

**KANSAS GEOLOGICAL SURVEY
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THE WATER BALANCE OF THE CHEYENNE BOTTOMS, KANSAS

by

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A report submitted to Thomas McClain,
KGS Coordinator of the Cheyenne Bottoms Study

Summary

All natural wetland functions are closely related to wetland hydrology. Water entering, stored in, and leaving a wetland can be expressed in terms of a water budget. In this study, a meteorological water budget called "Versatile Budget" is employed to estimate daily values of actual evapotranspiration, soil moisture content in several zones, or layers in the soil profile (and hence soil moisture deficits or surpluses), and water losses due to surface runoff and deep drainage.

In order to employ this water budgeting technique, the Cheyenne Bottoms Watershed was subdivided into three climatic zones and four dominant soil associations. Predominant vegetation covers were small grains and native grasses. Results from this water budgeting procedure demonstrate that precipitation is the principle water supply of the Cheyenne Bottoms (much larger than the combined flows of the Blood and Deception Creeks, and the inlet canal water imports), while actual evapotranspiration is the major water depletion process and of comparable magnitude to precipitation.

It is also demonstrated that the water resources of the basin are not sufficient to meet the natural water demands, resulting in appreciable soil moisture deficits. The effects of vegetation on water use is significant, with prairie grasses, cattails, and alfalfa transpiring higher amounts of water and creating larger soil moisture deficits compared to small grains. However, deep drainage from small grains is larger compared to the other vegetation types considered in this report.

The interaction between surface and groundwater was also demonstrated in this report by conducting a stream-aquifer pumping test along the Arkansas River near Great Bend. As a result of pumping, the groundwater gradients feeding the stream were reversed, that is the stream was losing water to the aquifer, resulting in streamflow declines directly attributable to groundwater pumping.

Introduction

Wetlands are dynamic ecosystems with fluctuating boundaries. They can be characterized in terms of hydrology, vegetation and soils. The three components interact with each other and with geology and topography to give a wetland its distinctive characteristics. Water entering, stored in, and leaving a wetland can be expressed in terms of a water budget. According to Carter et al. (1978) all natural wetland functions are a result of, or are closely related to, wetland hydrology. Most nutrients, whether dissolved or in particulate form, move

through the wetland in or with water. Therefore a basic understanding of the hydrology of the wetland is needed in order to determine overall nutrient budgets.

In order to establish the value of wetlands, we must identify and quantify the hydrologic and biologic functions the wetlands perform. Because hydrology is the dominant influence on all wetland functions, we need to provide an accurate definition of the hydrologic characteristics of wetlands.

Water Budget

Water budgets are often used in hydrologic analysis of wetlands. The water budget method allows the planner to compute a continuous record of soil moisture, actual evapotranspiration, groundwater recharge and surface runoff from a meteorological record and some observations on the soil and vegetation. The power of such a technique in planning is obvious. The water balance has been used for computing soil moisture stress under which natural vegetation can survive, the prediction of streamflow and water table elevations, the flux of water to lakes and variations of water level and salinity. The most obvious use of the water balance is in a basic description of the hydrology of a place or region. The water balance is also useful in predicting some of the human impacts on the hydrologic cycle. The hydrologic effects of changes in weather or changes in vegetation cover can be quickly estimated at a very early stage in planning.

Versatile Soil Moisture Budget (VB)

Most water budgeting techniques make use of the well-known concept of potential evapotranspiration as an indicator of the possible maximum loss of water from the soil under conditions where soil water supply is not limiting. Budgeting methods for estimating soil moisture and actual evapotranspiration from vegetated soil, when water supply is at times limited, are comparatively more complicated, since they account for various soil and plant characteristics that modulate or alter the potential rate. In this report a meteorological soil moisture budget called "Versatile Budget" (Baier et al. 1979), which is a multigeneration evolution of the Holmes and Robertson (1959) modulated budget, is employed.

The Versatile Soil Moisture Budget (VB) requires as minimum input only daily observed data on precipitation and estimates of potential evapotranspiration, PE, or the total sky and solar radiation at the top of the atmosphere (which is available from standard tables as a function of latitude), and daily minimum and maximum temperatures if daily PE values are not available, as in the present case. The VB computerized procedure simulates variations in daily soil-moisture content by making use of physical and biological concepts of water movement in the soil and water uptake by plant roots. The VB output contains daily estimates of actual evapotranspiration, AE, soil moisture content in several "zones" or layers in the soil profile, and water losses due to runoff and drainage. Because the data from climatological stations are usually considered to be representative of the surrounding area, it can be assumed that the estimates of the various hydrologic components based on such data are also

representative of this same area and of the soil for which the water characteristics are specified in the particular computer run.

The basic structure of the budget can be described by the flow chart presented by Baier et al. (1979), shown in Fig. 5.1. Model components can be split into evaporation functions, including all vegetation cover and soil water extraction characteristics, and recharge functions including infiltration, drainage, runoff and snowpack submodels.

The validity of the estimates from the VB has been extensively verified by comparison with measured data, and by evaluating the efficiency of such estimates in explaining variations of observed crop yields. For further details on the VB and verification the reader is referred to Baier et al. (1979) and Sophocleous and McAllister (1986).

Water Budget Implementation

a) Climatic zones: The Cheyenne Bottoms watershed was subdivided into three climatic zones in order to model the water budget for the entire basin, based on the distribution of available National Oceanic and Atmospheric Administration (NOAA) climatological stations covering the basin (Fig. 5.2). The three climatological stations recording daily maximum and minimum temperature and precipitation are the Claflin station covering mainly the northeastern portion of the basin, the Great Bend station covering the southwestern portion and the Bison station covering the northwestern portion of the basin (Fig. 2).

b) Soils: There are four dominant soil associations (Dodge, et al., 1981) composed mainly of nine different soil series within the basin (Fig. 5.3). For each soil series the available water capacity was determined from the Barton County Soil Conservation Service (SCS) soil survey (Dodge, et al., 1981) to depths of one, three and five feet. The one foot soil depth was used to model the available soil moisture for cattails, since they have a rooting depth of up to one foot; the three foot soil depth was used to model the available soil moisture for winter wheat and other small grains, since they have a rooting depth of approximately three feet. The five foot depth, which is generally the depth limit of the SCS soil surveys, was used for all other vegetation covers in the basin, since the highest root density of most crops and grasses is in the upper five feet. Soil associations, soil compositions, and available water capacities for each soil are tabulated in Table 5.1.

