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Agriculture and Drainage
“Inseparable Science”
Research Summary
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The purpose of this technical report is to provide important information available to PPI on the importance of drainage for the agriculture industry.

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Agriculture and Drainage –

Inseparable Science

Introduction

US agriculture is an important contributor to the world's food supply and a major component of the US economy. Nearly one-fifth of the world's agricultural exports are shipped from the US. We have a heritage of productive agricultural lands and favorable climate that provides us with a comparative advantage. (Bucks, 1992)

All agricultural soils require drainage. Natural drainage processes are not sufficient for agricultural production on about 25% of the cropland in the USA and Canada. Artificial or improved drainage is necessary to produce crops on these lands. Improved drainage is needed on over 50 % of the cropland in some states and provinces. (Skaggs and Breve, 1991)

Current agricultural production would be very difficult to sustain if not for the drainage technology that has been developed over the past decades. Agricultural drainage continues to play a vital role in the sustainability of the world's food and fiber production. Drainage technology development and research has been a cooperative effort between universities and public and private sponsoring organizations.

The purpose of this white paper is to summarize many of the issues relating to agriculture, drainage and water quality and much of the research that has been performed. This information will be used to formulate a platform to support the on-going drainage activities and direct future developments and research.

History of Drainage

It has been said that those who ignore lessons from history are doomed to repeat them. This section is a brief compilation of historical documentation that drainage has not always been for agricultural production alone. In many instances, drainage served the purpose of making lands productive and even habitable.

Historically, water management for agricultural purposes can be traced to Mesopotamia some 9,000 years ago. A major reason for the decline and disappearance of some ancient civilizations based on irrigation was their failure to heed the need for drainage. Drainage, the practice of removing excess water from agricultural land, has its origin at least 2,500 years ago when Herodotus wrote about drainage works near the city of Memphis in Egypt. Marcus Porcius Cato, 234 to 149 BC, apparently wrote the first specific directions for draining land. Land drainage is also apparent in the records of the Greek, Egyptian, and Roman civilizations. Land drainage to re-claim areas adjoining the North Sea in England began in the tenth century. The Dutch began converting land by draining and diking around 1550. Russia inaugurated drainage works in 1710 to make St. Petersburg habitable. (Economic Research Service, 1987), (Donnan)

Much of the United States was not habitable or capable of agricultural production in its pre-development condition. Much of East central Illinois, for example, was…"swampy land considered worthless for farming. Problems of human health were frequently reported such as epidemics of malaria, cholera, milk sickness, ague, and fever. Plagues of mosquitoes and flies were also reported. It is easy to understand the account of the young man who refused to trade his horse and saddle for a full section (640 acres) of swampy land in that period." (Economic Research Service, 1987) A 640-acre tract would sell for more than three million dollars at the highest agricultural land prices in that same area within the last several years.

Pickels (1925) noted that Government Land Office records show that one-fourth of Illinois and still larger portions of other states were swampland. Twenty-one counties in northwestern Ohio and northeastern Indiana included much low land originally too wet to cultivate. Much of the land in north central Iowa, at the time of settlement, was in shallow sloughs too wet for normal cultivation. Large areas in western Minnesota, northeastern Arkansas, the gulf plains of Texas, and the delta areas of Mississippi and Louisiana were originally swamp and overflow areas. Drainage permitted cultivation of these areas. (Economic Research Service, 1987)

The report on Long's expedition to the source of the St. Peter's River in 1823 stated, "Near to this house we passed the state line which divides Ohio from Indiana…The distance from this to Fort Wayne is 24 miles, without a settlement; the country is so wet that we scarcely saw an acre of land upon which a settlement could be made. We traveled for a couple of miles with our horses wading through water, sometimes to the girth. Having found a small patch of esculent-grass (which from its color is know here by the name of bluegrass), we attempted to stop and pasture our horses, but this we found impossible on account of the immense swarms of mosquitoes and horse flies. From Chicago to the place where we forded the Des Plaines, the country presents a low, flat and swampy prairie, very thickly covered with high grass, aquatic plants, and among others, the wild rice." (Economic Research Service, 1987)

The first known colony-wide drainage law was enacted in New Jersey in 1772. A City of New Orleans drainage outlet was constructed around 1794. Patterns for molding the first subsurface drains in the United States were recorded as imported from Scotland in 1835. (Economic Research Service, 1987)

Early interest in the United States was not confined to development and enhanced agricultural production, but also stressed human health aspects, as illustrated by the draining of Central Park in New York City in 1858. In recent years, these health benefits were taken for granted, or overlooked. Most of the great swamps and extensive breeding grounds for mosquitoes have been eliminated, although just in the last few years mosquito-born diseases, such as the Nile virus, have become a concern in many parts of the United States.

Drainage in the United States occurred in two primary developmental periods, during 1870-1920 and during 1945-1960. The first period was initiated around 1830 when increased public pressure was brought to Congress to release federal swamp and wetlands for private development. By 1920, more than 53 million acres out of a total of 956 million acres of US farmland had received some form of drainage. The United States Department of Agriculture (USDA), 1982 Natural Resources Inventory (NRI) inventory identified about 107 million acres of wet soils as being prime or adequately drained, of which 72 percent was then cropland. (Economic Research Service, 1987) The NRI of 1982 indicated that nearly 28 million acres of existing non-irrigated crops and pastures had drainage problems, of which 15-20 percent were also considered wetlands. More recently, an added 12 million acres of rural land have been found to have at least a medium potential for drainage and conversion to crop production. (Brown and Zucker, 1998)

An estimated 110 million acres of agricultural land in the United States benefited from artificial drainage as of 1985. At least 70 percent of this drained land is in crops, 12 percent in pasture, 16 percent in woodland, and 2 percent in miscellaneous uses. (Economic Research Service, 1987) In eastern Canada over 6.2 million acres of farmland had been tile drained, as of 1992. (Madramootoo, et. al, 1992)

It is estimated that the accumulated total investment in drainage since 1855 is \$56 billion (1985 dollars). The average US real cost of providing subsurface drainage has fallen to $415 / acre from 1965 to 1985 which reflect the impact of drainage technology: trenching machines, corrugated plastic tubing installed with laser controlled high-speed trenchers or plows, and computerized design methods and models. (Economic Research Service, 1987)

On state and regional basis, approximately 40 percent of the crops in North Carolina are grown on poorly drained soils. The drainage of cropland has been one of the most important components of land management in eastern North Carolina with drainage projects initiated as early as the late 1600's. (Evans and Skaggs, 1987. Real estate values for 256 predominately agricultural counties throughout the Eastern States with a high incidence of drainage averaged 27 percent more than values in 1,422 other agricultural counties, according to an analysis of 1982 Census of Agriculture data. (Economic Research Service, 1987) In Minnesota, although the percentage of cropland drained is lower than other Midwestern states, the 1985 NRI estimates for total cropland acres drained (6.37 million) are significant. (Brown and Zucker, 1998)

Drainage, while currently viewed as an agricultural production practice, has accomplished many purposes in water management, conservation and improvement of human health conditions throughout human development history.

