Application of a Three-Dimensional Water Management Model

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ABSTRACT

COMPUTER simulations were conducted to evaluate the effects of channel water level control on the conservation and management of shallow groundwater resources in agricultural drainage districts. Drainable water stored in the profile, crop evapotranspiration, and relative corn yields were used to evaluate the conservation of stream flow and rainfall. The effects of management of shallow groundwater were determined and evaluated for the availability of channel water for withdrawal. The simulations were performed for a 0.734 km^2 area adjacent to a section of Mitchell Creek near Tarboro, NC for 2 yr, 1983 and 1984.

Channel water level control increased the simulated drainable water stored in the profile by 85 mm in 1983 and by 84 mm in 1984. Simulated relative corn yields were increased in land areas upstream from the water control structure. Yield increases were greatest for land within 100 m of the controlled channel. Channel control provided sufficient shallow drainable groundwater for 17 days of drought compared to only 4 days without control for the periods simulated.

INTRODUCTION

There are approximately 3.4 million ha of drained sandy loam and organic soils in the South Atlantic Coastal Plains from New Jersey to Texas (Wenberg and Gerald, 1982). Soil Conservation Service, USDA, personnel estimate that approximately 1.5 million ha of these soils are in Virginia, Maryland, Delaware, and New Jersey. These soils generally hold small amounts of available water for plants and the root zone supplies enough water to meet evapotranspiration demands for 4 to 7 days in the absence of a shallow water table.

Drainage improvements sometimes increase the occurrence of deficit soil water conditions by lowering the water tables during the growing season. However, drainage is required on most of these soils to provide trafficable conditions for planting and tillage operations and to protect the crop from excess soil water conditions during wet periods in the growing season.

In drainage districts, such as the Conetoe Creek Drainage District near Tarboro, NC (Doty et al., 1984), improvement of drainage outlets has minimized flooding and improved trafficability during the spring and fall months. However, the lower water tables with improved drainage has aggravated the problem of drought during the summer months.

A water control structure was installed in Mitchell Creek, a main drainage channel, in a 7.0 km^2 watershed in 1982 (Doty et al., 1985). The channel water level was lowered in the spring and fall to facilitate planting and harvesting operations and raised during the summer months to help alleviate drought. Doty et al. (1984) reported 20% higher corn yields upstream from the water control structure than before the structure was installed for non-irrigated fields.

During drought periods, producers may rely on natural rainfall or provide water by either surface or subsurface irrigation. Subsurface irrigation is a viable option where field topography is flat and the water levels in the main drainage channels are controlled. Areas with more relief can be irrigated with conventional sprinkler or surface methods. Drainage channels can provide the water supply for irrigation when there is sufficient upstream flow, lateral subsurface seepage, and surface flow.

Badr (1983) developed and used a two-dimensional model to study the Mitchell Creek Watershed. His model enables comparisons of the performance of channel water level control on a yearly basis for either water movement between parallel channels or to a single channel. Using computer simulations of perpendicular transects to controlled main drainage channels, he reported that the channels could provide sufficient water to irrigate up to 3.0 km^2 or 50% of the watershed.

In most watersheds, the channels are not straight and intersecting lateral ditches complicate the analysis. For this reason, a comprehensive three-dimensional water management model, WATRCOM, (Parsons, 1987) was developed to describe water flows in watersheds with intersecting channels along with parallel and single channels. The overall objective of this paper was to use WATRCOM to analyze the effects of stream water level control on drainage, evapotranspiration, crop yield, and water conservation in the Mitchell Creek Watershed.

PROBLEM DESCRIPTION

A schematic of a cross-section of a watershed drained by a single channel is shown in Fig. 1. Controlling the channel water level during the growing season reduces drainage and raises the water table in the field by conserving stream flow and rainfall. The collection and analysis of field data to determine the effectiveness of channel control is costly and time consuming. Data records on water table elevations, crop yields, stream flow, and other parameters must be collected for a few years before and after channel control is installed. The

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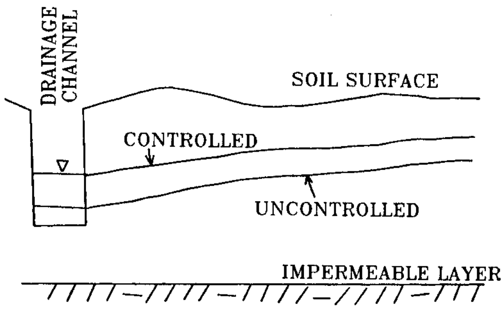

Fig. 1—A schematic of a cross-section of a watershed drained by a single channel.

effects of management of the control structure on the watershed are limited to the conditions during the testing period. A more cost-effective and less time consuming approach is to utilize computer simulation models to analyze the benefits of channel water level control. By using a computer simulation model, the user can simulate water movement, storage, and utilization by crops for many different channel control strategies for years with different weather patterns. This would enable the engineer to select the optimum control strategy for a given watershed.

MODEL

The three-dimensional water management model for small agricultural watersheds (WATRCOM) was described in detail by Parsons (1987). The model inputs are summarized in Table 1. The watershed is divided in subregions according to soil types. Saturated hydraulic conductivity and drainable porosity are generally functions of the profile depth and are assigned by subregion. Other soil property inputs such as the soil water characteristics, upward flux, and infiltration parameters are also assigned by subregion. Crop input data (crop type, planting and harvest dates, and rooting depth versus time) are specified for each subregion.