c) Vegetation: In the Cheyenne Bottoms basin the dominant vegetation types are dryland winter wheat and native grasses (grassland, pasture); in addition, in the Cheyenne Bottoms proper, cattails are prevalent. The vegetation parameters are represented in the versatile budget by crop coefficients. There is a coefficient for each "standard" soil zone and a different set of coefficients for each stage of crop growth. At different plant-growth stages the roots can utilize the moisture in the soil profile at different depths and rates. Crop coefficients for winter wheat (and small grains) were modified from Baier et al. (1979) and Vanderlip and Brown (1974).

TABLE 5.1 -- Soil Characteristics--Cheyenne Bottoms Drainage Basin

Soil Association (area)	Soil Percentage Composition	Total Available Water Capacity for Upper 5 ft. (inches)
Pratt-Carwile (4.00 mi ²)	Pratt - 55% Pratt - Tivoli - 11% Narum - 15% Tabler - Drummund - 10%	6.89
New Cambria-Hord-Bridgeport (24.15 mi ²)	Hord - 50% New Cambria - 23% Harney - 22%	10.82
Drummond-Tabler (59.88 mi ²)	Drummond - 35% Tabler - Drummond - 20% Tabler - 5% Hard - 4% Naron - 3% (Water-covered area - 25%)	8.89
Harney-Crete (149.87 mi ²)	Harney - 60% Crete - 15% Nibson - Wakeen - 8% Wakeen - 8%	10.17

Crop coefficients for natural growth (simulated as brome grass) and alfalfa are those presented in Baier et al. (1979). With regard to cattails we had difficulties obtaining crop coefficients. A literature search resulted in very few relevant publications, the most useful of which was the study by Krolikowska (1978). Analysis of actual and potential evapotranspiration data from that publication in conjunction with field observations at the Cheyenne Bottoms resulted in the crop coefficients used in this study. The various crop growth stages and corresponding dates, as well as the crop coefficients adopted in this report are shown in Table 5.2.

The components of the water balance resulting from the versatile budget procedure were added by a specially written program to check for input errors and determine the range of error within the calculations. The utility program calculated the hydrologic balance equation error as:

$$PCP + SD - ET - DR - RO = \text{error}$$

where PCP = precipitation (in)
SD = soil moisture deficit (in)
ET = evapotranspiration (in)
DR = deep drainage (in)
RO = surface runoff (in)

Large errors were considered to be input errors and were traced to their cause and corrected. Small errors, generally less than one percent of total precipitation were considered to be due to cumulative rounding errors.

TABLE 5.2

CROP	STAGE DATES	GROWTH STAGES	CROP COEFFICIENTS					
	9/20-10/17	Fallow	.40	.15	.12	.10	.02	.01
	10/18-11/30	Planting to emergence	.40	.15	.12	.10	.02	.01
Wheat- Fallow	12/1-3/1	Dormancy	.40	.15	.12	.10	.02	.01
	3/2-5/1	Spring growth to heading	.17	.13	.10	.07	.09	.02
Small Grains	5/2-5/20	Leading to softdough	.33	.15	.14	.12	.01	.05
	5/21-6/15	Soft dough to ripening and harvest	.22	.13	.12	.10	.06	.04
	6/16-10/10	Fallow	.40	.15	.12	.10	.02	.01
Brome Grass	9/20-3/15	Dormancy	.50	.20	.10	.04	.02	.01
(grass- land, pasture)	3/16-10/10	Growth	.55	.19	.17	.08	.03	.01
Cat- tails	9/20-3/15	Dormancy	1.97	.75	.39	.16	.08	.04
	3/16-10/10	Growth	2.16	.79	.67	.31	.12	.04
	9/20-11/20	Fullcover	.50	.25	.25	.20	.18	.12
	11/21-4/1	Dormancy	.50	.20	.10	.04	.02	.01
	4/2-4/9	Spring growth to full cover	.50	.20	.15	.12	.08	.05
Alfalfa	4/10-5/20	Full cover to 1st cut	.50	.25	.23	.22	.15	.10
	5/21-6/10	1st cut to full cover	.50	.22	.18	.15	.15	.10
	6/11-7/10	Full cover to 2nd cut	.50	.25	.25	.20	.18	.12
	7/11-8/1	2nd cut to full cover	.45	.25	.20	.20	.20	.15
	8/2-9/5	Full cover to 3rd cut	.50	.25	.25	.20	.18	.12
	9/6-10/10	3rd cut to full cover	.45	.25	.20	.20	.20	.15

Results and Discussion

Cheyenne Bottoms and surrounding Drummond-Tabler soil association area:

Table 5.3 summarizes the results of the water budget for the non-water covered area (more than 86% of total area) of the Drummond-Tabler soil association which encompasses the Cheyenne Bottoms (Fig. 5.3). This budget was run for the last two water years for which data were available at the time (October 1, 1982 to September 30, 1984) and the results for the area not covered by open water were averaged for a water year period (Table 5.3). Using native grasses as an example, actual evapotranspiration from the grasses (23.21 in.) was higher than the precipitation in the area (21.76 in.), resulting in a soil moisture deficit

of 3.09 inches. Runoff from grassland, during the accounting period, amounted to 0.48 inches, while deep drainage was 1 inch (Table 5.3).

It is seen that natural precipitation is the dominant water source in the area, while actual evapotranspiration is the predominant water "loss" term. Soil moisture deficit, which is the next (second in magnitude) water "loss" term, indicates that climatic, vegetation and animal water use consumption exceeds the combined sum of precipitation, canal water import, and moisture of the soil profile. It should also be noted that final soil-moisture deficit values are not monotonically cumulative, like values of precipitation, evapotranspiration, drainage, and runoff, but is a running algebraic total (with positive and negative values). Because the final soil deficit indicated in the tables of this report is responsive mainly to the weather conditions of the previous few weeks, the reader is referred to the time distribution of water balance components shown in figures 5.7 to 5.9 (to be discussed in greater detail later).

