Water table management for field-sized areas in the Atlantic Coastal Plain

By Adel Shirmohammadi, C. R. Camp, and D. L. Thomas

WET soil conditions caused by shallow water tables were the primary reason for development and use of drainage systems in humid regions. In the eastern United States, precipitation in excess of evapotranspiration during a significant portion of the year causes the ground water level to rise into the root zone. Shallow water tables severely restrict agricultural production on about half of the Atlantic Coastal Plain. These shallow water tables and poor natural drainage create an excessive soil-water condition that severely limits field cultural activities, delays planting, and restricts crop growth and subsequent production.

In most humid regions, wet agricultural soil conditions during winter and early spring are followed by intermittent dry periods during the growing season. This necessitates irrigation for consistently profitable crop growth and production. Low water-holding capacities of soils in the Atlantic Coastal Plain cause soil moisture deficiencies whenever there is no rainfall or irrigation during relatively short time periods (5-10 days). This has caused serious crop production losses in recent years.

Humid regions with these characteristics—wet during winter and the early part of the growing season and dry during much of the growing season—require improved water management. In areas with suitable topography and soil type, water table management offers many advantages. Such systems are known by various names: drainage, controlled drainage, drainage-subirrigation, controlled drainage-subirrigation, controlled and reversible drainage, and Irri-Drain. Subirrigation as a method of irrigation was first used in areas of Florida, Michigan, and western Indiana (*33*).

Research to improve water table management was given considerable emphasis in the United States during the 1970s. Ideas developed by Schwab (*20*) and van Schilfgaarde (*32*) led to improved system development by these same researchers and others (*4, 6, 8, 25*).

The Food Security Act of 1985 emphasized the environmental problems created by agricultural expansion in the 1970s, and it eliminated indirect federal incentives to convert wetland into cropland under the swampbuster provision. Heimlich and Langner (*16*) concluded that the social benefits of draining wetlands for cropland are likely to be zero or negative under the current crop surplus conditions. This may be a legitimate concern, given the fact that even drainage of present agricultural land during the wet portion of the year may have negative environmental impacts. Water table management with controlled drainage or controlled drainage-subirrigation not only prevents indiscriminate drainage of land but it actually provides water quality benefits by promoting anaerobic activities of denitrifying bacteria. Associating water table management on existing agricultural land with wetland drainage, therefore, may be misleading.

Field-sized systems

Water table management started with the concept of lowering shallow water tables in wet areas to improve trafficability. Manmade surface drainage systems were installed in the early days of farming by digging furrows and ditches (*24*). More recently, many open ditch systems have been replaced by subsurface drains. Although subsurface drains were known in the 17th century, subsurface drainage in the 18th and 19th century was carried out mainly with open ditches and subsurface drains made of locally available materials. These materials were laid in the bottom of trenches, which were backfilled with soil after installation. Examples of material used as drains are brushwood, stone culverts, turf, wooden boxes, bamboo pipes, and rice straws.

Modern subsurface drainage materials include clay or concrete tile and corrugated, perforated plastic tubing. Use of plastic tubing started with Schwab's 1947-1954 research, in which he installed several field experiments using polyethylene plastic tubes of various diameters and wall thicknesses (*21*). De Jager conducted drainage experiments in The Netherlands with polyethylene tubes pulled into mole drains (*3*). He abandoned his studies because of siltation problems that led to the clogging of the tube perforations during installation. Extensive research and development on corrugated polyethylene plastic tubing and laser-controlled, plow-type installation equipment was conducted in the United States during the 1960s and early 1970s.

Water table management for flood control or for improved agricultural production has progressed from the concept of drainage alone to that of controlled drainage and controlled drainage-subirrigation (combined drainage and subirrigation). Fox and associates studied the design of subirrigation systems with respect to steady water table control (two feet below the soil surface) over and midway between the drains (*13*). To account for the effects of climate and soils, Skaggs used a model to evaluate drainage water table control systems for shallow water table conditions on two soils in the humid eastern United States (*26*). That model, DRAINMOD (*27*), evaluates the performance of a proposed design using historical weather records. The model has been tested and verified for North Carolina, Ohio, Florida, Louisiana, Georgia, and other parts of the United States under various climatological and soil conditions. Other work by Skaggs (*28*) demonstrated that system operation during both drainage and subirrigation should be considered in system design.

