The Mississippi Alluvial Valley (USA)

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Abstract

The Mississippi Alluvial Valley (MAV) is over 800 km long, drains about 41% of the conterminous United States, and is the largest continuous system of wetlands and aquatic habitats in North America comprising approximately 10 million ha. Elevation and hydrology primarily influence the frequency, duration, and periodicity of flooding, which in turn determine plant community composition and species distribution. Largely forested prior to the arrival of Europeans, flood control for agriculture and human settlement caused nearly 75% loss of riparian forests in the MAV by the

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late twentieth century, with only highly fragmented patches remaining today. However, diverse landforms and ecological communities in the MAV provide unique habitats for myriad species. Many sources of nonpoint source pollution (e.g., fertilizers, toxic chemicals, livestock waste) negatively influence water quality in the MAV. Primary crops grown in the MAV include corn, cotton, rice, and soybeans. Rice fields are especially important to diverse waterbirds during migration and winter.

Keywords
Bottomland hardwood forests · Delta · Floodplains · Hydrology · MAV · Mississippi · Mississippi River · Waterbirds · Waterfowl · Wetlands

Introduction

The Mississippi Alluvial Valley (MAV) is over 800 km long, ranges from 32 to 128 km wide, and comprises approximately 10 million ha in seven states including Arkansas, Kentucky, Illinois, Louisiana, Mississippi, Missouri, and Tennessee (Reinecke et al. 1989 [and references therein], Fig. 1). This vast floodplain begins at the convergence of the Mississippi and Ohio Rivers at Cairo, Illinois, extends to the northern Gulf of Mexico, and drains about 41% of the conterminous United States (Reinecke et al. 1989; Klimas et al. 2012). The MAV was largely forested prior to the arrival of Europeans, following which flood control for agriculture and human settlement caused nearly 75% loss of riparian forests in the MAV by the late twentieth century, with only highly fragmented patches remaining today (Gardiner and Oliver 2005; Klimas et al. 2012). Moreover, the Mississippi River was channelized and leveed for flood protection at unprecedented rates following the 1928 Flood Control Act (King et al. 2005; Oswalt 2013 [and references therein]). Primary crops grown in the MAV include corn, cotton, rice, and soybeans. Rice fields are especially important to diverse waterbirds during migration and winter (Reinecke et al. 1989; Petrie et al. 2014).

Hydrology

Climatic events of the Pleistocene (Quaternary Period) largely shaped the MAV (Reinecke et al. 1989; Klimas et al. 2012). The Mississippi River sculpted the MAV with alluvium through advancing and retreating glaciers, which also caused the Gulf Coast sea level to rise and fall. The floor of the MAV today rises gradually northward at nearly 0.1 m/km from near sea level in south Louisiana to about 100 m in southeastern Missouri (Reinecke et al. 1989).

The MAV contains six drainage subbasins including the St. Francis, Western Lowlands, Arkansas Lowlands, Yazoo, Boeuf, and Tensas. The mostly flat, broad alluvial plain with river terraces and levees contributes to the MAV being the largest continuous system of wetlands in North America. Elevation and hydrology primarily influence the frequency, duration, and periodicity of flooding, which in turn

