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AGRICULTURAL DRAINAGE MANAGEMENT, QUALITY AND DISPOSAL ISSUES IN NORTH AMERICA†

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ABSTRACT

The North American continent, comprising Canada and the United States of America, has a wide range of climatic, soils and cropping conditions. Surface and subsurface drainage is required to remove excess soil water in the wetter regions of the continent, as well as to maintain a favorable salt and water balance in the crop root zone in the drier irrigated regions. Drainage and water table management practices are essential for the production of food and fiber. However, these practices may sometimes cause third-party impacts, which are largely of a water quality nature. Drainage practices have therefore evolved from removal of water for increased crop productivity, to a method of environmental control. Consequently, much effort over recent years has been in designing and installing drainage systems, which have multiple objectives. A very recent notable institutional development is the formation of the Agricultural Drainage Management Systems (ADMS) Coalition, comprised of farmers, drainage contractors and the drainage industry, government advisors, and water management and agricultural specialists, to promote research, education and adoption of drainage water management as a practice that can reduce the delivery of pollutants to streams. This paper describes the need, extent and status of drainage in North America, including water quality issues, drainage water management and disposal problems. Copyright © 2007 John Wiley & Sons, Ltd.

KEY WORDS: agricultural drainage; management; quality; disposal; North America

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RÉSUMÉ

L'Amérique du Nord, composée du Canada et des États-Unis d'Amérique, présente un large éventail de conditions climatiques, de sols et de cultures. Le drainage, de surface et souterrain, est nécessaire pour enlever l'excédent d'eau contenu dans le sol des régions les plus humides, de même que pour maintenir un bilan d'eau et de sels minéraux dans la zone racinaire propice aux cultures dans les régions irriguées plus sèches du continent. Le drainage et la gestion de la nappe phréatique sont, par conséquent, des pratiques essentielles à la production de nourriture et de fibres textiles. Toutefois, ces pratiques de drainage ne peuvent pas toujours être effectuées sans causer d'impacts sur une tierce partie. Les pratiques de drainage ont évolué à partir du simple prélèvement d'eau afin d'augmenter la production des cultures à une méthode de maîtrise environnementale visant à réduire les impacts sur la qualité de l'eau causés par ces pratiques. Par conséquent, au cours des dernières années, les efforts se sont concentrés sur le développement et l'installation de systèmes de drainage à objectifs multiples, prenant en

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considération la plante, l'hydrologie, le sol et l'environnement. La création de la Coalition sur la Gestion des Systèmes de Drainage Agricole (Agricultural Drainage Management Systems (ADMS) Coalition), composée d'agriculteurs, d'entrepreneurs de drainage, d'experts gouvernementaux, et de spécialistes de la gestion de l'eau et du monde agricole, afin de promouvoir la recherche, l'éducation, et l'adoption de la gestion de l'eau par le drainage comme une pratique innovante qui peut réduire les polluants dans les cours d'eau, constitue une avancée récente du monde institutionnel. Cet article décrit les besoins, l'étendue et la situation du drainage en Amérique du Nord, incluant les problématiques de qualité, de gestion et d'élimination de l'eau. Copyright © 2007 John Wiley & Sons, Ltd.

MOTS CLÉS: drainage agricole; gestion; qualité; élimination; Amérique du Nord

THE NEED, EXTENT AND STATUS OF DRAINAGE

Canada

The eastern Canadian provinces of Quebec, Ontario, New Brunswick, Nova Scotia, Prince Edward Island, and Newfoundland and Labrador experience a moist temperate climate, with annual snow and rain precipitation of approximately 1200 mm yr^{-1}. The evaporation varies from 400 to 500 mm yr^{-1}. This results in excess soil water, particularly during the spring and autumn periods. The wet soil conditions in the spring limit field vehicle mobility and delay tillage operations and seedbed preparation. The problem is exacerbated in the relatively flat cropland areas which exhibit low hydraulic gradients to rivers and watercourses, and the fact that the soils were compacted by glaciers and therefore have relatively low hydraulic conductivities. The region also contains large tracts of very heavy clay soils. Due to the poor internal soil drainage, methods of water removal are required for high-value crop production. The central Canadian province of Manitoba and the Pacific coastal province of British Columbia also experience wet conditions.

