposition can deplete the oxygen, resulting in fish kills and population shifts (Osterman 2006). Nitrogen tends to be the limiting nutrient in estuarine and coastal systems. In freshwater systems, P is usually the limiting nutrient in plant growth (Smith and Schindler 2009). The hypoxic zone in the northern Gulf of Mexico is the largest hypoxic zone in the United States and second largest in the world. This seasonal hypoxic zone in the Gulf of Mexico begins in late spring, reaches a maximum in midsummer, and disappears in the fall. The current five-year average size is 14,644 km^2 (5,654 mi^2), with the greatest extent measured in 2002 at 22,000 km^2 (8,494 mi^2) (Rabalais et al. 2007). The Mississippi River/Gulf of Mexico Watershed Nutrient Task Force developed an action plan in 2001 to reduce the five-year average extent of the hypoxia zone to less than 5,000 km^2 (1,931 mi^2) by 2015, a decrease of nearly one-third of the current five-year average size (USEPA 2007).

Rabalais et al. (2002) reported that 90% of nitrate in the Mississippi River is estimated to be from nonpoint sources, with 74% originating from agriculture. Of the estimated 11.6 million t (25,573 million lb) of N input annually into the Mississippi River Basin, an average of 1.5 million t (3,306 million lb) enters the Gulf of Mexico (Goolsby and Battaglin 1997). This large influx of N from agriculture is attributed largely to states in close proximity to the Mississippi River and to sources next to faster flowing rivers (Alexander et al. 2008).

In Arkansas, 42% of streams do not meet standards for designated use, and 47% of this impairment is attributed to agriculture (Arkansas Department of Environmental Quality 2008). Statewide, water quality impairment includes siltation or suspended sediments and nutrient loading (Arkansas Department of Environmental Quality 2008). Siltation or suspended sediment causes direct and indirect biological effects to aquatic systems (Berry et al. 2003), with direct effects including abrasion and clogging of filtration mechanisms that interfere with ingestion and respiration and habitat burial (Wilber and Clarke 2001). Indirect effects such as decreased light penetration and stream bed changes result in decreased habitat (Berry et al. 2003). Substrate loss and change in composition and interstitial space are cited as important for the relationship between sedimentation and benthic communities (Waters 1995). Freshwater mussels also experience decreased feeding rates due to high levels of suspended sediment (Wilber and Clarke 2001). Reduction of sediments and nutrients in waterways will protect Arkansas' rivers and streams and reduce the sediment and nutrient influx to the Gulf of Mexico.

While delivery of excess nutrients to the Gulf is a basin-wide issue, efforts to identify critical source areas within the region have relied primarily on regional simulation models such as SPAtially Referenced Regressions On Watershed Attributes (SPARROW), which relates in-stream water quality data to watershed characteristics on a basin-wide scale (Alexander et al. 2008). While such efforts are useful in identifying eight-digit watersheds that may be the origin of excessive nutrients, they cannot replace targeting of remedial efforts based on local knowledge and understanding of agricultural systems and practices, including some quantification of nutrient and sediment losses at the edge of fields. It is, in part, for this reason that a statewide edge-of-field monitoring network has been formed.

WATER QUANTITY

Nationally, Arkansas ranks fourth amongst the states for number of irrigated acres after Nebraska, California, and Texas. Though precipitation is abundant in the region, the timing and quantity may not coincide with specific agricultural needs. As a result, producers have increasingly turned to irrigation to achieve consistent crop yields. In addition, the aversion to risk on the part of lenders and farmers has fueled the widespread adoption of irrigation. Irrigation in Arkansas occurs on 1.82 million ha (4.5 million ac) (USDA NASS 2008), the majority of which is located in eastern Arkansas. Roughly 77% of the irrigated acreage is in rice and soybean production, with the remainder in cotton (11%) and other crops. Irrigation in Arkansas is dominated by furrow irrigation (46%) and by controlled flooding (35%) for rice production, with the remainder in sprinkler (18%). Irrigation in the LMRB is similar to the breakdown in Arkansas, with slightly fewer acres in flooded irrigation and 22% of the irrigated acres serviced with sprinkler (USDA NASS 2008).

