SECTION THREE

Conserving Water Quality and Quantity in North American Ricelands



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ABSTRACT

Ricelands are a dominant feature in landscapes of the Mississippi Alluvial Valley (MAV), Gulf Coast, and Central Valley of California. An average 1.3 million ha/year (3.2 million acres/ year) have been planted since 2000, with an annual value of \$1.7 billion (USDA ERS 2004). Rice agriculture not only plays an important economic role in these regions, but also plays an important role in the management of water resources. Because rice is irrigated and produced using intensive water management, water quality and water quantity are affected. Research has shown that holding water on ricelands significantly improves quality of runoff waters. Examples include impoundment of abundant winter rainfall in the MAV, retainment of water after preparation for wet seeding along the Gulf Coast, and holding times designed to dissipate organic chemicals in the Central Valley of California. With respect to water quantity, production agriculture continues to be a major consumer of water resources. Research and field practices have demonstrated reduction in total water use by implementing capital improvements such as underground irrigation pipe, concrete flumes for conveyance, permanent outside levees in fields (i.e., turnrows), water-control structures for precision drainage, and recycling with tailwater recovery systems. Great strides have been made with respect to improving water quality and reducing water use in ricelands. The next major step is to harmonize North American ricelands with parent ecosystems. The most important questions are centered around "how much is enough?" Specifically, (1) how much rice area, and area of rotation crops, must be managed to improve water quality to the point that receiving waterways and ecosystems remain viable and productive; (2) how much water is needed for production agriculture and for maintenance of the surrounding ecosystem; and (3) how can these goals be met among competing interests while assuring an economically sound and sustainable rice industry?

INTRODUCTION

With the enactment of the Clean Water Act in 1972, the United States began the important task of cleaning up and maintaining the nation's water resources. For more than 30 years, federal, state, local, tribal, and private businesses and organizations have implemented a variety of programs and practices to improve water quality. These include those established by the Clean Water Act, the Coastal Zone Management Act, and recent Farm Bills. The result is a dramatic improvement of the quality of our nation's waters, and a rebirth of diverse environmental, economical, and recreational values of many of our most treasured cities and rural landscapes (USEPA 1998a, 1998b, 2002).

Indeed, all citizens of the United States should be proud of the progress made toward cleaner water over the past 30 years. In the 1970s, estimates showed that only 30–40% of our nation's waters met water-quality goals such as being safe for drinking, fishing, and swimming. Today, state monitoring data indicate that 50–60% of our nation's waters meet water-quality goals (USEPA 2002). Since the early 1980s, soil erosion from cropland has been reduced by more than 33%, keeping more than a billion metric tons (Mg) of soil each year on the

farm and substantially reducing inputs of sediments, nutrients, and other pollutants that reach streams, lakes, and rivers (USEPA 2002). The most significant strides have been made in municipalities and industry, where technology and regulation have removed these entities from being the greatest threat to water quality today.

Citizens of the United States should also be proud of progress in conserving use of water resources. In 1980, the U.S. population of 230 million reached its highest use of freshwater at 1.14 million acre feet (MAF) per day, a per capita use of 1,622 gallons/day (gal/d) (Hutson et. al 2004). By 2000, the U.S. population of 285 million used 1.06 MAF per day, a per capita use of 1,211 gal/d. Therefore, our nation has witnessed an approximate 7% decline in our overall use of freshwater resources in the past 20 years, with per capita reduction of 25%. The decline in freshwater withdrawals is especially significant in light of the fact that our population and economy continue to grow. Clearly as a nation, we are all using our surface and groundwater resources more efficiently. This conservation of water resources, both in terms of quality and quantity, proves that there can be a measurable and significant public response to economic and regulatory factors.

Despite significant progress in conservation of water resources in the United States, many hurdles still remain. Today main threats to water quality originate from the nation's vast agriculture, forest, and urban areas. Here diffuse sources of sediments, nutrients, and other pollutants move incessantly to points of concentration in our lakes, rivers, and streams. This nonpoint source (NPS) pollution is the greatest obstacle facing the management of water quality, with the most detrimental effects present in the Mississippi River and Gulf Coast regions. The main threats to water quantity are depletion of groundwater supplies and competition for all water sources among agriculture, urban populations, and industry. In no part of the United States is this more pronounced than the 17 contiguous western states, where many urban populations continue to rise at a rate well above the national average, and where irrigation agriculture accounts for 34% of the nation's entire freshwater consumption. Indeed, NPS pollution and competition for freshwater resources exemplify the challenges facing the United States today, and as in the past, public awareness and positive actions will be required for continued progress.

THE BIG PICTURE

NonPoint Source Pollution

Nonpoint source pollution is defined as movement and deposition of sediments, nutrients, organic chemicals, etc., from diffuse sources to points of concentration. These pollution sources emanate from construction sites, harvested forest lands, agricultural lands, and atmospheres above metropolitan areas. In contrast, point source pollution is defined as the discharge of waste products (e.g., municipal sewage) from a defined point. Whereas point source pollution has diminished over the past two decades, NPS pollution continues to pose a major environmental problem, and is now the leading cause of surface water impairment in the country. (Thomas 1985, USEPA 1990, Baker 1993, Goolsby and Pereira 1995, USEPA 1998a, 1998b, 2002). Thirty-nine percent (39%), 45%, and 51% of inland rivers, lakes, and estuaries, respectively, have been designated impaired (i.e., not fully supporting intended uses) during a 2000 water-quality inventory (USEPA 2002). Sediments and nutrients from agriculture were responsible for 48% of impaired rivers, 41% of impaired lakes, and also played a significant role in impaired estuaries (18%).

The most important NPS pollutant is sediment (Robinson 1971, Beasley et al. 1984, Novotny et al. 1986, USDA 1987, Novotny and Chesters 1989, USEPA 1990, Baker 1993, USEPA 1998a, 1998b, 2002). An estimated 3.6 billion Mg of topsoil were lost annually in the United States during the late 1970s and early 1980s (Beasley et al. 1984). The USDA (1990) estimated an annual loss of 2.7 billion Mg of sediment from agricultural lands during the same period. Annual offsite costs of these sediments ranged from \$2–\$6 billion, with an additional loss of \$1 billion in agricultural production (USDA 1987). Sediment reduces quality of drinking water and decreases storage capacities of lakes and drainage ways. Sediment degrades aquatic wildlife habitat by reducing light transmission for submerged plants, and covers feeding and nesting sites for fish. Most importantl, sediments are a transport mechanism carrying insoluble nutrients, organic chemicals, and trace metals.

Nitrogen and phosphorus are also important components of NPS pollution. In its various forms, nitrogen contributes to eutrophication of surface waters (Keeney 1973, Stoddard 1991), groundwater contamination (Nielsen and Lee 1987), and acidification of forest watersheds (Baker et al. 1991, Baker 1993). Nitrogen is particularly important in estuaries where algal growth is usually nitrogen limited (Stoddard 1991, Howarth 1998). Considerable information exists on point source nitrogen pollution from industry and municipal wastewater treatment plants. Nonpoint source nitrogen is derived from atmospheric sources (Morris 1991) and agricultural lands (USDA 1990, Baker 1993, USEPA 1998a, 1998b, 2002). In the United States, an estimated 9–12 million Mg of nitrogen fertilizers were used annually from 1980 to 2000, compared with 6.5 million Mg in 1970 (USDA 1990, Turner and Rabalais 2003). Researchers have reported a positive correlation between nitrate levels in water and agriculture use(Smith et al. 1987, Baker 1993, Burkart and James 1999, Kliess et al. 2000, Rabalais 2002, Turner and Rabalais 2003), supporting the contention that fertilizers have contributed to increasing trends in nitrogen NPS pollution.