Originally the croplands of eastern Canada were surface drained using parallel open field ditches and cambered beds. However, this did not provide adequate water removal, and with the advent of large tractors, planters, combines, sprayers and grain wagons, the closely spaced ditches hindered field machine operations. Subsurface pipe drainage systems were therefore introduced to improve field drainage. Early systems comprised randomly laid clay tile at shallow depths. However, in the 1970s, corrugated plastic pipe was introduced, and parallel lateral and mainline systems are now commonly installed. It is estimated that there are about 8 million ha of drained land in Canada (Shady, 1989), with about 2.5 million ha in eastern Canada.

The Prairie provinces of Saskatchewan and Alberta have significant agricultural operations in the southern parts of these two provinces. Their climate is semiarid, with annual rainfall of 300 mm or less. Irrigation is therefore necessary for sustainable crop production. There is very little tile drainage in the irrigated regions, although some surface drainage is required to dispose of irrigation tailwater and surface runoff. The northern parts of these two provinces are somewhat wetter, and some surface drainage is practiced where there is systematic cropping, although this is not very extensive.

Eastern and Midwest United States

The general distribution of drained land in the US is shown in Figure 1. The figure is dated, but the general distribution of drained land in the US has not changed over the past three decades. Many of the early settlers to the eastern United States came from Europe where wet soils had been drained for centuries; thus, they brought knowledge that drainage may be necessary and the methods to accomplish it. Historical records indicate that George Washington and five other investors formed a company to drain 16 000 ha in the Great Dismal Swamp of Virginia and North Carolina in 1763 (Brown, 1970). Since then, drainage of wet soils has been a part of US land policy debate for over two centuries. Notable legislation included: Federal Swamplands Acts of 1849 and 1850; Federal Drainage Districts Acts of 1885, 1903, 1919; Federal Flood Control Act of 1944; and the 1954 Federal Watershed Protection and Flood Prevention Act (PL-566).

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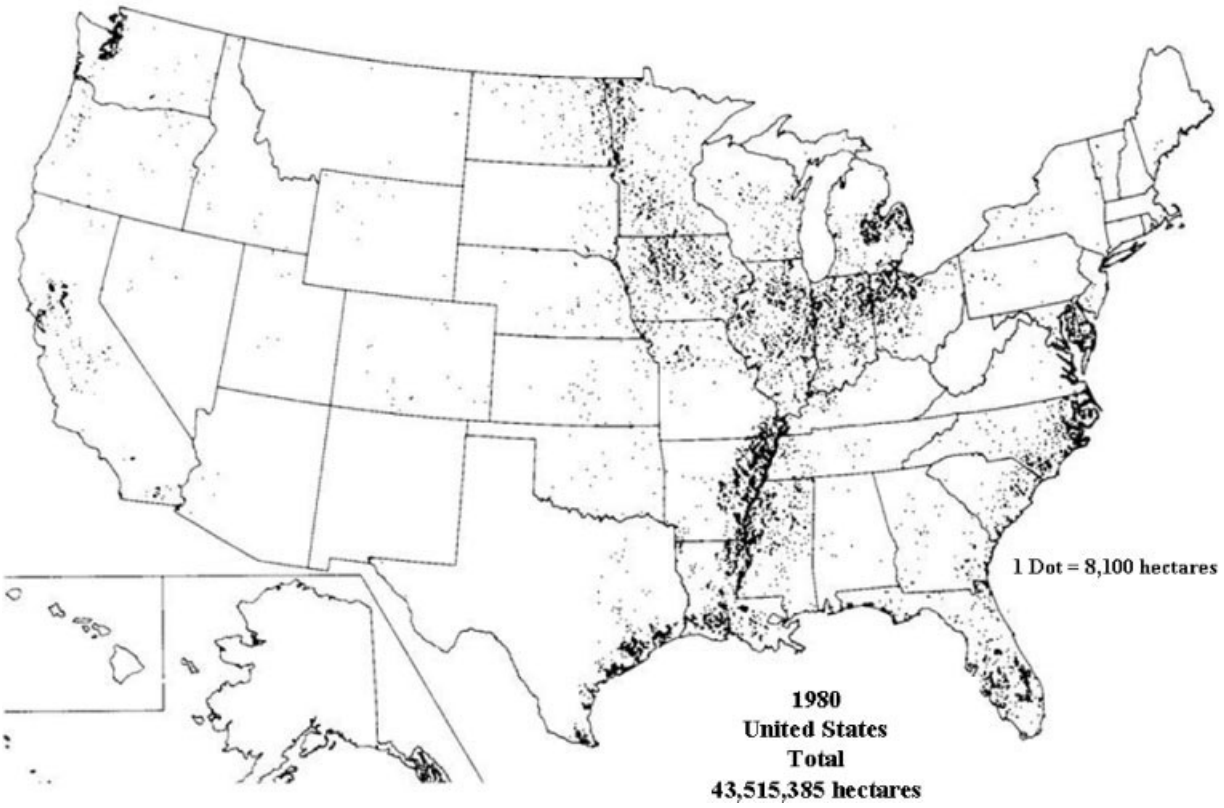