The model employs the finite element method to solve the Boussinesq equation for flow in the saturated zone.

TABLE 1. SUMMARY OF WATRCOM INPUTS

Type	Parameter or property
Site parameters	Finite element grid of the area Soil surface elevations in m Channel boundary elevations in m versus time in d Soil surface depression storage in cm Soil types
Soil properties	Saturated hydraulic conductivity in m/d and Drainable porosity in m/m as a function of profile depth in m and location Soil water characteristic curves (Volumetric water content in cm^3/cm^3 versus head in m) Upward flux in cm/h versus water table depth in m Green-Ampt infiltration parameters (A in cm^2/h and B in cm/h) versus water table depth in m
Crop	Crop type grown in each area of the site Root depth in m versus time in d Planting and harvest dates in d Wet and dry stress weighting factors in %/cm deficit versus time in d from planting
Weather	Daily potential evapotranspiration in cm/d Breakpoint or hourly rainfall data in cm

At each solution time step, the model uses the boundary conditions and solves the saturated problem iteratively. The solution for the saturated zone is coupled with a one-dimensional water balance in the unsaturated zone. Routines in the model for the unsaturated zone include those to estimate surface runoff, to infiltrate and redistribute rainfall, and to extract water from the root zone.

On a daily basis, channel water storage, total channel discharge, and drainable stored water in the soil profile are computed as described by Parsons (1987). Channel water storage is computed for each node on the boundary assuming trapezoidal shaped channels. Total water stored in the channels is found by summing the product of the water storage at each node and the channel length.

The lateral discharge or seepage to and from the channel, in m^3/d per m of channel, is computed for each node along the channel boundary. Total lateral seepage to or from the channel is found by summing the amounts for each of the boundary nodes.

Water storage is estimated as the amount of groundwater above the channel bottom available for drainage, (Badr, 1983). The reference elevation for computing water storage at each node is the elevation of the bottom of the main drainage channel. The water storage, S, is computed as

$$S = \int_e^h f(h)\, dh, \qquad h > e \quad \ldots\ldots [2]$$

where:

h = the water table elevation in m at the grid node
e = the channel bottom elevation in m on the transect containing the grid node
f(h) = the drainable porosity function at the grid node.

The model simulates evapotranspiration by computing both potential evapotranspiration (PET) and the amount of soil water available to the crop. When upward movement of water from the water table plus water stored in the root zone is not sufficient to satisfy PET demands, the crop is assumed to be stressed and a stress-day-index is calculated. Models for corn growth and development described by Skaggs et al. (1982, 1983); Hardjoamidjojo et al. (1982a, b); and Shaw (1974, 1976, and 1978) are used. Similarly, the model estimates excess wet stresses using the procedures described by Skaggs et al. (1982, 1983) and Evans et al. (1986). The total wet and dry stress for the growing season is found and related to yield using a corn response model for deficient soil water conditions and a model for predicting corn response to excess soil water conditions (Skaggs et al.,

TABLE 2. SUMMARY OF WATRCOM OUTPUTS

Parameter	Output frequency
Water table elevations in m	daily, time step
Channel water storage in m^3	daily
Saturated soil storage in m^3	daily
Discharge to and from the channels in m^3	daily, time step
Runoff in m^3	daily
Surface depression storage in cm	daily, time step
Actual evapotranspiration in cm	daily
Water in the crop root zone in cm	daily, time step
Crop water deficit in cm	daily
Wet and dry stress indices in %/cm deficit	daily
Relative yields in %	growing season

1982, 1983; and Evans et al., 1986). The details of the implementation of these computations in the WATRCOM are described by Parsons (1987).

Model outputs are summarized in Table 2. Analyses of water table and storage response to channel water level control can be performed. Predicted crop water use, availability, deficit, and relative yields are also available for analysis. Water stored in the profile, subsurface lateral discharge to the channels, channel storage, runoff, crop evapotranspiration, and relative yields can be summarized by selected subsection of the site; for example, above and below a channel water level control section. Many of the outputs such as drainable water storage and channel discharge are output as volumes and as depths of water over the area.

The computer simulation model, WATRCOM, was tested and verified by comparing predicted water table elevations to measured values for 26 wells from the Mitchell Creek Watershed (Parsons, 1987). Comparisons were made for a 2-yr period, 1983-1984, utilizing over 14,000 daily points. Results showed that the model can be expected predict water table elevations within 0.1 m on the watershed.

DESCRIPTION OF THE WATERSHED AND MODEL INPUTS

A computer simulation analysis was conducted for a 0.734 km^2 section of the Mitchell Creek Watershed containing a channel water level control structure. The site is part of the project area described in detail by Doty et al. (1984, 1985).

The finite element grid, the channel boundaries, and the location of the dam are shown in Fig. 2. Soil surface elevations were assigned to each node using topographic maps of the area and contours within the simulation area shown in Fig. 3. The subregions of the area used to specify the saturated and unsaturated soil inputs are also shown in Fig. 3.