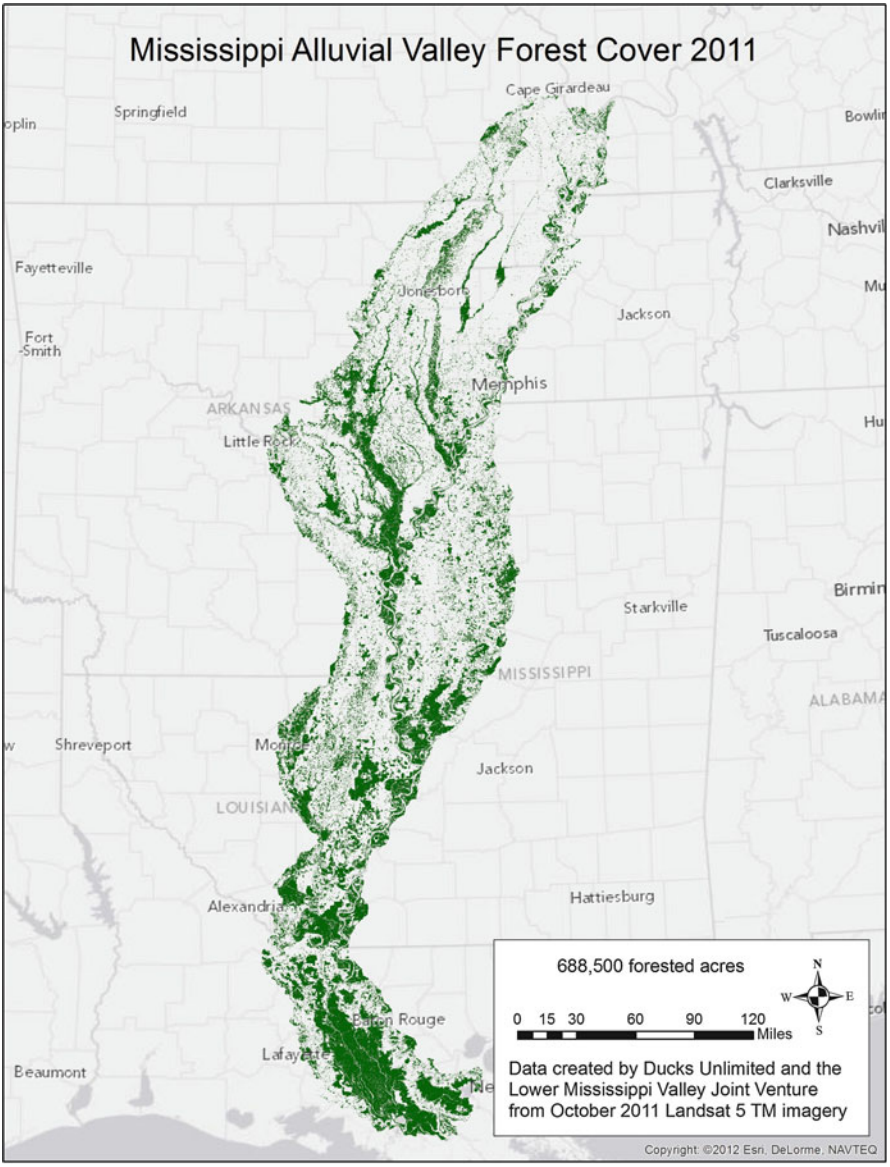

Fig. 1 Distribution and abundance (278,636 ha) of forest cover in the Mississippi Alluvial Valley (*MAV*), 2011; the MAV is contained within the forest cover perimeter (Image credit: Lower Mississippi Valley Joint Venture © with permission)

determine plant community composition and species distribution (Reinecke et al. 1989; Klimas et al. 2012).

Average annual precipitation is 137 cm in the MAV; 111 cm in Puxico, Missouri (northern MAV); and 154 cm in Baton Rouge, Louisiana (southern MAV) (Barlow and Clark 2011). Despite abundant rainfall, hydrological modifications have greatly affected flood frequency. For example, in western Mississippi, a 2-year flood, or the water level that would be reached or exceeded on average in 1 in every 2 years, originally inundated >1.8 million ha but has been reduced to approximately 415,000 ha (Reinecke et al. 1989).

Wetland and Aquatic Systems

The MAV contains a complex of wetland and aquatic habitats that include rivers, seasonal emergent wetlands, bottomland hardwood forest, scrub-shrub, natural lakes, flood control reservoirs, and aquaculture ponds (Reinecke et al. 1989). Wetlands are typically categorized as lacustrine and palustrine. Palustrine wetlands are further subdivided into emergent herbaceous, forested, and scrub-shrub wetlands. In addition to natural wetlands, post-harvested rice fields, particularly when flooded, provide important habitats to autumn migrating and wintering waterbirds.

Riverine Wetlands

Hydrofluvial processes of the Mississippi River and its tributaries formed the MAV's meandering streams, rivers, oxbow lakes, and scrub-shrub wetlands (Brown et al. 2000). River water levels are predominately driven by winter rains that cause overbank flooding of the associated floodplain, inundating forested and herbaceous plant communities and agricultural fields.