Alfalfa, prairie grasses and cattails consumed on an area-weighted average 34.5% more water than small grains, such as wheat and millet, during the water budget accounting period. The largest contributor to deep drainage losses, however, was the small grains group, mainly because of its shallower root system compared to the prairie grasses group, and its lower transpiration activity. In comparing the values of the water balance components from this and other following tables, the different depths of the root zone for various vegetation covers should be kept in mind. Thus, for the Drummond-Tabler soil association, the available water capacity, which is a measure of the maximum possible soil deficit, is 1.9 inches for cattails, 5.3 inches for small grains and 8.8 inches for grasses and alfalfa over the soil thickness of the root zone.

It is worthwhile noting (refer to Fig. 5.4) that during the two water year budget accounting period an average of only 4429 ac-ft/yr were imported in the Bottoms through the inlet canal and none was released at the outlet, compared to 10000 to 20000 ac-ft/yr, on the average, imported during the 60's and 70's (Fig. 5.4). Streamflow data from Blood Creek are not available since 1980. If the average streamflow data during the water years 1978 and 1979 were taken as representative of recent conditions, then less than 2000 ac-ft/yr would have entered the Drummond-Tabler soil association, which amounts to approximately 0.6 inches of water over the Drummond-Tabler area. Contributions from the Deception Creek, which were never measured, are expected to be less than half of those from the Blood Creek subbasin due to the smaller size of the Deception Creek subbasin (Fig. 5.2). These amounts of water were probably consumed in the Bottoms general area since canal outflow during the 1983 and 1984 water years was zero. It is interesting to note that the total water imports to the Cheyenne Bottoms from the Blood and Deception Creeks and the inlet canal from the Arkansas River are much less than the amount of water contributed to the Bottoms from natural precipitation. For example, during 1980, the last year for which streamflows in the Blood Creek are gaged, the total water imports to the Bottoms was less than 20 percent of natural precipitation at the Bottoms area (Table 5.3).

Two Consecutive Water Year Budget ('83 and '84) Average For the
 Drummond-Tabler Soil Association
 (Units in inches, except those
 in parentheses which are in acre-feet)
 total area = 59.88 square miles = 38,323 acres

PCP	AE	SD	RO	DR	AREA	WEIGHT*	VEG. COVER
21.76 (59,869)*	19.11 (52,578)	1.99 (5475)	0.71 (1953)	3.65 (10,042)		.44	Small Grains
21.76 (59,869)	23.21 (63,858)	3.09 (8502)	0.48 (1321)	1.00 (2751)		.40	Grasses
21.76 (59,869)	21.53 (59,236)	0.17 (468)	0.25 (688)	0.02 (55)		.12	Cat- tails
21.76 (59,869)	24.17 (66,500)	2.92 (8034)	0.51 (1403)	0.00 (0)		.04	Alfalfa

AREA WEIGHTED AVERAGES:

21.76 21.24 2.25 0.55 2.01

CANAL INFLOW: 1.39
 CANAL OUTFLOW: 0.00

*Excluding water areas (approx. 5,307 acres)

PCP -- precipitation
 AE -- actual evapotranspiration
 SD -- soil-moisture deficit
 RO -- surface runoff
 DR -- deep drainage

Blood and Deception subbasins

A water balance simulation was also run for the entire Blood (approx. 112.5 sq.mi.) and Deception (approx. 46.6 sq.mi.) creeks subwatersheds (Fig. 5.2) to assess the various hydrologic components of the water budget during dry, wet and average years with regard to precipitation. In addition, the water budget simulation was used to obtain surface runoff estimates in the area as a function of precipitation amounts. The available weather data in the area since the 1950's were examined (Fig. 5.5) to find above and below average precipitation years. The water budget results for a below average, average and above average water year are shown in Table 5.4 for the Blood Creek subwatershed, and in Table 5.5 for the Deception Creek subwatershed. Two vegetation covers were assumed to be the predominant types in these subbasins, winter wheat (small grains) and native grasses (pasture). Thus, for example, during the 1984 water year the Deception Creek subbasin received 23.90 inches of precipitation (Table 5.5) and using grasses or pasture as the native vegetation cover, 23.44 inches were estimated as being lost to evapotranspiration, and 0.84 inches to surface runoff (which is a gain for the Cheyenne Bottoms). Deep drainage during this period is estimated to be 4.67 inches. All these water losses resulted in an estimated soil moisture deficit of 5.09 inches (Table 5.5). It could be readily recognized from these tables that actual (not potential) evapotranspiration is of the same order of magnitude as precipitation. Following natural precipitation and

actual evapotranspiration, the largest component of the water balance in the area is the soil water deficit, indicating that the water resources of the two subbasins are not meeting the natural water demands. It should be noted that seeming "anomalies" in some components of the hydrologic balance, such as the apparent higher deep drainage values during the average water year, compared to the above average one, are the results of the pattern and timing of precipitation events. Thus, if the highest precipitation amounts fell during the summer months, they will contribute minimal amounts to deep drainage as compared to spring rains.

TABLE 5.4

Blood Creek Subbasin
 Area = 71,972 acres
 (units in inches, except those in
 parentheses which are in acrefeet)

WATER YEAR	TYPE	PCP	AE	DR	RD	SD	CROP
1956	Dry	11.92 (71,492)	16.87 (101,180)	.45 (2699)	.49 (2939)	5.71 (34,247)	WH
1984	Normal	24.01 (144,004)	19.09 (114,495)	6.94 (41,624)	1.27 (7617)	3.70 (22,191)	WH
1957	Wet	35.20 (211,118)	26.78 (160,618)	6.78 (40,664)	1.98 (11,875)	0.39 (2339)	WH
1956	Dry	11.92 (71,492)	18.88 (113,236)	.32 (1919)	.44 (2639)	8.21 (49,241)	GR
1984	Normal	24.01 (144,004)	24.33 (145,923)	4.06 (24,351)	.82 (4918)	5.44 (32,627)	GR
1957	Wet	35.20 (211,118)	35.25 (211,418)	1.89 (11,336)	1.82 (10,916)	3.85 (23,091)	GR