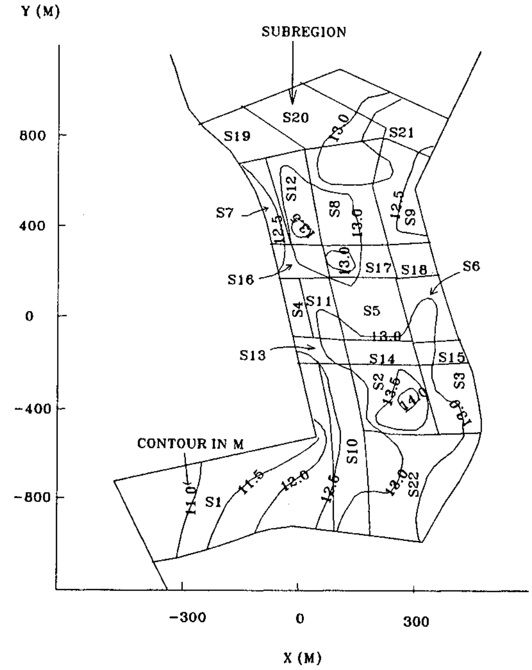

Fig. 3—Plan view of the watershed showing the soil surface elevation contours and the subregions used to specify saturated and unsaturated soil inputs.

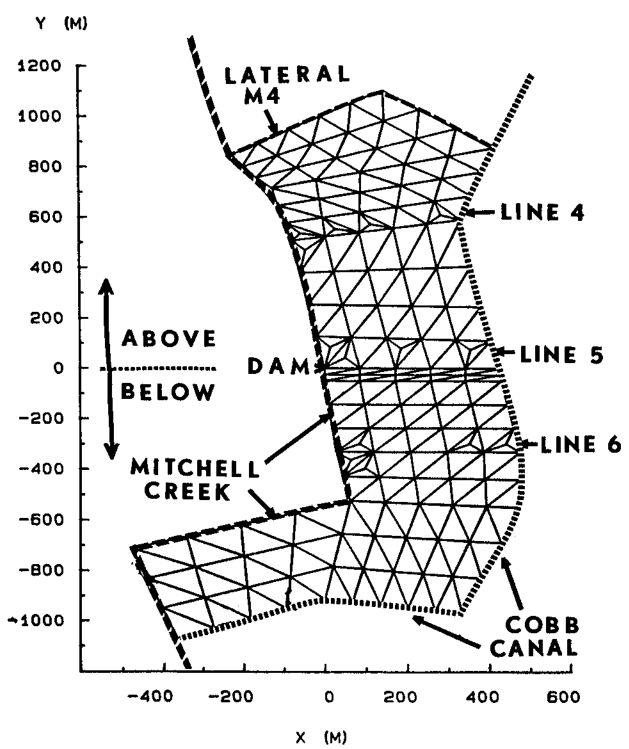

Fig. 2—Plan view of the watershed showing the channel boundaries and finite element grid used for the simulations.

Soils in the area were mapped as four series: Altavista sandy loam, Augusta sandy loam, Portsmouth loam, and Portsmouth sandy loam, coarse loamy variant. The soil water characteristics used in the model simulations were presented by Badr (1983) and Parsons (1987). The volumetric water contents at saturation and wilting point are presented in Table 3. The Green-Ampt infiltration parameters and the maximum steady upward flux functions for each soil type are summarized in Table 4. These soils are poorly to somewhat excessively drained and underlain by a coarse sand aquifer 1.5 to 2.5 m below the surface. The coarse sand is underlain by an

TABLE 3. UNSATURATED SOIL PROPERTIES SUMMARY FROM BADR (1983) AND PARSONS (1987)

Soil type	Depth range, m	Saturated	Wilting point
		water contents, cm^3/cm^3	
Altavista sandy loam	0.0-0.3	0.379	0.054
	0.3-0.6	0.313	0.149
	0.6-1.2	0.323	0.180
Augusta sandy loam	0.0-0.3	0.357	0.056
	0.3-0.6	0.404	0.120
	0.6-1.2	0.389	0.027
Portsmouth loam	0.0-0.3	0.321	0.114
	0.3-0.6	0.301	0.101
	0.6-1.2	0.350	0.150
Portsmouth sandy loam, coarse loamy variant	0.0-0.3	0.371	0.073
	0.3-0.6	0.375	0.150
	0.6-1.2	0.393	0.040

TABLE 4. GREEN-AMPT INFILTRATION PARAMETERS AND MAXIMUM STEADY UPWARD FLUX FOR THE SOILS USED IN THE MODEL FROM PARSONS (1987) AND BADR (1983)

Water table depth, m	Altavista sandy	Augusta sandy	Portsmouth loam	Portsmouth sandy loam variant
	Green-Ampt infiltration parameters			
	A parameter, cm^2/h			
0.3	1.08	12.9	0.20	2.25
0.6	2.50	20.9	0.61	9.28
1.2	2.73	173.1	0.54	12.36
1.5	2.70	214.2	0.67	12.87
4.0	2.69	331.5	0.85	15.52
	B parameter, cm/h			
0.3	1.95	29.0	0.37	7.81
0.6	1.41	26.0	0.60	9.66
1.2	1.13	114.5	0.62	10.58
1.5	1.08	132.4	0.74	10.76
4.0	0.94	177.2	0.80	11.22
	Maximum steady upward flux, cm/h			
0.1	9.210	70.250	1.025	417.920
0.2	0.755	7.810	0.200	10.700
0.3	0.175	2.161	0.770	1.270
0.4	0.062	0.869	0.039	0.280
0.6	0.014	0.240	0.015	0.033
0.9	0.003	0.066	0.006	0.004
1.4	0.001	0.016	0.002	0.000
2.0	0.000	0.005	0.001	0.000

impermeable layer of reduced clay at a depth of approximately 4.1 to 6.1 m. The drainable porosity profiles used in the model simulations are shown in Table 5. The lateral saturated hydraulic conductivity for the sand aquifer ranged from 0.6 to 46 m/d with most observations in the range of 5 to 15 m/d. The effective saturated conductivity of the profiles and the soil types assigned to each subregion are shown in Table 6.