Effects of Drainage

Drainage practices are broadly viewed as having both strengths and challenges. The following discussion is to point out the diversity and interaction of drainage effects. This section must be read in context with the following one on water table management and sub-irrigation to gain an overall feel for the existing research and its variability in results.

The effects of drainage can be categorized broadly into ten groups. These ten groups will be discussed: soil aeration, soil moisture and trafficability, nutrient / pesticide effectiveness and transport, soil temperature, toxic substances and disease, soil erosion and flooding, plant health and crop yield, water supply, and salinity control. All of the impacts are positive from an agricultural perspective and illustrate the value of drainage technology to agricultural production. The sum total of the effects indicate that agriculture, as we know it, would be un-sustainable in many regions of the world despite the challenges in water quality.

Soil Aeration:

The first purpose of a system designed to drain land for agricultural production in humid areas is to improve soil aeration. Water logged soils decrease the air exchange between soil and the atmosphere resulting in a decrease in $O_{2\text{ around}}$ the plant roots and an increase in CO_2. It has been found that at low O_2 concentrations there is a decrease in mineral content in plants. Low O_2 concentrations in the soil also exert an influence on the growth rate. Aeration conditions in soils have a large influence on the availability of nitrogen. (Van Schilfgaarde, 1974) The better soil aeration resulting from good drainage permits deeper and more extensive root development and a more favorable environment for beneficial soil microorganisms. (Palmer, 1977)

Soil Moisture and Trafficability:

Several factors make drainage a necessity for agricultural production on some land. These factors include slow soil permeability, flat or depressional topography, restrictive geologic layers underlying the soil profile, and periods of excess precipitation. (Brown and Zucker, 1998) Performing farming operations when the soil is too wet results in soil compaction, soil structure degradation and equipment becoming stuck during field operations. (Van Schilfgaarde, 1974) Compaction on agricultural land from the use of production equipment on wet soils also creates a layer that restricts the downward movement of water. Compaction research conducted by the USDA and the University of Minnesota provided new insight into how soil water content affects the potential for soil compaction. This research points to the benefits of subsurface drainage to reduce compaction, and furthermore the need to maintain existing drainage systems. (Brown and Zucker, 1998)

Reduction in labor has forced farms to larger and larger sizes and more mechanized equipment, reinforcing the need to pay attention to trafficability. (Irwin, 1981) Trafficability is a term that has been used to describe the capability of a soil to permit the movement of a vehicle over the land surface. Trafficability in agriculture means being able to perform the required farm operation in such a way as to create a desired soil condition or to get an operation done expediently. Drainage plays an important role in all aspects of trafficability for farm operations. The effect of lack of timeliness in performing farming operations may range from complete crop failure, if planting is delayed too long, to reduced yields if tillage, weed control, harvesting, or other operations are not performed on time. (Van Schilfgaarde, 1974)

Research in Indiana showed that most of the measurable improvements in soil tilth and organic matter in the cover crop and rotation treatments were greater in the presence of subsurface drainage than in its absence, and no-till treatments performed better with subsurface drainage. Perhaps the most significant benefit of subsurface drainage is in areas of a field where surface drainage is poor – in some years the swales without subsurface drainage had enough ponded water to destroy the crop in that area, whereas drained plots were able to more quickly remove the ponded water. (Brown and Zucker, 1998)

Drainage removes soil water and at the same time makes more soil moisture available to the plants. This paradox occurs because of the improved physical condition of the soil, that is, better soil structure that results in larger volumes of water held under low tension. (Irwin, 1981) This results in deeper root depths and increased water availability during dry periods.

Longer growing seasons can be achieved with good drainage due to the possibility of earlier planting dates. (Palmer, 1977) In Ontario, there are about five fewer days for spring planting available to the farmers on poorly drained soil compared to those who farm well drained soil. (Irwin, 1981) In Finland, the worlds' most northern agricultural country, the growing season is short, only 100 days in northern Finland and only 160 days in the southern areas of the country. Drainage is a must to prepare the soil for cultivation as quickly as possible. The rule of thumb "a day in spring is a week in autumn" well describes this aim. (Saavalainen, 1987)

The most recent technological change is the application of water management systems that incorporate drainage, drainage restriction, and sub-irrigation in one sophisticated operation to optimize soil water conditions for crop growth. Economic optimization procedures can be applied to develop "best" drainage systems. (Economic Research Service, 1987)

Nutrients / Pesticides (Effectiveness and Transport):

Agriculture is listed as a source of pollution for 70% of the impaired river miles surveyed in the United States. (EPA Contract #68-C99-249, 2000). Agricultural drainage, whether surface or subsurface, sometimes contains nutrients and chemicals in sufficient concentrations to be of significance to subsequent users of the water or to the aquatic environment. Agricultural drainage is never pure, nor is the precipitation from which it originated. (Van Schilfgaarde, 1974)

The primary issues related to water quality in drainage projects are sediment transport, salinity discharges, agricultural chemicals and trace elements that are leached or that run off. Sediments often carry agricultural chemicals that are adsorbed on soil particles. Thus practices such as filter strips, grass protection of channels and sediment traps can help control these types of water quality problems. Agricultural chemicals not adsorbed on soil particles such as nitrate nitrogen, which often leaches into drainage effluent, can contribute to eutrophication of water bodies downstream. Eutrophication is a process where algae and related organisms feed on excess N, expire and their decay robs water of oxygen, thus favoring plants over animal life. (Ochs, 1987)

Extensive research conducted in the United States, Canada and Europe has documented some of the effects of subsurface and surface drainage on hydrology, soil erosion, and water quality. In most cases, surface drainage has been related to higher peak runoff rates and greater sediment losses than subsurface drainage. Some studies have indicated subsurface drainage reduces both nitrate N and phosphorus losses, while other researchers have found subsurface drainage can increase both NO3-N and P losses. It is obvious there is not universal agreement on which drainage method produces minimum effects on water quality. This controversy indicates that the mechanisms governing loss of pollutants from drained soils are complex and vary with management practices, soil, crop and climate. Promising research has shown that drainage systems can be designed and managed to minimize nutrient losses. (Skaggs and Breve, 1991)

The total cultural energy input from fertilizers is estimated to be 36% of the total "cultural" energy used by the farm in corn production. (Baker et al., 1974) Increasing the intensity of subsurface drainage generally reduces losses of phosphorus and organic nitrogen while increasing losses of nitrates and soluble salts. (Skaggs and Breve, 1992)

Nitrate and soluble Phosphorus are the nutrients probably affected most by fluctuating aeration status. Nitrate is the most sensitive. Nitrate nitrogen is usually rapidly de-nitrified to N_2 gas by submergence of the soil. (Baker and Johnson) For ammonia (NH4) and phosphate ($PO_{4)}$, less surface runoff because of increased percolation should reduce losses of these ions because they are adsorbed by soil particles. Opposite these beneficial effects are the higher NO_3 losses expected. Because of lower water tables, shorter times of saturation in the organic zone after precipitation, and shorter transit times in the subsoils, less denitrification will occur. Within the root zone, this would be an economic plus; however, once below the root zone the higher NO_3 concentrations would result in greater losses from the system. (Van Schilfgaarde, 1974) Fleming (1990) in an Ontario study found that NO_3-N concentrations in tile drain flow were not related to manure usage at the farm, but appeared to be related to total N applied to cropland regardless of the source. (Madramootoo, et. al, 1992)

