

CONTROLLED AND REVERSIBLE DRAINAGE
PAST, PRESENT, AND FUTURE

by

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SUMMARY:

Past research, present operational systems, and the future of water table management are summarized as they apply to highly permeable soils of the southeastern United States.



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5 INTRODUCTION

6 Controlled and Reversible Drainage (CaRD) is a new name for an old
7 system. Controlled drainage is managing water whereby only that which
8 will hinder crop production is allowed to leave the land. For example,
9 if the rooting depths of plants are 0.6 meters, then the drainage
10 system may allow the water table to be lowered to 0.8 meters. All
11 water below 0.8 meters would remain in the soil profile for future use.
12 Reversible drainage (subirrigation) means placing a positive head of
13 water on the tile or ditch system to maintain the water table at the
14 desired elevation. CaRD systems is a term used to denote that drainage
15 and subirrigation are accomplished with the same system.

16 Past Research

17 French scientists, Bordas and Mathieu (1931) reported higher
18 yields from a controlled water table than from other irrigation sys-
19 tems. Some practical aspects of controlled subsurface drainage were
20 considered by Morris (1949) who concluded that in the future all arti-
21 ficial drainage may be controlled drainage.

22 Fox et al. (1956) presented theoretical criteria for depth and
23 spacing of conduits for subirrigation systems. They suggested that
24 subirrigation required rigid control of the water-table depth. Plant
25 growth can be retarded or stopped completely if the water table is too
26 shallow or too deep. No field data were reported.

27 Kalisvaart (1958) reported on subirrigation in the Zuiderzee

1 Poldus in the Netherlands where only agricultural land with low water-
 2 holding capacities needed irrigation. In portions of this land, water
 3 can be supplied by subirrigation which might be termed--drainage in
 4 reverse. He points out that in fields where the subsoil consists of
 5 deep and very permeable low terrace sands, "as a rule subirrigation
 6 (reversible drainage) will be the most suitable method" for irrigation.
 7 He listed five things that may cause drought in portions of the fields
 8 under subirrigation: (1) a lack of water supply and low impounded
 9 elevation, (2) extremely dry and hot days when evapotranspiration
 10 exceeds the ability of the soil to transmit ample water for plant use,
 11 (3) excessive lateral losses or seepage away from the canals to prevent
 12 controlling the water level, (4) variations in the soil may cause
 13 local drying out and crop stress, and (5) defects in the tile system
 14 with blockage from silting, iron compounds, and roots which penetrate
 15 the lines as principle causes.

16 In the Unites States most data on subirrigation must be gleaned
 17 from drainage research. For example, we find in Table 2.2, pages 34
 18 and 35 of Wesseling (1974), that in 21 of the 35 cases reported,
 19 yields decreased when the water table was maintained below certain
 20 levels from the surface. Water table depth for maximum yields varied
 21 with crops and soil classifications. However, for all soils classified
 22 as loams, sandy loam, and loamy fine sands, he showed that there was a
 23 minimum water table depth that produced maximum yields. But, for any
 24 greater depth to the water tables, yields were reduced.

25 Tovey (1969), grew alfalfa in lysimeter studies in Nevada with
 26 controlled water tables. Water tables were maintained at 60, 122, and
 27 244-cm (2-, 4-, and 8-feet) depths by continuous subsurface drainage.

1 The results showed that alfalfa can adapt its rooting pattern to either
2 shallow or deep nonfluctuating water tables and produce about the same
3 yield. Irrigation water applied to the soil surface produced little
4 increase in forage yield.

5 Carter and Floyd (1972) controlled the water table at various
6 depths in small plots of sugarcane in Louisiana. Plots were irrigated
7 by surface and subsurface methods. However, cane yields from irrigated
8 and nonirrigated plots did not differ significantly. In this investi-
9 gation, the water-holding ("field") capacity of the upper 60 cm (2 ft)
10 of the soil profile was relatively high, 12 cm (4.8 in) which could
11 explain the finding of no difference in yields due to irrigation.

12 Campbell and Seaborn (1972), Williamson and Carreker (1970),
13 Williamson and Kriz (1970), and Williamson and Van Schilfgaarde (1965)
14 used crop yield and soil aeration criteria for establishing the desired
15 depth of the water table in lysimeter studies.