Figure 1. Distribution of drained lands in the United States. After Pavelis (1987). Note: The only significant change from what is shown above in the US drainage acreage over the past 25 years has been the restoration of approximately 500 000 ha of formally drained wetlands

The climate along the Atlantic and Gulf Coast states is humid, with rainfall exceeding evapotranspiration (ET) on average. In some locations, rainfall may exceed ET by 500 mm in some years. Excess rainfall coupled with relatively flat topography results in significant expanses of poorly drained soils. Up to 25% of the land area in many Atlantic and Gulf Coast states is occupied by poorly drained soils (Pavelis, 1987). In many of these states, upwards of 50–60% of cropland relies on past drainage improvements for efficient production. In areas within 100 km of the coast, drainage is often required on over 90% of the land area. Much of the existing drainage infrastructure – main canals and waterways – was not originally constructed to satisfy agricultural drainage requirements. Instead, early main canals were dug for inland boat transportation or to provide fill material to elevate and provide better drainage of roadbeds. Once the main canals were constructed, nearby landowners initiated on-farm drainage projects. Edmon Ruffin, commissioned to assess land use in eastern North Carolina in 1836, described an extensive network of on-farm drainage canals and feeder ditches such as seen in Figure 2. This network of drainage ditches is still commonly used today throughout much of the Atlantic and Gulf Coast region.

The open-ditch drainage network shown in Figure 2 is designed to provide primarily surface drainage. Subsurface drainage using underground conduits is more typically utilized in irregular patterns in areas of wetter or hard to drain sections of fields. While some parallel subsurface drainage systems have been installed, open-ditch surface drainage with irregularly spaced subsurface drain tiles is more common. While the open-ditch system is thought of as a surface drainage system, significant subsurface drainage may still result in these systems because of the highly permeable subsoils. In many cases, as much as 50% of the drainage volume on an annual basis occurs as subsurface flow (Evans *et al*., 1995) even where ditches are spaced 100 m apart.

Since about 1970, drainage has become associated with loss of wetlands. With increasing social preference to protect wetlands, drainage has become socially unpopular because of the perception that any land needing drainage

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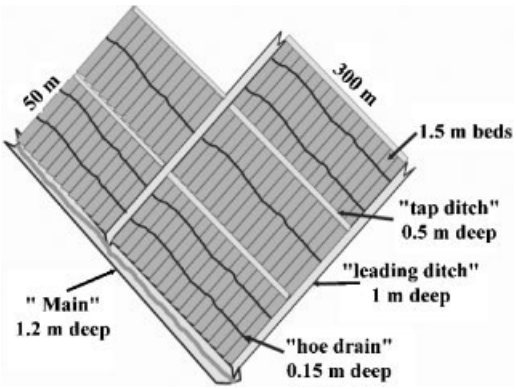

Figure 2. Intensive on-farm drainage system observed in eastern North Carolina in 1836. (Developed from Ruffin 1861)

improvement must be wetlands. As a result, there have been very few drainage improvements in terms of draining new areas or installing more extensive drainage systems along the Atlantic and Gulf Coasts over the past two decades. Instead, drainage activities are typically restricted to maintenance. In many watershed-scale projects, maintenance is confined to ''snagging'' and removing only the fallen trees in the main channels with strict policies against removing sediment, especially when public monies are providing the maintenance. It is becoming popular belief among landowners in these areas that the drainage infrastructure is gradually deteriorating and the frequency of flooding, ponding or excessive soil-water conditions is on the increase.