The data clearly show that the magnitude of loss (nitrogen) is highly variable and depends on the soil type and its management. No single value can be applied to either concentration or total quantity of N loss. A frequent error in the literature is to relate the losses to percentage of the fertilizer N applied. Although fertilization may have increased the loss, the conclusion cannot be drawn that the N lost came from the fertilizer or that stopping fertilizer use would stop N loss. All fertile soils lose nitrate by percolation regardless of the source of the N-fertilizers, animal wastes, soil organic matter, or nitrate accumulated in the past. (Van Schilfgaarde, 1974)

Although the data is highly variable, it can be concluded that subsurface drainage expedites the transport of nitrate nitrogen from the soil to surface waters. (Brown and Zucker, 1998) Because of the improved productivity of the tile-drained land, the impact of additional nitrate losses must also be weighed against the need for production. Hopefully, better N management, either by existing means or those developed in the future, will allow a close matching of nitrate availability to plant needs, and thus reduce losses. (Baker and Johnson)

Research in Ohio and Minnesota shows that subsurface drainage promotes mellower soil conditions and reduces compaction potential. Where soil infiltration is promoted by practices such as subsurface drainage and conservation tillage, significant reduction has been found in total dissolved phosphorous and sediment concentrations of surface waters. At an Ohio site, subsurface drainage reduced the losses of sediment, phosphorous and potash by 40, 50 and 30%, respectively, over a 14-year period, compared to surface drained cropland. In another study, the reduction in loss of phosphorus ranges up to 45%, and is related to the reductions in total runoff, peak runoff rate, and soil loss. (Brown and Zucker, 1998)

One of the ways phosphorus does move through the soil profile is through the series of macropores, cracks and earthworm and root channels, also known as preferential flow paths. Stamm measured soluble-reactive and particulate phosphorus fluxes and attributed the phosphorus transport to flow in preferential flow pathways based on the characteristics of the relationship between phosphorus concentration and drain flow rate.

It has been estimated that about 50 percent of the phosphorus entering Lake Erie is by runoff from agricultural land, the other major source being discharges from wastewater treatment plants. There is a strong consensus among the jurisdictions in the US and Canada that the most effective means of significantly reducing agricultural sources of phosphorus is through erosion control, and that this control can best be achieved through wide spread adoption of conservation tillage practices, including no-till. No-till can potentially reduce total phosphorus losses by as much as 90 percent and conservation tillage phosphorus reductions may be as high as 50 percent. Tile drainage can potentially affect the impact of conservation tillage and no-till on phosphorus losses in two ways: a) crop yields are often reduced with no-till adoption on very poorly drained soils; and b) tile drainage may enhance the increased infiltration which is often observed with no-till compare to plowing. It is assumed here that any water that flows through tile will have lower concentrations of phosphorus than those in surface runoff because of the adsorption of phosphorus to soil particles. (Logan, 1987)

Water quality monitoring at the Klamath Experiment Station of Oregon State University during 1998-2000 provided data on nutrient loading of surface waters in the upper Klamath Basin indicating that agricultural contributions are less than predicted from previous studies.

The primary reason for our interest in preferential flow processes is the impact that such processes have on the quality of surface water and ground water resources. Preferential flow has always been conceived to have a detrimental impact on water quality because it moves solutes beyond the soil zone where both biotic and abiotic chemical reactions are usually at their highest potentials. (Nieber, 2001)

Small amounts of pesticide can move quickly through the soil into subsurface drainage water during the first several rainstorms after application. The amounts are less than 1% of what was applied (often less than 0.1%), while the majority of the pesticide is sorbed and / or degraded in the topsoil. Preferential flow of pesticides occurs during the first month or two after pesticide application in the spring. (Brown and Zucker, 1998) Characteristics of preferential flow processes include an early arrival time, a large peak concentration and a long-tailed recession. Rapid transport of tracers has been observed to occur, with breakthrough times on the order of 5 minutes for wet initial conditions. (Nieber, 2001)

At least six processes: volatilization, chemical, photochemical and microbial decomposition, movement, and adsorption are responsible for the behavior, fate, and persistence of pesticides in soils. Pesticides in waters may be toxic to fish, wildlife, and plants. Chlorinated hydrocarbon insecticides are potentially injurious to aquatic organisms. Many are highly toxic to aquatic animals. Chronic effects may be caused by the assimilation and storage of residues in the animal tissues. The carbamate insecticides are similar to the organic phosphates in that their toxicological action in animals is due to suppression of certain enzyme activity. There appears to be little or no hazard from chronic accumulation of these chemicals. Tillage systems had minimal impacts on atrazine concentrations in drainage waters. Concentrations of alachlor in drainage waters from fine-textured soils appear to be minimal. Organic phosphate insecticides are generally characterized as hydrolyzing in water and having a relatively short residual life. Some of the members of this group of chemical are highly toxic to both warm- and cold-blooded animals. (Van Schilfgaarde, 1974), (Brown and Zucker, 1998)

Based on studies performed, it appears that there is much more evidence for the preferential transport of solutes to surface water resources than to ground water resources. This may be due to the fact that it is easier to measure the breakthrough of solutes to surface waters than to ground water. The vast majority of studies have shown very strong evidence that preferential flow processes are very effective at transporting solutes and suspended mass through the soil profile. The backfilled trench above drain tiles was also considered to be a pathway for preferential transport of nitrates. Most of the studies related to the impact of preferential flows on surface water quality have been associated with tile-drained fields. (Nieber, 2001)

In one study, Elliot found the pesticide clopyralid throughout the soil profile of a tile-drained field following a process of irrigation to remove salts in a field in Saskatchewan. The pesticide was transported to the tile flow much faster than expected based on the hydraulic conductivity of the soil matrix. (Nieber, 2001)

Soil Temperature:

Thermal properties of soils determine the way in which heat is distributed in the profile after it has been absorbed by the soil surface. Undrained soils are known to be cold and late as regards crop growth. (Van Schilfgaarde, 1974) Soils warm up more quickly in the spring when free water is removed by tile drainage. (Palmer, 1977)

Toxic Substances and Disease:

Drainage helps eliminate diseases that harm people, crops and livestock. The benefits for mankind are greater life expectancy and improved quality of life. The benefits for crops and livestock are healthier, more vigorous, and more productive plants and animals, resulting in increased economic value. Drainage helps eliminate stagnate water which serves as breeding areas for mosquitoes or parasitic organisms that transmit or cause disease and illness. (Economic Research Service, 1987) Certain toxic substances and disease organisms (e.g.

virus and bacteria vectors from septic leach fields) are removed from the soil due to better drainage and better aeration. (Palmer, 1977)