16 Rogers and Klute (1972) describe general concepts in terms of non-
17 saturated flow theory regarding the dynamics between water-table fluct-
18 uations in a sand, and changes in soil moisture content above the water
19 table.

20 Skaggs et al. (1972) and Skaggs (1972) reported that sufficient
21 water can be supplied by subirrigation to meet normal plant needs of
22 certain Coastal Plain soils by controlling the water table with tile
23 lines spaced at 15 m. However, their field studies did not provide ap-
24 propriate data for determining optimum depth and/or methods of control-
25 ling the fluctuations of the water table to maximize crop yields.

26 At Clemson University, Warner (1972) developed a computerized
27 management model, using calculated soil moisture content and forecast

1 probability for rainfall as a tool for making daily decisions for
2 controlling the water table.

3 Follett et al. (1974) reported that for the irrigation area of
4 North Dakota, corn, sugarbeet, and alfalfa produced maximum yields on a
5 sandy soil with a shallow water table (less than 1 m deep). Neither of
6 the crops responded to irrigation in the test over the shallow water
7 table.

8 In a field trial on low water-holding capacity sandy soils, Doty
9 et al. (1975) showed a nonlinear relationship for the number of days
10 the water table was maintained at less than 107 cm (42 in) from the
11 surface. Corn silage yields were increased by 1.1 t/ha (0.5 ton per
12 acre) for each additional day that the water table was at 107 cm (42
13 in) or less from the surface. The water table was at less than 107 cm
14 (42 in) from the surface for a range from 29 to 55 days where the yield
15 and water table measurements were made.

16 Doty and Parsons (1977) found that a water mound built above the
17 natural water table by a positive head on the tile lines was difficult
18 to maintain as the natural water table dropped. However, yields of
19 shelled corn were increased by 0.07 tons/ha (.03 t/a) for each ad-
20 ditional day the water table was maintained between 0.7 and 1.0 meters
21 (28 and 39 in) from the soil surface in a sandy clay loam soil.

22 Skaggs, 1978, provided a model that explains the formulas and
23 physical laws involved in both drainage and subirrigation. This also
24 shows how the CaRD systems function and has good agreement with the
25 actual operation of several systems in North Carolina.

26 Benz et al. (1978) reported that yields for three crops (corn,
27 sugarbeets, and alfalfa) grown over a shallow water table (1.2-1.8 m

1 deep) were much higher than those for medium (about 1.8-2.4 m deep) and
2 deep (about 2.1-2.7 m deep) water table on a Hecla sandy loam soil in
3 North Dakota. The reported three-year average for applied-water-use
4 efficiencies for corn grown under the shallow water table ranged from a
5 high of 26.7 kg/ha/mm for the nonirrigated treatment to a low of 11.5
6 kg/ha/mm for the maximum irrigation treatment on which 1.5 times the
7 estimated irrigation requirements were applied each week. Yields of
8 sugarbeet sucrose and alfalfa showed similar results. The addition of
9 only 0.5 percent of the estimated irrigation requirements reduce yields
10 significantly on the shallow water table treatment. This indicates
11 that water supplied to the crop from the water table was ample and
12 additional irrigation was excess.

13 Doty (1979) concluded that a CaRD system on a sandy clay soil fur-
14 nished ample water for corn production over a three-year period with
15 the exception of one eight-day period. During those eight days, evapo-
16 transpiration was about 1 cm per day. Because the hydraulic conduc-
17 tivity of the soil was only 120 cm/day, water could not be supplied
18 through the soil fast enough to meet evaporative demands.

19 Recharging Ground Water

20 Palkovics et al. (1975) showed that the rate of stream flow and
21 the water table level in the soil changed similarly on a forested
22 watershed in central Pennsylvania. Further, Palkovics and Peterson,
23 (1977) calculated stream flow from the decline in water table in the
24 soil. Their "results indicated water yield from the soil aquifer ex-
25 plained stream flow." If the water table level affects the stream flow
26 rate, then there is reason to believe that the water table level in the
27 field can be controlled at the desired depth by controlling the stream