WH = small grains
 GR = native grasses

TABLE 5.5

Deception Creek Subbasin
 Area = 29,841 acres
 (units in inches, except those in
 parentheses which are in acrefeet)

WATER YEAR	TYPE	PCP	AE	DR	RD	SD	CROP
1956	Dry	10.80 (26,857)	15.98 (39,738)	0.94 (2338)	0.08 (199)	5.81 (14,448)	WH
1984	Normal	23.90 (59,433)	18.38 (45,706)	8.02 (19,944)	0.89 (2213)	3.51 (8728)	WH
1957	Wet	36.86 (91,662)	25.67 (63,835)	10.68 (26,558)	1.12 (2785)	0.75 (1865)	WH

1956	Dry	10.80 (26,857)	18.23 (45,333)	0.29 (721)	0.08 (199)	8.14 (20,242)	GR
1984	Normal	23.90 (59,433)	23.44 (58,289)	4.61 (11,464)	0.84 (2089)	5.09 (12,658)	GR
1957	Wet	36.86 (91,662)	34.54 (85,892)	4.56 (11,340)	1.18 (2934)	3.57 (8878)	GR

WH = small grains

GR = native grasses

The effect of native grasses as contrasted to small grains on the components of the water balance is apparent from Tables 5.4 and 5.5. Thus, actual evapotranspiration (AE) and soil moisture deficit (SD) are higher, and deep drainage (DR) and surface runoff (RO) are lower in grasslands compared to small grain lands.

A compilation of surface runoff estimates from several daily water budget simulations of the area with varying precipitation inputs (including the ones in Tables 5.4 and 5.5) resulted in the rainfall-runoff relationship shown in Fig. 5.6. Such a relationship is essential for development and engineering works at the Cheyenne Bottoms since the expected surface runoff amounts could be predicted using this relationship for various amounts of yearly rainfalls. Unfortunately, streamgaging records at the Blood Creek near the Boyd gage, during the chosen average, below and above average years are not available for comparison of simulated and observed runoff values. However, a simulation run during the 1965 water year, for which stream flow data at the above mentioned station are available, resulted in a Versatile Budget estimate of 1.01 inches for small grains, resulting from 23.59 inches of precipitation during that water year, which amounts to 3,113.5 acre-feet (drainage area up to the streamflow gaging station is 36,992 acres). This compares well with the measured streamflow of 3070 acre-feet during that water year.

Time patterns of hydrologic variables

The time distribution of maximum and minimum daily air temperature, precipitation, soil moisture deficit of the root zone, deep drainage and runoff, as well as cumulative values of actual evapotranspiration and precipitation are shown in figures 5.7, 5.8 and 5.9 for three plant covers (cattails, native grasses and small grains) for the Drummond-Tabler soil association encompassing the Cheyenne Bottoms. Note the minimal amounts of deep drainage and runoff from areas covered by cattails (Fig. 5.7), as compared to areas covered by small grains (such as wheat - Fig. 5.9); areas covered with prairie grasses (Fig. 5.8) exhibit intermediate deep drainage and runoff values, but create higher soil deficits because of their deeper root system and longer growing season. Note the relatively constant water demand of cattails which results in a relatively constant water deficit over time as shown in Fig. 5.7. This water demand is so high that the entire precipitation amount over time is consumed--note the cumulative precipitation (PCP) and actual evapotranspiration (AE) for cattails compared to small grains and grasses.

In conclusion, it is demonstrated that precipitation is the principle water supply of the Cheyenne Bottoms, while actual evapotranspiration is the major water depletion process and of

comparable magnitude to precipitation. Both these water balance components dominate and control all other hydrologic variables, such as runoff, deep drainage, and soil moisture deficit. It is also shown that the water resources of the basin are not meeting the natural water demands, resulting in appreciable soil water deficits. The effects of vegetation on water use is significant with prairie grasses, cattails, and alfalfa transpiring higher amounts of water and creating larger soil moisture deficits compared to small grains. However, deep drainage from small grains is larger compared to the other vegetation types considered in this report.

Streamflow-groundwater interaction

The close association between ground and surface water means that a thorough understanding of wetland hydrology requires the study of both. The hydrologic system, of which the wetland is a part, is sufficiently complex that alterations to one part of the system may have far reaching effects upon the other components (Carter et al. 1978). For example, heavy pumping of ground water may lower the water table locally, decrease base flows, or induce recharge from wetlands. Disturbance of the river bed by channelization may alter the base flow. Impoundment may cause a rise in local ground water levels causing destruction of, creation of, or changes in nearby wetlands.

During the last several years streamflows in the Arkansas River from Kingsley to Great Bend have been declining so severely, that no water could be diverted from the Arkansas River at the Kansas Fish and Game Dundee Diversion Dam to the Cheyenne Bottoms via the inlet canal, specifically designed to provide water to the Bottoms during critical periods. One of the reasons for these streamflow declines is believed to be the large groundwater-based irrigation development in central and Western Kansas and Eastern Colorado.

In order to quantify the effects of groundwater-based irrigation on streamflow, a pump test was conducted along the Arkansas River near Great Bend (T.19S, R.13W, Sec.36). A 20-inch irrigation well (95' deep) approximately 200 feet from the south bank of the Arkansas River and more than 20 observation wells were installed for the stream-aquifer testing. On April 21, 1986 an 8-day pumping test was initiated with the pumping well discharging 1750 gpm. In addition to water level monitoring in the numerous observation wells, streamflow and geochemical measurements were also conducted during the pump test period.

