SUBSURFACE DRAINAGE — WHAT'S NEXT?

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ABSTRACT

Subsurface drainage is a critical element in sustaining and protecting the investment in irrigated agriculture. There have been significant developments in the state of the discipline in the last 30 yrs. There has been a steady progression away from the basic elements of the system design and construction to developing management strategies that conserve water and contribute to the remediation of poor quality drainage water. In the past, the ecological impact of drainage was given little consideration but this has changed significantly in recent times. This manuscript will briefly discuss the current state of the art in drainage system design and management and speculate on what the future holds for this critical discipline.

INTRODUCTION

Drainage has been identified as the forgotten factor in sustaining irrigated agriculture (Scheumann and Freisem 2001). Surface and subsurface drainage provides the following functions: protects the resource base for food production; sustains and increases yields and rural incomes; protects irrigation investment; protects lives and assets against flooding and high groundwater levels; provides improved health conditions; protects water quality. These seven functions encompass both subsurface and surface drainage. Subsurface drainage is generally assumed to be required whenever irrigated agriculture is practiced. The emphasis in this paper will be to discuss the current state of the art in subsurface drainage design and management and consider what the future may hold. This is not to diminish the importance of surface drainage in providing a healthy ecosystem and environment but the author's experience has been in subsurface drainage.

Comparing the topics investigated in the Third Drainage Symposium and proposed for the Ninth Drainage symposium sponsored by the American Society of Agricultural and Biological Engineers provides insight into how the discipline as changed from 1976 symposium to the call for papers for the 2010 symposium. The topics considered in the call for papers have been categorized as follows; theory, design, soil properties, materials and construction, modeling, management, environmental impacts, and drainage institutions and policy. The number of sessions in each of these categories in 1976 and 2010 are summarized in Table 1.

The most apparent aspect has been the shift from theory and basic design to management over this period of time. The concept of drainage water management and environmental impacts has had a significant shift in the time frame from the very first drainage symposia to the 2010 call for papers.

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Table 1. Sessions allocated to specific topics in Drainage Symposia in 1976 and 2010.

Topic	1976	2010
Theory	1	
Design	1	1
Materials and Construction	1	
Modeling	1	1
Management		3
Soil Properties	1	1
Environmental Impact		3
Drainage Institutions		1

The objective for the remainder of this paper will be to briefly discuss the current state of the art in the individual topics highlighted in Table 1 and speculate on what the future might be with regard to each of these topics.

CURRENT STATE OF THE DISCIPLINE

Theory and Design

The theory of flow of water in porous media and specifically for flow to drains has been developed over the years based on the Bossinesq and Dupuit-Forcheimer theories. Most of the basic theory has been accepted and used as the basis for implementing designs for a subsurface drain system. Hooghoudt developed a steady state approach in the Netherlands that has been adopted for humid areas throughout the world (van der Ploeg et al., 1999). The drainage design in humid areas generally is based on the idea of a steady state system and the design criteria require the removable of a specified depth of water in a given period of time to ensure adequate aeration of the soil.

In arid irrigated areas rainfall is a minimal consideration in the design of a drainage system and the major source of excess water is a result of irrigation inefficiency. The design then incorporates the irrigation schedule and proposed irrigation system inefficiencies in the design. This has resulted in a transient analysis procedure developed by the US Bureau of Reclamation (USBR) called Dynamic Equilibrium (Reclamation, 1993). In this method the midpoint water table depth between two drainage laterals returns to the design depth at the end of the irrigation cycle. The water table position follows a succession of declining and then increasing increments as the irrigation season progresses. Design of transient systems has been implemented in the agricultural drainage planning program (ADPP) developed by Colorado State University (www.ids.colostate.edu). Donnan developed a steady-state procedure for design of subsurface drainage in irrigated areas as well (Reclamation, 1993).

Soil Properties

Successful design and implementation of subsurface drainage systems requires an accurate description of the soil properties including hydraulic conductivity, soil layers, soil types, saturated zones, and the specific yield of the soil. The USBR in the drainage manual (Reclamation 1993) has described the necessary field techniques to gather all the data needed for design and construction of subsurface drainage systems. This is a very labor intensive and costly process when large irrigation systems are being developed that require drainage. Natural Resource Conservation Service (NRCS) has developed many soils maps that cover most of the soils in the United States that can be used for initial reconnaissance and design (websoilsurvey.nrcs.usda.gov).