1 flow. In a discussion of groundwater levels based on data from Ahoskie
2 Creek watershed and Creeping Swamp watershed, Winner and Simmons (1977)
3 state, "if the increase in base runoff results from increased ground-
4 water recharge, we would expect a greater range in groundwater-level
5 fluctuation after the channels are deepened, with the greatest change
6 in amplitude occurring near the stream and relative little change in
7 amplitude occurring at the divide." In discussion of the water budget,
8 they state, "because deeper channels result in an increased fluctuation
9 in groundwater levels, with the lowest levels being reached during the
10 summer growing season, it might seem that evapotranspiration losses
11 from the surficial aquifer would be reduced". However, as pointed out,
12 this should be reflected in increase in total runoff; this was not the
13 case on Ahoskie Creek watershed (Knisel et al. 1977), and was not pro-
14 jected for Creeping Swamp watershed (Winner and Simmons, 1977). Water
15 table depths increasing to 5 feet from the surface have been shown to
16 reduce evapotranspiration (Whisler and Brater, 1967). If the water
17 table can be controlled at the proper depth, then the crop can use
18 water from the fringe area to supply water for the evapotranspiration
19 process, Palkovics et al., 1975, and Reicosky et al., 1976.

20 Weston and Swain (1979) studied the physical possibility of arti-
21 ficially recharging the groundwater system in the South Platte River
22 basin in Colorado. "The analysis indicate that recharge of the al-
23 luvial aquifer is physically possible, but some problems associated
24 with high water tables and differences in water quality may be expect-
25 ed." Waterlogging conditions are likely to develop in areas that lie
26 within 1 to 3 km of the river. High concentrations of dissolved solids
27 in the recharge water may deteriorate ground water enough to make it a

1 poor source for domestic and municipal water supplied in some areas.

2 Present South Carolina System

3 Mr. Lance Williams, a farmer in Marion County, S. C., is one of
4 the leaders in developing a total water management system. He is
5 controlling an entire stream which in turn controls the water table on
6 his farm. A dug lake is used for storage. All excess water leaves the
7 farm through an 18-inch culvert spillway in the storage reservoir. Mr.
8 Williams uses both subsurface and flood irrigation in his water manage-
9 ment system.

10 On the Spring Island Plantation, off the South Carolina coast near
11 Beaufort, the Soil Conservation Service designed and assisted in the
12 installation of drainage on a 160-ha system consisting of parallel
13 ditches spaced 90 to 150 m apart. Following installation, crops did
14 not grow satisfactorily because of extreme drought. However, after
15 control structures were added and the water table raised to within 1 m
16 of the soil surface, the crops were no longer subject to drought and
17 produced 6.3 t/ha of corn.

18 Mr. Johnny Brailsford, Brailsford's Nursery, Orangeburg, S.C.,
19 grows trees for commercial transplanting. He uses a CaRD system in a
20 dual purpose (1) to supply moisture for faster growth on his trees and
21 (2) to keep the soil moist and conditioned for tree removal. Mr.
22 Brailsford operated his system in the following manner: When the trees
23 needed water, the ditches were filled which allowed the soil to be
24 saturated through the tile lines. When the soil was moist to the sur-
25 face in the fields, the water level in the ditches was dropped to
26 facilitate drainage. At present, he controls the water table by keep-
27 ing the water level in the ditches at an almost constant depth.

1 Mr. Earl Marvin, Wildwood Plant Nursery, Walterboro, S. C., has a
 2 multiirrigation system consisting of overhead sprinklers, trickle, and
 3 two CaRD systems. One of the CaRD systems is on a slope of about 2
 4 percent. The control ditch is at the top of the slope and the tile
 5 lines run from the ditch down slope in the direction of the mean contour.
 6 During the extreme drought of 1977, he sustained heavy losses every-
 7 where but in the CaRD fields. Because of labor and time, he was unable
 8 to irrigate all the areas covered by the sprinkler and trickle irri-
 9 gation systems. However, in the field with the CaRD system, very
 10 little labor was required which resulted in no loss from drought. In
 11 addition, the soil remained in excellent condition for plant removal.
 12 He is very pleased with CaRD systems and has replaced the sprinkler and
 13 trickle systems in four fields with CaRD systems and is in the process
 14 of doing so in his other fields.

15 Mr. Frank West, of Marion County, S. C., has two CaRD systems. One
 16 system uses only the water from natural rainfall, which is stored in
 17 the ditches and underground. This 1,000-acre system has produced
 18 excellent yields of corn, oats, and soybeans. The water, stored under-
 19 ground, is transferred from the soybean side of the field to the corn
 20 side when the corn need water. After the corn is mature, all water is
 21 returned to the soybeans through the ditch system. In another 400-acre
 22 system, wells are provided and the CaRD system is used to distribute
 23 the water from these wells to the entire area.