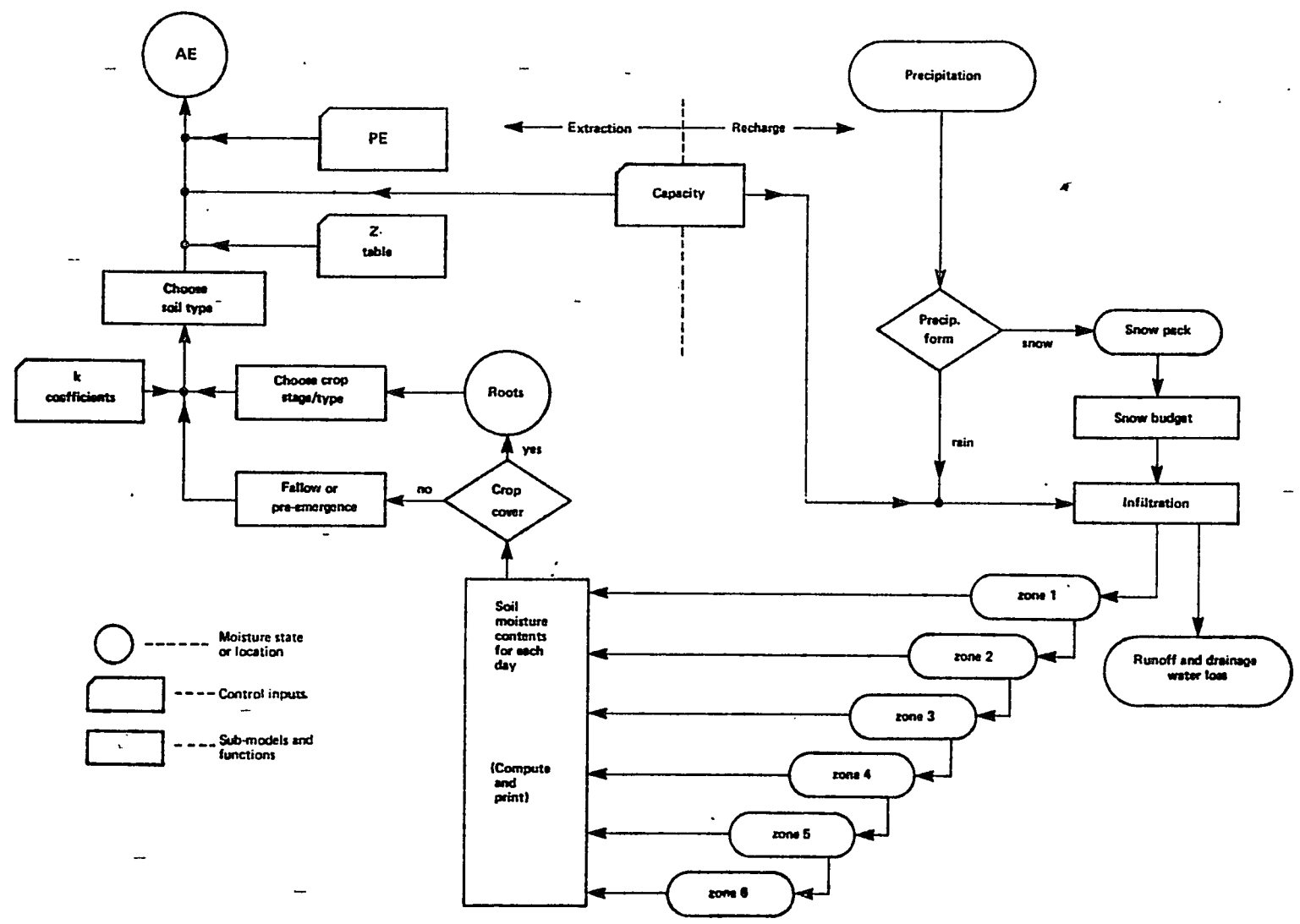
Analysis of streamflow measurements indicate that during the pump test streamflow in the Arkansas River decreased at a rate of approximately 1 cubic-foot per second (cfs)/day as a result of pumping. The average Arkansas River streamflow decreased from approximately 6 cfs on April 21, before the pump test, to approximately 2 cfs by April 25, the fourth day of pumping. A streamflow recovery was observed after the pumping well was shut off on April 29, as can be seen in Fig. 10. It was also observed that the groundwater gradients just below the streambed were reversed during the pumping test; before the testing, the stream was a gaining stream, that is it gained water from the aquifer; during the test it became a losing stream, that is, the stream was feeding the aquifer, and losing streamflow. When the pump was shut off, the stream again gained water from

the aquifer. These gradient reversals can be seen in Fig. 11, where the groundwater gradients between two and three feet below the streambed are shown, as measured by minipiezometers. Such data prove beyond any doubt the stream-aquifer interrelationship. Data analysis from this test is still continuing, and a more detailed comprehensive report on the stream-aquifer testing will be presented separately when all data analysis is completed.

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Fig. 1. Soil-root-atmosphere pathways for water in the Versatile Budget.