The primary source of irrigation water in eastern Arkansas is and has historically been the shallow Mississippi River Valley alluvial aquifer. In Arkansas, approximately 80% of irrigation water comes from groundwater (NASS (National Agricultural Statistics Service) 2008). The alluvial aquifer is 15 to 45 m (50 to 150 ft) deep and extends north from Arkansas into Missouri and south to Louisiana, under the Mississippi River to Tennessee and Mississippi, and underlies the Mississippi Alluvial Plain. Due to a shallow confining layer, the alluvial aquifer has limited recharge capacity (Fitzpatrick 1990).

Records of pumping from the alluvial aquifer in Arkansas began in the early 1900s. In 2009, the alluvial aquifer in Arkansas was pumped at 21.531×10^6 m^3 d^{-1} ($5{,}687 \times 10^6$ gal day^{-1}), but it is estimated by the Arkansas Natural Resources Commission that the sustainable yield is 11.307×10^6 m^3 d^{-1} ($2{,}987 \times 10^6$ gal day^{-1}) (Fugitt et al. 2011). This produces an unmet demand of 10.224×10^6 m^3 d^{-1} ($2{,}700 \times 10^6$ gal day^{-1}). Approximately 96% of the total water is pumped for agriculture. Several counties in Arkansas have been designated as critical groundwater areas as a result of the pumping of the alluvial aquifer. Critical groundwater status allows producers to have additional access to otherwise unavailable funding sources for irrigation improvements. Some producers have already taken advantage of these incentive programs to build on-farm irrigation reservoirs and install tail water recovery systems that allow irrigation runoff to be recycled and used.

The reduction of readily accessible irrigation water has forced some producers to go deeper into the alluvial aquifer and in some cases into the underlying Sparta Aquifer, significantly increasing production costs. However, the recharge rates of this deeper aquifer are much slower and it is the drinking water source for municipalities in the region. As the needs of municipalities increase, so will demands on lower-lying aquifers. The competing uses of water in the state may force producers to modify their practices.

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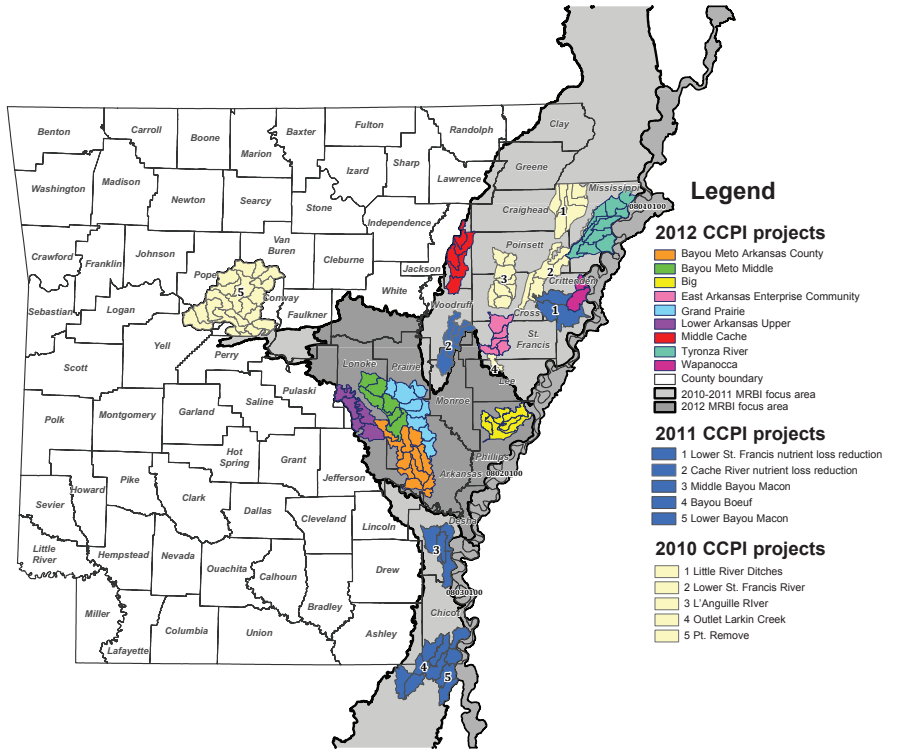
MISSISSIPPI RIVER BASIN HEALTHY WATERSHED INITIATIVE