Weather data from the 1983 and 1984 growing seasons, collected on the site with an automatic weather station (Parsons, 1987), were used as input for the computer simulations. Potential evapotranspiration was estimated from air temperature and solar radiation data using the Jensen-Haise procedure (Jensen, 1974). The equation, calibrated for 29-yr of weather data, 1950 to 1978, from Wilson, NC, was

$$PET = [(7.799 * 10^{-3} * T) + 2.524] * R_s \quad \ldots\ldots\ldots [1]$$

TABLE 5. DRAINABLE POROSITY INPUT DATA FROM BADR (1983) AND PARSONS (1987)

Water table depth, m	Altavista sandy	Augusta sandy	Portsmouth loam	Portsmouth sandy loam variant
	m/m			
0.3	0.070	0.043	0.085	0.054
0.5	0.090	0.099	0.075	0.144
0.7	0.108	0.176	0.087	0.230
0.9	0.121	0.176	0.099	0.305
1.3	0.160	0.282	0.134	0.340
1.8	0.369	0.282	0.290	0.355
2.2	0.369	0.310	0.280	0.355
3.0	0.370	0.350	0.340	0.370

TABLE 6. SOILS INFORMATION BY SUBREGION FROM PARSONS (1987)

Subregion	Effective K m/d	Soil type
S1	9.0	Altavista
S2	37.8	Augusta
S3	1.4	Portsmouth variant
S4	31.0	Portsmouth variant
S5	24.3	Altavista
S6	3.7	Portsmouth
S7	11.6	Portsmouth variant
S8	24.4	Altavista
S9	4.0	Portsmouth
S10	21.9	Altavista
S11	21.0	Altavista
S12	11.7	Altavista
S13	12.8	Portsmouth
S14	12.8	Altavista
S15	18.2	Augusta
S16	9.4	Portsmouth variant
S17	21.4	Altavista
S18	46.1	Portsmouth
S19	4.9	Portsmouth
S20	7.8	Portsmouth
S21	6.2	Portsmouth
S22	23.0	Augusta

where
PET = daily potential evapotranspiration, mm
T = average daily temperature, °C, and
R_s = total daily solar radiation, MJ/m^2

A record of rainfall was collected as breakpoint data for each 2 mm change in rainfall. The 1983 growing season was relatively dry with 263 mm of rainfall compared to about 566 mm of PET. In 1984 the growing season was average to wet with 599 mm of rainfall and PET was estimated at 551 mm. Monthly summaries of the PET and rainfall are presented in Table 7.

Corn was grown on approximately 50% of the watershed (Doty et al., 1984, 1985). In this analysis, corn was assumed to grow on the entire site. The planting date was assumed to be day 105 with day 225 as maturity. A maximum effective rooting depth of 600 mm was used and the rooting depth as a function of time is shown in Fig. 4.

For the computer simulations, the channel water level upstream from the water control structure (dam) was assumed to be raised to the maximum elevation of 11.55 m above MSL during the growing season, day 105 to day 225, in both 1983 and 1984. Prior to and following the growing season, observed channel water levels were used (Doty et al., 1984). These results were compared to those obtained from simulations assuming no channel water

TABLE 7. SUMMARY OF PET AND RAINFALL DATA DURING THE GROWING SEASON FOR WATRCOM SIMULATIONS

	April 14-30	May 1-31	June 1-30	July 1-31	August 1-12	Totals
	mm					
1983						
PET	47	131	148	176	64	566
Rain	43	93	58	61	8	263
1984						
PET	48	136	172	136	59	551
Rain	61	183	58	250	47	599

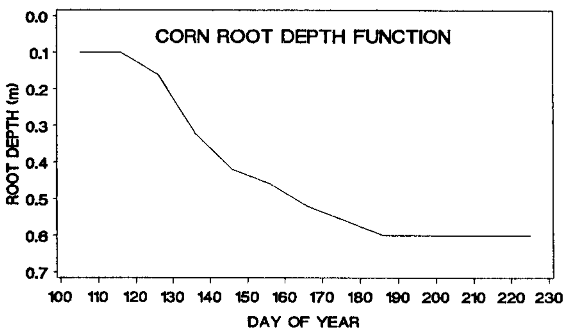

Fig. 4—Corn root depth as a function of time used in the simulations derived using the procedures of Skaggs et al. (1983).

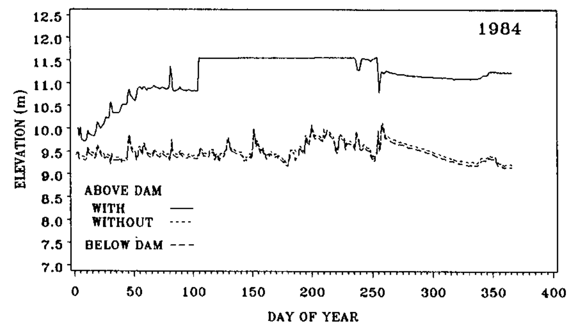

Fig. 6—Channel boundary conditions above and below the dam in 1984, with and without channel water level control.