24 Presently, Henry Young, of Orangeburg, S. C. has completed about
 25 150 acres of a proposed 1,000-acre CaRD system. The soils in the area
 26 range from a Coxville sandy loam to a Raines loamy sand. Mr. Young has
 27 a well which produces about 2500 gal/min to supply water for the sys-

1 tem. In addition, water can flow by gravity from a large swamp area
2 adjacent to the fields. Eventually, the ditch system will carry water
3 from the well to the entire 1,000 acres by gravity flow.

4 The 1.7 ha research CaRD system on the new Pee Dee Experiment
5 Station, Florence, SC, has been operated for the past five years. The
6 system was installed in a Goldsboro soil on a site that would not
7 normally be used for controlled and reversible drainage, to study water
8 supplied by a CaRD system in a slowly permeable soil by building a
9 water mound by means of a head on the tile lines. A water mound can be
10 built, but when the natural water table in the surrounding area drops,
11 so does the mounded water table. Research is needed to study the
12 control of the water table over a larger area than that with which we
13 are presently involved.

14 A Look at the Future

15 The future of agricultural progress in the Southern Coastal Plain,
16 an area with abundant water supplies and radiant energy, lies in devel-
17 oping more efficient systems for managing available water resources.
18 The development of new and/or improvement of current soil and water
19 management systems to compensate for the natural water deficiencies and
20 excesses which adversely affect plant growth and hinder farming opera-
21 tions is a major need for this area. Totally new concepts and investi-
22 gative approaches must be developed. Much of the drainage and irriga-
23 tion technology, developed primarily for the midwestern and western U.
24 S., cannot be adapted directly to conditions in the Southern Coastal
25 Plain because of different soil, topography, and climatic factors.

26 Soil Conservation Service personnel in North and South Carolina,
27 Florida, Georgia, Maryland, Delaware, and Virginia are continually

1 receiving requests for assistance in designing water table management
2 systems.

3 The impending energy crunch may have a direct bearing on the
4 future development of water management systems. Energy may not be
5 available to pump water from deep aquifers for irrigation or to furnish
6 pressure for sprinkler irrigation systems. Therefore, farmers may have
7 to use a readily available and abundant source of energy -- gravity and
8 slope gradient.

9 CaRD systems are designed to use gravity as their main force for
10 an energy source. In the future, more and more CaRD systems will be
11 completed.

12 Inadequate surface-water supplies are becoming a problem. "Anal-
13 ysis show that instream flows generally are considered inadequate in
14 the West and they also indicate that instream flows are of concern in
15 the East." (U. S. Water Resources Council, 1978).

16 CaRD system will help eliminate these problems. Stream flows will
17 be checked and the water stored underground near the stream channels
18 and used for irrigation and domestic use instead of flowing downstream
19 and wasted into the ocean.

20 Ground water is being diminished in several areas of the United
21 States. "Diminished artesian pressure, declining spring flow and
22 stream flow, land subsidence, and salt-water intrusion generally in-
23 dicate that ground water is being withdrawn at a rate greater than an
24 aquifer is being replenished." (U. S. Water Resources Council, 1978)

25 Also, in this report there are concern for our wetlands. "Wetlands
26 provide food and cover for waterfowl, wildlife, and sport and com-
27 mercial fish. Waterfowl depend on wetlands for breeding and wintering

1 habitat, particularly along migratory routes. Wetlands also can retain
 2 flood waters and trap pollutants. Because of the conflicts between the
 3 interest to drain land for crops and the need for wetlands for fish and
 4 wildlife, planning for drainage should include a thorough evaluation of
 5 economic, social, and environmental effects."

6 The use of CaRD systems on complete drainage districts will in-
 7 crease the amount of groundwater stored and at the same time protect
 8 wetlands. Portions of the water stored underground should percolate
 9 downward and replenish the underground water supply. Control, with
 10 various CaRD systems, can be implemented in such a way that swamplands
 11 may be left for wildlife and the surrounding farm land utilized to
 12 produce more abundant crops. Proper design of the CaRD system will meet
 13 the requirements for a total water management system.