Despite the field studies outlined in the drainage manual there are still problems associated with characterizing soil properties that will impact flow to the drains. One particular problem is preferential flow from the soil surface to the drain that bypasses the soil matrix. This has the potential for rapid transport of pollutants from the soil surface to the drainage water without the benefits of remediation in the soil profile. An accurate description of the saturated zone above the water table and the aeration status is critical in the design and potential management of a drainage system.

The spatial variability of these parameters also represents a significant problem when considering the design of a system. Simple field testing for these parameters may not be adequate to characterize the variation in soil type, soil layering, hydraulic conductivity, salinity, and toxic elements.

The symposia topics show that the problem of the necessary inputs in the design in particular the soil properties is an ongoing problem and one that still requires much attention.

Materials and Construction

It appears based on Table 1 that materials and construction are no longer a major component for research. There have been significant improvements over the years in the construction of drainage systems and the drain "tile". The drain tile has progressed from individual pieces of pipe made of wood, clay, or cement (Figure 1) to a continuous pipe of plastic. The installation process has evolved from a machine dug trench with hand laid tiles (Figure 2) to a continuous pipe that is trenched (Figure 3) or installed into the ground using a laser controlled plow (Figure4). Envelope materials have progressed from graded sand or soils to fabric "socks" that enclose the drain pipe.

Figure 1. Drain tile shapes.

Figure 2. Hand installation of drain tile.

Figure 3. Laser controlled trenching of plastic drainage lateral.

Figure 4. Laser controlled plow installation of plastic drain lateral.

Modeling

Modeling was part of the program in 1976 and continues into the latest drainage symposium in 2010. Over the years there has been extensive development of models for both the design and management of subsurface drainage systems (Skaggs, 1999). These models have become more sophisticated as the computer power has improved going from large mainframe computers to personal computers that have more power than the original mainframes.

DRAINMOD (Skaggs, 1982)(Figure 5) is the best known of the water balance models and is used extensively in the United States and throughout the world for designing and management of drainage systems in humid areas. This model has been adopted by the NRCS for use in designing drainage systems in the United States. Development on DRAINMOD has continued to include modules for nitrogen and salinity transport. Chang et al. (1983) tested DRAINMOD for application in irrigated agriculture and Wahba et al. (2002, 2005) and Wahba and Christen (2006) have used it for water management studies in irrigated areas of Egypt and Australia.

Models being used for drainage design particularly in arid irrigated areas include the Colorado State University irrigation and drainage model (CSUID) (www.ids.colostate.edu) and the Soil-Water-Atmosphere-Plant environment (SWAP) model (Kroes et al., 1998).