As effectiveness and design considerations for controlled drainage-subirrigation were established, research was directed toward evaluating other important characteristics, such as water and energy use efficiency. Doty and Parsons showed that subirrigation on a controlled drainage-subirrigation system provided nearly all the water required by

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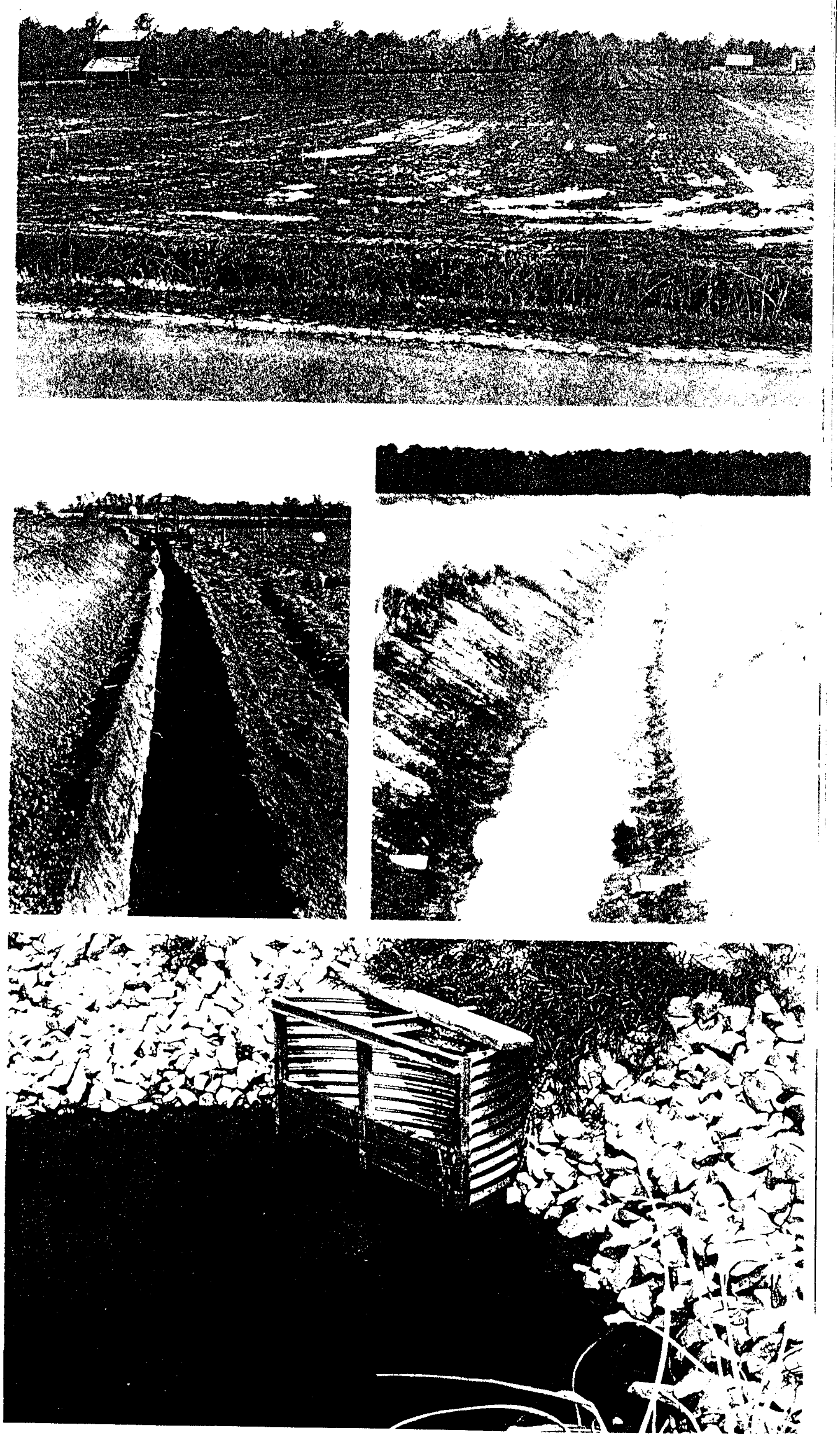