Phosphorus is another important NPS pollutant affecting rivers, lakes, and estuaries (Miller et al. 1974, Baker 1993, USEPA 1998a, 1998b). Algal blooms, supported by high phosphorus loads, degrade wetlands by consuming oxygen and reducing light transmission to submerged plants. Phosphorus is slightly soluble in water but readily bonds to soil particles. Therefore reduction of NPS sediments would reduce phosphorus loading in aquatic ecosystems (Taylor 1966, Robinson 1971, Beasley et al. 1984, Baker 1993).

Total Maximum Daily Loads

As water-quality management has ascended from controlling point source to NPS contributions, focus has turned from managing individual rivers, lakes, and estuaries to managing complete watersheds. As part of the original Clean Water Act of 1976, focus has turned to pollutant loadings of individual watersheds, with a measurement system known as Total Maximum Daily Loads (TMDLs). Federal regulations define TMDLs as a quantitative assessment of pollutants that cause water-quality impairments (Houck 1999). A TMDL specifies the amount of particular pollutant that may be present in a waterbody, allocates allowable pollutant loading among sources, and provides a basis for attaining or maintaining water quality standards (USEPA 2000). On a four-year cycle, each state is required to quantitatively assess water bodies, identify those that are impaired for uses such as drinking water, recreation, irrigation, and fish and wildlife resources, then develop allocations of the maximum amount of a pollutant each impaired water body can receive yet still meet desired quality for intended uses. This action produces what is known as the Clean Water Act Section 305(b) report, and therein are listed impaired waters of each state. For these impaired water bodies, a TMDL report and action plan must be established, with specific reference to the nature and extent of NPS pollutants, recommendations as to what programs must be undertaken to control these sources, and an estimate of costs of implementing such programs. This is no small task.

To the agricultural producer, TMDL requirements could pose significant challenges. In an extreme case, given sediment runoff from row crop production was deemed the main NPS pollutant in a watershed and was declared responsible for an impaired water body, allocations could be imposed as to what amount can be exported from one's farmland. Because exports vary based on season, weather patterns, soil types, crop, and other uncontrollable factors, regulation of sediment exports would be most difficult. At this time, implementation of the load allocation for impaired watersheds is based on current state and local mechanisms, including NPS abatement programs. Almost all programs are implemented on voluntary and incentivebased actions. However, should improvements in watershed quality not be achieved in this manner, more stringent regulatory actions may someday occur. For the agricultural producer, abiding by these potentially stringent regulations will also be no small task.

Gulf Of Mexico Hypoxia

One of the best examples of the cumulative effects of land and water-quality management is demonstrated in the northern Gulf of Mexico. At a point where runoff water from 41% of the continental United States meets the ocean, nutrient loading from the Mississippi River results in an extensive area of depleted oxygen. This hypoxic zone, where bottom layers of ocean waters contain <2 ml/L of dissolved oxygen, stretches from the mouth of the Mississippi River to coastal Texas. The hypoxic zone is greatest in spring and summer when nutrient influx and production of phytoplankton are greatest. This area averaged 8,300 km² (3,205 miles²) from 1985 to 1992, and has increased to 16,000 km² (6,180 miles²) from 1993 to 2001 (USEPA 1997, Rabalias et al. 2002a, 2002b). The maxima was reached in summer 2001 with an area of 20,700 km² (7,990 miles²), greater than the size of New Jersey. The extent and intensity of this hypoxic zone is second only to the Baltic Basins of Europe.

It is important to understand the principal factors that lead to development and persistence of hypoxia in the northern Gulf of Mexico. First, development of hypoxia begins with nutrient rich waters from the Mississippi River driving increased production of phytoplankton, and zooplankton grazers, the very base of the oceanic food web. Organic carbon remnants from all plankton, plus fecal material of grazers, sinks to the ocean floor where they decompose. This decomposition process consumes significant amounts of oxygen. Second, and important to persistence of hypoxia, is the seasonal stratification of waters. Waters from the Mississippi River are relatively warm and fresh, are less dense, and therefore remain on the surface. Cooler and more saline waters within the Gulf remain on the bottom. These differences in temperature and salinity lead to strong physical stratification of the water column, with no mixing of oxygen from surface layers. The combined effect of organic carbon enrichment of the benthos, accelerated oxygen consumption from decomposition, and no mixing of oxygen rich surface waters, results in the hypoxic zone witnessed each spring and summer. Although other factors contribute to Gulf Coast hypoxia, there is very compelling evidence that this combination of nitrogen flux, primary productivity, and stratification of the water column are the collective cause (Goolsby et al. 1999, Mississippi River/Gulf of Mexico Watershed Nutrient Task Force 2001, Rabalais et al. 1999, 2002a, 2002b, Turner and Rabalais 2003). Gulf Coast hypoxia is one of the greatest examples of how land management practices and cumulative effects alter entire ecosystems over time.

The true costs of Gulf Coast hypoxia are far from being well understood, however some effects are well documented. For example, the commercial catch of brown shrimp in Texas and Louisiana has decreased as the hypoxic zone continues to expand (Zimmerman et al. 1997, Downing et al. 1999, Zimmerman and Nance 2001). The hypothesized mechanism is that the hypoxic zone acts as a barrier to brown shrimp migrating between inshore and offshore habitats that are required to meet annual life cycle needs. Most species of crustaceans, fish, and other wildlife simply migrate out of the growing hypoxic zone throughout summer (Craig et al. 2001). The consequences of this redistribution of so many species is not understood. Some examples of what are at risk include Louisiana's \$770 million commercial and recreation fisheries. More important is the loss of biological diversity that comes with reduced biomass of some fisheries and forced migration of fisheries and other wildlife. Lastly, one must consider the great costs of potential irreversible damage that may result from continued expansion of Gulf Coast hypoxia across both time and space (Keithly and Ward 2001).

Competition for Water in the American West

Water has played a vital role in the development of the American West and is a perpetual source of competition and debate. Vast areas of western agriculture exist only as a result of large-scale water projects designed to capture and convey seasonal precipitation. In the 17 states west of the 100th meridian, (a traditional dividing line between rain-fed and irrigated agriculture,) there are more than 180 water projects operated by the U.S. Bureau of Reclamation (USBR). These water projects are in virtually every major river basin. The USBR investment



Water is a precious natural resource vital to agriculture, wildlife and fisheries, and people of the American West

alone, for completed project facilities through 1992, was about \$11.0 billion (Weinberg 1997). In addition, numerous state projects were developed by nonfederal partnerships, including giants such as the State Water Project in California. Historically, the first and foremost objective of these projects was to support agriculture and encourage settlement of the American West. Now the West is being urbanized at a rate well above the national average, and the need for residential and industrial water supplies follows suit. With the com-

bined needs for urbanization, agriculture, and wildlife and fisheries, the competition for water will continue to grow.

The USBR's service to agriculture illustrates the dependency of many western producers on water projects and associated conveyance systems. Among the five USBR service areas (Figure 1), the percentage of irrigated land with no other water source ranges from 15% in the Mid-Pacific to 77% in the Lower Colorado (Table 1). Should water allocation converge to a market-driven model, the greatest impact will occur on areas producing low value crops, with few supplementary water sources that lie close to major urban areas.

Agriculture in the Mid-Pacific area, including the Central Valley of California, relies on a combination of ground water, state project water, and USBR project water (California Department of Water Resources 1987). Consequently, the dependence on USBR water is relatively small on a regional basis. Similarly, all six of the Great Plains states have access to ground water to supplement irrigation needs. In contrast, the Lower Basin, where water allocation is fiercely debated, is largely dependent on the Colorado River.