Several factors have influenced the historic need and extent of drainage in the Midwest of the United States. The two primary factors are: the region's glacial history and the impact of that history on the properties of the soils that formed in the glacial deposits; and the region's cool, humid climatic regime that assures seasonal patterns of precipitation and evapotranspiration that yield periods of excessive soil water content. These factors led to the development of extensive drainage infrastructure to make agriculture economically viable in this region (USDA-ERS, 1987).

Zucker and Brown (1998) summarized the drainage statistics for the individual states in the Midwest. They concluded that subsurface drainage has been installed on roughly 37% of the total cropland acres in the region. While the total number of acres reportedly drained by subsurface drains remains relatively constant, the intensity of the drainage continues to increase. Random drains into wet spots in fields have been replaced by systematic drainage of the entire field, and the previously adequate drain spacing used in the 1960s and 1970s is being narrowed by placing additional drains between the existing drains. Modern farming practices involving fewer farmers, larger fields and larger equipment producing annual cash grain crops of corn and soybeans creates a demand for more intensive drainage to assure trafficable field conditions for planting and harvesting. Many additional miles of subsurface drains are installed annually throughout this region.

Western United States

Drainage problems resulting from the irrigation of agricultural land in the semi-arid and arid areas of the United States are located in the 17 western states (see Figure 3). Figure 3 shows the extent of irrigated land in the United States as of 1992 (USDA-ERS, 1997). The location of the irrigated land is a good indication of the location of principal irrigation and agricultural drainage water quality problems particularly in the semiarid Central Valley of California and the humid area of the Mississippi River drainage basin.

The problems occur mostly in alluvial valleys with perennial rivers and developed water supplies. Since 1904, the US Bureau of Reclamation (USBR) has been the agency principally responsible for developing both the irrigation and drainage systems for USBR projects in this region of the United States. The USBR designed drainage systems for the irrigated land using the dynamic equilibrium method, which is a transient method that includes

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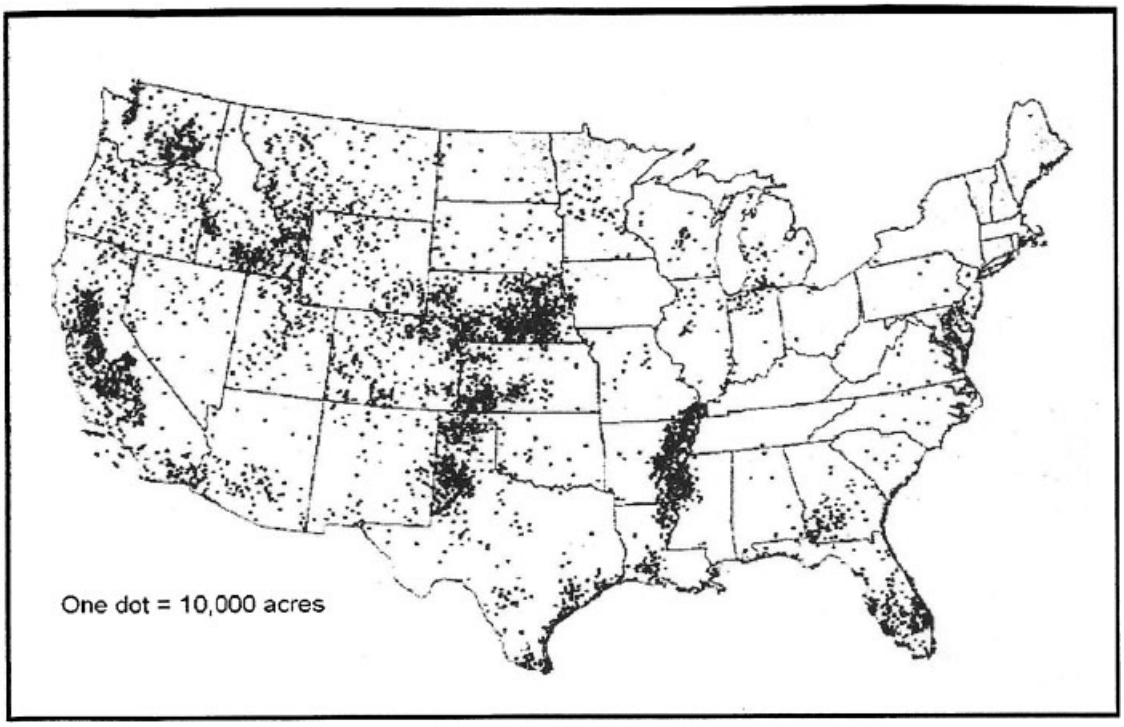

Figure 3. Irrigated land in the United States in 1992 (USDA-ERS, 1997)

consideration of irrigation system type and efficiency, and cropping patterns (US Department of Interior, 1993). The design resulted in the installation of widely spaced deep open drains or deep subsurface drains with widely spaced laterals.