Wet soil conditions in the Coastal Plain, as in this South Carolina field (top), have been overcome by conventional drainage—old clay tile (middle, left) or modern plastic tubing—and by new water table management systems, such as controlled drainage (bottom).

corn during two growing seasons (*15*). Strickland and associates compared the water and energy requirements of controlled drainage-subirrigation and center-pivot irrigation systems for producing corn (*30*). The two systems were located on similar fields five miles apart in South Carolina. The total water applied to the subirrigation site was about 2.5 inches per crop year greater than was applied to the center-pivot site. Subirrigation required only 25 percent of the energy used by the center-pivot system. Worm and associates performed an economic evaluation of the same two systems (*34*). For two growing seasons, corn yields on the subirrigation field averaged 156 bushels per acre, 45 percent higher than the yields on an adjacent nonirrigated field that averaged 107 bushels per acre. Corn yields on the center-pivot site and adjacent nonirrigated areas were 170 bushels per acre (25 percent higher) and 136 bushels per acre, respectively. They concluded that, for the conditions studied, subirrigation was a better investment than center-pivot irrigation. Shirmohammadi and associates found that controlled drainage-subirrigation systems, if properly designed, could save up to $58 per acre and $52 per acre compared to center-pivot/drainage and traveling-gun drainage systems, respectively (*22*).