The leaching of trace elements can also degrade water quality. Some elements such as selenium have accumulated naturally in soils. Drainage water can leach some of these trace elements and when concentrated in an evaporation reservoir can harm fish or wildlife as well as affect human health. It is important to evaluate trace elements in soil profiles when developing drainage projects since it can have a major influence on disposal alternatives. (Ochs, 1987) Leaching of trace elements in toxic concentrations can occur from natural geologic formations; e.g., high levels of selenium, boron, and molybdenum have been found.) (Economic Research Service, 1987) Toxic quantities of iron and manganese are solubilized by the reduced chemical condition of the wet soil and may retard plant growth. (Irwin, 1981) Toxic substances, such as ethylene, or high concentrations of manganese may occur, which also adversely affect root growth. (Irwin, 1981)

Soil Erosion and Flooding:

Improved subsurface drainage on agricultural lands has been found to have both positive and negative impacts on hydrology and surface water quality. (Baker and Johnson) Among the significant hydrologic effects of subsurface drainage are a lower water table, shorter duration of surface ponding, more percolation, less surface runoff, less base flow and the "short circuiting" of some base flow as tile flow. (Skaggs and Breve, 1991)

Where land is used for agricultural production, improved drainage has been found to reduce runoff, peak outflow rates, and sediment losses, compared to undrained agricultural land. (Brown and Zucker, 1998)

Well-drained soil reduces the hazard of erosion since surface runoff is substantially reduced. (Irwin, 1981) Soil erosion can be reduced on a well-drained soil by increasing its capacity to hold rainfall, resulting in less runoff. (Palmer, 1977)

Runoff from a 10-year 24-hour storm was 3 cm for good subsurface drainage as compared to 6 cm for the same soil with poor subsurface drainage. (Skaggs, 1981)

The reduction of the total runoff that leaves the site as overland flow ranges from 29 to 65%. The reduction in sediment loss by water erosion from a site ranges between 16 to 65%. This reduction relates to the reduction in total runoff and peak runoff rate. The reduction in the peak runoff rate ranges from 15 to 30 %. (Brown and Zucker, 1998)

Crop Yields:

Increased crop yield has long been the most important measure of drainage benefit. It is easily visualized, and greatly appreciated by farmers. (Irwin, 1984, 1985) Increased crop yields and improved crop quality result from favorable soil moisture conditions with good tile drainage. (Palmer, 1977) The underlying objectives in draining wet soils on farms are to minimize risk, improve efficiency, and increase net income. Drainage is best viewed as a water management practice, whose practical purpose is different for different climatic regions and land uses. (Economic Research Service, 1987) Timeliness in performing farming operation improves efficiency in the production system. Delays increase the costs or reduce the production of the system. Harvesting delays can be costly through loss of either quantity or quality of the product. (Van Schilfgaarde, 1974) Subsurface drainage is, therefore, essential for optimal crop production on wet or poorly drained soils. (Madramootoo, et. al)

Average yield increases for long-term studies conducted in Indiana and Ohio report annual increases in corn yields of 14 to 23 bu/acre, and 20 to 30 bu/ acre, respectively, for crops grown with subsurface drainage versus without. Even larger increases in yield were obtained where subsurface drainage system function included the capability for water table management. Michigan results show corn yield increased 9% in an above average rainfall growth season, and 58% in a below average rainfall growing season. Soybean and corn yields in Ohio were on average 43% and 30% greater, respectively, for subirrigation / drainage systems compared to conventional subsurface drainage alone. (Brown and Zucker, 1998)

1979 Ontario Crop Insurance Commission (Irwin); 62% of farmers stated they had changed their crop or crop rotation pattern after drainage. 93% stated they had had an increase in yield. In a comparison over 3.4 million acres of tiled land to 2.6 million acres of land with no tile, in Ontario, differences in yield averaged 25% for soybeans, 33% for corn, 38% for winter wheat and 71% for spring grain. Yield differences are probably minimum since the period of evaluation has been a favorable spring planting conditions and plant growth, did not include total crop failures and also did not include last minute planting decisions predicated on soil wetness, e.g. changing from corn to soybeans because of wet soil conditions. (Irwin, 1981,1984, 1985)

The importance of good drainage for the production of vegetable and horticultural crops has been recognized for centuries. Restricted drainage and the presence of a water table alter the growth rate and metabolic processes such as ion adsorption and water use efficiency. (Irwin, 1981)

Water Supply:

Tiling hillside seeps and piping the water to stock water tanks results in valuable livestock water supplies. Spring development has long been a viable water supply development process that involves the principals of subsurface drainage. (Palmer, 1977)

Salinity Control (and Waterlogging):

Drainage is required in many irrigated, arid lands to prevent rise of the water table, waterlogging and salinity buildup in the soil. The history of irrigated agriculture is replete with failures caused by salt buildup in the soil that could have been prevented by adequate drainage.

Drainage to control salinity is, by definition, intended to remove salt, and will usually have a negative impact on the quality of receiving waters. (Skaggs and Breve, 1992) Salinity is almost a universal threat because irrigation waters normally contain hundreds and in extreme cases thousands of mg/l of salts. Since salts in the soil can be removed effectively only by leaching, internal soil drainage becomes the key to soil desalination and salinity control. (Van Schilfgaarde, 1974)

Salinity discharges can be minimized through proper irrigation water management, reuse of drain water where possible, mixing with good irrigation water when appropriate, use of evaporation basins in some cases and by using separate master drains to discharge highly concentrated drain effluents to the sea or other safe disposal area. (Ochs, 1987)

Effects of Water Table Control and Subirrigation

Water table control is differentiated from drainage by the idea of managing the water table to maximize economic and environmental benefit. The practice of controlled drainage began about 1930. This is a practice where the elevation of the drainage outlet is controlled to manage the water table in the crop production area to its optimum level and limit nutrient and pesticide contamination of surface and ground water. (Economic Research Service, 1987) Controlled drainage for the purposes of reducing nitrogen and phosphorus losses in drainage water began in North Carolina in the 1970's.

Research into nitrate contamination of drainage water in eastern Canada by Milburn and MacLeod (1991), Madramootoo et al. (1992), and others has found that nitrate concentrations in drain flow could be as high as 40 mg/L. This discovery has led to an emphasis on developing integrated cropping and water management systems that reduce nitrate pollution of water resources. (Madramootoo, et. al) The above concerns have resulted in a rapid shift in North Carolina from conventional drainage systems to water table management systems. These systems provide drainage during wet periods, but also eliminate over drainage by using control structures to manage the water level in the drainage outlet, and provide sub-irrigation during dry periods. When properly designed and intensively managed, these systems have shown tremendous potential to improve drainage water quality. (Evans and Skaggs, 1987)

Strategies for water table control and management are complex but have been shown to have a significant impact on potential nutrient migration. Intensive management of these systems is required for both production and water quality because the management indicators are hidden from view and response to adjustments is not usually immediate. (Evans, et. al.) Nitrate pollution of the ground water is reduced by controlled drainage and water table management through three principal mechanisms: nitrates are retained in the soil matrix for future plant uptake, higher soil moisture may slow the nitrification process, and denitrification may occur before nitrates leach to groundwater. Nitrification is the process whereby ammonia (NH_4) and nitrites (NO_2) are transformed into nitrates (NO_3) while denitrification is the process whereby nitrates are transformed into nitrogen gas (N_2) under anaerobic conditions. (Madramootoo, et. al) It is believed that the denitrification process is accelerated under high water table conditions due to the presence of higher concentrations of dissolved organic carbon (Kalita and Kanwar, 1989), (Steenvoorden, 1989).