The water of the Colorado River is used by both the Upper Basin (Colorado, New Mexico, Utah and Wyoming) and Lower Basin states (Arizona, California and Nevada), as well as by Mexico (Metropolitan Water District 2004). In accordance with the Colorado River Compact, the Upper and Lower Basin states are each entitled to the exclusive beneficial consumptive use of 7.5 million acre feet (MAF) of Colorado River water each year, in perpetuity. Mexico is entitled to 1.0 MAF per year. The total commitment of 16.0 MAF exceeds the long-term average flow of the river, 13.5 MAF (Engelbert and Scheuring 1982). Thus there is more water allotted than available in many years. In addition, an option is granted to the Lower Basin states for the use of an additional 1.0 MAF for beneficial consumptive use. The 1929 California Limitation Act limits California's annual consumptive usage to 4.4 MAF, plus no more than half of any excess or surplus water not apportioned by the compact. The stage is set for fierce competition.

| REGION | ACREAGE WITH NO OTHER WATER SOURCE (%) | AMOUNT OF WATER THE BUREAU DELIVERS (acre-feet acre ⁻¹) |
|-------------------|---|--|
| Pacific Northwest | 53 | 4.1 |
| Mid-Pacific | 15 | 1.6 |
| Lower Colorado | 77 | 5.0 |
| Upper Colorado | 39 | 1.9 |
| Great Plains | 43 | 1.4 |

TABLE I Agriculture dependence on water delivered by the U.S. Bureau of Reclamation, 1989 and 1990.

Source: U.S. Department of Interior Bureau of Reclamation, 1989 and 1990. Summary statistics: Water, land, and related data. U.S. Government Printing Office, Denver, Colorado, USA.

The Lower Basin hosts the largest agricultural water district in the United States, the Imperial Irrigation District (IID), headquartered in the Imperial Valley, California. There are more than 404,700 ha (1 million acres) in the IID, half of which is farmland. The IID has consumptive water rights of 2.6 MAF from the Colorado River per year, an average 9% of the historical average flow. Since 1942, water has been diverted at Imperial Dam on the Colorado River through the All-American Canal, all of which the IID now operates and maintains (Figure 2). And, 98% of the water that the IID transports is used for agriculture. The Lower Basin also hosts the metropolitan areas of Los Angeles, San Diego, Las Vegas, Phoenix, and Tucson. There are nearly 19 million people in the Los Angeles-San Diego urban continuum, with average precipitation below 38 cm per year (15 inches/year). The Metropolitan Water District (MWD), for example, that serves much of this area is allocated 0.50 MAF of Colorado River water annually, which falls short of urban and industrial demand. The MWD delivered 1.74 MAF of water in 2004 (MWD 2004), relying on the fact that not all states divert their full entitlement of Colorado River. However, in recent years the Lower Basin states have consumed their allotments, thereby forcing urban water districts in Southern California to search elsewhere to meet growing demand.

Population growth resulted in California's use of the Colorado River to exceed the normal annual entitlement by as much as 0.80 MAF (U.S. Department of Interior 1989, 1990). Concerns raised by the Upper and Lower Basin states prompted the U.S. Department of Interior to direct California to develop a plan to balance use and allotment. A key component of the overall resulting plan is the Quantification Settlement Agreement (QSA), which is a collection of agreements among four water agencies (i.e., MWD, IID, State of California, USBR), and the U.S. Department of Interior. One of the main provisions of the QSA is the transfer of up to 0.303 MAF by 2026 of conserved agricultural water from the IID service area to other Southern California districts, while protecting the historical water rights of IID. District-wide and on-farm conservation measures will be implemented in 2008. All fields volunteered to participate will be removed from production. Water delivery gates will be locked and fields will be inspected to ensure compliance. To ensure adequate conservation and protect against overruns, the IID purchased over 16,590 ha (41,000 acres) of farmland in 2004. Participating producers will be compensated from the proceeds of water sales to the urban districts, which averaged \$276/AF in 2005. The MWD Integrated Resource Plan (MWD 2004) calls for securing another 0.50 MAF through conservation and transfers from other water projects in the state, including the Central Valley and State Water Projects, both of which are major suppliers to agriculture.

The QSA constitutes the largest water rights transfer in the history of the United States. This policy demonstrates that rigid earmarking of large quantities of water for one segment of the economy (i.e., agriculture) does not allow the flexibility needed across a range of social and economic circumstances. The transition of California into a post-industrial economy will require the reallocation of water resources (U.S. Department of the Interior 1997, Howitt 2000). The implications of this precedenetting QSA will undoubtedly influence the restructuring of water policy in California, and the role of agriculture in meeting the competitive demands for water.



FIGURE 1 The U.S. Bureau of Reclamation's 5 service regions in the Western United States.

FIGURE 2 Federal water projects in California.



Why This Big Picture?

The magnitude of these water conservation challenges are continental in scale. All of society will play an important role in addressing these challenges. As leaders in the agriculture indus-

try and conservation community, we must make management decisions to positively affect water quality, water use, and societal views on stewardship of these important resources. This big picture is intended to provide a backdrop for the conservation actions and opportunities of the rice industry and natural resource conservationists to be told.

STATE OF OUR KNOWLEDGE

Conservation Practices for Water Quality



Agriculture and conservation communities must continue their active roles in conserving water resources for the future

Loss of sediments, nutrients, and organic chemicals from agricultural lands, and consequent NPS pollution downstream, have been primary concerns for producers and conservationists for decades. Great costs are incurred at both origination and destination sites (Pimental et al. 1995). Origination costs include: (1) decreased crop production, (2) decreased infiltration and water-holding capacity, (3) increased tillage costs of compacted subsoils, and (4) increased fertilizer costs. Costs at destination site include: (1) decreased water quality, (2) decreased transport and storage capacities of streams, canals, lakes, and reservoirs, and (3) degradation of wildlife habitat. The most basic mechanisms for control of NPS discharge are both physical and biological in nature. Management must be done over ample time and space in order to accomplish the desired landscape effect.

Wetlands are the Kidneys of the Landscape

It is often said that wetlands serve the vital functions of kidneys in our landscape, cleansing waters of excess sediments and nutrients (Mitsch and Gosselink 1993). Wetlands, with their complex composition of alternating wet and dry soils, nutrient cycles, micro-organisms, plants, and animals, influence water quality by both physical and biological means. For example, physical mechanisms that allow wetlands to remove NPS variables from the water column include simple settling as flow energy dissipates, evaporation and volatilization into the atmosphere, and the attachment or adsorption to wetland soils and organic matter (McHenry et al. 1982, Wesley et al. 1994). Biological mechanisms that remove or transform NPS variables are more complex, and include nutrient cycling and incorporation into plant and animal tissues (Mitsch 1994, Martin et al. 2001, Keenan and Lowe 2001, Wetzel 2001). The capacity of wetlands to treat water

quality has encouraged an era of using constructed wetlands as a management tool (Hammer 1989, Moshiri 1993, Mitsch 1994). The conceptual difference between constructed and natural wetlands is that constructed wetlands are engineered, built, and managed to meet water-quality goals, while natural wetlands function to support diverse plant and wildlife communities while contributing positively to water quality and other ecological functions.

Conservation Tillage

Another means of reducing loss of sediments, nutrients, and organic chemicals, and subsequent NPS pollution downstream is conservation tillage. Conservation tillage refers to an array of practices, including tilling and planting crops along elevation contours, reducing depth and frequency of soil disturbance, and leaving crop residues to buffer rainfall (Barisas et al. 1978, Beasley et al. 1984, Schwab and Frevert 1985, Carter 1994, Tyler et al. 1994, Unger 1994, Gaynor et al. 1995). Contour farming is prevalent in the southeastern U.S. and aides irrigation (Beasley et al. 1984, Schwab and Frevert 1985). Many rice producers feel that crop residues need to be tilled to increase soil contact, and encourage decomposition of organic residues, which compete for nitrogen if present the following summer (Schomberg et al. 1994). Nonetheless, conservation tillage is the most varied and widely used practice for water-quality management in the agricultural landscape, and plays an important role in rice production.