Palustrine Emergent Wetlands

Seasonally flooded wetlands generally dry out or contain exposed mudflat sometime between spring and summer (i.e., March to July) that produce annual plant communities (Fig. 2). Annual grasses and weeds such as barnyard grass (millets, *Echinochloa* spp., panic grasses *Panicum* spp., and smartweeds *Polygonum* spp. are a few species indicative of seasonal herbaceous wetland (Reinecke et al. 1989). These systems may flood anytime during the year with overbank flooding from rainfall or deliberate inundation by wetland managers from fall-spring. Wetland managers deliberately flood (≤45 cm deep) these habitats to attract wetland-dependent birds, primarily in fall and winter (November to March). Combined dry mass of seeds and tubers may be ≥496 kg/ha in seasonal, or moist-soil, wetland impoundments (Kross et al. 2008).

Bottomland Hardwood Forest

Once covering 10 million ha, bottomland hardwood forest was the dominant ecosystem of the MAV. Extensive deforestation over the past two centuries has resulted in

Fig. 2 Seasonally flooded palustrine emergent wetland, e.g., moist-soil impoundment, flooded in fall-winter to provide high-energy natural seeds (e.g., annual wetland grasses and sedges), tubers, browse, and aquatic invertebrates for migrating and wintering waterfowl and other waterbirds (Photo credit: R.M. Kaminski © Rights remain with the photographer)

2.6 million ha of highly fragmented patches of forest as of 2005 (Conner and Sharitz 2005). Bottomland hardwood forests (Fig. 3) of the MAV are generally categorized as (1) oak-gum-cypress and (2) elm-ash-cottonwood communities (Conner and Sharitz 2005). Dominant tree species in these communities include sweetgum *Liquidambar styraciflua L.*, green ash *Fraxinus pennsylvanica*, bald cypress *Taxodium distichum*, sugarberry *Celtis laevigata*, red maple *Acer rubrum*, American sycamore *Platanus occidentalis*, water tupelo *Nyssa aquatica*, eastern cottonwood *Populus deltoides*, black willow *Salix nigra*, elms *Ulmus* spp., hickories *Carya* spp., and at least nine species of oak *Quercus* spp.

Flooding of bottomland hardwood forest is dynamic and varies both temporally and spatially according to winter rains and river levels (Fig. 4). Succession of forest tree species generally occurs in three situations in the MAV: (1) on poorly drained sites at low elevations in major river bottoms (e.g., overcup oak *Quercus lyrata*, common buttonbush *Cephalanthus occidentalis*, and bald cypress), (2) on better drained higher-elevation sites in major river bottoms (e.g., sycamore, sweetgum, oak-hickory), and (3) in minor river bottoms on poorly drained sites (e.g., black willow, tupelo) and better drained sites (e.g., elm-ash, oak-hickory). Contemporary forests have increased in maples and hickories as they replace sweetgum and oaks, largely because of fire suppression and modified flooding regimes in parts of the MAV. Passage of the 2002 Security and Rural investment Acts (Farm Bill) has

Fig. 3 Cypress-tupelo brake of the Mississippi Alluvial Valley, Mississippi, USA (Photo credit: Ducks Unlimited, Inc. © Rights remain with the organization)

Fig. 4 Bottomland hardwood forest flooded during fall-winter for waterfowl hunting and conservation, Bayou Meto Wildlife Management Area, eastern Arkansas, USA (Photo credit: Ducks Unlimited, Inc. © Rights remain with the organization)

particularly spawned reforestation in the MAV through programs like the Wetland Reserve Program (WRP; see "Conservation Status" section below). More than 260,000 ha of land were enrolled in WRP in Arkansas, Louisiana, and Mississippi from 1992 to 2011 (Oswalt 2013).

Palustrine Scrub-Shrub

Densely vegetated wetland habitat dominated by common buttonbush and eastern swamp privet *Forestiera acuminate* interspersed with open water. Scrub-shrub environments provide loafing habitats for waterfowl and cover from predators for wood duck *Aix sponsa* broods and perches for other birds (Reinecke et al. 1989).

Lakes

Usually permanent deep-water (>2 m) habitat supports obligate hydrophytes and freshwater fish and provides roosting and feeding sites for some waterbirds, commonly oxbow lakes formed by abandoned meanders of the Mississippi River (e.g., Moon Lake, Mississippi).

Reservoirs (Lacustrine)

Reservoirs have earthen dams that are typically constructed by the US Army Corps of Engineers (USACE) for flood control and recreation throughout the MAV. Mississippi contains four of these reservoirs (e.g., Sardis Lake, Sardis), which are operated by the USACE. Some reservoirs provide excellent fishing opportunities for recreationists, but reservoirs are generally flooded too deeply to provide significant foraging value for most wetland-dependent birds (e.g., shorebirds and waterfowl). Some wetland birds use lake edges when water levels permit access to seeds and invertebrates or forage on mudflats when exposed in late summer-early fall (Reinecke et al. 1989).