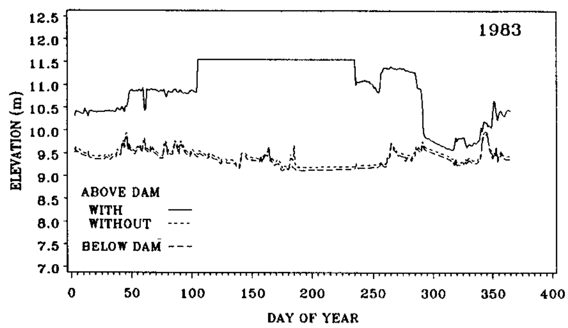

Fig. 5—Channel boundary conditions, above and below the dam for 1983, with and without channel water level control.

level control during the growing season. Channel water elevations for this case were estimated from the channel bottom slope using the measured elevation below the dam as the reference downstream elevation. Boundary conditions above and below the dam are presented with and without channel water level control in Fig. 5 for 1983 and in Fig. 6 for 1984.

The procedure was to simulate water movement and storage in the watershed shown in Fig. 2, with and without channel water level control. Results of the simulations were analyzed to determine the effect of channel water level control on water availability to the crop, water table position, evapotranspiration, and water stored in the soil profile.

RESULTS

To analyze the effects of channel water level control, the study area was divided into two sections, above and below the dam (Fig. 2). The area above the dam was 0.475 km^2 and the area below the dam was 0.259 km^2. The results for the two simulation years are summarized in Table 8. The largest effect due to channel water level control was the reduction in drainage. For example, channel water level control in 1983 reduced drainage by 143 mm. In that moderately dry year, channel water level control caused a total of 22 mm of water to move by subirrigation from the channel into the adjacent land area. This increased predicted average relative yields 15% over the free drainage case. Predicted relative yields near the channel were increased much more than the average as will be shown subsequently.

Simulated Storage

Predicted amounts of water stored in the soil profile with and without channel control are plotted in Fig. 7 for 1983 and 1984. In 1983, the drainable water stored with channel water level control was 764 mm at the start of the growing season and declined to 702 mm at the end. Without channel water level control, the stored water declined from 692 mm at the start to 567 mm at the end of the growing season. The maximum difference due to channel water level control was 132 mm in 1983. This occurred at the end of the growing season on day 225.

Drainable water stored in the profile in 1984 did not decline as rapidly as in 1983. Rainfall was greater and more evenly distributed in 1984. Channel water level control increased storage by a maximum of 119 mm on day 194 following a relatively dry period (Fig. 7). Storage with channel control at the start of the growing season was 763 mm and 772 mm at the end. Without channel control, the storage at the start of the growing season was 686 mm and declined to 675 mm at the end. The minimum difference in storage, 81 mm, occurred on day 129 following 60 mm of rainfall from day 127 to day 129.

Channel water level had a small effect on storage in the soil profile downstream from the dam. At the end of the growing season, channel control increased profile storage

TABLE 8. COMPARISON OF CONTROLLED STREAM WATER LEVEL TO FREE DRAINAGE (WITHOUT DAM) ON MITCHELL CREEK DURING THE CORN GROWING SEASON IN 1983 AND 1984

Year and control level	Rain (mm)	PET (mm)	SET (mm)	Drainage (mm)	Sub-irrigation (mm)	Minimum storage (mm)	Relative yield, %
1983	263	571					
With dam			374	2	22	702	49
Without dam			338	145	0	567	34
1984	588	530					
With dam			465	22	5	733	79
Without dam			420	162	0	614	69

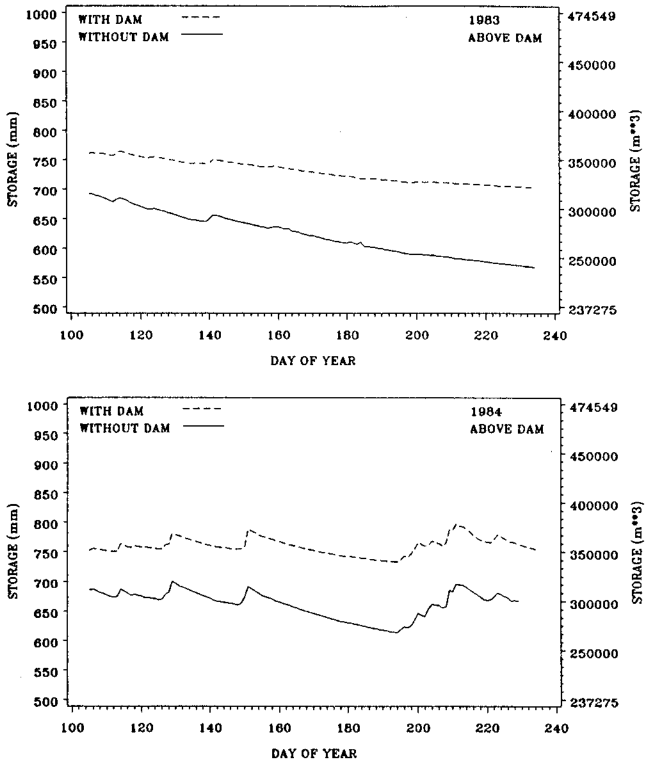

Fig. 7—Simulated drainable storage above the dam, with and without channel water level control for 1983 and 1984.