These designs reduced the cost of construction and installation, but had significant consequences for drainage water quality. The second agency in the western US that has had a significant responsibility for providing technical assistance in the areas of irrigation and agricultural drainage to landowners is the US Department of Agriculture (USDA). The USDA has worked with individual landowners in developing on-farm irrigation and drainage systems, whereas the USBR has developed mostly project-related systems. The USDA designed drainage systems similar to the USBR systems, but on a smaller scale.

Agricultural drainage techniques have evolved over the years from the laborious use of heavy clay (early 1900s) and concrete (mid-1900s) drain tiles, that were first placed in hand-dug and then later in wide machine-dug trenches. The development of extruded plastic drain tubing (late 1900s) installed mechanically with modern trenchers has substantially reduced the work of installing agricultural drains. Many of the drainage systems in the western US were installed before the 1980s, as there was an increased concern for water quality in the United States about that time. The need for agricultural drainage has not decreased. However, very few agricultural drainage systems have been installed in the western United States over the past 20 years because of problems associated with the discharge of agricultural drainage water. These problems will be discussed in the following sections of this paper.

MANAGEMENT AND WATER QUALITY ISSUES ASSOCIATED WITH DRAINAGE

Canada

Several studies have pointed to the problems of nutrient, pesticide and bacterial contamination of rivers and lakes, by agricultural drainage effluent in eastern Canada (Fleming, 1990; Bastien and Madramootoo, 1992;

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Jamieson *et al*., 2003). Bacteria, particularly *E. coli* from manure applications, have been found to move to tile drains, particularly when macropores are formed in the soil profile. It has been noted that viable fecal bacteria can remain in drainage water several months after manure application. Bacterial levels are highest at the beginning of drain flow events, and then decrease as the event progresses (Stratton *et al*., 2004). Nutrient pollution, primarily excess nitrogen and phosphorus, are of most concern. Madramootoo *et al*. (1992) measured nitrogen concentrations ranging from 1.7 to 40 mg l^{-1}, and phosphorus concentrations of 0.002–0.052 mg l^{-1} in tile effluent from a potato cropped field on a sandy loam soil. Such high N concentrations are of significant concern with respect to eutrophication of rivers and lakes. While nitrogen was originally considered the limiting nutrient in many nutrient management programs, the focus has now shifted to phosphorus. Enright and Madramootoo (2004) highlighted the issues of phosphorus contamination by surface and subsurface drainage runoff, and stated that up to 40% of annual P losses in total runoff from agricultural fields could come from P in tile flows. Much attention is therefore now focused on the problems of algal blooms in Quebec lakes, and the fact that agricultural drainage effluent is a major contributor to eutrophication and the formation of blue-green algae, as well as cyanobacteria. Highly elevated soil P levels, due to excessive land manure applications, has led to P now being the limiting nutrient in nutrient management plans. Apart from the environmental consequences, there are increasing economic and human health implications due to the formation of algal blooms. The aesthetics of the water bodies are impaired, and there are taste and odour problems of the fresh water. Recreational activities are reduced and the economies of the towns surrounding the lakes are severely impacted.

Eastern and Midwest United States

Many of the poorly drained soils along the Atlantic and Gulf Coasts are adjacent to environmentally sensitive and ecologically important surface waters such as the Chesapeake Bay, Albermarle-Pamlico Estuary and the Gulf of Mexico. The locations of water quality concern are closely correlated to the locations of most concentrated drainage as depicted in Figure 3. Much of the drainage water from inland areas ultimately discharges into these water bodies. It is well documented that drainage discharges from agricultural lands affect total outflow, peak outflow, and sediment and nutrient transport – primarily nitrogen and phosphorus – to the receiving waters (Evans *et al*., 1991; Skaggs *et al*., 1994). The consequences of these discharges can be changes in the freshwater/salinity interface in estuarine waters (Miller, 1985; Pietrafesa, 1985), eutrophication leading to nuisance algae blooms (Paerl, 1983, 1987) and areas of low dissolved oxygen or hypoxic zones (Rabalais *et al*., 1999).