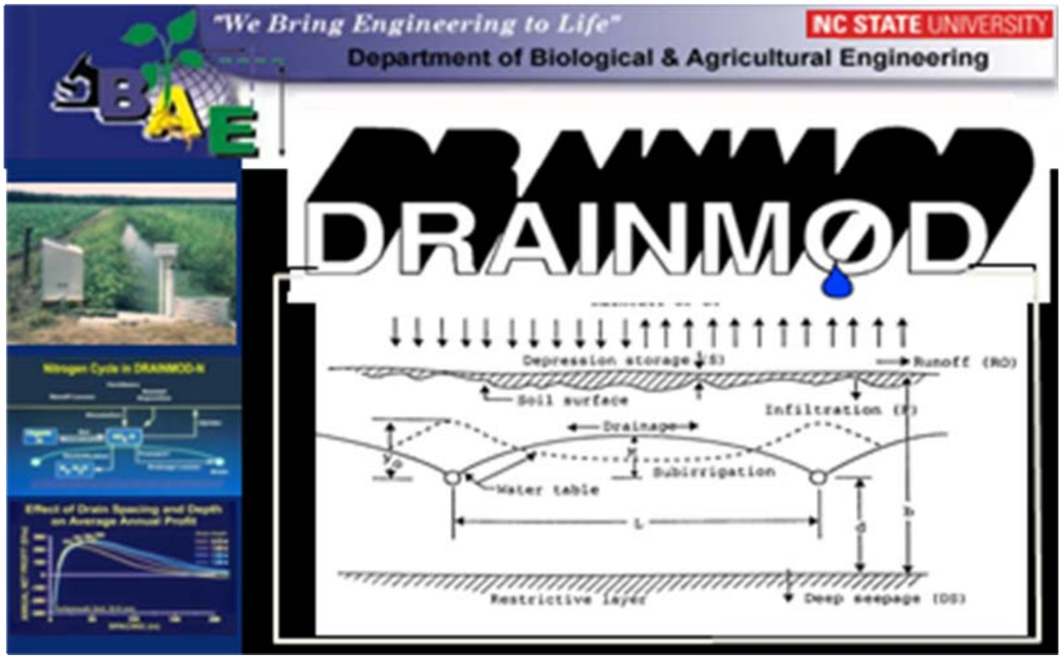

Figure 5. DRAINMOD characterization.

Management

Active management of subsurface drainage systems is a reasonably new concept and initial studies have been accomplished in the eastern United States in conjunction with the development of the DRAINMOD model. The information in Table 1 demonstrates that the idea of management is a developing concept and one that has much interest around the world. The goals for management include reduced drainage flows, improved water quality in drainage flows, and improved soil water conditions and in situ use of water by crops. Subsurface drainage system management in irrigated conditions is a new development since concerns with the accumulation of salt in the profile above the drains have limited this approach. Studies (Ayars et al. 2006a; Ayars 2007) have demonstrated that management of drainage systems in arid areas is possible without developing a salinity profile in the root zone that impacts production.

Figure 6. Drainage control structure in humid region.

Environmental Impact

Comparing the number of sessions between 1976 and 2010 it is apparent that the environmental impact of drainage has reached a significant crossroads and requires extensive research. In the past drainage systems were designed for continuous operation and very little consideration was given to the environmental impact of the drainage water on surface water quality. Continuous operation of drainage systems in arid areas results in over drainage of irrigated fields (Doering, Benz et al. 1982) with the resultant loss of water and an excessive load of salt being transported to surface water (Christen, Ayars et al. 2001) along with any dissolved agricultural chemicals The problem with accumulation of selenium in the Kesterson Reservoir highlights the environmental concerns associated with drainage from arid irrigated lands (San Joaquin Valley Drainage, 1990). Now not only salinity but toxic elements found in the drainage water are of concern. There are major concerns with nitrate pollution in the Gulf of Mexico and the discharge of phosphorus, and pesticides in drainage water in humid areas. In response to the environmental impacts of drainage water new research is being conducted on managing drainage water discharges to reduce the total load of nitrates in the drainage water and the salinity in drainage water. The Agricultural Drainage Management Systems (ADMS) task force was developed in the mid west to find solutions to the transport of nitrate in drainage water from agricultural land that was contributing to the hypoxic zone in the Gulf of Mexico (Figure7).

Figure 7. Drained area that contributes to the hypoxic zone in the Gulf of Mexico.

Drainage Institutions

Drainage water management in the past has oftentimes fallen to the control of the irrigation districts providing the water service to the farms. In the humid areas drainage was the responsibility of the farmer who discharged drainage water into existing surface water bodies. Drainage on a large scale often involved controlling surface flow and was the responsibility of local political entities or districts formed for that purpose.

FUTURE CHALLENGES

Theory and Design

The basic theory for design of subsurface drainage systems has been well developed and is reasonably mature. There will probably be additional studies that may refine the theory and provide simpler methods of design but there will be few changes to the underlying processes. However, the design criteria need to be revised to implement additional criteria besides simply water table position and rates the recession of the water table. New criteria should include the effect of the design on water quality (Ayars et al. 1997; Guitjens et al. 1997), the potential for in situ use of shallow groundwater (Ayars et al. 2006a; Ayars et al. 2006b), and the oxygen status in the root zone above the water table. Figure 8 gives the outline of a proposed new drainage design procedure that includes consideration of water quality criteria and the use of controlled drainage and highlights the benefits of the new approach.

Soil Properties

This is an area that is critical to the design and installation of new drainage systems. As noted, data collection for characterization of soil properties needed in the design of drainage systems is an expensive and time-consuming task that does not necessarily completely characterize the site. New methods are needed to characterize the soil properties on a distributed basis such that these can be incorporated into new models and design programs. Techniques such as electromagnetic induction and ground penetration radar along with ground truthing may be the future for improved characterization of soil parameters needed in drainage system design and management (Allred et al. 2008).