Terracing and Grass Filter Strips

Grass-filter strips are another means of decreasing NPS discharge from agricultural lands. Challenges are inherent in designing effective filter strips with regard to shape, placement, and size (Vanderholm and Dickey 1980, Baker and Johnson 1983). Using grass-filter strips, Aull et al. (1980) demonstrated a 25–52% reduction in soil, nitrogen, and phosphorus losses. Feagley et al. (1992, 1993) demonstrated effectiveness of grass-filter strips in reducing sediment discharge from wet-seeded ricefields. Sediments in water released after rice seeds sprouted were reduced 37%. Additionally, grass-filter strips have proven effective in retaining organic chemicals present in agricultural runoff (Asmussen et al. 1977, Rohde et al. 1980, Shaw and Webster 1994).

Ricelands - A Combination of the Important Elements

Loss of sediments, nutrients, and organic chemicals are a product of concentration of these NPS constituents and runoff volume. Ricefields can be managed to positively affect both of these parameters. For example, no- or reduced-tillage practices, characterized by reductions in depth and frequency of soil disturbance and maintenance of crop residues, are known to decrease both NPS concentrations and runoff volume (Beasley et al. 1984, Carter 1994, Tyler et al. 1994). Retention of agricultural runoff in natural or constructed wetlands also reduces NPS discharge (Cooper and Knight 1989, Cooper and Knight 1990, Baker 1993, Higgins et al. 1993). When used on ricefields, these conservation tillage and water-management practices reduce rainfall impact and overland flow energies, and provide time for potential pollutants to settle and dissipate (Novotny et al. 1986, Novotny and Chesters 1989, Johnson and Lavy

FIGURE 3 Total suspended solid (sediment) export, concentration, and runoff volume from experimental ricefields in the Mississippi Alluvial Valley, winters 1995-1997. Note sediment export closely follows pattern of sediment concentration. (i.e. water quality).





1995). These practices also allow time for evaporation and subsoil seepage of water, thus reducing runoff volume.

Manley (1999) found that fall no-till practices maintained rice straw cover and deterred soils from becoming suspended, whereas initial impoundment of winter runoff promoted settling effects after rains. Later in winter, when flooded fields were fully impounded, shallow waters also served as a protective layer buffering soils from rainfall impact. Differences in sediment exports among treatments followed that of sediment concentration, suggesting that management affected water quality, which greatly influenced sediment exports (Figure 3). A combination of leaving stubble stand after harvest, followed by flooding until early March, reduced sediment loss 32-fold, from 1,121 to 35 kg/ha. Other NPS variables followed similar trends. When one considers all ricefield management options, such as conservation tillage, water control, contour levees, and release of irrigation and runoff waters through grass filter strips, the capabilities of producers to positively affect water quality are significant. The key elements of water-quality management are inherent in rice agriculture systems, and when applied over the landscape will reduce NPS contributions to the environment.

Conservation Practices for Water Use

Irrigation for agriculture remains the largest use of freshwater in the United States., totaling 0.42 MAF per day in 2000, 40% of all freshwater consumption (Hutson et al. 2004). Historically, mostly surface water was used, but now the percentage of total irrigation from ground water is on the rise, from 23% in 1950 to 42% in 2000. Irrigated acreage more than dou-

bled between 1950 and 1980, then remained constant before increasing another 7% between 1995 and 2000. Now there are 25 million ha (62 million acres) of irrigated agricultural lands in the United States Leading states include California (4.1 million ha), Texas (2.6 million ha), and Arkansas (1.8 million ha).

Conservation generally is the most economical and efficient means of perpetuating quantities and benefits of any natural resource. Although on-farm conservation measures for irrigation incur significant costs, rarely

California, Texas, and Arkansas are leading states for irrigated agriculture

are these practices more expensive than establishing new water sources and delivery systems. Virtually all rice in the United States is grown on irrigated lands and requires significant volumes of water (Chang and Luh 1991, Beyrouty et al. 1994). Flood irrigation is used as much for weed control as actual watering of the crop. Estimates of water required typically range from 2.0–5.0

AF per year (Griffin et al. 1984, Parsch 1986, Pringle 1994, Hill et al. 2006). Water losses occur through vegetative uptake and transpiration, percolation, seepage, and runoff. Conservation of water resources that supply important irrigation waters is paramount for profitable and sustainable agriculture (Peralta et al. 1985, Beyrouty et al. 1994, Pringle 1994). Agricultural researchers have found that the very minimum water requirements for rice production range from 1.0 to 2.0 AF per year, with differences being related to region, climate, soils, rice varieties, and water management (Griffin et al. 1984, Pringle 1994). The ultimate goal of conservation practices would be to make these minimums the norm and discover methods to maintain these conservative requirements in the near future.

On-farm capital improvements

Flow Meters and Timers - Conservation of irrigation waters often necessitate on-farm capital improvements that increase efficiency (USBR 1997). Costs must be recovered with decreased cost of irrigation and increased production. Flow meters are an important capital investment that allow accurate measurement of water quantity and delivery rates, and help pinpoint inefficiencies in need of attention. An additional benefit of flow meters is the detection of reduced groundwater and surface water supplies, and decreased irrigation system performance. Timers can be installed on electrical and internal combustion engines, or solenoids for irrigation valves and gates, to define periods of water application. These tools assist in making decisions that improve efficiency, while striving to approach minimum water consumption for rice production.

Precision Land Leveling - One of the most capital intensive investments in rice water management is precision land leveling. Laser-guided earthmoving equipment is used to create uniform grades and slopes within fields, ranging from 0.0 to 0.2%. Precisionleveled fields have numerous benefits such as increased water control, fewer internal levees, and more efficient crop harvesting (Miller 1983). The addition of permanent pads and pipes on the perimeter of the precision-leveled field brings additional benefits such as elimination of levee seepage and ability to easily impound winter runoff for wildlife benefits and NPS control. Cooke and Caillavet (1993) determined that precision-leveled fields in Mississippi reduced water use from 46 to 32 acre-inches, with a yield increase of 16 bushels/acre, and a return over total specified expenses of \$35.67/acre. Laughlin and Merle (1996), also in Mississippi, demonstrated a similar pattern in yield increase of 8 bushels/acre in precision-leveled fields, and a return over total specified expenses of \$81.40/acre. These gains were attributed to many savings, including irrigation. When coupled with permanent perimeter levees and water-control structures, this practice also reduces NPS discharge from fields and facilitates management of shallow water in winter for waterfowl and other wetland wildlife.

Recycling systems - An irrigation tailwater recovery system provides for the capture and reuse of any irrigation water exiting on a farm, in essence making it a closed system (Hill et al. 1994). The practice can be further extended to also capture rainfall and snow melt. These

recycling systems typically consist of a canal or reservoir that captures and stores irrigation and natural runoff, a pump to relift captured water, and a delivery system to a second point of use. Such systems may be relatively small and designed for seasonal use, or very large and intended for long-term storage and use of water. Water-quality benefits are also achieved though the reduction or elimination NPS discharge, and systems can be designed and operated to benefit fisheries and wildlife. Research in Arkansas has estimated the recycling of an average 8.4 acreinches of rainfall and irrigation runoff, per cropped acre, thus supporting increases in irrigation efficiency (Robinson et al. 2003).

Maximizing Rainfall

Additional opportunities exist to maximize use of rainfall and runoff in rice-growing regions of the South. Pennington and Wolf (1989) reported an estimated 12.7–17.8 cm (5–7 inches) of rainfall can be captured during the summer to supplement irrigation in Mississippi. Rice producers maintained water levels slightly below normal, permitting capture of summer rainfall. Estimates of average annual water use ranged from 61.0 to 122.0 cm (24–48 inches), with rainfall representing 10–29% of the total. Brown et al. (1978) suggested reducing late-season irrigation to conserve water soon to be discharged before harvest. Side-inlet systems allow water to be independently applied to each section (cut or paddy) of a ricefield, versus cascading irrigation from top to bottom of the field, and this too increases efficiency of capturing rainfall (Vories et al. 2005). These practices are a simple reflection of irrigation water management, and demonstrate how careful attention to balancing water needs and use results in conservation of important water resources.