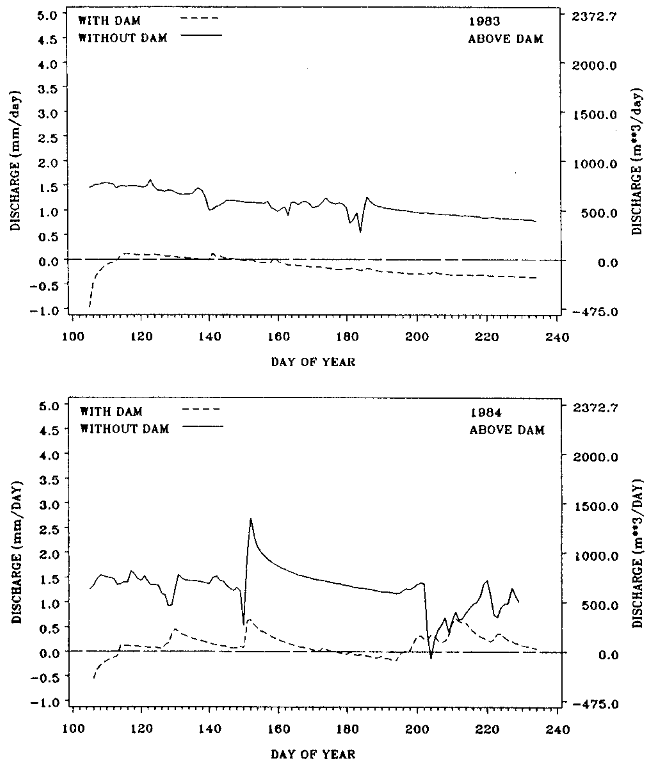

Fig. 8—Simulated drainage from the soil profile upstream from the dam in 1983 and 1984, with and without channel water level control.

by 17 mm in 1983 and by 11 mm in 1984. This increase in storage was caused by seepage from the land area upstream from the dam to the area below the dam.

Simulated Discharge

As expected lateral seepage to the channel is reduced when the channel water level is controlled (Fig. 8). Raising the water level in the controlled channel section reduces the hydraulic gradient during drainage events, and, in some cases, reverses the gradient so that water moves from the channel into the adjacent lands. This is shown as negative discharge in Fig. 8. The largest movement of water from the channel occurred on day 105 in 1983, -1.0 mm/d (470 m^3/d from the 0.475 km^2 area above the dam) following the raising of the water control structure to an elevation of 11.55 m. In 1983, from day 160 to the end of the growing season, water moved from the channel into the adjacent land areas (negative discharge). Without channel control, water movement to the channel occurred during the entire growing season, and ranged from 1.6 mm/d (740 m^3/d) at the start of the growing season to a minimum of 0.8 mm/d (380 m^3/d) on day 182.

Increased rainfall in 1984 caused greater changes in the discharge relationships. For natural (uncontrolled) conditions, the drainage rate varied from -0.2 mm/d (70 m^3/d) on day 203 to 8.6 mm/d (4100 m^3/d) following 101 mm of rainfall on days 148 to 151. Channel water level control reduced the discharge and caused the drainage rate to vary from -1.1 mm/d (-510 m^3/d) when the dam was raised to a maximum of 0.6 mm/d (300 m^3/d) on day 151.

Drainage into uncontrolled channels was 145 mm in 1983 and 165 mm in 1984 (Table 8). Since this area is typical of uncontrolled areas upstream from the watershed, there was sufficient flow from these areas to supply the water required to maintain the water level in the controlled section. This would generally be the case when the upstream drainage area is large enough to supply the water to the controlled section during dry periods.

Discharge rates from the 0.259 km^2 drainage area downstream from the dam were consistently higher with channel water level control than without control in both years. The mean increases were 0.2 mm/d, (50 m^3/d), in 1983 and 0.5 mm/d (120 m^3/d) in 1984.

Simulated Evapotranspiration

Simulated evapotranspiration (SET) at each node was computed on a daily basis and analyzed at transects perpendicular to the main channel upstream and downstream from the dam.

Both PET and SET are plotted as functions of the distance from the main channel in Fig. 9. These relationships were obtained for the transect 118 m upstream from the dam. In both 1983 and 1984 channel water level control had the greatest effect on SET in the land near the channel. The SET/PET ratio with channel water level control was 0.9 or greater for a distance of approximately 75 m from the controlled channel, compared to less than 0.5 without control. Increases in the SET/PET ratio of 0.05 to 0.10 occurred for distances of 100 m to 250 m from the channel. For other transects upstream from the dam, the results were similar. Results for the area below the dam were similar to those for uncontrolled channel conditions above the dam.