14 Economics is another factor to consider for a CaRD system. For
 15 example, in some of the low-lying areas of the Coastal Plain, drainage
 16 is necessary; the seedbed cannot be prepared without drainage. But
 17 come July, the soil is so dry that crops cannot grow. A tile system is
 18 a must and so is irrigation. Therefore, with a CaRD system, the farmer
 19 essentially gets both the irrigation and drainage system for the price
 20 of the drainage system.

21 The drainage channels of the 65,000-acre drainage district on Con-
 22 netoe Creek (Conetoe, NC) were constructed in 1967. Here, thousands of
 23 acres of cropland that once were flooded several times a year are now
 24 receiving flood protection and improved drainage. However, to drain
 25 parts of the district it was necessary to cut large channels over 3 m
 26 deep, Fig. 1. A preliminary study was started by C. W. Doty, SEA, and
 27 SCS personnel to determine the water table drawdown at various dis-

1 tances away from the deep and shallow channels. These deep channels
2 draw the water table down about 2 m below the surface, Fig. 1, and
3 affect the water table at least 500 to 700 m from the channel. With
4 shallow channels this effect is not as drastic, Fig. 2. Knisel et al.
5 (1977) reported that the base flow of streams was greater on Ahoskie
6 Creek in N. C. after channelization which means that water is being
7 removed from the fields on each side of the stream. Farmers of the
8 area are reporting an increasing need for irrigation and lowering of
9 some shallow wells near the channels. One farmer reported that yield
10 increased in relation to the distance going away from the drainage
11 channel. This report was from the same field where the water table was
12 measured in Fig. 1, indicating that the closer the water table is to
13 the surface (within limits) the better the yield. Knisel et al. (1977)
14 reported, "groundwater in the Yorktown aquifer was recharged to near
15 capacity each year with the channel system that now exists in Ahoskie
16 Creed watershed. While some water drained from the aquifer during the
17 growing season and maintained beneficial low flow, the acquifer was re-
18 charged annually to near capacity during the dormant season." However,
19 it is during the growing season that the farmer is concerned. The Soil
20 Conservation Service and the farmers in the Coastal Plain are concerned
21 that drainage channels are a must, but better water control system
22 during dry times are also needed.

23 Studies are now being conducted to evaluate present methods for
24 design and operation of water management systems and to develop field-
25 derived criteria to modify these systems for economic efficiencies in
26 water resource projects in the Coastal Plain. CaRD systems on a drain-
27 age district basis should have an impact not only on the farm land but

1 should also impact on ecology as well.

2 SUMMARY

3 Past research has shown that controlling the water table between
4 60 and 100 cm depth will provide increased yields and that it is physi-
5 cally possible in the more permeable soils to control the water table
6 to this depth.

7 CaRD systems now in operation in South Carolina are gaining farmer
8 acceptance. Lending agencies are looking at water table control as a
9 sound investment for the farmer.

10 Controlled and reversible drainage systems provide a possible
11 means to minimize irrigation water requirements. The soil is an eco-
12 nomical storage reservoir for water. However, when the soil reservoir
13 remains full too long, crop suffer from oxygen stress. Computer models
14 at N.C. State and Clemson Universities, and field research at N.C.
15 State, Clemson, and Florence, S.C., and in Florida have shown drainage
16 and subirrigation through the same tile system to be very beneficial
17 for increased crop production. Research has shown that in the low
18 water-holding-capacity soils, crops suffer from drought stress in three
19 to seven days after a saturating rain. In the humid regions, high
20 intensity and extended rainfall periods make the installation of drain-
21 age systems necessary. An economical approach to amelioration of
22 short-term droughts is to irrigate through the existing drainage sys-
23 tems.

24 Water level control is applicable to 1.5 million acres of land in
25 South Carolina alone and can be utilized in the Coastal Plain states
26 ranging from Delaware to Texas. It can be practical on small plots or
27 on large fields.

1 Research is needed on a complete watershed without any island
2 effect to determine if a CaRD system will affect yields at various
3 distances from the channel and what effect it will have on water man-
4 agement systems, water quality, ground water recharge, yield, and the
5 timely conduct of farming operation.

6 In water management planning, we sometimes like to "have our cake
7 and eat it, too." This may be possible in the future provided we "play
8 our CaRDS right."
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WATER TABLE ELEVATION

SECTION 1
DEEP CHANNEL - MITCHEL CREEK

WATER RESOURCE PROJECT
CONETOE, N.C.