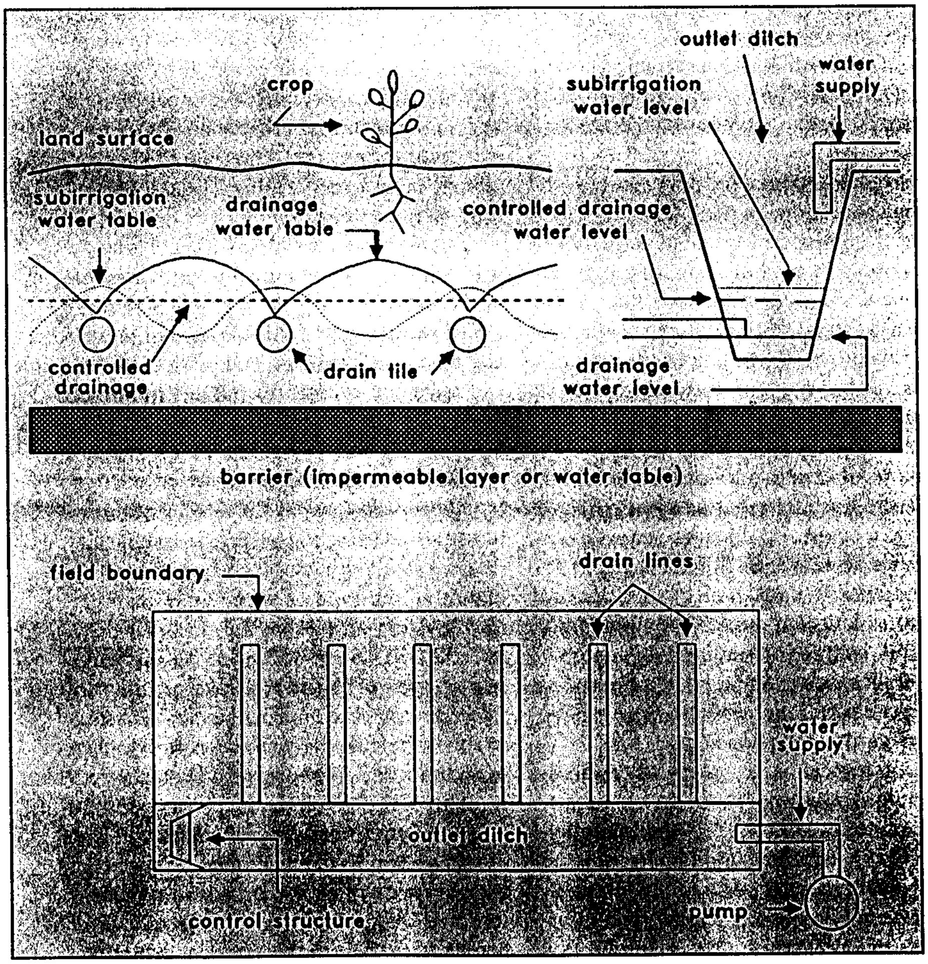
The impact of water table management on water quality has been studied on a limited scope, primarily in North Carolina. Applicability of the results from North Carolina to other states, however, is now being investigated. Since the 1970s, emphasis has been placed on nonpoint-source pollution. Most states prepared agricultural water quality plans that recommended certain best management practices (BMPs) be installed on agricultural fields and suggested that their impact on water quality be evaluated (*18*). Drainage alone was not considered as a BMP because of the lack of reliable water quality data for these systems. Research on a limited scale has attempted to address water quality concerns related to conventional (surface and subsurface) drainage and other forms of water table management, however. Subsurface drainage reduced total potassium and phosphorus losses in outflow water on a clay loam soil in southern Louisiana (*2*). Total nitrogen decreased slightly, but the data were sufficient for a definite conclusion. Gilliam and associates reported that controlling the water table throughout the year in muck and clay soils of North Carolina possibly increased denitrification and reduced the nitrogen leachate from the study site (*14*). Subsurface drainage also has been reported to result in a 10-fold increase in nitrate-nitrogen, but controlled drainage can reduce this to a fivefold increase for similar situations. Nitrate-nitrogen concentrations were less than 10 parts per million, the U.S. Environmental Protection Agency health standard for drinking water, for all outflow samples on Flatwood's soils in south Georgia, although groundwater samples within the fields exceeded this limit (*31*).

Systems in use

Water management alternatives for humid regions may be categorized as drainage alone—surface drainage and subsurface drainage—and water table control—controlled drainage and controlled drainage-subirrigation. System selection depends upon such factors as soils, topography, climate, intended use, and farm economy. Farm-scale water management systems in the Atlantic Coastal Plain traditionally consist of open ditch systems. Ditch spacings vary on the basis of soils and other site conditions; commonly, 300 to 600 feet in most areas. Depth, length, and cross-section of ditches also depend upon site conditions. These systems generally provide good surface drainage and reduce shallow water table elevations. But they often cause erosion and nutrient loss during high runoff periods. Such practices as embankment stabilization or ditch lining may help to reduce erosion. Also, open ditch systems require more land area, limit farm traffic, and can result in yield reduction. If ditches are excessively deep, drainage from adjacent soil profiles can cause deficit soil-water conditions during droughty periods and significantly reduce yields. Stream or channel water level control may be required in such cases (*5*).

Subsurface drainage generally is accomplished using underground conduits, which have been constructed of many different materials during their historical development (*24*). Corrugated and perforated plastic tubing is used commonly today to remove water from the root zone by lowering the shallow groundwater level. These tubes also may be used to perform controlled drainage and controlled drainage-subirrigation. Tubes, ranging in size from four to six inches in diameter, are placed three to five feet below the soil surface at a spacing appropriate for the soil and site conditions and for the intended purpose, ranging from 50 to 200 feet.

Schematic of a water table management system. External source of water is necessary for subirrigation phase. Precipitation is the only water supply used for controlled drainage.