Aquaculture Ponds (Lacustrine)

Leveed impoundments are primarily used for commercial channel catfish *Ictalurus punctatus* production and flooded ~1 m deep. Dominant bird species that use commercial ponds during fall-winter include lesser scaup *Aythya affinis*, double-crested cormorant *Phalacrocorax auritus*, and ruddy duck *Oxyura jamaicensis*, as do generalist species (e.g., northern shoveler *Anas clypeata*, American coot *Fulica americana*, great blue heron *Ardea herodias*, and great egret *Ardea alba*). As many as 150,000 birds used catfish ponds in the mid-1980s, with an average of 100,000 individuals using the ponds weekly. Some waterbirds seek catfish ponds as some impoundments may contain >50 kg/ha of macroinvertebrates and abundant small fish (Feaga 2014). Commercial aquaculture has declined in the MAV because of competition from foreign markets, infrastructure and fuel costs, and other reasons. There were 64,000 ha of commercial aquaculture ponds in Mississippi, Louisiana, and Arkansas in 2001, but only 25,000 ha were operational in those states by 2012. Drained aquaculture ponds with exposed mudflats provide important substrates for shorebirds. An estimated 1,100 ha of mudflats were available to shorebirds in MAV regions of Arkansas, Louisiana, and Mississippi in fall 2009 (Lehnen and Krementz 2013). Idle aquaculture ponds that shallowly flood (≤45 cm) also provide important seasonal wetland habitats for migrating and wintering birds when early succession grasses and weeds germinate and mature from exposed mudflats (Feaga 2014), similar to moist-soil impoundments.

Rice Agriculture

Commercial rice production composes >809,000 ha in MAV states of Arkansas, Louisiana, Mississippi, and Missouri, and approximately 20% of all harvested rice is flooded in the MAV. Harvested rice fields yield approximately 79 kg/ha of waste rice for wintering waterfowl, or approximately 11% of total food energy acquired by these birds during winter in the region (Petrie et al. 2014).

Biodiversity

The MAV contains diverse landforms and ecological communities that provide unique habitats for myriad species (Reinecke et al. 1989; Brown et al. 2000). Species biodiversity of the MAV is broad and includes ≥183 freshwater fish, 50 mammals, 45 reptiles and amphibians, and 37 mussels (Brown et al. 2000). There are three federally threatened vertebrates, piping plover *Charadrius melodus*, Louisiana black bear *Ursus americanus luteolus*, and loggerhead *Caretta caretta*; eight endangered vertebrates, Bachman's warbler *Vermivora bachmanii*, ivory-billed woodpecker *Campephilus principalis* (likely extinct), red-cockaded woodpecker *Picoides borealis*, interior least tern *Sternula antillarum athalassos*, Attwater's greater prairie chicken *Tympanuchus cupido attwateri*, gray myotis *Myotis grisescens*, West Indian manatee *Trichechus manatus*, and Kemp's ridley sea turtle *Lepidochelys kempii*; and one endangered vascular plant, pondberry *Lindera melissifolia* (Griep and Collins 2011) (US Fish and Wildlife Service, http://www.fws.gov/endangered/index.html). The manatee and sea turtle primarily associate with coastal waters of the southeastern and eastern United States. The MAV is used by approximately 60% of all species of birds in the lower 48 states (Brown et al. 2000). Wood duck and hooded merganser *Lophodytes cucullatus* nest in the MAV, and some individuals of these species remain year-round. During migration and winter, waterfowl forage primarily on acorns, wetland plant seeds and tubers, aquatic invertebrates, and waste grain (Reinecke et al. 1989; Kross et al. 2008). Wetlands containing mudflats and water depths of up to ≤45 cm are generally accessed by most waterbirds (Reinecke et al. 1989). Complexes of habitats are generally important to some wintering waterfowl in the MAV, for instance, habitats comprised of 47% cropland, 20% forested or scrub-shrub wetland, 20% emergent or seasonal wetland, and 13% open water contained the greatest mallard abundances at local (20 ha) and landscape (5,024 ha) scales in the Mississippi portion of the MAV in the mid-2000s (Pearse et al. 2012). Rice fields are an important agricultural resource in the winter habitat complex for waterfowl and other birds (Petrie et al. 2014).