* = SOIL SURFACE
 † = 3.0 IN. RAIN
 O = DRY PERIOD
 X = 7/17/78

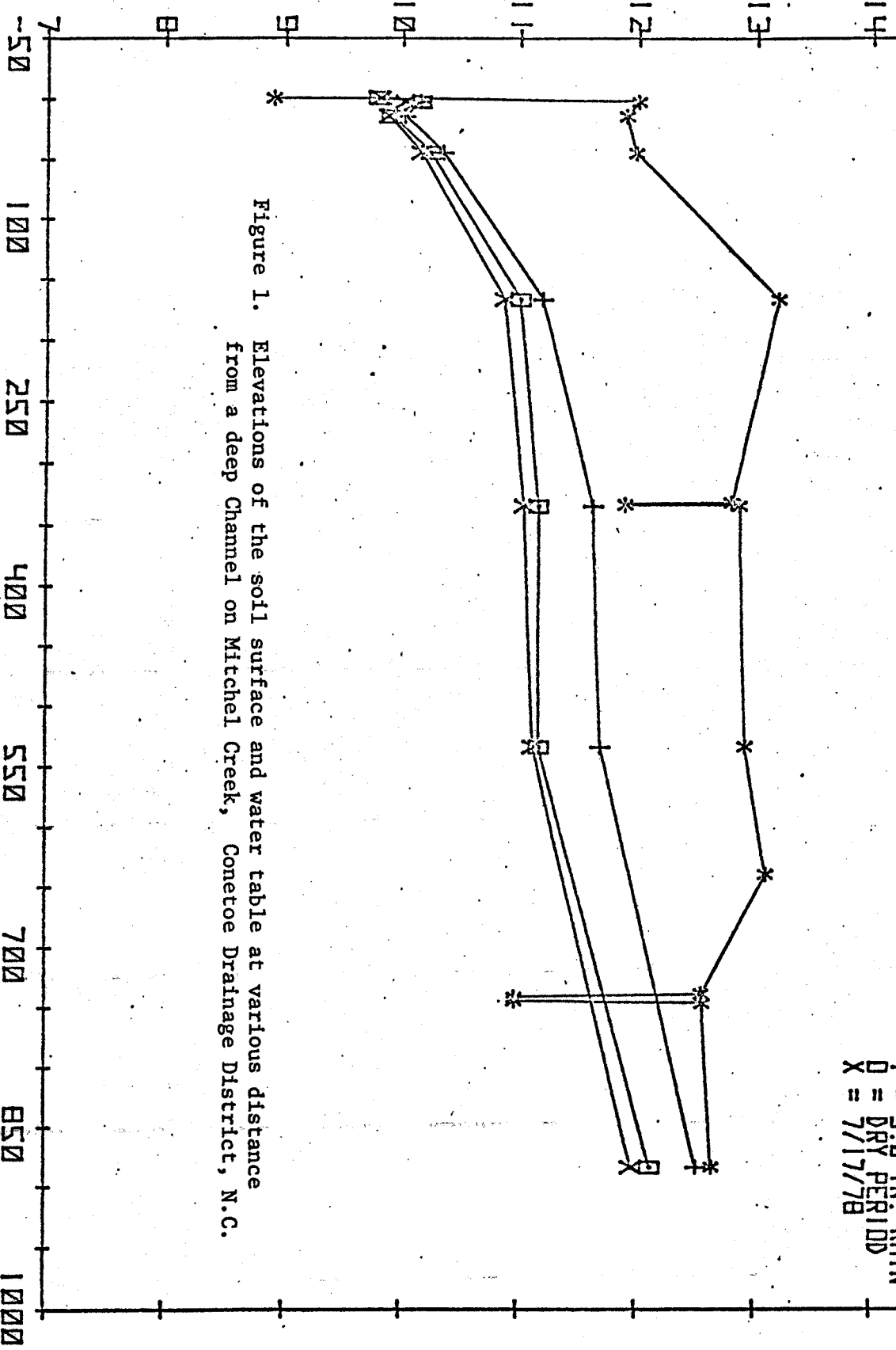


Figure 1. Elevations of the soil surface and water table at various distance from a deep channel on Mitchel Creek, Conetoe Drainage District, N.C.