Water table management strategies in the Atlantic Coastal Plain can be grouped into three categories: subsurface drainage, controlled drainage, controlled drainage-subirrigation.

The first category, subsurface drainage alone, mainly lowers the water table during wet periods until an equalibrium condition exists, governed primarily by drain depth. Drainage is accomplished by open ditches or subsurface conduits. In the eastern United States, supplemental irrigation water from a surface system often will be required during drought periods with this system because the water table drops below the drain-line depth. However, when drainage and irrigation are both required during part of the year, it may be more feasible to consider a combined drainage and subirrigation system, if site characteristics permit it.

Controlled drainage is achieved by placing a control structure, such as a flashboard riser, in the outlet ditch or subsurface drain outlet to control the rate of subsurface drainage. No supplemental water, other than rainfall, is added to the system. With this system, the water table drops below a preset level as evapotranspiration and natural drainage occur. As the water table continues to drop, it may reach a level too low to support crop growth if rainfall or irrigation does not occur. Eventually, this may result in crop stress and reduced yield.

The third option, controlled drainage-subirrigation, may be the most economical and feasible method for the shallow water table conditions in the eastern United States. This system is similar to the controlled drainage system, except that supplemental water is pumped into the system to maintain the water table at a present level during drought periods. This system provides drainage during wet periods by allowing excess water to flow over the control structure, which may also be adjusted in elevation depending upon rainfall amounts. It also provides irrigation to maintain the water level at the control structure, which may also be adjusted to a higher elevation if necessary by introducing supplemental water into the system. Therefore, water will flow from the outlet ditch into the drain lines and the soil profile during subirrigation and from the soil profile and drain lines into the ditch and over the control structure during drainage.

System design

To design a successful and efficient water table management system, five tasks must be peformed: preliminary evaluation and feasibility of the site, detailed field investigation, design computations, system layout and installation, and operation and management. Evans and Skaggs (*7*) provide a detailed discussion of each of these tasks.

Preliminary evaluation and feasibility of the site. Six site characteristics should be considered for successful performance of water table management systems:

1. *Drainage characteristics.* The site must require improved subsurface drainage to remove excess water that otherwise would restrict farm operations and crop growth. Soils classified as "somewhat poorly drained," "poorly drained," and "very poorly drained" are prime candidates for water table management. Soil Conservation Service soil survey manuals provide soils maps and classifications for each state within the Atlantic Coastal Plain.

2. *Topography.* Surface slopes should not exceed one percent for the system to be economically feasible. As the slope increases, more control structures are necessary to maintain a uniform water table.

3. *Barrier.* A shallow natural water table or shallow impermeable layer within 6 to 20 feet of the soil surface should exist for controlled drainage or controlled drainage-subirrigation systems to perform sufficiently. The deeper the barrier, the larger the volume of water required to fill the soil profile and raise the water table during rrigation.

4. *Hydraulic conductivity.* Moderate to high soil hydraulic conductivity values (about $K_s > 1.9$ cm/hr) are required for efficient system performance and timely water table response, especially in the subirrigation mode. Soils with low hydraulic conductivity values require closer tile spacings, which will increase system cost and reduce its cost effectiveness. Hydraulic conductivity values reported in the SCS Soils 5 sheet series may be sufficient for preliminary planning. A detailed measured hydraulic conductivity data is necessary to compute the system design, however.

5. *Drainage outlet.* A good gravity or pumped drainage outlet is needed to provide adequate flow capacity for expected peak discharges. For gravity flow systems, the drainage outlet should be at least four feet below the average land surface (*7*). A sump equipped with an appropriate pump may be constructed to collect the surface and subsurface drainage flow where an adequate natural drainage outlet is not present.

6. *Water supply.* An adequate water supply must be available for the subirrigation mode. Location, quantity, and quality of the water must be taken into consideration during the planning stage.

A preliminary evaluation of the site provides a basis for estimating the cost of the proposed system, which is a necessary step before completing the remaining design steps. A design engineer must discuss the assessments made during this first phase with the farmer and obtain approval for further planning.