Blood and Deception Creek Drainage Basins and Associated Climatic Regions

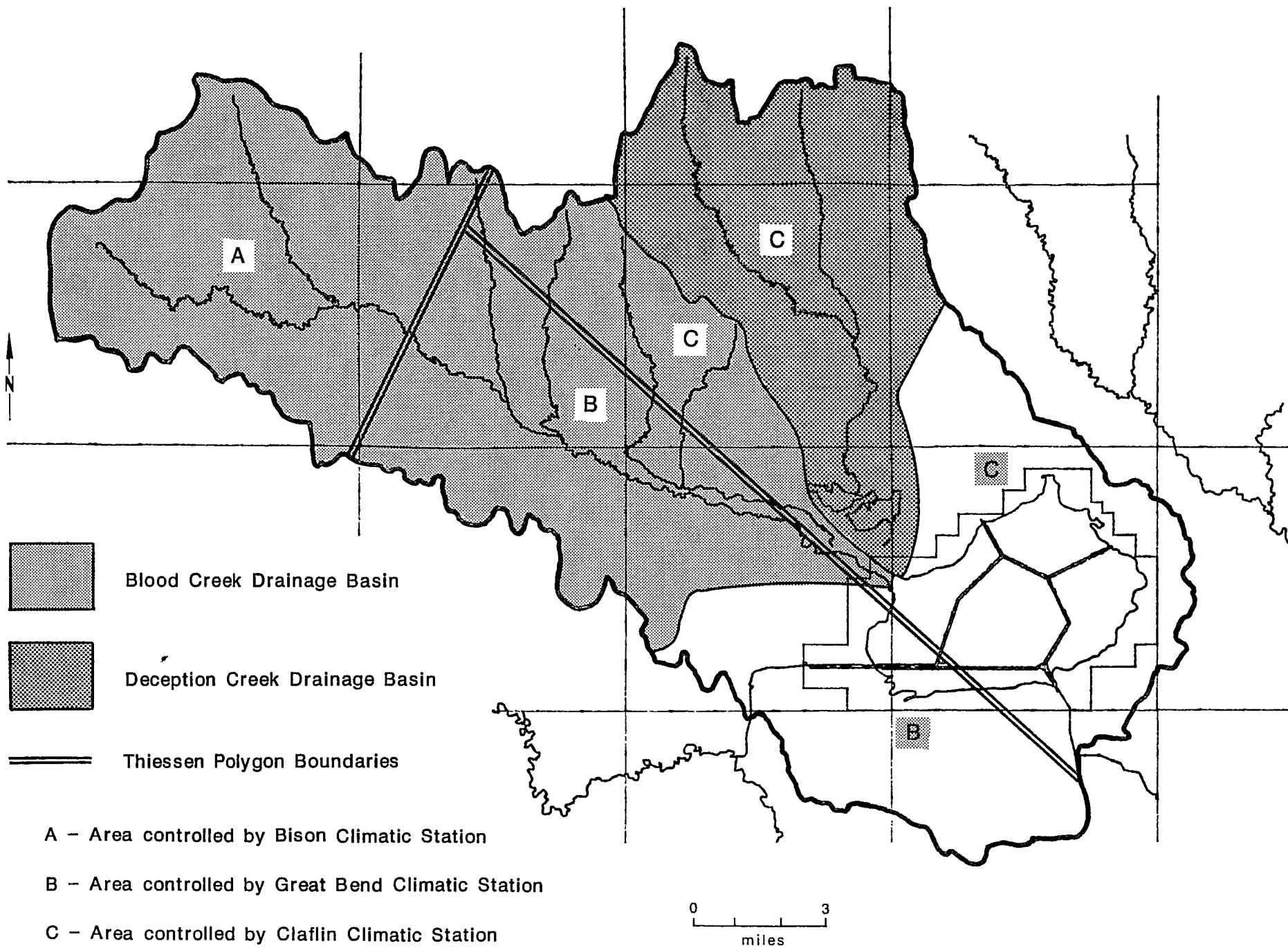


Fig. 2

SOIL ASSOCIATIONS -- Cheyenne Bottoms Drainage Basin