The primary water quality issue associated with subsurface drainage in the Midwest is the offsite delivery of nutrients, especially nitrate-nitrogen. Considerable documentation exists that subsurface drainage waters from Midwest agricultural fields contribute large amounts of nitrate to streams and rivers draining to the Gulf of Mexico and the western basin of Lake Erie, and that this nitrate is the major cause of the extensive hypoxic conditions in these coastal waters (Goolsby *et al*., 1999; Rabalais *et al*., 1996). The annual cash grain farming practiced within this region, coupled with the intensive subsurface drainage infrastructure, assures that any soluble nitrate present in the root zone will be flushed out of the soil and into the local streams.

Another potential drainage water quality issue present in the region is recent evidence of increasing concentration of dissolved reactive phosphorus in local streams. The source of the phosphorus is unclear, but is thought to be associated with the shift to no-till management of cropland, along with the intensification of subsurface drainage on those lands.

There continues to be an increase in confined animal feeding operations (CAFO) in the Midwest, and these enterprises depend upon being able to dispose of manure on cropland. These manures contain soluble nutrients and various potential pathogens and other compounds used to maintain the health of the animals, all of which may move to local surface water via the subsurface drainage infrastructure.

Western United States

The major components in agricultural drainage that impact water quality in the western United States are derived from both natural and man-made sources. The natural sources include native soil materials and water used for

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irrigation. Man-made sources include fertilizers, pesticides and other chemicals used for the production of agricultural crops and waste from animal production facilities.

Soils in many of the irrigated areas in the western United States are derived from marine sediments and as a result contain high levels of salt and trace elements, e.g. boron, selenium, arsenic (Sylvester *et al*., 1988). Examples are the soils found in the San Joaquin Valley of California and the Grand Valley in Colorado. In addition to the natural soil salinity, all irrigation water includes varying amounts of salt depending on the source or the location along a river. Studies have demonstrated that the principal source of salt in drainage water is salt stored in native soil material (Ayars and Tanji, 1999; Ayars and Meek, 1994). Drainage systems with wide lateral spacing collect water from deep within the soil profile in regions with the highest salt concentration (Grismer, 1989, 1990). In order to reduce the salt mined from the ground below the bottom of the drains, that is to minimize the salt contribution from deeper groundwater flows, it is necessary to change the drainage design criterion (Ayars *et al*., 1997; Guitjens *et al*., 1997).

Trace elements occur in drainage water throughout the western United States, some with high levels of selenium. The bioaccumulation of selenium in vegetation due to the storage of drainage water in the Kesterson Reservoir resulted in significant negative environmental impacts on wildlife in the Central Valley of California. This resulted in the closure of the reservoir, the decommissioning of a major drainage system and the elimination of drainage water disposal from large areas of agricultural land (San Joaquin Valley Drainage Program, 1990).

DRAINAGE WATER MANAGEMENT AND DISPOSAL

Canada

With the increasing environmental and societal concerns about the quality of agricultural drainage water, there have been several initiatives to design and implement methods of reducing nutrient loadings in tile effluent. These initiatives have centered on water table management through subirrigation and controlled drainage (Drury *et al*., 1996; Kaluli *et al*., 1999). Research has shown that by maintaining the water table at 50 and 75 cm from the soil surface, NO_3-N concentrations in drain flow were reduced by 61 and 52%, respectively, compared to regular free outlet drainage systems for a corn–soybean strip cropping system (Mejia and Madramootoo,1998). This reduction in NO_3-N was attributed to the denitrification that occurred under water table management (Elmi *et al*., 2000). An added advantage of subirrigation is that crop yields can be increased during dry years. The existing drainage system can be used to supply water to the crop root zone via upward flux. This is a very inexpensive method of irrigation, where soil type and topography permit. Mejia *et al*. (2000) measured corn and soybean yield increases of up to 14 and 37%, respectively, above the yields of those two crops on fields with regular free outlet drainage. This confirms the environmental and economic benefits of water table management practices such as subirrigation and controlled drainage. There is ongoing work to evaluate the use of constructed wetlands to treat drainage water, and the treated water can then be reused for irrigation during dry periods (Kroeger and Madramootoo, 2006).