Rice Varieties and Water Use

The role of rice varieties and water use presents a promising future for conserving agricultural water resources. Inherent traits of rice that can influence water use are herbicide resistance, length of growing season, and plant physiology. For example, early-season herbicides in a resistant rice variety could replace the need for flood irrigation to control weeds. Shorter season varieties would require fewer days to reach maturity and less irrigation needs. These future inherent traits represent promising opportunities to reduce consumption of irrigation waters while providing increased net returns for rice producers, and thus deserve special attention in future research and education programs.

REGIONAL PERSPECTIVES

Mississippi Alluvial Valley

The MAV contains important rice-growing areas in four states: Arkansas, Louisiana, Mississippi, and Missouri. Arkansas' Grand Prairie is contiguous with the MAV. Northeast Louisiana contributes a small portion of rice-growing area to the MAV, with the majority of production occurring along the coastal prairies of Southwest Louisiana. Of the yearly average 1.3 million ha (3.2 million acres) of rice planted in the United States. since 2000, the MAV has accounted for more than 795,000 ha (2.0 million acres), approximately 60% of the entire U.S. rice-growing area.

The main challenge facing producers and conservationists in the MAV is water quality, though water quantity is a growing concern. Sediment loss from agricultural lands in the MAV ranged 5–18 MT/ha annually during past decades (Dendy 1981, Murphree and Mutchler 1981, Dendy et al. 1984). Although the landscape is flat with slopes of <2%, high rainfall, frequent cultivation, and vulnerable soils result in loss of sediments, nutrients, and organic chemicals (McHenry et al. 1982, Cooper and Knight 1989, McDowell et al. 1989, Cooper 1991, Pennington 1996). All of the conservation practices for water quality described earlier are showing promise in reducing NPS discharge in the MAV. Conservation tillage and impoundment of agricultural runoff in reservoirs resulted in NPS control (Gill et al. 1976, Rausch and Schrieber 1981, Cooper and Knight 1989, 1990, Maul and Cooper 2000). Harvested ricefields lend themselves well to these strategies, and conservation tillage and holding winter runoff has demonstrated a 32-fold decrease in sediment loss (Manley 1999). For the most part, conservation practices to reduce NPS discharge from rice and other agricultural lands are largely known, and future challenges lie in our ability to apply these practices to improve water quality throughout the landscape.

Gulf Coast

Agricultural activity in south Louisiana, particularly rice production practices, continues to be intensely scrutinized for their contribution to NPS pollution. Rice production is particularly vulnerable to this scrutiny because of the traditional seedbed preparation practice referred to as "mudding in." Ricefields prepared for planting with this method are simply cultivated under flooded conditions, which results in a smooth and weed-free seedbed. Two distinct advantages are realized with this practice and include the ability to prepare rice land for planting during periods of inclement weather, and the suppression of red rice, a noxious conspecific of rice that is not easily controlled. However, this practice also results in the release of sediment-laden discharges during the early growing season and reduces dissolved oxygen in surface waters. Under current water-quality guidelines, more than 70% of Louisiana's freshwater bodies and 50% of the estuarine water bodies are classified as impaired (State of Louisiana 2000, Coreil 2004). The establishment of TMDL's by the Louisiana Department of Environmental Quality are expected to impose more responsibility upon Louisiana rice producers to reduce NPS discharges from fields.

Recent climatic events have had an even greater impact on the long-term stability of the Gulf Coast rice industry. Hurricanes Katrina and Rita all but destroyed primary rice-producing areas in 2005, and it is estimated that Louisiana's rice acreage was reduced by as much as 30% in 2006. Furthermore, significant rice acreage has been affected by the saltwater tidal surge, making land unsuitable for rice production. It is not now known what the long-term effects of Hurricanes Katrina and Rita will be on the Gulf Coast rice industry. However, without significant rainfall in the years following these storms to flush accumulated salt from the landscape, there is little chance that these areas will recover to their past production capacity.

Mitigating water quality concerns

In the early 1990s research was initiated in Louisiana to evaluate the potential for adapting alternative tillage practices in rice production to lower production inputs and alleviate environmental concerns. The emphasis was on reduction of sediment losses during ricefield draining. Results indicated that using no-till or stale seedbed techniques in both the water-seeded and dry-seeded cultural systems was effective in reducing sediment loss and offered economic benefits (Bollich 1991, Bollich 1992, Feagley et al. 1993, Bollich and Feagley 1994). By 2003, approximately 32% of Louisiana's rice acreage was being produced on reduced tillage seedbeds, approaching 80,940 ha (200,000 acres) statewide (Bollich 2004). More recently, large-scale demonstrations have shown that implementation of these practices are successful in meeting target water-quality standards (Gaston and Bollich 2004, Gaston et al. 2006).

The commercial development of herbicide-resistant rice gave rice producers a tool to selectively control red rice in the planted crop (J. Saichuk, personal communication). The traditional water-seeded, "mudding in" system offered suppression at best, but red rice sprouting after the commercial crop was planted could not be controlled and both rice yield and quality losses occurred. Herbicide-resistant rice production is totally changing the approach to rice weed control, especially the control of red rice, and has allowed producers to move from waterseeded to drill-seeded systems.

The move toward conservation tillage practices along the Gulf Coast also has a positive impact on soybean production, the most common crop that is rotated with rice. About 80% of current soybean production occurs within conservation tillage systems (D. Lanclos personal communication). While the driving force behind this change is the lowering of production costs to improve economic sustainability, the same reduced tillage practices implemented in rice have shown considerable promise in soybean production with respect to water quality. No-till and stale seedbed systems have also been studied in large-scale demonstrations to determine the effect of these practices on sediment and nutrient losses during runoff events (Lindau et al. 2004).

Crawfish production is another very popular rotational crop that fits into rice and soybean cropping systems. Crawfish culture provides additional habitat for wetland wildlife on lands often considered marginal for row crop production (Romaire et al. 2004). This industry has also come under scrutiny for its contribution to NPS pollution. To address this concern, ongoing research is testing practices that increase storage capacity, alter late-season harvesting practices, and end-of-season dewatering (Romaire et al. 2004).

Water Conservation

Gulf Coast producers have a heightened awareness of the real value of ample water supply for rice production (Alston et al. 2000). Water was once perceived as an abundant commodity and there was little thought given to the scenario whereby shortages could occur and that rice production could be impacted. But competition and periodic drought has changed that perspective and water usage in rice is getting serious attention by producers and other conservationists.

Underground irrigation systems, laser land leveling, recycling irrigation water, and improved water management are all practices that have been adopted by the rice industry.

A preliminary study was initiated in 2002 to estimate the amount of water used in various rice production systems (Saichuk et al. 2004). Ten commercial fields across southwest Louisiana representing differing soil types, field preparation methods, and planting methods were evaluated. While there were differences in water use within each of these factors, averages indicated fairly uniform requirements across all factors. When comparing laser-leveled with water-leveled fields, 1.22 acre-inches more were needed with water leveling. Heavy-textured soils required 0.67 acre-inches more than light soils, and water-seeded fields required 0.96 acre-inches more than drill-seeded fields. Averaged across all factors and years, 23.86 acre-inches of water were pumped on these commercial fields. Degree and time of tillage, and rainfall during the cropping season affected overall usage. In recent years, speculations regarding the water requirement in rice may have been exaggerated. Water costs for rice production are continually increasing, and producers are much more aware of the need to efficiently manage water in their rice crops.