Controlled drainage clearly increases denitrification as determined by the dramatically reduced nitrate concentrations in the saturated, reduced zones. Drainage control has little effect on total nitrogen concentrations in drainage outlet ditches. The big impact on nitrogen loading is the effect of controlled drainage on total outflow. (Skaggs and Breve, 1991) Controlled drainage, when managed all year, reduces total outflow by approximately 30 percent compared to uncontrolled systems. Outflows do vary depending on soil type, rainfall, type of drainage system and management intensity. (Evans, et. al.)

Madramootoo, et al. (1992) observed, in a lysimeter study, that with the water table controlled at 60 to 80 cm, soybean yield was greater than with conventional drainage. They also determined that the elevated water table reduced nitrate levels in the soil by approximately 52%, as compared to conventional drainage. Farmers in North Carolina are now encouraged to manage their systems year round. (Evans, et al, 1989, Gilliam, et al, 1979, Skaggs and Gilliam, 1981).

Subirrigation is a form of water table management. Nitrate-N and atrazine concentrations were measured in shallow ground water beneath conventional subsurface drainage and subirrigation /drainage systems for corn and soybean from 1991 to 1997 at the Northwest Branch Station of OARDC near Hoytville, Ohio. There was a 76% reduction in nitrate-N concentrations in ground water when subirrigation was used instead of conventional drainage. Atrazine was not detectable in most shallow ground water samples. When detected, they were less than 0.1 ppm. Nitrate concentrations were reduced from 48 mg/L to 16 mg/L (1997 seasonal average). (Brown and Zucker, 1998)

In Michigan, subirrigation yield results suggest that for field crops, at present market value, subirrigation provides a positive return on investment until the capital cost of subirrigation improvement exceeds about $600 / acre more than the cost of a conventional subsurface drainage system. (Brown and Zucker, 1998)

Even though separated in the preceding discussion, the effects of drainage and water table management are complex and intertwined. One management strategy resulting in a positive response in one area might have challenge in another, and vice versa. As stated by many researches, we still do not understand all of the impacts and interaction of drainage and water management technologies.

Migration of Drainage Policy in the United States

Once upon a time, farmers and federal conservationists were busy developing land for agricultural production through drainage practices. The last twenty-five years has witnessed a change in policy that impacts the way that land is developed, farmed and crops are grown, particularly in the United States. Conservationists have shifted gears to a more regulatory mode on drainage activities and farmers are working their way through the red tape of permitting drainage improvements. Never the less, the advance in drainage technology, water table management, drainage system maintenance and reconstruction has continued, reflecting the strong connection between drainage practices and viable, sustainable agricultural production.

Some of the milestones with respect to drainage policy in the United States follow:

Federal Swampland Acts of 1849, 1850 and 1860; transferred land to States on condition that proceeds from sale be invested in works to reclaim them.

Reclamation Act of 1902; federal government became directly involved in land reclamation and associated drainage enterprises.

Flood Control Act of 1944; affected flood control and water rights along the Missouri River.

Federal Watershed Protection and Flood Prevention Act of 1954; broadened government involvement in drainage projects.

National Environmental Policy Act of 1969; 1972 Amendments to the Federal Water Pollution Control Act, set 1983 goal to achieve fishable and swimmable water quality in all navigable waters.

Clean Water Act 1977; The Clean Water Act (CWA) is a 1977 amendment to the Federal Water Pollution Control Act of 1972, which set the basic structure for regulating discharges of pollutants to waters of the United States. The law gave EPA the authority to set effluent standards on an industry basis (technology-based) and continued the requirements to set water quality standards for all contaminants in surface waters. The CWA made it unlawful for any person to discharge any pollutant from a point source into navigable waters unless a permit (NPDES) is obtained under the Act.

Executive Order 11990, 1977; Furtherance of the National Environmental Policy Act of 1969, as amended (42 U.S.C. 4321 et seq.), in order to avoid to the extent possible the long and short term adverse impacts associated with the destruction or modification of wetlands and to avoid direct or Indirect support of new construction in wetlands wherever there is a practicable alternative.

Food Security Act of 1985; Denied farm program benefits to those who grew crops on converted wetlands. (Bucks, 1992) USDA wants to base water quality policy on sound science. The restrictions on land development and drainage imposed by the 1985 Food Security Act in conjunction with the depressed agricultural economy have significantly reduced the expansion of many farming operations through land clearing and drainage. Instead, farmers are looking to more intensive management practices to increase yields and improve production efficiency on land already in cultivation.

Tax Reform Act of 1986: Directs federal agencies to avoid, where possible, the long and short term adverse effects of destroying or modifying wetlands. Trying to protect remaining wetlands.

Decennial census of drainage was eliminated by Congress in 1986. (Economic Research Service, 1987)

President Bush, 1989 Initiative on Enhancing Water Quality to protect ground and surface waters from contamination by agricultural chemicals. (Bucks, 1992)

"No Net Loss"; A goal established during the first Bush administration which has been the guiding principle of the national wetlands regulatory program.

Conflicts have arisen over a broad array of policy questions, such as clearing and draining the Mississippi Delta, draining prairie potholes, managing return flows irrigated land, controlling water level on coastal lands, and draining wet soils. (Economic Research Service, 1987)

Currently, civil court cases in the United States are struggling to redefine the jurisdictional authority of state and federal agencies in regulating activities dealing with wetlands and their management.

Challenges and Successes

The literature is full of accounts of successes in reducing human health risks, increasing yields, enabling farmers to farm more and more acres and effectively feeding a growing percentage of the world's growing population. Much has also been published about the challenges facing the drainage industry. What is collected here is a brief sampling of the literature reviewed.

Madramootoo (1992) indicated that the major environmental issues surrounding irrigation and drainage projects are: salinization, waterlogging, water quality, spread of waterborne diseases, public health, ecological changes due to reservoir and canal systems, proliferation of aquatic weeds, destruction of wetlands, oases, marine ecosystems, waterfowl and wildlife, pathogen contamination of humans and food products due to wastewater irrigation, disposal of drainage water, modification of the hydrologic regime, and changes in biodiversity. (Madramootoo, 1992)

Kesterson Reservoir in California's San Joaquin Valley…. Selenium, leached from geologic deposits by irrigation drainage water, became concentrated in the reservoir at levels toxic to aquatic organisms and waterfowl. Consequently drainage outlets were blocked under court order in the largest irrigation district in the US. (Skaggs and Breve, 1992) The San Joaquin Valley Drainage Program has proposed a plan to enable irrigation and drainage to continue for the next 50 years without providing a drainage outlet to a sink such as the ocean. The first two parts of the plan will have a direct impact on future drain design and operation. (Ayars, 1992) Even with all the challenges, drainage activities must continue if the abundant agricultural production in the San Joaquin Valley is to be maintained.