Eastern and Midwest United States

While wetness is still the major concern to landowners, intensive drainage systems sometimes remove more water than necessary, especially on sandy soils during drier periods leading to overdrainage (Doty *et al*., 1982). Controlled drainage has become a management practice implemented in several Atlantic Coast states, in particular Florida, North Carolina and Maryland, to address the issue of overdrainage and agricultural drainage water quality. Controlled drainage involved the use of some type of adjustable, flow-retarding structure placed in the drainage outlet that allows the water level in the outlet to be artificially set. Many types of structures can be used in open ditch systems depending on the layout of the drainage system (Evans and Skaggs, 1985; Evans *et al*., 1992). When properly managed, controlled drainage has been documented to reduce the transport of nitrogen in agricultural drainage waters by as much as 40% (Evans *et al*., 1995). At this point, controlled drainage is most extensively implemented in the states of Florida (600 000 ha) and North Carolina (200 000 ha). Controlled drainage has been adopted as a water quality best management practice (BMP) in several states to minimize the adverse impacts of

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drainage. As such, it qualifies for costs share assistance to landowners to encourage them to implement the practice. In addition to reducing nitrogen and phosphorus transport to receiving waters, many farmers have observed modest yield increases in the range of 5–10% compared to conventional drainage in some years, especially on sandier soils.

In addition to increasing the transport of nutrients from cropland, drainage practices in humid regions historically focused on straightening and deepening natural channels to increase their hydraulic capacity. These traditional channel improvements typically disassociated the channel from the natural floodplain, especially for smaller storms, further degrading water quality and ecological functions associated with the natural stream and riparian floodplain. Over the past 10 years several pilot studies have been implemented to demonstrate and evaluate alternative channel management strategies and design geometries to identify alternatives that will enhance water quality and ecological functions while maintaining the necessary drainage function. Channel alternatives include: establishment of in-stream wetlands, lowering of the floodplain to reconnect the channel with the floodplain, redesign of channels using natural channel design principles, and establishment of conservation easements to encourage establishment of perennial riparian buffer vegetation. Nitrogen transport has been reduced by 20–40% with in-stream wetlands (Bass and Evans, 2000). Reconnecting the channel with the floodplain dampened the hydrograph peak and reduced the ''out-of-floodplain'' risks. Some channel alternatives have shown benefits in terms of achieving more natural sediment transport resulting in channel stability and enhanced aquatic habitat (Lindow *et al*., 2007) and improved riparian zone function (Dukes *et al*., 2003).

Drainage water management is an emerging management concept for the Midwest. Landowners and land managers understand the value and impact of subsurface drainage as a practice rooted in ridding the soil of excess water. The recent advent of within-field, spatial yield monitoring has strengthened their conviction that drainage increases yields, and has encouraged the move to narrower, more intensive drainage systems.

While research has shown strong evidence that growing season water table management (subirrigation-drainage) can reduce year-to-year yield variability and ensure consistent high yields, Midwest farmers have not adopted this approach, probably because of the lack of an available adequate water supply (Allred *et al*., 2003).

Recent research in the Midwest has shown that nitrate delivery to streams can be reduced by raising the drainage outlet elevation during the winter (Fausey, 2005). While farmers are known to be good environmental stewards, this nontraditional approach (restricting drainage outflow), along with the absence of any proven return on investment, has largely prevented drainage water management adoption.

Western United States

Drainage water management in the arid and semiarid western United States can be divided into two categories: (1) on-farm management and (2) off-farm management or disposal.

On-farm management. Farm management of drainage water is generally limited to the reuse for irrigation of crops or evaporation as a means of disposal. The application of irrigation over the long term must prevent the accumulation of salts in the crop root zone in order to sustain crop production. The potential to use any drainage water for irrigation use depends on the salinity and the amount of various other constituents in the drainage water that may be harmful to the crop being grown. For example, boron is a limiting element in terms of managing the disposal of saline drainage water for reuse, as many crops are sensitive to boron and it is a prevalent element in arid and semiarid areas in the western United States (Ayars *et al*., 1993; Ayars and Basinal, 2005; Grattan *et al*., 2004). Therefore, when drainage water containing boron is reused as an irrigation supply, the drainage effluent must be carefully applied or not used at all on crops sensitive to boron. While selenium may have severe impact on wildlife, it has little impact on plant development.