Simulated Relative Yields

Predicted relative corn yields, the percent of the potential yield that would be obtained for optimal soil

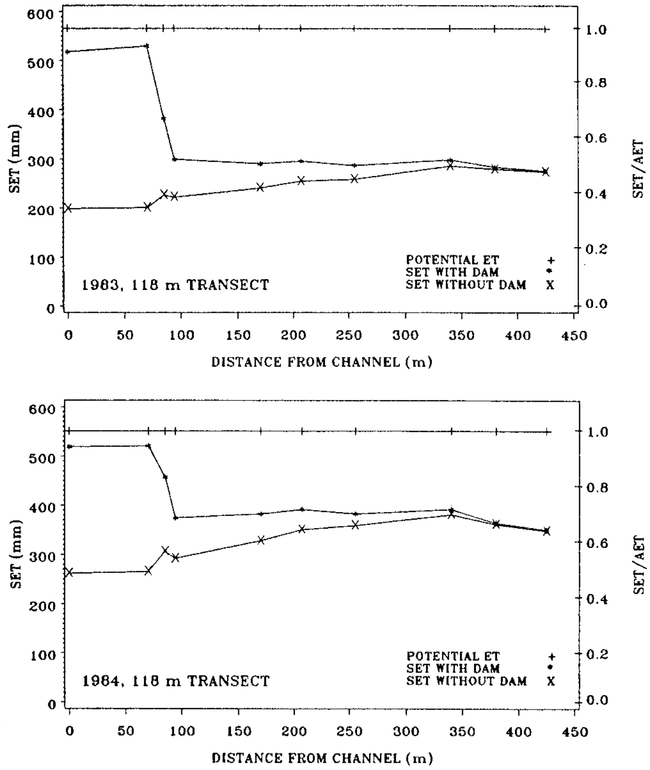

Fig. 9—Simulated ET (SET) and SET/PET ratio as a function of distance from the main channel, with and without channel control at 118 m upstream (above) from the dam in 1983 and 1984.

water and management conditions, are presented as a function of distance from the drainage channel in Table 9 for the transect 64 m upstream from the dam (line 5, Fig. 2) and in Table 10 for the transect 505 m upstream from the dam (line 4, Fig. 2). The average relative yields for each transect reported in Tables 9 and 10 were computed by weighting the relative yields at each distance from the channel by the area associated with the location. On line 5 the average difference between predicted corn yields with and without channel water level control was 19% in 1983 and 14% and 1984 (Table 9). As expected from the results for SET (Fig. 9) channel water level control had the greatest effect on predicted

TABLE 9. SUMMARY RELATIVE YIELDS AT LINE 5, LOCATED 64 M ABOVE THE DAM

Distance from Mitchell Creek, m	1983 Without dam	1983 With dam	1984 Without dam	1984 With dam
	Relative yield			
	%			
0	6	88	39	88
70	6	96	40	96
86	12	40	48	72
94	11	30	46	65
171	16	28	55	66
207	18	29	58	68
257	19	26	60	65
342	26	29	66	68
380	26	27	61	62
427	29	29	61	61
Area weighted mean	18	37	55	69

TABLE 10. SUMMARY RELATIVE YIELDS AT LINE 4, LOCATED 505 M ABOVE THE DAM

Distance from Mitchell Creek, m	1983 Without dam	1983 With dam	1984 Without dam	1984 With dam
	Relative yield			
	%			
0	6	100	40	100
36	8	100	44	100
44	10	100	48	100
84	12	24	50	63
117	20	41	62	91
168	36	80	96	100
253	14	17	53	57
336	25	31	67	74
378	49	53	89	95
421	41	44	74	75
Area weighted mean	31	57	82	97

relative yields next to channel from 6% to 88% in 1983 and 39% to 88% in 1984. At 171 m from Mitchell Creek, channel water level control increased relative yields from 16% to 28% in 1983 and from 55% to 66% in 1984.

Channel water level control increased the average simulated relative yields from 31% to 57% in 1983 and from 82% to 97% in 1984 along the transect at line 4, 505 m above the dam (Table 10). Channel control had the greatest effect on relative yields within a distance of 168 m from Mitchell Creek in both years.

For the transect at Line 6, 332 m below the dam (Fig. 2), there was no channel water level control. Average simulated relative yields in 1984 (68%), were better than those in 1983 (28%), because of greater rainfall which was distributed more evenly through the growing season. Doty et al. (1984) measured corn yields at locations near the water table wells in the area. His yields were used to compute relative yields below the dam of 27% in 1983 and 67% in 1984 indicating that the relative yields simulated by WATRCOM were comparable.

Water Availability

Water in the drainage channel is used to supply several sprinkler irrigation systems on the Mitchell Creek Watershed. Channel water level control increases the amount of water stored in the soil profile (Fig. 7) as well as in the channel itself. However, the water stored in the profile must drain to the channel before it can be pumped to supply an irrigation system. In the most extreme case, drainage from upstream watersheds cannot be assumed and the water supply is limited to that which originates on the controlled watershed. After the water stored in the channel is used the maximum withdrawal rate is equal to the rate that water drains to the channels.

Water available for irrigation was determined for four periods in 1983 and 1984 and compared to the amount of water needed to satisfy potential evapotranspiration demands on the watershed. Prior to each period, water in the root zone was near maximum; rainfall during the period was near zero. Each withdrawal period was simulated for free drainage (without dam) and for channel water control (with dam). At the start of each period, the water available for irrigation was set equal to

TABLE 11. WATER AVAILABILITY COMPARISONS OF CONTROLLED STREAM WATER LEVEL (WITH DAM) TO FREE DRAINAGE (WITHOUT DAM) IN A 0.475 KM^2 AREA FOR SELECTED DROUGHT PERIODS IN 1983 AND 1984

Year and period	Rain	PET	SET	Deficit without irrigation	Irrigation supply	Deficit with irrigation	Days of irrigation supply
	mm						
1983							
1. Days 160-179	2	111					
With dam			37	74	60	14	15
Without dam			26	85	26	59	4
2. Days 187-202	5	97					
With dam			43	54	50	4	14
Without dam			37	60	22	38	6
1984							
3. Days 153-172	0	121					
With dam			54	67	63	4	17
Without dam			41	80	41	39	8
4. Days 153-202	0	268					
With dam			82	186	107	79	17
Without dam			67	201	81	129	8

that stored in the channel and the boundary condition on the main channel was set to the bottom elevation. The sum of the water in the channel and the discharge from the adjacent land area was assumed to be the available water supply for irrigation. The deficit soil water on each day was assumed to be the difference between PET and SET. The sum of the daily soil water deficits constituted the demand for the water supply.