Detailed field investigation. To design an efficient water table management system, soil type and arrangement of soil horizons, soil hydraulic properties, crops, water supply, and various climatological and topographical parameters should be considered. Soil type, arrangement of soil horizons, soil hydraulic properties, and hydraulic conductivity (lateral conductivity values and soil-water characteristics data) determine drain line depth and spacing.

The crop and its rooting system can influence system design. For example, certain crops, such as blueberries, are more tolerant to drought than such crops as corn. Thus, a wider drain spacing can be used for blueberries than with corn. Limitations created by tillage pans or acidic subsoils, conditions common in North Carolina, should be considered in determining the effective root zone depth (*7*). Crop rotation on the site may be considered.

An accurate topographic map is necessary to evaluate the slope of the land and its adequacy for any type of water table management system. A general guideline is to install the drain lines perpendicular to the slope of the land. However, this guideline may be modified, depending on the site conditions. Small contour intervals (6 to 12 inches) are necessary to evaluate the location and number of control structures necessary for creating uniform water tables. Doty and associates reported steps required to design a controlled drainage-subirrigation system for several soils in humid areas (*5*). They produced a nomogram of soils that can be used as a design guide. The nomogram uses soil hydraulic conductivity, approximate drain spacing, and ratio of a controlled drainage-subirrigation system spacings to subsurface drainage spacings.

Climatological data, such as rainfall, temperature, and solar radition, are important parameters. Knowledge of climatological data can provide a good understanding of crop water use and periods of peak water requirement. Crop water requirement information is necessary for a controlled drainage-subirrigation system to determine the external water supply size, pumping plant size, and overall management strategy. Design criteria also should be evaluated for each site based on economic as well as environmental quality considerations.

Design computations. Detailed field investigation enables the design engineer to compute proper drain depth, drain spacing, drain grades, number and size of control structures needed to maintain a uniform water table, and a proper pump capacity required for both the water supply and the drainage outlet, if a sump is used at the outlet. Soil horizon arrangement data, topography, and crop rooting characteristics will help to determine the proper drain depth, which generally ranges from three to five feet, depending upon site conditions (*7*). Soil hydraulic conductivity values and depth to impermeable layer will enable the engineer to evaluate the drain spacings, using the Hooghoudt's steady state drainage rate method for drainage conditions. However, other procedures must be used to evaluate the drain spacings if subirrigation is a part of the overall plan (*7*).

DRAINMOD, a water table management model for shallow water table conditions, is probably the most comprehensive model available for design of subsurface drainage, controlled drainage, and controlled drainage-subirrigation systems, provided the required input data are available (*27*). This model operates on an IBM-compatible personal computer and provides on-screen instructions for the user. Thus, the final design should be evaluated using DRAINMOD's long-term simulations.

System layout and installation. Using the information obtained during the first three steps, the design engineer needs to prepare a map showing the field, location of laterals and mains, and location and number of control structures. For example, minimum grades for four-inch plastic tubing may be 0.55 percent and 0.07 percent for soils with and without a siltation problem, respectively. Appropriate grades for drain lines must be specified using the available design standards and site information (*1*). Information regarding the type of water table management system—for example, an open ditch and a closed system where laterals discharge into an open ditch and control structures are located within the ditch and a closed system where laterals discharge into a nonperforated main drain and float-operated control structures are installed on the main line—should be specified before final installation. The closed system has an operational advantage over the open ditch system because of flexibility in raising the water table to a level higher than the ground surface, which increases the hydraulic gradient and speeds up the subirrigation phase (*22*).

A contour map prepared during the second phase of planning must be used to identify the location and grade of the drain lines as well as the control structures. Locations of the control structures are selected so that they provide the most uniform water table elevations possible. Water table fluctuations of 1 to 1.5 feet and 0.5 to 0.67 foot may be tolerated for grain crops and shallow rooted vegetable crops, respectively (*7*).