Forests of the MAV promote avian diversity because forests form a continuous pattern of vertical structure with different seral stages, providing forest-interior species and niche specialists with essential habitat (Brown et al. 2000). Forest birds of the MAV choose habitat based on the vertical structure of hardwoods, flood regimes, and microhabitats such as vine tangles, canebrakes, Spanish moss *Tillandsia usneoides*, and scour channels (Brown et al. 2000). Shorebird use was likely limited to sandbars and riverine mudflats historically in the MAV (Brown et al. 2000). However, today's largely open, agriculturally dominated landscape of the MAV has supported ~29 species of continental shorebirds (Ranalli and Ritchison 2012). Aquatic species such as the channel catfish and red swamp crayfish *Procambarus clarkii* support commercial fisheries of local and national economic importance.

Conservation Status

A coalition of natural resource partners represented by state and federal agencies, universities, and nongovernmental organizations work to champion conservation in the MAV. The Lower Mississippi Valley Joint Venture (LMVJV) operates as a branch of the US Fish and Wildlife Service's Migratory Bird Program (LMVJV Management Board 2013). The LMVJV is one of the 22 regular (and more recently three species specific; see mbjv.org) joint ventures that were formed via the North American Waterfowl Management Plan in 1986, arguably one of the most effective wildlife management plans ever conceived. There are five working groups of the LMVJV: the Forest Resources Conservation, Landbird, Shorebird, Waterfowl, and Winter Rice Food Availability working groups. The LMVJV is the primary science entity for sustaining bird populations and related habitats in the MAV and Gulf Coastal Plain regions. To build on an already successful model, 22 Landscape Conservation Cooperatives (LCC) (http://www.fws.gov/landscape-conservation/lcc.html) were formed in the United States by the Secretary of the Interior in 2010. The LCCs are represented by myriad conservation interest groups to champion landscapes that sustain natural and cultural resources for current and future generations. Like the LMVJV, LCCs are science based and strive to understand and disseminate information on the effects of climate change and other environmental stressors at landscape scales. The Gulf Coastal Plains and Ozarks LCC, covering the ecoregion of the MAV, works across 72 million ha in 12 states, mostly in the southern United States. Restoration of wetlands, riparian forests, and other important resources in the MAV is largely guided by the LMVJV and GCPO LCC entities.

Fig. 5 Restoration of bottomland hardwood forest in the Grand Prairie region, Arkansas, USA. Note spacing between tree rows, a method to encourage sunlight in forest floor to facilitate growth of palustrine emergent herbaceous wetland plants, e.g., moist-soil vegetation, such as annual wetland grasses and sedges (Photo credit: J.Pagan © Rights remain with the photographer)

Approximately 82% (2.9 million ha) of the forested area of the MAV is privately owned. Of the remaining 18% (526,000 ha), 52% is owned by state and local governments, 31% by the US Fish and Wildlife Service, and the remainder by other federal agencies (Oswalt 2013). Preserving existing forest land is important to many constituents of the MAV, and restoration of wetlands and associated habitats from marginal agricultural lands is a priority. Some 11,000 landowners that managed >1.07 million ha have enrolled in the Wetlands Reserve Program (WRP) across the United States since the program's inception ~1992. The WRP has been significant in the MAV where 261,708 ha were reforested per 1,857 private landowner agreements in Arkansas, Louisiana, and Mississippi from 1992 to 2011 (Oswalt 2013; Fig. 5). The WRP is arguably the most significant and effective wetland and associated forest restoration program on private lands in the world. The WRP was established to restore and protect functions and values of wetlands in agricultural landscapes, emphasizing habitat for migratory birds and wetland-dependent wildlife, protection and improvement of water quality, flood attenuation, ground water recharge, protection of native flora and fauna, and educational and scientific scholarship (Faulkner et al. 2008). Examples of other conservation programs that assist private landowners in the MAV include the Conservation Reserve Program, Wildlife Habitat Incentive Program, and Environmental Quality Incentives Program.