There has always been an interest in conserving water in rice production systems due either to economics or limited supply. Sprinkler and furrow irrigation are noteable alternatives to continuous flooding. Sprinkler irrigation studies in Louisiana (Westcott and Vines 1986) and Texas (McCauley 1990) showed grain yields to be significantly reduced. Furrow-irrigated rice studies in Louisiana (Bollich et al. 1988, Bollich et al. 1989) were designed to investigate nitrogen fertilizer management, and while there was no direct comparison with continuous flooding, it was observed that weed control and disease management were a concern. Vories et al. (2005) reported in Arkansas that there are yield reductions associated with furrow irrigation. Contemporary rice varieties continue to be adapted to lowland rice conditions, and before alternate irrigation methods can be further considered, production concerns such as yield, fertilizer management, disease, and weed control will have to be addressed.

California Central Valley

Water Quantity in California -At the center of the statewide debate is the resource itself—the annual flow of surface water within California, the groundwater stored in the state's immense aquifers, and the un-captured outflow. California's water supply varies geographically and seasonally. About 71% of the water originates in the northern portion of the state, and 75% of the urban and agricultural demand is south of the Sacramento Valley. As a point of

The Glenn-Colusa Irrigation District (GCID) provides important water supplies for rice agriculture in California's Central Valley

reference, the Central Valley of California extends from the Tehachapi Mountains near Bakersfield in the south to the Cascade Mountains near Redding in the north. The Central Valley north of the Sacramento is referred to as the Sacramento Valley and south of Sacramento as the San Joaquin Valley. California rice is produced on approximately 202,350 ha (500,000 acres), primarily in the Sacramento Valley.

California has a Mediterranean-style climate where most of the runoff occurs from November to March. Consequently, facilities to store and convey water from one area to the other are required. No major new facilities have been developed since 1968, and yet the Central Valley is one of the fastest growing regions in the West where the population is expected to triple by 2040 (American Farmland Trust 1995). In addition to the loss of substantial amounts of Colorado River water as discussed earlier, an additional 0.80 MAF was diverted from the Sacramento River to sustain habitat requirements for waterfowl and migrating salmon as a result of the Central Valley Project Improvement Act (Weinberg 1997). These changes further highlight the inherent competition for water resources that will continue into the future.

Average water costs for rice production increased from about \$45/acre in 1998 to \$54/acre in 2001 (Hill et al. 2006). Water transfers from northern California to the San Joaquin Valley and southern urban areas once was unthinkable, and in some cases not permitted, yet is now acceptable. Issues arising from water transfers include preservation of water rights, conserving local supplies, environmental effects and indirect impacts on agriculture. In the latter case, for example, tenant producers who would not gain from a water sale and may also lose their water for the cropping season. Powerful political forces are gradually changing California water supply, costs, rights and allocation priorities. Competition for water supplies for rice will continue into the future.

Water Supply to Rice - The majority of the water used for rice production comes from two large projects, the Central Valley Project and the State Water Project (Figures 2 and 4). The USBR's Central Valley Project (CVP) is the largest water supply project in the country, serving 1.05 mil-

lion ha (2.6 million acres) of farmland. Ninety-five percent (95%) of the CVP water is delivered to agriculture. Using the 5.3 MAF of water delivered by the project, California growers produce crops worth about \$3 billion per year. Total agricultural output in the Central Valley is more than \$22 billion. The CVP delivers water to over 60,700 ha (150,000 acres) of rice in the Central Valley, led only by deliveries to alfalfa and cotton (Weinberg 1997).

Rice is a major water user among irrigated crops in California. Rice is similar to several crops in terms of

Lake Oroville captures water from the Feather River to supply much of California's Central Valley

evapotranspiration but second only to alfalfa based on application quantities per acre (Hill et al. 2006). Seasonal water delivery to rice is approximately 7.8 AF. The actual amount ranges from 5 to 10 AF, depending on the soil type, management, and delivery system. Extensive laser leveling of fields and regulations restricting drainage after pesticide applications has improved irrigation efficiency. The widespread adoption of short-season varieties over the last two decades reduced evapotranspiration by 16% (Hill et al. 2006).

The success of the CVP impacted the Sacramento River and Delta Region ecosystem. The delta (including the San Francisco Bay) supports 37 species of fauna and flora that are listed, or are candidates for listing, under the Endangered Species Act (Moyle 2000). Significant quantities of CVP water may be necessary to preserve those systems. The Delta Region (southwest of the City of Sacramento) also serves as the sole water conduit connecting northern and southern California delivery systems. Drinking water for 22 million people passes through the delta on its way to urban areas in southern California.

An example of how the conflicting demands for water in California are gradually changing the political landscape is the Central Valley Project Improvement Act. Signed into law in 1992, the legislation gives the USBR a mandate to address environmental problems associated with the CVP and the ability to address economic inefficiencies in allocating water (Weinberg 1997). The value of the act is still strongly debated. Key provisions of the bill state that: (1) producers or landowners may sell water to any user at any price, (2) water districts will pay a higher percentage of the true cost of the water, (3) \$50 million per year will be committed to environment restoration, (4) roughly 20% of the deliveries to water districts or contractors (0.80 MAF) will be diverted to ecosystem restoration and maintenance, and (5) water conservation must be implemented. To some degree, all of these provisions will have some impact on the rice industry and conservation.

As was mentioned above, water sales will not benefit tenant producers. Generally, water sales require that acreage proportional to the amount of water sold be left fallow. If the landowner sells the water, the tenant producer may not be able to farm the land, and it is estimated that 70% of the riceland in California is rented (Farm Services Agency, personal communication). Second, the cost of water will increase in many areas of rice production. The USBR is currently conducting an "ability to pay" analysis for water districts serving rice farms. The cost of water from the CVP could increase by more than 30% in some areas. Associated with the additional cost of water is a \$6.00/AF for environmental restoration specified in provision 3 of the above-mentioned act. It is unclear how the 0.80 MAF of water allocated to the ecosystems will impact rice production and other agriculture in California. The USBR estimates that once fully enacted, the CVP Improvement Act could result in a gross loss of revenue to agriculture of \$100 million (Weinberg 1997). In general the CVP Improvement Act reflects a market-based strategy for water allocation that has been suggested by economists for years. In that model, the foundation of the next era of water management in California will include water-markets, efficient water use, and active conjunctive use (Howitt 2000). Policy changes introduced in California could very likely serve as a model for restructuring water policy throughout the American West.

Water Quality - California agriculture is governed by strict water laws pertaining to both point source and NPS pollution. Rice has always been heavily scrutinized for potential degradation of water quality because flooded ricefields dominate many landscapes. In the late 1970s, fish kills were attributed to the rice herbicide molinate and later a metabolite of thiobencarb was found to cause off-flavors in municipal drinking water in Sacramento (Domagalski et al. 2000). The rice industry responded with a highly successful program to reduce off-farm movement of herbicides. A combination of research, education, and regulation largely solved the problem. Through publications, meetings, and demonstration projects, producers learned to hold water in conventional flow through fields for up to 30 days following herbicide applications to allow for chemical degradation. The program continues today and has reduced mass flow of pesticides in the Sacramento River by 97% (Domagalski et al. 2000). The California rice industry has become a recognized leader in the agricultural and regulatory policy networks for its coordinated and sustained response to improving quality of agricultural runoff.

Unfortunately, the problem is not entirely resolved. The legal framework changed and public sentiment for further reductions in farm runoff is growing. Currently, the agriculture community has a short extension of a waiver from NPS regulations (Warnet 2002). Within that short period, each agricultural industry must file an irrigation management plan that addresses their particular water pollution issues (Hill et al. 1991). The rice industry is promoting its current pesticide monitoring plan as sufficient to meet regulatory requirements. If unsuc-

cessful, at a minimum the industry would have to bear the cost of highly expensive routine water sampling to prove compliance. Ironically, one of the NPS components of concern is dissolved organic carbon; a direct product of disposing of rice straw by soil incorporation and winter flooding of fields. This practice was adopted in response to air quality regulations and continues to provide important habitat for wetland wildlife.