USDA NRCS established the MRBI to facilitate the implementation of conservation practices and systems that avoid, control, and trap nutrient runoff; improve wildlife habitat; and maintain agricultural productivity (USDA NRCS 2012). USDA NRCS uses two programs within MRBI to reach these goals: Cooperative Conservation Partnership Initiative (CCPI) and the Wetlands Reserve Enhancement Program. Funds are provided through MRBI initiatives and programs with multiyear agreements with cooperators to encourage adoption of conservation practices, including nutrient and water management. USDA NRCS provides a mechanism to monitor the impact of these practices. An improved understanding of the impact these practices have on water quality will make better management of the resources possible.

Nearly all of the monitoring sites in the statewide Arkansas network were established to monitor water resources related to various MRBI CCPI project areas in Arkansas. Between fiscal years 2010 and 2013, USDA NRCS will fund US$320 million in support of the MRBI projects through CCPI, Wetlands Reserve Enhancement Programs, Conservation Innovation Grants, and other grants in the 13 participating states. Arkansas had five MRBI CCPI project areas selected in 2010, five in 2011, and nine in 2012 (figure 2), with four-year project funding of US$16.4 million, US$15.7 million, and US$49.6 million, respectively. The funds are expected to impact over 1.38×10^6 ha (3.4×10^6 ac).

Figure 2

USDA Natural Resources Conservation Service Mississippi River Basin Healthy Initiatives project areas from 2010, 2011, and 2012 in Arkansas with Cooperative Conservation Partnership Initiative (CCPI) projects (USDA NRCS 2012).



PARTNERSHIP

Given the water resources issues in the state of Arkansas and the importance of agriculture, partnerships were formed among producers, natural resource managers, and scientists to identify issues and potential solutions. The primary partners in establishing the statewide network of Arkansas were Arkansas State University, University of Arkansas, University of Arkansas at Pine Bluff, USDA Agricultural Research Service, USDA NRCS, Arkansas Natural Resources Commission, Arkansas Association of Conservation Districts, and agricultural producers representing the major commodities of the state. The primary entities worked and continue to work closely with individual producers to ensure the monitoring and management proceeded as planned. The development of this network among primary partners has been greatly catalyzed by close support of the Arkansas Department of Environmental Quality, Arkansas Game and Fish Commission, US Environmental Protection Agency, and US Geological Survey. Stakeholder groups have also been instrumental in establishment and continued success of the network and include Arkansas Soybean Promotion Board, Arkansas Rice Research and Promotion Board, Cotton Incorporated, Arkansas Corn and Grain Sorghum Promotion Board, United Soybean Board, Monsanto, and Arkansas Farm Bureau.

NETWORK DESCRIPTION

Field Installation. The two objectives of edge-of-field sensor installation were to automatically collect water samples for subsequent laboratory analysis and measure runoff volume (Sharpley et al. 2008). Edge-of-field sites consist of a water sampler, flow sensors, data loggers, and communication devices—all housed in a weather-resistant shelter. Water quality samples and runoff measurements were triggered to collect based on threshold values of discharge. Both irrigation and precipitation events trigger sampling at the stations.

At each station, an ISCO (Teledyne Technologies Inc., http://www.teledyne.com) automated water sampler was installed to automatically collect water samples once the threshold of flow was detected. Automated sampling was flow-weighted, meaning a sample was triggered when the cumulative flow reached a threshold value. A composite or discrete sample was collected as a function of the study objective, with the majority of the stations set to collect composite samples. Each sample was analyzed for suspended solids, sediment, and dissolved and/or total nitrogen and phosphorus.

Runoff volume was calculated from pressure transducer measurements of depth at the outlet structure with the appropriate equations for the flow structure. Where flumes were not in place, automatic velocity measurements were collected in addition to depth to calculate discharge. Precipitation

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was also measured at the monitoring stations to have an accurate field or farm specific measure. Additional sensors at select monitoring locations include atmometers, soil moisture sensors, turbidity meters, and flow meters.