Drainage appears to strongly influence farm real estate values in the Southeast. (Economic Research Service, 1987) Land that is drained has a significantly higher value.

On-going analysis of the data from studies at Bannister and Saginaw Bay, in Michigan, show that water table control by subirrigation/ subsurface drainage can reduce non-point source pollution when compared to both wet cropland and cropland with tile systems used only for drainage. (Belcher, 1992) At the Bannister site the total dissolved nitrate-N delivered from the field to the outlet ditch by the underground pipe system was reduced 64% by subirrigating. Subirrigation had little effect on the dissolved phosphate-P delivered by the pipe system. (Belcher, 1992) Corn production on the above sites, indicate that controlling the water table by subirrigation offers agricultural producers the ability to reduce discharge of nitrate-N with increasing dissolved phosphate-P discharge. At the same time, water table management provides economic benefit by increasing production efficiency. Thus, in many situations, subirrigation is a water quality best management practice that pays for itself. (Belcher, 1992)

On the Iowa River, Hanway and Laflent, 1974, monitored subsurface drainage at two separate locations from 1970 through 972 and found that annual flow-weighted inorganic N ranged from 7 to 21 ppm, with an overall average of 16 ppm. (Baker et al., 1974)

Willrich (1969) sampled 10 tile drainage outlets, when flowing about twice monthly from 1965 through 1969. He found values of NO3-N ranging from 1 to 66 ppm with a flow-weighted average of 19 ppm.

The results from the Iowa River study point out the complexity of trying to predict water-quality trends of a waterway draining agricultural land. This is further illustrated by data gathered from a number of sources (Johnson and Baker, 1973) which showed that the average annual NO3-N content of the Iowa River increased from 0.63 ppm in 1906 and 1907 to 1.7 to 3.2 ppm during the period 1944 to 1951. It could be concluded from these data that there was a decrease in water quality associated with increased agricultural activity. However, further sampling from 1966 to 1969 showed a decrease in the average annual NO3-N content to a range of 0.17 to 0.76 ppm.

The Minnesota River focus group C.U.R.E. (Clean up the River Environment) has been successful in focusing public awareness and taking action to restore the river water quality. They have attempted to organize a group that represents all interests in the drainage basin and have promoted support for a voluntary, incentive-based conservation program targeted at reducing sediment and runoff from agricultural land. They have worked with local, state and federal officials and have received private grants for operating. It appears to be a good example of a motivated group working with all of the stakeholders to achieve a widely held goal of water quality improvement.

Even though we see research reports and opinions that reflect variation in drainage impacts on water quality and wildlife habitat, it is becoming increasingly clear that drainage and related water management systems must be designed and managed to consider both agricultural and environmental objectives. (Skaggs and Breve, 1992)

Acceptance of Agricultural BMP's

Agricultural drainage always has been viewed as a process of land conversion, improvement of the soil environment for plants either with or without irrigation, and elimination of operational hazards and nuisances. Drainage is now seen as a key aspect of water management, not as a purpose or activity in itself. Water is the resource involved, whether the purpose is to remove or otherwise control it on cropland, to avoid offsite environmental challenges, to control salinity on irrigated soils, or to limit agriculture and other land conversion of wetland areas. The most recent technological change is the application of water management systems that incorporate drainage, drainage restriction, and sub-irrigation in one sophisticated operation to optimize soil water conditions for crop growth. Economic optimization procedures can be applied to develop "best" drainage systems that are key components in best management practices. (Economic Research Service, 1987)

Improved agricultural stewardship of land and water resources has led to reductions in phosphorus and sediment loading from agricultural land, however nitrate-N losses to surface waters have continued and are increasing in some areas. Although the relative loading of nitrate-N to surface waters from different sources and the mechanisms by which nitrate-N loss occurs remains a matter of debate requiring more scientific research, agricultural production in the North Central Region is a key contributor. Certainly, subsurface drainage acts as a conduit for the movement of nitrate-N to surface waters. In addition, there is a potential for nitrate-N loss when available N exceeds plant requirement. Fortunately, innovative water table management methods are being developed, tested, and increasingly used (e.g. subirrigation and controlled drainage). Systems that link subsurface drainage with wetlands serve to further reduce soluble pollutant loadings to surface water. (Brown and Zucker, 1998)

Research conducted suggests the following strategies would minimize nitrate-N loss to surface waters:

1) Fine-tuning fertilizer N management. Research shows that applying the correct rate of N at the optimum time would have a substantial effect on reducing nitrate-N losses. Also, banded application reduces nitrate leaching (Wiese, et. al.).

2) Design new subsurface drainage systems or retrofit existing drainage systems to manage soil water and water table levels through controlled drainage or subirrigation, lowering concentration of nitrate-N in shallow ground water. The cost of retrofitting existing systems for subirrigation can be compared to the benefit of increased yields.

3) The use of alternative cropping systems that contain perennial crops would also likely reduce nitrate-N losses. However, obtaining a market

and a satisfactory economic return presents some barriers.

4) The development of improved soil N testing methods to determine the availability of mineralizable N and carryover N from the previous crop would be effective, especially following dry years, legumes, or past manure applications. (Wiese, et. al.) Soil variability impacts nitrogen management.

5) Implement wetland restoration areas, denitrifying ponds or managed riparian zones where drainage water could be “treated” to remove excess nitrate-N before discharge into drainage ditches or streams. This may be a cost-effective alternative in portions of the Midwest.

Improved management of animal manures would also contribute to lower nitrate-N losses in livestock producing areas. Knowing the nutrient content and application rate of the manure, spreading it uniformly, and incorporating it in a timely manner would all lead to better management and confidence in manure N as a nutrient source. (Brown and Zucker, 1998)

One must also consider the impact of mitigation efforts on crop yield. Although a certain BMP might result in significant environmental improvements, it is unlikely that the practice will be adopted if crop returns per acre are reduced significantly. Additional concern is that BMPs for phosphorus reduction by erosion control are not necessarily compatible with BMPs for nitrogen reductions through subsurface drainage management. These qualifications must be considered when formulating government policy to control sediment, phosphorus, and other pollutants. (Hatch, et. al., 2001)

Irrigation water management can reduce nitrate pollution. Matching irrigation amounts more closely to plant needs reduces nitrate leaching during the growing season. Nitrate leaching can also be reduced by changing from conventional to surge flow irrigation in furrow, irrigating every other furrow, applying nitrogen in the non-irrigated furrows. (Wiese, et. al.)

There is a need for improved management practices to reduce the chemical losses in water percolating to subsurface drains and to groundwater. Under present economic conditions, only a limited number of alternatives may be available. Lower chemical application rates, better applications timing, use multiple applications, incorporation of chemicals, and better methods of application might be used to reduce chemical leaching. (Kanwar, et. al., 1986)

Controlled drainage has been found to reduce nitrogen and phosphorus losses by 45% and 35% respectively, in North Carolina. (Skaggs and Breve, 1992)

It is demonstrated that riparian forests have the potential to reduce nutrient (nitrogen and phosphorus) flux from cropland to streams through uptake of nutrients and filtering of sediment and adsorbed compounds. (Hatch, et. al., 2001)

Studies have shown that water table management systems can improve drainage water quality when properly designed and carefully managed. Controlled drainage designated a BMP, therefore qualifies for cost-share assistance under the North Carolina Agricultural Cost Share Program (NCACSP). Unlike many BMP's, controlled drainage benefits both production and water quality. The program's purposes are met only after the environmental concerns or problems for a given site have been taken into account and incorporated in a management strategy for that site. (Evans, et. al.)