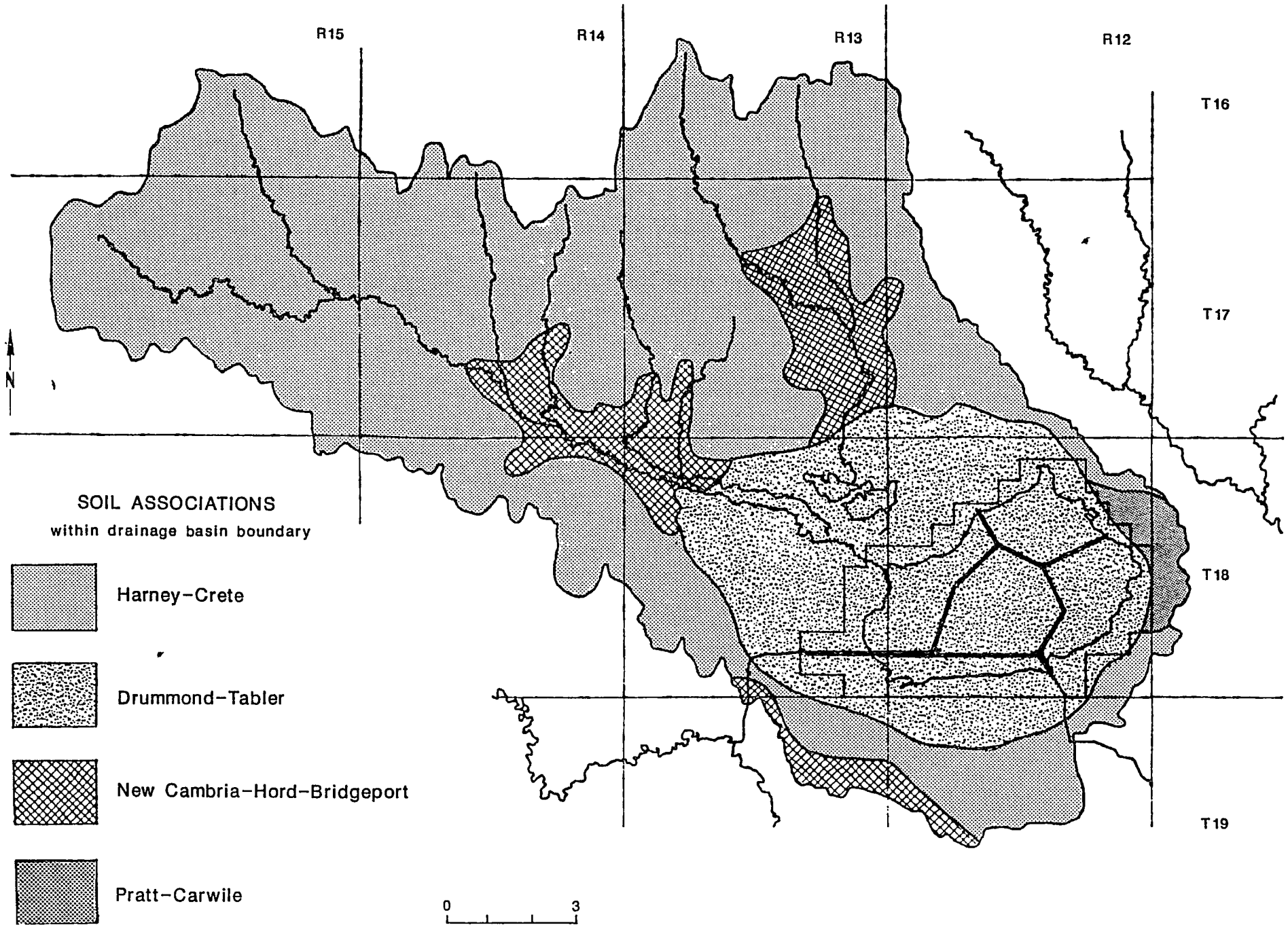


Fig 3

Water received at Cheyenne Bottoms

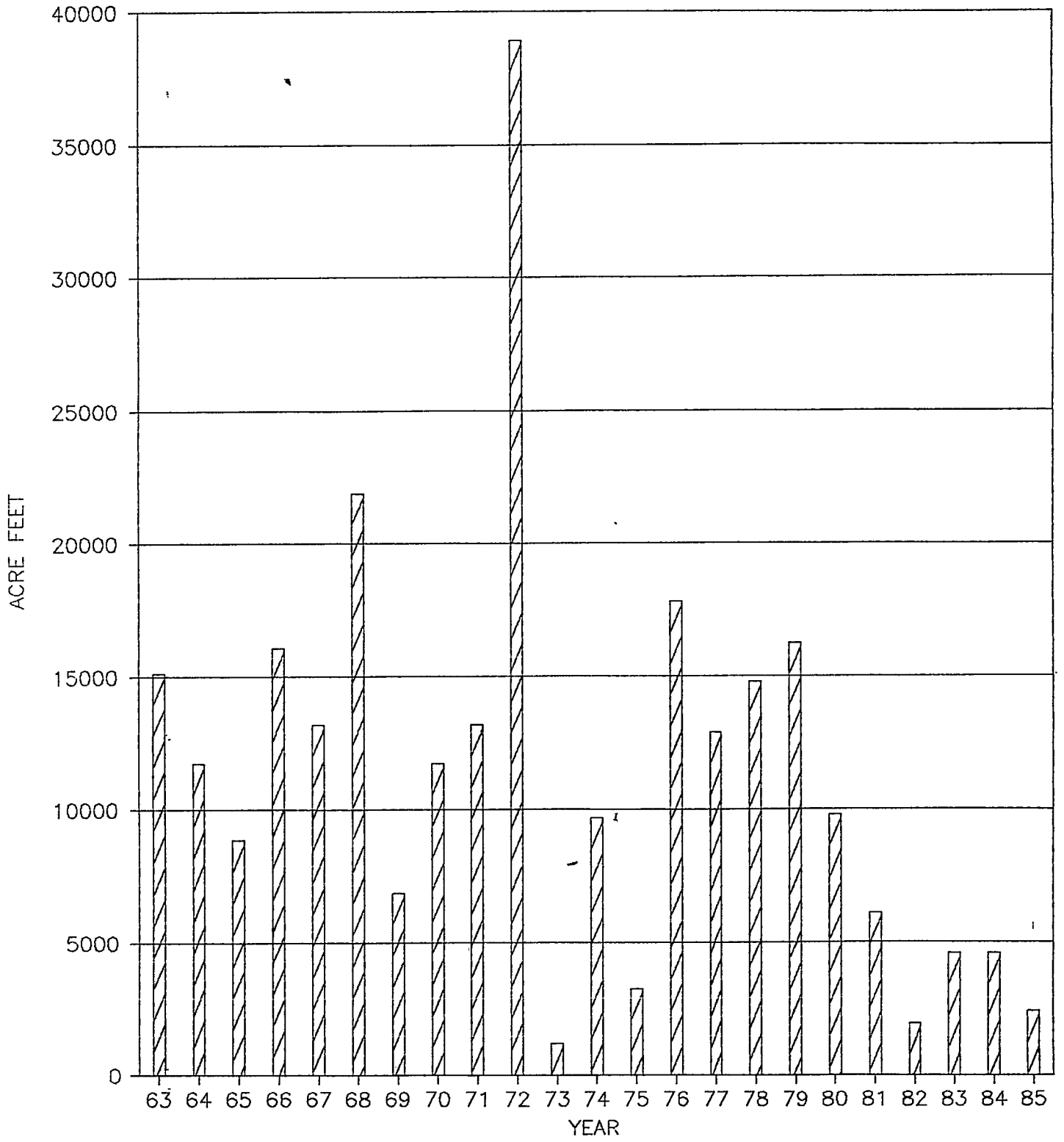


Fig. 4

GREAT BEND CLIMATE STATION