Ecosystem Services

The WRP has generated as much as $300 M annually through the provision of ecosystem services (King et al. 2005; Jenkins et al. 2010; Oswalt 2013). When agricultural land is retired and enrolled into a WRP easement, by default the nitrogen (N) losses driven by fertilizer application, fixation, and tilling cease (Jenkins et al. 2010). Nitrate (NO_3) is the N compound that is most closely associated with the hypoxic zone in the Gulf of Mexico (see "Future Challenges" section), and WRP reforestation in the MAV provided an estimated social welfare value of $1248/ha/year in N mitigation (Jenkins et al. 2010). Relative to greenhouse gas (GHG) dynamics, BLHFs store more than eight times the level of carbon and have greater denitrification potential than agricultural fields (Faulkner et al. 2008). When retired agricultural land is reforested via WRP, the monetized net mitigation value of GHG, or the difference between WRP and agricultural sites, has ranged from $171 to $222/ha/year for the social values (Jenkins et al. 2010). By combining values of GHG mitigation, N mitigation, and waterfowl recreation, Jenkins et al. (2010) estimated the market value of these services at $1,035/ha annually for the MAV, concluding that the WRP has provided a favorable return on public investment.

Socioeconomic impacts of hunting, fishing, bird-watching, and other outdoor-related activities in the MAV are significant. In the delta of Mississippi alone, outdoor recreation generated $2.7 billion in goods and services in 2005–2006; waterfowl hunting alone provided an adjusted $86.8 million (2009 USD) in economic impacts and supported 1,139 full- and part-time jobs in Mississippi (Henderson et al. 2010).

In addition, the channel catfish aquaculture industry of Arkansas, Louisiana, and Mississippi currently generates $56 million in annual payroll that supports many rural economies, and rice agriculture contributes nearly $10 billion to the regional MAV economy. Commercial harvest of red swamp crayfish is the most valued shellfish crop in the United States. Crayfish production was valued at $127 million annually in 2008, of which >93% of production occurs on about 43,000 ha in Louisiana, some of which originate from the Atchafalaya Basin or elsewhere in the MAV (National Aquaculture Sector Overview 2011).

Future Challenges

Significant anthropogenic modifications in the nineteenth to twentieth centuries have negatively affected most flora and fauna of the MAV. Water quality is a significant indicator of the health of the Gulf of Mexico. Many sources of nonpoint source pollution (e.g., fertilizers, toxic chemicals, livestock waste) negatively influence water quality in the MAV. Excess nitrogen and phosphorous result from urban development, industry, agricultural runoff, atmospheric deposition, and other sources throughout the entire Gulf watershed (Jenkins et al. 2010). Floodplain lakes of the MAV have experienced a 50-fold increase in sedimentation rates since land clearing for agriculture (Dembkowski and Miranda 2012). Agricultural runoff, largely from America's upper Midwestern "Corn Belt," currently contributes approximately 74% of the NO_3 load transported by the Mississippi River (Rabalais et al. 2002; Howarth et al. 2002; Faulkner et al. 2008). The increase in dissolved and particulate NO_3 levels causes extensive eutrophication and hypoxia (low oxygen) or "dead zone," in the northern Gulf of Mexico (Faulkner et al. 2008). Each summer the hypoxic zone forms in the Gulf from the mouth of the Mississippi River to the Upper Texas Coast. Hypoxia is a serious environmental concern because it creates uninhabitable conditions for marine life and threatens diverse and sustainable fisheries and sensitive ecosystems. Nutrient loading is also affected by stratification (layering) of waters in the Gulf of Mexico (Jenkins et al. 2010). To reduce NO_3 and subsequent hypoxia in the Gulf, Mitsch et al. (2001) recommended that an additional 971,800 ha of lands be used for creating wetlands and restoring riparian forests throughout the entire Mississippi River Basin (Faulkner et al. 2008).

The Mississippi River Valley alluvial aquifer is the third most used aquifer in the United States. Arkansas and Mississippi are the first and second greatest users, respectively, of the aquifer, mostly for crop irrigation. In Mississippi, for example, $>3.5^{10}$ m^3 are withdrawn from the aquifer each day. In several counties in the western Mississippi Delta, an estimated cumulative loss of nearly 186 million m^3/year in water storage has occurred from 1987 to 2009. An estimated 25% reduction in water use in that geographic region of Mississippi would result in a 32% improvement across the entire Mississippi Delta, which may be an important conservation strategy to ensure adequate water supplies in the future (Barlow and Clark 2011).

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