Each monitoring station was equipped with a data logger to automatically store collected data. All stations were equipped with remote access via cellular modems and/or radios. Communication to the stations allowed for troubleshooting, programming modification, and remote data collection. Most stations run on batteries recharged with a solar panel.

Laboratory Analysis. Water samples are collected from the field after storm and irrigation events, put on ice, and transported to one of three laboratory facilities: Arkansas State University Ecotoxicology Research Facility, University of Arkansas at Pine Bluff Water Quality and Ecosystems Health Laboratory, or Arkansas Water Resources Center Water Quality Laboratory.

The Arkansas State University Ecotoxicology Research Facility is located on campus in Jonesboro, Arkansas. It is US Environmental Protection Agency certified (AR#00917) for total suspended sediment (TSS) and nutrients (nitrogen dioxide [NO_2^-], nitrate [NO_3^-], phosphate [PO_4^{3-}]) testing. The Ecotoxicology Research Facility is also certified in acute and chronic whole effluent toxicity testing for the fulfillment of the National Pollutant Discharge Elimination System discharges.

The Water Quality and Ecosystems Health Laboratory is located at the University of Arkansas at Pine Bluff Aquaculture and Fisheries Center. The laboratory can handle basic and advanced water quality analysis, including dissolved oxygen, nutrients, sediments, pH, and metals analysis by American Public Health Association Standard Methods, and biological sample (algae, benthic macroinvertebrates, and fishes) analysis.

The Arkansas Water Resources Center Water Quality Laboratory is located at the University of Arkansas main campus in Fayetteville, Arkansas. It is US Environmental Protection Agency certified (#12-023-0) for turbidity, nitrate, orthophosphate, total Kjeldahl N, and total P testing, in addition to a long list of other water quality parameters.

Sediment and nutrient analysis was determined using American Public Health Association 2005 method 2540 D for TSS and methods 4500 for nutrients. Nitrate analysis (4500-NO_3-E) uses a cadmium reduction and analyzed NO_2 using a colorimetric reaction with a method detection limit (MDL) of 0.02 mg N L^{-1} (1.7×10^{-7} lb N gal^{-1}) and range from 0.2 to 5 mg N L^{-1} (1.7×10^{-6} to 4.2×10^{-5} lb N gal^{-1}). Orthophosphate (4500-P E) is determined with an ascorbic acid method with a MDL of 0.01 mg L^{-1} (8.3×10^{-8} lb gal^{-1}) and range from 0.05 to 1.0 mg P L^{-1} (4.2×10^{-7} to 8.3×10^{-6} lb P gal^{-1}). Total P and total N (4500-P J) utilizes persulfate digestions and ascorbic acid method for analysis of total P (MDL 0.01 mg L^{-1} [8.3×10^{-8} lb gal^{-1}] and range of 0.05 to 1 mg P L^{-1} [4.2×10^{-7} to 8.3×10^{-6} lb P gal^{-1}]) and cadmium reduction analysis for total N (MDL 0.02 mg N L^{-1} [1.7 x 10^{-7} lb N gal^{-1}] and range of 0.2 to 5 mg N L^{-1} [1.7×10^{-6} to 4.2×10^{-5} lb N gal^{-1}]). In addition to TSS, the suspended-sediment concentration was measured given concerns around TSS use in natural water systems or samples that are not wastewater (Gray et al. 2000). ASTM Method D3977-97 was used to determine suspended-sediment concentration.

Discovery Farms—University of Arkansas Division of Agriculture. The University of Arkansas Division of Agriculture established monitoring stations on six farms across the state (figure 1). Stations are located in Arkansas, Conway, Cross, Desha, and Washington counties. In 2010, construction of monitoring stations began, and by 2012, eighteen sites were established. The stations are equipped to monitor water quality and quantity from poultry/beef/pasture, rice/soybean/corn, rice/soybean, rice, and cotton production. The crop sites range in size from 8.5 to 32.4 ha (21 to 80 ac) fields. Paired fields are monitored for rice/soybean and rice/soybean/corn production at two locations. Water use is measured on an entire farm of approximately 485.6 ha (1,200 ac) that is equipped with a reservoir and tailwater recovery system. Three of the pasture fields are 26 ha (64 ac) and one is 72 ha (178 ac). Conservation practices of interest at these stations are nutrient management, water management including irrigation planning, cover crop, and tillage practices. Eleven sites are in MRBI focus areas of Lake Conway–Point Remove Watershed, L'Anguille River, and Middle Bayou Macon Watershed.