The results for the withdrawal periods are summarized in Table 11. The first period was 20 days, extending from day 160 to day 179 in 1983. During the period, the total rainfall was 2 mm. Results are presented in Fig. 10. With water level control, sufficient water was available for irrigation supply to meet the deficit soil water requirements for 15 days, until day 175. The water requirement could only be met for 4 days without channel water level control. At the end of 20 days of drought, the soil water deficit with channel water level control was 14 mm, compared to 59 mm without channel water level control. In both conditions, with and without channel water level control, channel sections below the dam supplied water to meet deficit soil water conditions for only 4 days.

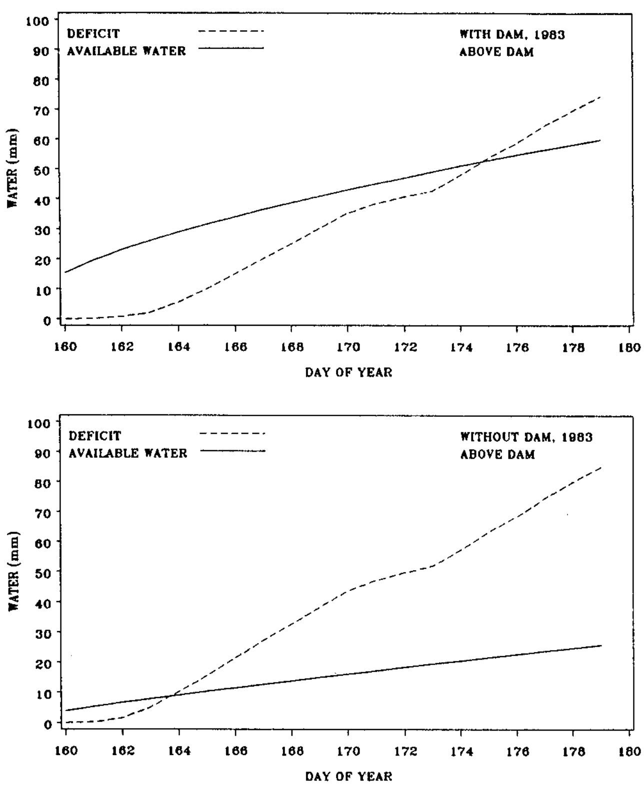

Fig. 10—Predicted water available for irrigation over a 0.475 km^2 area with and without channel water level control, for a drought period in 1983. The available water is compared to that required to satisfy the soil water deficit (DEFICIT).

The second withdrawal period extended from day 187 to day 202 in 1983. Again, rainfall was very light and consisted of 2 mm and 3 mm which occurred on day 188 and day 200. Withdrawal rates sufficient to meet deficit soil water requirements were sustainable for 14 days with channel water level control and 6 days without channel water level control (Table 11).

Days 153 to 172 in 1984 constituted the third period evaluated (Table 11). With channel water level control, the water available was sufficient to meet deficit soil water requirements for 17 days. The maximum water available for irrigation supply without water level control was sufficient to meet deficit soil water conditions for 8 days. Under controlled channel conditions, the soil water deficit at the end of this 20-day period was 4 mm, while the deficit in the uncontrolled conditions was 39 mm.

The third period was extended to day 202 without additional rainfall. At the end of this extended drought period (50 days) the water available for irrigation with channel water level control was 79 mm less than that required to satisfy the deficit soil water conditions simulted for this period (Table 11). Without channel water level control, the maximum water available was 120 mm less than that required to satisfy the soil water deficit for the period.

SUMMARY AND CONCLUSIONS

A comprehensive three-dimensional water management model for drainage districts, WATRCOM, was used to evaluate the effectiveness of a channel water level control for conserving and managing shallow groundwater resources. Simulations of soil water conditions on land adjacent to a section of Mitchell Creek, which includes a variable height dam, were conducted for 2-yr, 1983 and 1984, both with and without channel water level control.

Channel water level control increased drainable water stored in the soil profile over the uncontrolled cases by averages of 85 mm in 1983 and 84 mm in 1984. Evaluations of discharge rates to and from the uncontrolled channels indicated that channel water level control increased seepage to the channel in sections below the control structure over that for the uncontrolled conditions in both years. Predicted relative corn yields in the land areas above the control structure were higher in both years when channel water level control was simulated. Yields for sites closer to the controlled channels showed greater increases than those sites farther way from the channel.

Simulations were conducted to determine the availability of the stored water for irrigation. Results showed that channel water level control will typically provide sufficient water to supply crop requirements for 14 to 17 days during a drought. Without water level control, water was available at rates sufficient to meet soil water deficits for 4 to 8 days. Predicted soil water deficits for controlled conditions averaged 16% of the deficits occurring without channel water level control at the end of the periods evaluated.

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