In the context of CVP Improvement Act, the rice industry is well positioned to meet the conjunctive use provisions with regard to waterbirds and other wildlife. The winter flooding of more than 80,900 ha (200,000 acres) of riceland to facilitate straw decomposition provides winter habitat for millions of birds migrating along the Pacific Flyway. Additionally, the Sacramento Valley and associated ricelands are designated as Shorebird Habitat of International Significance by the Manomet Center for Conservation Science. The rice industry and conservation community have also invested heavily in the preservation of salmon populations and habitat. The rice production area co-occupies a region with the few remaining native salmonid fisheries in California. The salmon run is closely associated with stream flows and is a major environmental consideration for the allocation of water in the Sacramento Valley.

Challenges to Sustainability - Limited water resources in the American West will remain a perpetual source of competition and debate. In an era where the prospects of large water projects to increase supply are very slim, the conservation and reallocation of existing supplies are the driving forces of water policy debate. And perhaps nowhere in the West is the conflict more energized than in California. There are more than 35 million people in the state, most living far away from major water sources and governed by environmental laws that are often more stringent than federal standards. Policy changes intended to improve use of water are being put in place in parts of California served by the Central Valley Project, the largest water supply project in the United States.

California's forced integration of agriculture, natural resource conservation, and urbanization poses a unique and unprecedented set of challenges. The current natural resource issues must be cast in a changing context of a rapidly growing population, tightening regulations, and an enhanced regard for ecological goods and services. Water is still allocated in California based on historical water rights. This includes riparian and conjunctive water rights established by early settlers in addition to a generous share of water allocated from state and federal water projects. However, water rights are ultimately determined in the political arena where agricultural political power is increasingly diluted by the concentration of people in urban areas. Agriculture's historical control of water is facing more legal challenges. The agreement between the IID and metropolitan water contractors bears evidence that urban demand will influence the reallocation of water historically committed to agriculture.

During recent drought years, water destined for as much as 20,235 ha (50,000 acres) of riceland was sold to urban districts. Some northern California water districts that serve rice producers have entered into long-term agreements to provide water to cities in southern California. In general, water sales and transfers from agricultural to urban districts have been limited. Although the degree to which water allocation in California ultimately becomes market driven remains unclear, it represents a significant threat to rice agriculture and wetland wildlife.

Water 'export' to the population centers, and the need to meet the biological requirements of wildlife and fisheries, will force agricultural and conservation communities to adapt new technologies and public policy to maintain an adequate supply of water to meet needs.

COURSE FOR RESEARCH AND EXTENSION EDUCATION

Harmonizing Ricelands with Parent Ecosystems

Given this current state of our knowledge and regional perspectives on conservation of water resources in ricelands, we seek to chart a course for future research and education that will benefit the rice and conservation communities. The ultimate goal would be to harmonize rice agriculture with the parent ecosystems, seeking a balance among sustainable rice production and natural resources such as water, soils, and wildlife. In most regions, this must be done in light of an expanding human population and economy.

Conservation practices to conserve water quality and quantity are largely known. The challenge now lies in employing these practices across sufficient time and adequate space to see marked improvements. When it comes to conservation tillage and winter water management for managing water quality, or precision leveled fields and tailwater recovery systems for reducing irrigation water use, the pertinent questions are for how long, and across what portion of the landscape, must these be applied to see meaningful results. Simply put, "How Much is Enough?"

Case Study: Winter Sediment Retention in the MAV - Research by Manley (1999) in the MAV demonstrated a 32-fold decrease in winter sediment exports (i.e., total suspended solids [TSS]), as a result of leaving rice stubble stand after harvest and impounding winter rainfall, compared to fall disking with runoff exiting fields. Ricefields with only standing stubble or impoundment had intermediate results (Figure 3). These data were combined with land surveys of crop cover type and winter water management, using Geographical Information Systems technology, across two impaired watersheds in the MAV (Figures 5–7). These watersheds, the Big Sunflower Watershed (BSW) in Mississippi, and the L'Anguille Watershed (LW) in Arkansas, do not meet water quality standards to support aquatic wildlife or recreation largely due to excessive sediment loads.

The results and calculations demonstrated that the two watersheds had many similarities with regard to rice acreage, winter water management, and landscape exports of TSS. From 2001 to 2004, the BSW hosted 47,285 ha (116,840 acres) of ricefields, with the LW at 57,648 ha (142,448 acres) (Table 2). Of this rice area, a similar extent was under winter water management, 32.0 to 38.8%. The calculated daily load of TSS during winter was 0.40–0.43 Mg/km²/ day for the two watersheds (Table 3). Considering the TMDL for the BSW is 0.60–1.60 MT/ km²/day, proposed by Mississippi Department of Environmental Quality (2003), our study and calculations show that the rice landscape as managed in 2001–2004, was well below the threshold for TSS exports during the 120-day winter period.

However, there were differences between the two with important implications for watershed management. The LW has a much greater proportion of rice and greater proportion of

 TABLE 2
 Average areas of major agricultural crops and percentages under winter water management in the Big Sunflower¹ (Mississippi) and L'Anguille² (Arkansas) Watersheds, 2001-2004.

| WATERSHED CROP | CROP AREA (HA) | CROP AREA AS % OF WATERSHED | CROP AREA UNDER WINTER WATER MANAGMENT (HA) | AREA MANAGED AS % OF CROP | AREA MANAGED AS % OF ALL CROP |
|----------------------------|-------------------|--------------------------------|---|------------------------------|----------------------------------|
| Big Sunflower Watershed | | | | | |
| Rice | 47,285 | 5.8 | 15,125 | 32.0 | 3.1 |
| Soybeans | 215,019 | 26.5 | 31,369 | 14.6 | 6.5 |
| Cotton | 179,939 | 22.2 | 11,152 | 6.2 | 2.3 |
| Corn | 27,462 | 3.4 | 1,861 | 6.8 | 0.4 |
| Sorghum | 7,540 | 0.9 | 512 | 6.8 | 0.1 |
| Winter wheat | 6,644 | 0.8 | 486 | 7.3 | 0.1 |
| L'Anguille Watershed | | | | | |
| Rice | 57,648 | 23.1 | 22,362 | 38.8 | 13.5 |
| Soybeans | 81,068 | 32.5 | 17,136 | 21.1 | 10.4 |
| Cotton | 18,217 | 7.3 | 1,888 | 10.4 | 1.1 |
| Corn | 5,139 | 2.1 | 525 | 10.2 | 0.3 |
| Sorghum | 2,342 | 0.9 | 173 | 7.4 | 0.1 |
| Winter wheat | 1,169 | 0.5 | 58 | 4.9 | 0.0 |

¹ Big Sunflower Watershed is a segment of the Yazoo River Basin, Hydrologic Unit Code 08030207, total area 810,060 ha, average crop area 483,888 ha during 2001–2004.

² L'Anguille Watershed is Hydrologic Unit Code 08020205, total area 249,389 ha, average crop area 165,583 ha during 2001–2004.