Materials and Construction

The change from individual tile sections to continuously installed drainpipe is a significant improvement in the process of installation and construction as well as in material selection. It is not readily apparent what the future holds in this regard. With the new emphasis on water quality management there may be opportunities for changes in the construction that will incorporate materials that will be part of the solution to water quality issues. Filter materials are also an area that may provide opportunities for new materials and construction techniques.

Modeling

As long as there are Ph.D. candidates there will be models being developed and applied to the design and management drainage systems. There is real potential in this modeling effort to incorporate remotely sensed data into the designs of the system. This may include remotely sensed soil properties and salinity distributions. The design of a drainage system as part of an integrated water management system is an important goal to improve water productivity in humid areas and in irrigated areas and this will require models to evaluate the potential based on new designs and integrated water management strategies.

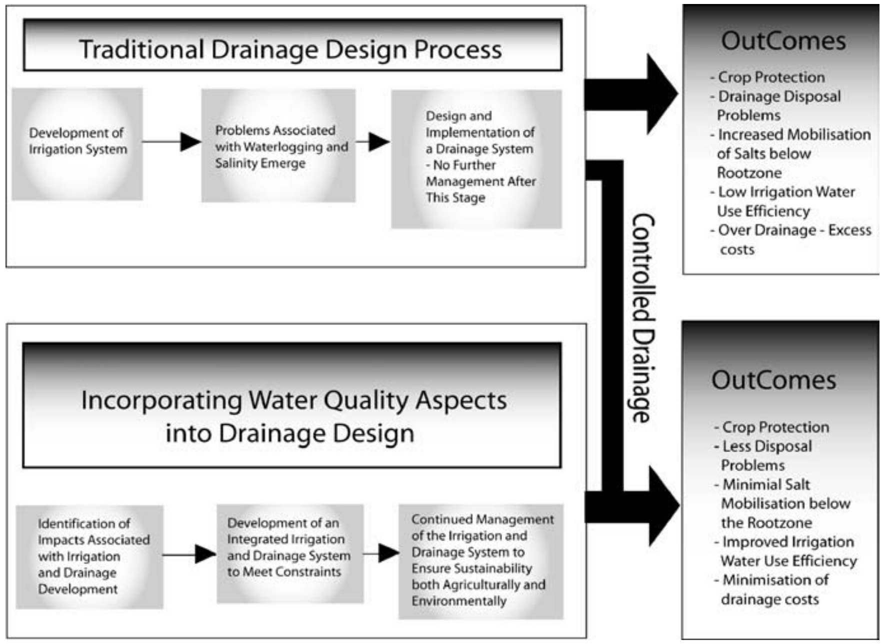

Figure 8. Schematic of drainage design methodology to include water quality criterion in subsurface drainage system design.

Management

Management of subsurface drainage systems is the next major area of research. This is being developed in the humid areas of the United States and other parts of the world and is yet to be fully developed in the arid and semi arid areas of the world. Extending our available water supplies will require that we minimize the drainage losses and improve water quality. Active management will be required to meet environmental quality goals. This is will present many challenges in humid areas subject to random rainfall events that require drainage discharge. In arid areas maintaining production sustainability and minimizing the impacts of salinity and toxic elements on the environment will be the critical consideration.

Environmental Impact

Moderating the environmental impact of subsurface drainage is critical for the sustained use of this practice. Future systems will have point of discharge structures that can be used to remediate drainage water by removing nitrates, phosphates, and toxic elements that may be present in the drainage water. This also provides an opportunity for developing distributed methods for remediation that may be included during construction. New design criteria should be developed to incorporate water quality as a criterion in the design. There is now an emphasis on the ecological restoration of previously drained areas particularly in wetland areas along the eastern seaboard of the United States. Studies also need to be developed to evaluate restoration of existing drainage systems to incorporate control structures or remediation structures needed as part of an environmental restoration.

Drainage Institutions

Drainage institutions will be faced with the challenge of providing the structure needed in ecological restoration. These will require significant cooperation between the farmer, the local governments, and the environmental community. In the developing world irrigation and drainage institutions need to be developed simultaneously as part of an integrated water management system.

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