Once the system layout is completed on a well-prepared map, the size, spacing, and grade of drain lines as well as the size and capacity of the control structures are specified. A contractor then may initiate the installation according to specifications. Autolevel, laser-controlled plows and trenchers that provide accurate and fast installation of the system presently are available. However, caution is necessary regarding the hand installation of laterals and main to the drain in a closed system to ensure that none will be left unattached.

Operation and management. This task is one of the most important aspects of the overall effort; traditionally, it has been performed by the producer and most usually on a trial-and-error basis. Selecting the proper weir elevation, maintenance of the system, and timing of the subirrigation and drainage phases are all part of the operation and management of the system. On large-scale fields (100 acres) there may be high spots and depressions that were not considered in designing the depth and spacings of the drain lines because of the economics of the system. During the operation mode, however, a producer may adjust the control structure setting so that neither drought in high spots nor excess water in depressions will harm the crop. Similarly, knowing when to reverse from the drainage mode to the subirrigation mode in a controlled drainage-subirrigation system requires experience as well as soil moisture measurement, using such devices as tensiometers. Tensiometers indicate the soil-water potential from which one may judge the timing of subirrigation. Weather forecasts can be used to evaluate the time for lowering the water table to provide proper storage for incoming rain.

Manual adjustment of the control structure setting is laborious; consequently, it is often not adjusted because of the farmer's conflicting schedule. Recent developments have enabled linking weather forecast data to the control structures through computers, modems, and telephone lines (*11*). This approach allows selection of the weir elevation in the field from a remote location based on the weather forecast data, probability of rainfall occurrence, and system characteristics. This system has been used only in a research setting in the Lower Mississippi Valley; its application to other areas as well as its economic feasibilty for a farmer's use need to be evaluated.

Trends in the humid East

Surface and subsurface drainage of rural land for agricultural purposes continued to increase in the United States from 1900 and 1985, respectively. The slower pace at which surface drainage was used after 1975 may be attributed to the decrease in the economic vitality of agricultural production and the increased public concern for surface water quality. Skaggs reported that surface drainage systems tend to have higher runoff rates, with higher concentrations of sediment, phosphorus, and pesticides, than do subsurface drainage systems (*29*). However, outflow water from subsurface drainage systems has a higher concentration of nitrates. Controlled drainage and controlled drainage-subirrigation systems have become more popular. Water table management can reduce nitrate outflow because of increased denitrification (*14*), which has supported the increased popularity of water table management systems in the last decade.

However, the land area under water table management (controlled drainage) in 1989 was an insignificant percentage of the total area of wet soils in seven eastern U.S. states. Hesitancy on the part of farmers to use water table management systems may be attributed to several factors. First, and possibly most important, is the lack of understanding regarding proper management of these systems. Unfamiliarity with the relatively new water table management concept may be perceived as a high risk by farmers, particularly with respect to expected yield and profitability. Second, there is a lack of broad-based research data to assess or predict the impact of these systems on surface water and groundwater quality. This may be more of a social or political barrier. Third, producers have not had capital to invest in water table management systems. However, water table management is growing, especially in states where the water quality benefits have been documented. This has led to cost-share incentives to promote installations for improved water quality.