Chemicals used to enhance crop production are another source of materials that impact on drainage water quality. Nitrate fertilizer is a major source of pollution in drainage water, since nitrogen is soluble and very mobile, and as a result moves quickly through soil with the deep percolate from irrigation. Other fertilizer materials including phosphorus and potassium are not nearly as mobile and do not readily move to groundwater. Excess phosphorus in surface runoff creates major problems in humid areas as described above. On-farm management practices that control surface runoff will reduce total loading from any adsorbed chemicals such as pesticides or herbicides. This

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is generally not a benefit on-farm, but control of surface drainage can be a major benefit for off-farm disposal. Protection of groundwater quality is another concern with regard to the management of both surface and subsurface drainage water.

Off-farm management or disposal. All drainage water needs to be managed. When the drainage water is beyond farm control, it then becomes a management and disposal problem for others. In the United States, federal and state laws and regulations have been adopted to reduce the impact of discharging drainage water (or any waste) into the waters of the United States or individual states (Porter Cologne Water Quality Control Act, California Water Code §13000 et seq.), (The Federal Clean Water Act, 33 USC §1251 et seq.). In general, agricultural drainage water degrades any water body, either surface or ground, into which it is discharged. Therefore, drainage water containing excess amounts of nitrogen, phosphorus, herbicides, pesticides or other chemicals must be managed or treated to minimize or avoid impacting on the users of the water body to which the drainage water is discharged. Runoff and deep percolation of wastewater from concentrated animal facilities, such as dairies and feedlots, are a major problem in many areas of the western United States.

Additional problems are created when farms around urban areas are asked to apply urban wastewaters, such as treated municipal sewage or industrial cannery waste, as irrigation water for pastures or crops. This is also called ''land disposal''. First, regulations generally prohibit the use of wastewater on crops where the residue from the wastewater will impact the quality or safety of the crop when harvested or the quality of the groundwater below the area where the waste is applied. Second, drainage water from the application of such waste materials to land increases the drainage problem for the landowner or farmer as additional treatment may become necessary to deal with other materials in the wastewater, such as pharmaceuticals and heavy metals, that could have a negative impact on the quality of any water into which the drainage water is discharged.

Institutional management of drainage water

The 1972 amendments to the Clean Water Act established water quality standards as set out in the total maximum daily load (TMDL) program of §303(d) of the Act. These standards lay largely dormant until the 1990s when they were activated by citizens' suits demanding control of nonpoint sources of pollution. As it became apparent that the source of nutrients fuelling hypoxia in the Gulf of Mexico was a result of agricultural activities in the Midwest including subsurface drainage, the United States Department of Agriculture (USDA) was seen as an agent for developing programs to combat environmental pollution from agricultural activities. The USDA has traditionally used a voluntary, incentive-based approach to reducing offsite impacts of agriculture. Based on earlier success in North Carolina using drainage water management to reduce nutrient levels in streams, USDA agencies, working through the Partnership Management Team, decide to establish an Agricultural Drainage Management Systems (ADMS) Task Force to devise an approach to improve drainage practices to reduce adverse offsite impacts of drainage waters. The focus of the ADMS Task Force is to work with farmers, contractors and agricultural advisors to implement improved drainage technologies and practices that reduce nitrate loads in drainage outflow and improve efficiency of production and economic return. Along with an industry-led Agricultural Drainage Management Systems Coalition, the ADMS Task Force promotes research, education and adoption of drainage water management as an innovative practice that can reduce the delivery of pollutants to streams.

The ADMS Task Force focuses on eight Midwest states: Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Ohio and Wisconsin. The goal is to work with farmers, contractors and agricultural advisors to: implement improved agricultural surface and subsurface drainage in both new and retrofitted systems; reduce nitrate loads in drain outflow, a major source of poor stream water quality and hypoxia in the northern Gulf of Mexico; and improve efficiency of production and economic returns through managed surface and subsurface agricultural drainage. Technical guidance is provided through the NRCS eFOTG, the Practice 554 document and accompanying technical note on Agricultural Drainage Water Management, and State Extension Bulletins. Implementation of managed drainage practices in the Midwest began in 2004. Using demonstration sites, the Task Force educates local sponsors and farmers and works with them to implement managed drainage on their own land. More information about the Task Force can be found at the following URL: http://www.extension.osu.edu/~usdasdru/adms/admsindex.htm.

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