TABLE 3 Calculated exports of total suspended solids from ricefields within the Big Sunflower¹ (Mississippi) and L'Anguille² (Arkansas) Watersheds, 2001–2004, and changes resulting from hypothetical increases in winter water management.

| TERSHED | RICE AREA | TO WINTER WATER | TAL SUSPEN FROM RIG STUBBLE | DED SOLIC CEFIELDS (I STUBBLE | D EXPORT MG) DISK | DISK | TSS TOTAL | DAILY LOAD | AREA IMPACTED |
|----------------------------------|-------------------|----------------------|-----------------------------------|-------------------------------------|-------------------------|-----------|--------------------------------|---------------------------|-------------------|
| | IMPACTED (%) | MANAGEMENT (HA) | FLOODED | OPEN | FLOODED | OPEN | EXPORT FROM RICEFIELDS (MG) | (MG/KM ² /DAY) | AS % OF ALL CROPS |
| MANAGEMENT D wer Watershed | | | | | | | | | |
| 2001-2004) | 32.0 | 15,125 | 266 | 3,563 | 2,537 | 18,023 | 24,389 | 0.43 | 3.1 |
| ttical increase 1 | 65.0 | 30,735 | 541 | 1,834 | 5,156 | 9,275 | 16,806 | 0.30 | 6.4 |
| ttical increase 2 | 100.0 | 47,285 | 832 | 0 | 7,932 | 0 | 8,764 | 0.15 | 9.8 |
| e Watershed | | | | | | | | | |
| 2001-2004) | 38.8 | 22,362 | 394 | 3,910 | 3,751 | 19,776 | 27,831 | 0.40 | 13.5 |
| etical increase 1 | 65.0 | 37,471 | 659 | 2,236 | 6,286 | 11,308 | 20,489 | 0.30 | 22.6 |
| etical increase 2 | 100.0 | 57,648 | 1,015 | 0 | 9,670 | 0 | 10,685 | 0.15 | 34.8 |
| ıflower Watershed | l is a segment of | the Yazoo River Basi | n, Hydrolo | gic Unit C | ode 08030 | 207, tota | ll area 810,060 h | a, average crop | area 483,888 ha, |

CONSERVING WATER QUALITY AND QUANTITY in North American Ricelands

Conservation in Ricelands of North America

2001-2004

² L'Anguille Watershed is Hydrologic Unit Code 08020205, total area 249,389 ha, average crop area 165,583 ha, average rice area 57,648 during

average rice area 47,285 ha during 2001-2004.

FIGURE 6 Distribution of major crops in the Big Sunflower Watershed, USDA National Agriculture Statistics Service, 1:1,000,000 scale Cropland Data Layer, 2001–2004.

FIGURE 7 Distribution of winter water managed rice and soybean fields within the L'Anguille Watershed. Image was generated by intersecting the USDA 2001–2004 Cropland Data Layers and Landsat 5/7 images classified to depict managed winter flooding (inset 1). Fields with managed flooding were identified by regularity of shape as defined by linear field boarders and levees as seen in the upper- and lower-right portions of inset 2.

all crops combined (Table 2). This magnifies the potential to affect TSS exports using winter water management. The study showed that 13.5% of all crops in the LW were positively impacted, simply by winter water management on rice. Furthermore, a hypothetical maximum (100%) of all rice under winter management would positively affect 34.8% of all crops (Table 3). This theoretical maximum would reduce daily loads of TSS from 0.40 to 0.15 Mg/km²/day across more than a third of the expansive LW crop base. Importantly, soybeans also made up a significant portion of all crops, with 21.1% of this area under winter water management (Table 2). Although the reduction of TSS exports from soybeans under winter water management is not as well studied, the practice is known to have a positive effect. Therefore, because the crop base comprises a significant portion of the LW (66.4%), and rice and soybeans dominate all crops (55.6% of all crops), winter water management offers a high-impact tool to reduce TSS exports into this impaired watershed during the critical winter period. The inherent question that still needs to be answered however, is "How much is enough?" In other words, in an impaired watershed dominated by rice and soybean agriculture, for how many years and over how many acres must conservation practices for water quality be applied and maintained to witness great improvements in aquatic wildlife for the Big Sunflower and L'Anguille Rivers.

Case Study: Providing Water Resources for Salmon in California - California's State Water Project (SWP) is the largest state-funded water project in the United States (California Department of Water Resources 1998). The SWP supplies water to 23 million people and 303,520 ha (750,000 acres) of farmland, including more than 40,470 ha (100,000 acres) of rice in the Sacramento Valley. The main source of water for the SWP is Lake Oroville, north of

Sacramento and on the east side of the Sacramento Valley (Figure 2). The lake captures water from the Feather River and its tributaries. The Feather River is an important spawning ground and hosts a fish hatchery that produces a significant portion of the ocean sport and commercial catch of salmon. These fish not only require high quality water in terms of low contaminate levels, but also in terms of temperature. Moreover, species of fish protected under the U.S. Endangered Species Act require cold water temperatures during a period that coincides with

Managing river flows and water temperatures to benefit both rice agriculture and salmon fisheries is very challenging

the majority of the rice-growing season. Water used for irrigation is often diverted from rivers where water temperatures are controlled to optimize fish habitat by releasing water at selected depths from reservoirs. Water is released from the project dam at less than 10°C (50°F). Water frequently reaches the ricefield at temperatures that are sub-optimal for rice production.

Yield reductions related to low water temperature were observed over a wide area of rice production that receives water from the SWP (Roel et al. 2005). The effect of cold water is not uniform across the field and may extend beyond the areas immediately adjacent to the water intakes and beyond the visibly impacted area. Field studies showed that 20°C (68°F) was a threshold for yield loss due to cold water effects with injury increasing with exposure time in a nonlinear fashion (Roel et al. 2005) (Figure 8).

Water used for rice taken from the SWP facilities near Lake Oroville is commonly less than 14°C (58°F) during much of the season. The water warms less that 2°C in the first 15 miles of the conveyance system (Roel et al. 2006). Preliminary estimates of yield loss due to low water temperature are calculated to be \$2 million (T. Trimble, Western Canal Water District, Nelson, CA; pers. communication). Arguably, the yield losses associated with low water temperature are hidden or unrecognized costs of environmental management borne by the rice industry. Additionally, the Lake Shasta Dam on the Sacramento River (Figure 3) was retrofitted with shutter gates to allow water to be released at selected temperatures. Lowering the water temperature in Sacramento River to benefit fish habitat is under discussion. At the present time, the water temperature of the Sacramento River at the major diversion points for rice production is around 15°C. Again, the inherent question that still needs to be answered is, "how much is enough?" In other words, in a region hosting the vast majority of California's rice production and salmon fisheries, how much of the river system must deliver warm irrigation waters to sustain a profitable rice industry, while ensuring that critical temperature for fish populations are maintained?

Future Needs in Research and Extension Education

• Together, the rice industry and conservation community should promote research on understanding the importance of scale, both time and space, of water conservation practices across the agricultural landscape. This includes practices to improve both water quality and consumption. We must be able to answer "how much is enough?" That is, how much and for how long must we apply a particular conservation practice to see meaningful results and sustain the rice industry?

• Research should focus on measuring responses to conservation practices for water quality, targeted on specific watersheds or portions thereof, to the point where improvements are highly evident. Success stories should be widely publicized.

• Research should seek to develop affordable and applicable monitoring methods for rice producers, to follow both water quality and irrigation consumption, thus empowering landowners to more closely study their own conservation and rice production endeavors. Every farm is its own laboratory.

• Research on rice varieties needs to consider conservation of irrigation waters. Traits such as herbicide resistance could delay spring flooding for weed control and conserve water quantity. Length or timing of growing season might afford savings in irrigation. All such traits must coincide with sustainable yields and milling quality.

SUMMARY

The ultimate question is, Can conservation of water resources meld with sustainable and profitable rice production across the three important rice landscapes: Mississippi Alluvial Valley, Gulf Coast, and California's Central Valley? We believe the answer is yes. However, there is much to be learned and more conservation practices to be applied across the landscape before additional improvements can be witnessed. Each region has inherent priority challenges, from water quality in the South, to water quantity in the West. By and large, we know what conservation practices improve the management of both, and the challenge lies in applying them over ample time and space to see marked improvements. The rice industry and the conservation community do not exist alone; we are integrated with all other land and natural resource consumers. Indeed, the rice industry and conservation community must continue to stand tall among these other entities, and provide leadership by example in the conservation of water, soil, wildlife, and all other natural resources.

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