The cost of water table management by subirrigation is less than other irrigation methods both in terms of capital cost and operation cost for cropland that requires subsurface drainage. (Brown and Zucker, 1998)

It has been argued that greater environmental benefits may result from targeting BMP's where the greatest phosphorus loss and erosion potentials are located in the United States. However, given the large number of farming operations in highly agricultural basins, governmental oversight and management of BMP's on an individual farm basis would be prohibitive due to excessive administrative and personnel costs. Voluntary adoption of incentive supported BMP's is crucial if environmental improvements are to be significant. (Hatch, et. al., 2001)

Direction for Future Developments

Albert Gore stated in his book, "Earth in the Balance", we ignore our environment at our peril. Fortunately, those of us interested in water management are learning to apply our technology in ways that enhance the primary objective of agriculture – crop production—in a manner that is compatible with our environment. (Van Schilfgaarde, 1992) At the same time, American consumers have benefited by resultant low-cost food and fiber. (Economic Research Service, 1987)

Expect a coming to terms of the developmental ethos and the environmental ethic. Solutions will be sought that enhance both agricultural production and a variety of environmental values, including wildlife protection. (Economic Research Service, 1987) Landowners will strive to improve production efficiency by raising production per acre and product quality. This will place greater demands on intensive drainage on currently cultivated lands. In the same vein, there is likely to be more emphasis on repair and maintenance of existing systems, and on replacement of deteriorating systems, activities not usually in conflict with the environment, wildlife, or other interest. (Economic Research Service, 1987)

A first research and educational challenge is to increase our understanding of how all drainage benefits and cost, in both a direct and opportunity sense can be related to each other in the same framework in analyzing alternative private decisions and public policies. (Economic Research Service, 1987)

The scientific link between artificial drainage and the health of receiving ecosystems is far from understood. Some studies have shown that high outflow rates associated with intensive artificial drainage reduce the salinity of estuarine headwaters sometimes resulting in stress, disease, of depressed production of certain pelagic species. Other studies observed very little influence of land based activities such as drainage on estuarine salinity. In some cases, fresh water outflow was found to stimulate growth of some demersal species. Clearly, further study is necessary to better correlate land-based activities to off-site impacts of poor water quality. (Evans, 1993)

Field research is necessary to examine the integrated effects of different cropping systems, water table management, and fertilizer rates on nitrate transformations in the soil-plant-water continuum, and to develop best management practices, which reduce soil and water pollution. (Madramootoo, et. al)

The full potential of drainage at the intensive margin has not been realized. Productivity gains from better water table control and longer-term resource enhancement are often possible. Also, environmental enhancement at the intensive margin through water quality control will be significant. Achievement of these values will depend upon scientific advances and market value of agricultural products. (Economic Research Service, 1987)

Current research and technical issues on the horizon including research in the North Central Region is focusing on methods that mitigate the adverse impacts of agricultural drainage. These techniques have the goal of sustaining agricultural productivity and profitability on existing cropland while addressing environmental problems. These innovative drainage methods are used on land that is already under agricultural production and do not require further drainage of remaining wetlands. Instead, they work to help make agriculture more environmentally sound and sustainable. Modern water management for agricultural production focuses on the management and enhancement of existing drainage systems to benefit water quality and the profitability of agriculture. (Brown and Zucker, 1998)

Promising “end of pipe” treatment technologies such as the bio-filters under study and development at universities in Illinois, Iowa and Canada will continue to be developed and need to be tested widely on a field scale basis.

In Illinois, in the Embarras River watershed, nitrate-N in subsurface drainage waters and rivers has been closely linked to intensive agricultural production. Wetlands that intercept agricultural drainage are being evaluated as a method to reduce agri-chemical inputs to rivers and reservoirs used as drinking water supplies, while maintaining agricultural production. Preliminary results indicate that nitrate-N can be removed during spring and summer periods. In the future, the removal of nitrate-N, phosphorus and atrazine will be evaluated. In addition, detailed studies will be made of chemical processes in order to improve the wetland design and function. (Brown and Zucker, 1998)

The Integrated Assessment of Hypoxia in the northern Gulf of Mexico, an effort that involved many scientists from a wide array of different fields have collaborated to produce six interrelated reports that examine various aspects of the hypoxia issue. Hypoxia is the condition in which dissolved oxygen levels are below those necessary to sustain most animal life. The assessment summarizes the state of knowledge, identifies alternatives for reducing hypoxia effects and examines cost and benefits associated with the reduction actions. Very low levels of dissolved oxygen occur naturally but evidence from the Gulf of Mexico and around the world indicates that human activities are intensifying the natural phenomenon.

The most significant trend reported in the hypoxia assessment with respect to nutrient loads has been in nitrate, which has almost tripled from 0.33 million metric tons per year during 1955-1970 to 0.95 million metric tons per year during 1980-1996. Other forms of nitrogen, as well as organic carbon and phosphorus, have not increased. Evidence indicates that the flux of organic carbon and phosphorus have probably decreased over the 20^{th} century. The principal sources of nitrate are river basins that drain agricultural land in southern

Minnesota, Iowa, Illinois, Indiana and Ohio. However, economic analysis of fisheries catch data did not demonstrate statistically significant effects attributable to hypoxia.

Experience in large ecosystems has demonstrated that they respond positively to nutrient reductions. Examples include the Chesapeake, Tampa and Sarasota Bays. In the Gulf of Mexico, reductions in total nitrogen flux of about 40% are necessary to return to loads comparable to prior to the 1950-1970 period.

The two primary approaches cited in the hypoxia report to reduce, mitigate and control hypoxia in the Gulf of Mexico are: (1) reducing the inputs of nitrogen to streams and rivers in the drainage basin and (2) restoring and enhancing natural denitrification processes in the drainage basin. The report also cites “nitrogen trading” to obtain least-cost reductions. The report also recommends targeting of drainage basins for treatment.