DISTANCE FROM CHANNEL (METERS)

ELEVATION (METERS)

SECTION 2.
SHALLOON CHANNEL - HIGHWAY 42

WATER RESOURCE PROJECT
CONETOE, N.C.

* = SOIL SURFACE
+ = 3.0 IN. RR IN
O = DRY PERIOD
X = 7/17/78

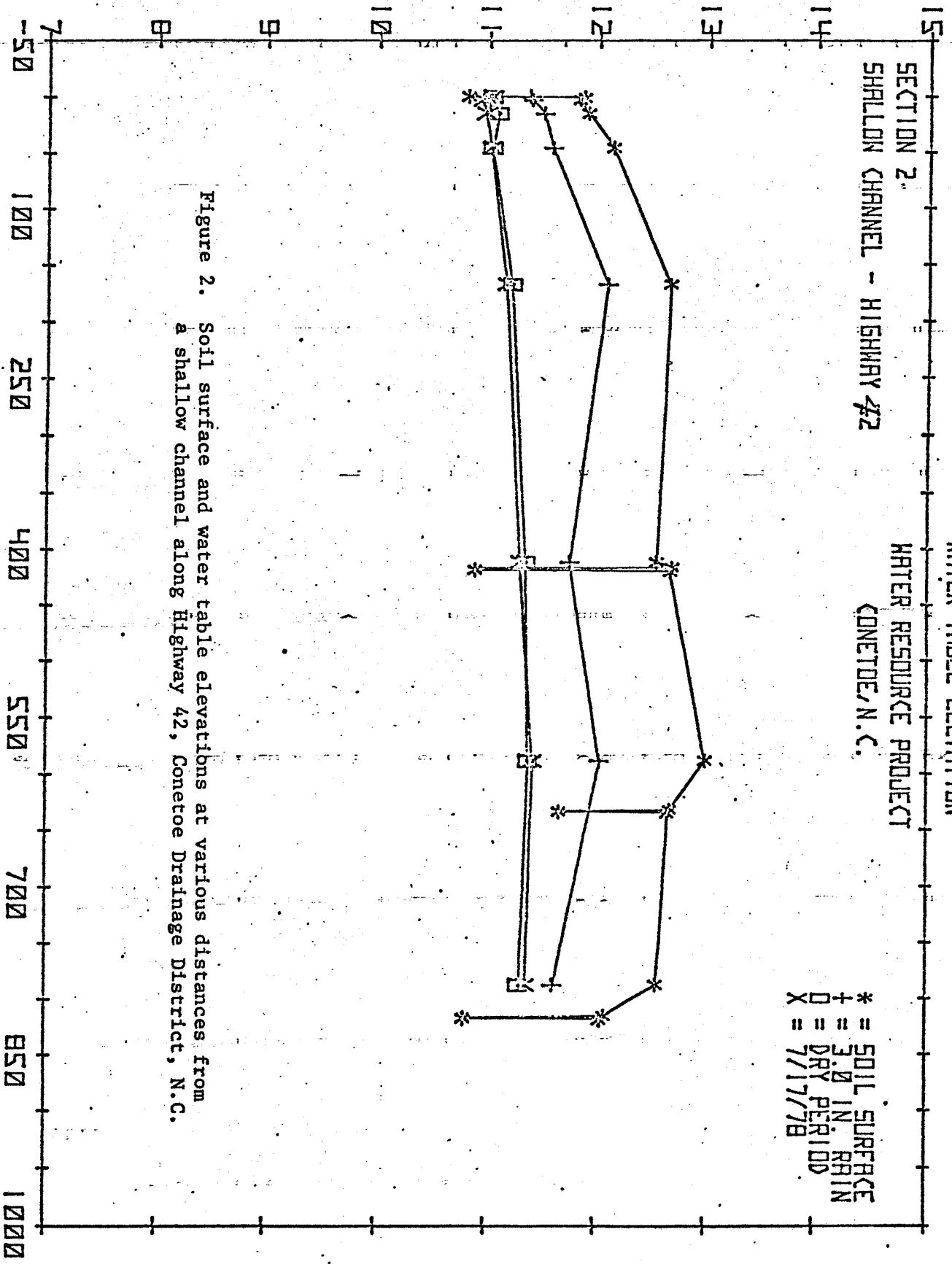


Figure 2. Soil surface and water table elevations at various distances from a shallow channel along Highway 42, Conetoe Drainage District, N.C.