Problems and future needs

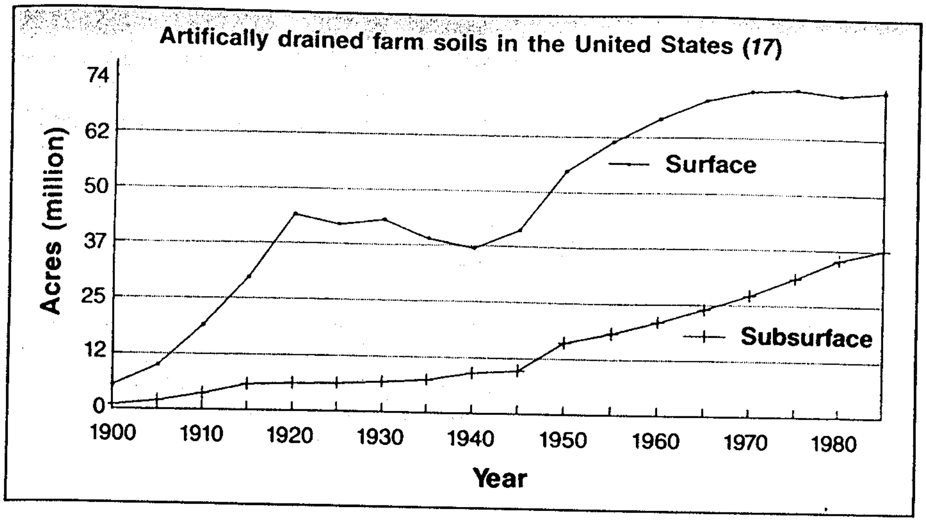
Problems related to water table management for a field-scale hydrologic unit may vary depending upon the location, soils, climate, design, and management strategy

Areal extent of water table management in seven states in the Atlantic Coastal Plain

			*Cropland Drained**		*Cropland with Water Table Management†*	
States	*Land Area Drained*	*Total Cropland**	*Total Acres*	*Percent of Cropland (%)*	*Total Acres*	*Percent of Cropland (%)*
	acres					
Delaware	460,000	1,287,000	321,000	25	2,000	0.16
Maryland	1,211,000	3,025,000	907,000	30	1,500	0.05
Virginia	-	-	-	-	5,000	-
North Carolina	5,400,000	9,721,000	2,429,000	25	150,000	1.54
South Carolina	1,755,000	4,213,000	1,053,000	25	3,000	0.07
Georgia	1,545,000	6,761,000	541,000	8	500	0.01
Florida	6,292,000	6,291,000	907,000	14	1,500,000	23.84
Total for 7 states	16,663,000	31,298,000	6,158,000	20	1,662,000	5.31

*Statistics are for 1985 (*17*).

†Personal communication with Gregory H. Williams, district conservationist, Soil Conservation Service, U.S. Department of Agriculture, Princess Anne, Maryland, and extension specialists from other states, 1989. Water table management is interpreted as controlled drainage, drainage-subirrigaion, and controlled drainage-subirrigation.


Artifically drained farm soils in the United States (*17*)

for each system (*4, 5, 10, 19, 23, 28*). However, the impact of water table management systems on surface water and groundwater loading of nutrients and pesticides either has not been adaquately studied or available data are geographically limited and inconclusive. The national concern for water quality has resulted in some misconceptions and opposition to drainage in most states. The degree of public opposition has varied, depending upon the geographic location, level of public awareness, and availability of applicable and convincing research data. For example, lack of management information about water table management systems on soils formed from sedimentary deposits on the Eastern Shore of Maryland and the public opposition to the Upper Chester River Watershed Plan have been major factors behind the lack of funding for the development of these systems in Maryland. The Upper Chester River Watershed Plan was proposed more than 10 years ago by SCS and provided for 97 miles of channel dredging for flood protection and effective water table management. Similar problems, differing in degree and nature, exist in Virginia, Delaware, North Carolina, South Carolina, Georgia, and Florida. None of these states have adequate data on the movement and fate of agricultural chemicals, especially with respect to pesticides, for water table management systems.

Acceptance and installation of water table management systems in the future depends upon development of high-quality research data to answer the identified problems. Much of the land drained using traditional systems, which constitutes a fair percentage of wet soils in each state, could be managed more effectively by using controlled drainage or drainage and subirrigation. However, the conversion of significant numbers of these systems will not occur unless improved information related to design, operation, and management of these systems and the fate of organic and inorganic chemicals in these systems is available. Reliable data and improved public education and awareness may promote the acceptance of water table management systems and result in increased yield and improved environmental quality. However, larger amounts of federal, state, and private funding are required to collect adequate research data regarding water table management systems if significant progress is to be made during the next decade.

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