Color infrared aerial photographs and GIS analysis were used to map existing drains. This method appears to be promising and cost effective tool as compared to conventional probing methods. The procedure is based on the fact that the soil over subsurface drains dries faster than the soil at other locations in the field and has higher reflectance in the infrared region of the radiation spectrum. (Brown and Zucker, 1998)

Subsurface drainage systems are important, if often overlooked modifiers of flood peaks and floodwater quality in rivers, ditches and streams. Most existing watershed-scale flood models do not include the effects of subsurface drainage systems, while subsurface drainage models tend to focus on single fields. Research is being conducted to develop improved models for simulating flood flows and nutrient transport in the flat, subsurface drained watersheds typical in central Illinois. (Brown and Zucker, 1998)

Controlled drainage has significantly reduced N and P transport in drainage water compared to no control conditions. Further reductions in N transport are believed possible by carefully managing fertilization rates and timing to match crop uptake. Further N reduction may be absolutely imperative if we are to sustain the productivity and health of the receiving water ecosystem. Our understanding of the impact of drainage control on pesticide transport is severely lacking. To further minimize the off-site impacts of agricultural production will require a better understanding of the mechanisms of fate and transport of nutrients and pesticides and their interaction with drainage and other water management alternatives such as controlled drainage. A better understanding of the chemical, physical and biological processes occurring in the receiving environments is also needed if we are to effectively apply our knowledge of land based processes to reduce off-site impacts. (Evans, 1993)

The interaction between water table management, trafficability and the potential development of tillage pans is not well understood. Historically, the development of tillage pans on poorly drained soils with conventional drainage practices has not been considered a problem. Since adoption of water table management on some soils, there have been occurrences of problems associated with tillage pans. (Evans and Skaggs, 1987). Additional research is needed ensure effective water table management in these soils.

With the advent of irrigation on more and more acres worldwide, the need for drainage is also on the rise worldwide. The concept of drainage as a management tool, rather than a necessary evil, has opened up an almost unlimited potential for future drainage systems to be installed. (Donnan 1977)

Very few irrigated areas in the dryer climates around the world have the fortunate combination of good geologic formations, which provide long-term natural drainage, and proper irrigation water management with minimum seepage from canals and reservoirs to allow sustainable agriculture without eventually installing an artificial drainage system. (Ochs, 1987) Subsurface drainage remains the best available technology for lowering the water table and keeping salts out of the root zone. (Madramootoo, 1992)

There are over 250 million ha of irrigated land worldwide, of which nearly 30 million ha are affected by salinity and waterlogging. It is estimated that nearly 1.5 million ha of cropland are being destroyed by salinization each year. Yields of major crops have been reduced on 16 million ha of irrigated land in Pakistan, 8 million ha in India, and 3.5 million ha in Egypt. (Madramootoo, 1992)

India is in need of a revolution in concepts and approach and technological modernization for water resources development. A total 1015 thousand hectares have been found to be water logged and 948 thousand acres under soil salinity problems. (Kazmi and Naorem, 1987)

In France, 1.8 million hectares of humid areas are benefited by subsurface drainage. About 5 million hectares (15% of agricultural land) have still to be drained in the future. Half a million hectares is permanently waterlogged due to a high ground water table. The main effect of excess water is to delay farm operations in winter and spring. Installation rates are about 130,000 hectares per year. (LeSaffre, 1987)

Subsurface drains are needed on at least 1.5 million hectares of the Quebec portion of the St. Lawrence lowlands if the food production capabilities of these lands are to be achieved. Subsurface drains are being installed at a rate of about 80,000 hectares per year. (Rashid-Noah, 1987)

New approaches for water table control will continue to be developed. The use of modified land drainage systems or dual-line irrigation/drainage systems may also afford the recycling of nutrients and chemicals that would otherwise leach to the water table, providing another tool to reduce chemical / nutrient leaching. The resolution of such a complex problem as the leaching of land-applied chemicals from agricultural practices will require input from many disciplines. Such studies, as described here, have often not qualified for support as hydrogeologic studies because they were agronomic research. It is important that the need for such integrated research is recognized, as we try to cope with ground water contamination and solute transport problems related to all forms of land-application of chemicals or wastes. (Hallberg, 1987)

While drainage improvements will continue to be needed on existing cropland to sustain and improve agricultural productivity. Economic conditions will determine whether such improvements will be profitable to the farmer. Based on existing and historical conditions, and on the potential of the broader concept of water table management, it seems likely that economic forces will support continued drainage and related water management practices. The application of these practices will almost certainly be affected, probably controlled, by their environmental impacts. About 25% of the row cropland in the US require drainage for efficient agricultural production. There is more opportunity to design and manage drainage systems to produce desired water quality effect than we ever have with naturally well-drained soils. (Skaggs and Breve, 1991), (Skaggs, 1989)

It is possible to directly integrate a regional approach into management plans for the purpose of targeting sub-regions of watersheds where BMP's for agricultural sediment and phosphorus can be implemented with the least resistance from farmers. By targeting BMP's to specific regions within major watersheds, local managerial resources will be used more effectively and costs of reducing sediment and P pollution will be minimized. (Hatch, et. al., 2001) This framework can be used to ensure that money flows to the most critical areas. (Hatch, et. al., 2001) This targeted approach of BMP adoption and monitoring is consistent with the present government approach of agency partnerships and seems to have the greatest potential for public acceptance among available choices. (Hatch, et. al., 2001)

There are usually several water management alternatives that can be used to satisfy agricultural objectives. The challenge is to select those methods that will minimize negative environmental impacts. In some cases, increasing subsurface drainage intensity to reduce surface runoff and sediment losses would be a “best management practice” for controlling nonpoint source pollution. In others, the best management practice may be the use of controlled drainage to reduce nitrate-nitrogen and to conserve water. Past research and field experience has provided a rational basis for selection and design of these systems. While there have been significant advances in our knowledge of environmental impacts and methods for managing these systems, there is much yet to be learned about the complex mechanisms governing losses of pollutants from drained soils. (Skaggs, et. al.)

The 2002 Farm Bill, Title II, Conservation, confirms a direction toward public support of initiatives that maintain and improve environmental quality. The legislation emphasizes conservation on working land by increasing funding for Environmental Quality Incentives Program (EQIP) and establishing a new Conservation Security Program, which pays producers to adopt or maintain practices that address resources of concern. Funding for EQIP has moved from $1.3 billion over the last seven years to a total of $5.8 billion over fiscal years 2002 through 2007.

The new Conservation Innovation Grants can be used to stimulate innovative approaches to leveraging Federal investment in environmental enhancement and protection. Grants are to be awarded on a competitive basis, to governmental and non-governmental organizations and persons for innovative projects involving producers, such as market-based pollution credit trading and adoption of best management practices.

The EQIP ground and surface water conservation provisions provide funding, in addition to what is available for the regular EQIP program, for ground and surface water conservation, including cost share for more efficient irrigation systems.

The Conservation Security Program (CSP) provides payments to producers for adopting or maintaining a wide range of management, vegetative, and land-based structural practices that addresses on or more resources of concern, such as soil, water or wildlife habitat.

Even though the Farm Bill reflects strong support of natural resources conservation in agriculture, the challenge remains to make sure that drainage practices are viewed in a positive perspective with respect to these initiatives and part of the terminology when conservation best management practices are discussed.

In addition to the Farm Bill, the Environmental Protection Agency (EPA) published a notice in the Federal Register, May 23, 2002, soliciting public comment on the design of its proposed watershed initiative. The EPA initiative is a community-based initiative that will supply grants to support local communities with their efforts to protect, preserve and restore waterways.

The need for agricultural food and fiber production will continue to grow as the world's population grows and develops. This summary of existing research has shown that, while challenged, drainage science and technology has continued, expanded, and redirected to address the water quality challenges. It is clear that agriculture and drainage are inseparable sciences.

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