University of Arkansas at Pine Bluff. The sites at University of Arkansas at Pine Bluff target the soybean/rice/corn rotation that is common in the southeastern portion of the state. The fields were 44 and 24 ha (109 and 60 ac) each and were both located in Chicot county in the Bayou Boeuf and Lower Macon watersheds, respectively (figure 1). The rice was irrigated with straight levees and side-inlet delivery, and the corn/soybean rotation was furrow irrigated with water pumped with a diesel-powered groundwater pump. Both sites were established in 2011, and target conservation practices were water and nutrient management.

USDA Agricultural Research Service and Arkansas State University. A partnership between USDA Agricultural Research Service and Arkansas State University established monitoring on 4 farms at ten fields in northeastern Arkansas. Each study site consists of two paired fields of approximately the same size, soil characteristics, and crop type. The study sites are located in the MRBI project areas of Lower St. Francis and Little River Ditches; both of these subbasins are tributaries of the Mississippi River (figure 1). The pairing of the fields allows for implementation of conservation practices on one field while the other is treated conventionally. The conservation practices of interest are nutrient management, water management, irrigation planning, cover crops, buffer strips, and shallow water development for waterfowl use. There are five field pairs: three in cotton, one in soybean, and one in rice. The paired cotton fields are approximately 32, 11.7, and 7.2 ha (80, 29, and 18 ac) each, while the soybean and rice fields are approximately 16 ha (40 ac) each. Irrigation at all stations is from groundwater with either electric or diesel engines. The rice is flood irrigated with straight levees, and all other crops are furrow irrigated. From 2010 to 2012, flow-weighted discrete samples were collected along with automatic turbidity measurements to compare to sediment concentration from laboratory analysis. In 2013, composite samples will be collected.

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FUTURE

Support for the statewide network is expected to continue through the universities, organizations, and government entities currently involved. USDA NRCS is expected to complete a major revision to the monitoring practice and will result in a conservation activity with specific guidelines to monitoring edge-of-field sites for water quality. General guidelines within the revised activity will follow similar instrumentation and sampling protocol as described for sites within the statewide Arkansas network.

In late 2012, the primary network partners received a Conservation Innovation Grant to utilize existing monitoring stations to evaluate the performance of lower-cost sampling equipment developed by the University of Wisconsin at Platteville. The grant will develop a training guide and program to help USDA NRCS expand its capacity to provide local, edge-of-field monitoring. This effort will provide more data to help target the placement of conservation practices, provide information for producers to utilize adaptive management, and provide much needed data to verify, calibrate, and validate field-scale simulation models and to characterize the cause and effect relationships between agriculture and in-stream water quality.

Arkansas was fortunate to have nine new MRBI CCPI project areas established in 2012 (figure 2). All of the new areas cite monitoring as a project priority. Monitoring of these study areas will expand the existing statewide network significantly.

CONCLUSIONS

It is our research and extension challenge to innovate in order to maintain or increase crop yields for an increasing population with existing and potentially dwindling water resources while maintaining designated water quality uses. The producer is a steward of the land who can benefit society and the environment, but only if armed with tools that will allow for better management while still producing consistent crop yields. An important step in this process is the improved understanding of how specific conservation practices affect water quality and water quantity.

The monitoring network described in this document is focused on field-scale to farm-scale quantification of water resources, including both water quality and water quantity, related to the production of Arkansas's major cropping systems. Though specific to Arkansas, the stations, issues, and conservation practices described are representative of the LMRB. Judicious management and conservation of water in the LMRB and specifically in the state of Arkansas supported by aggressive monitoring of innovative conservation practices will propel agriculture in this region into a more productive, sustainable future.

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