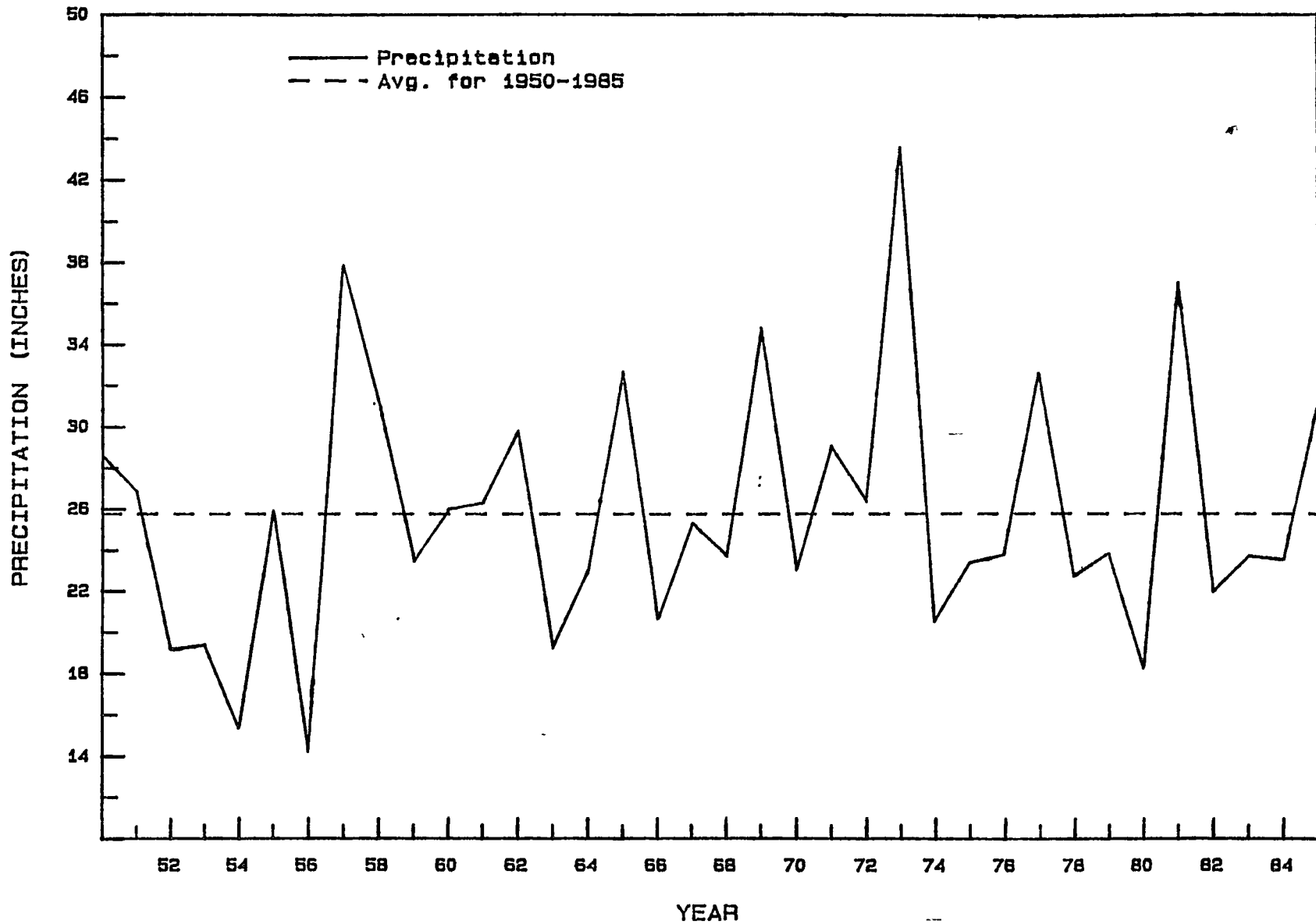


Fig 5

Average rainfall-runoff relationship in the Cheyenne Bottoms watershed

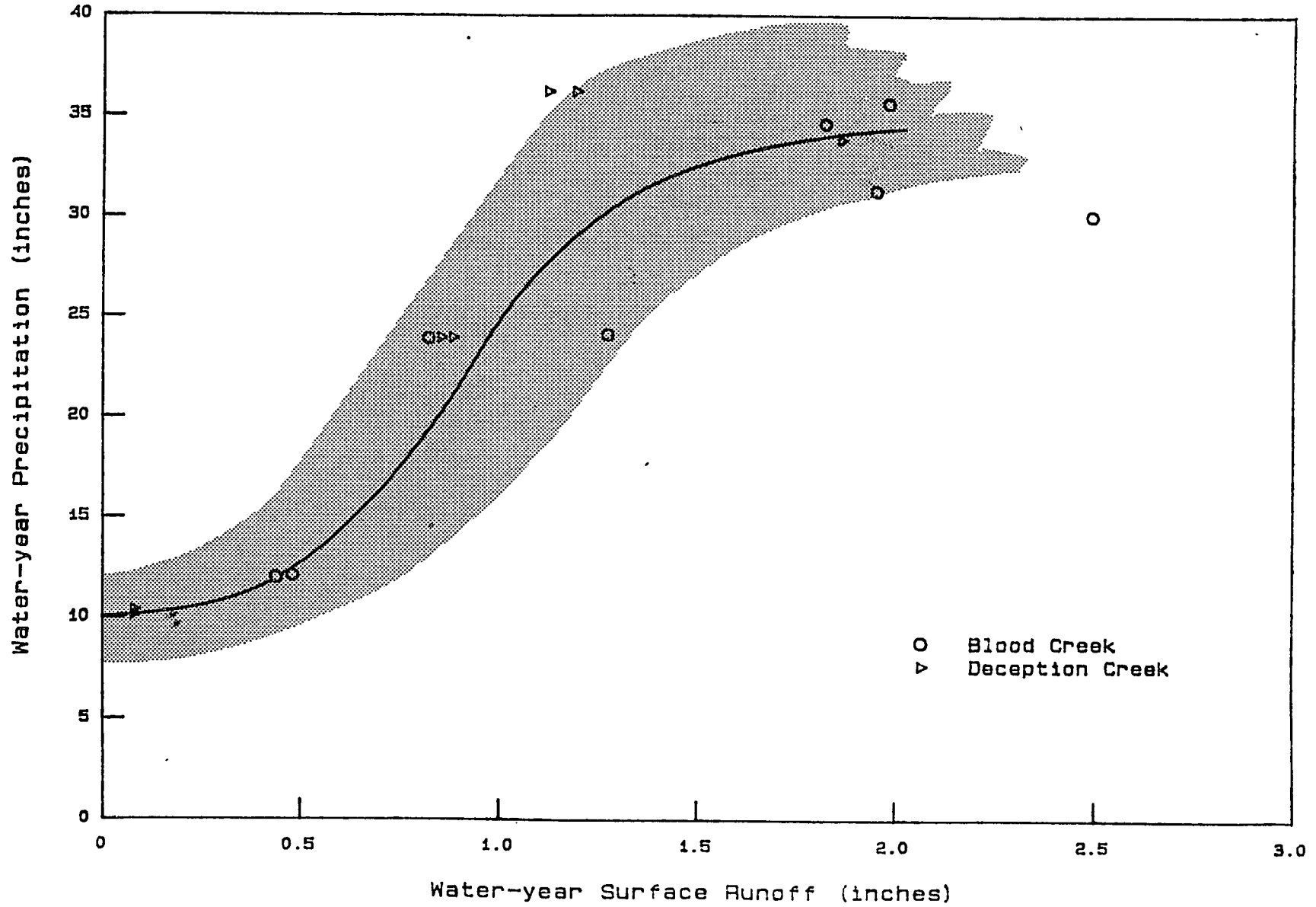
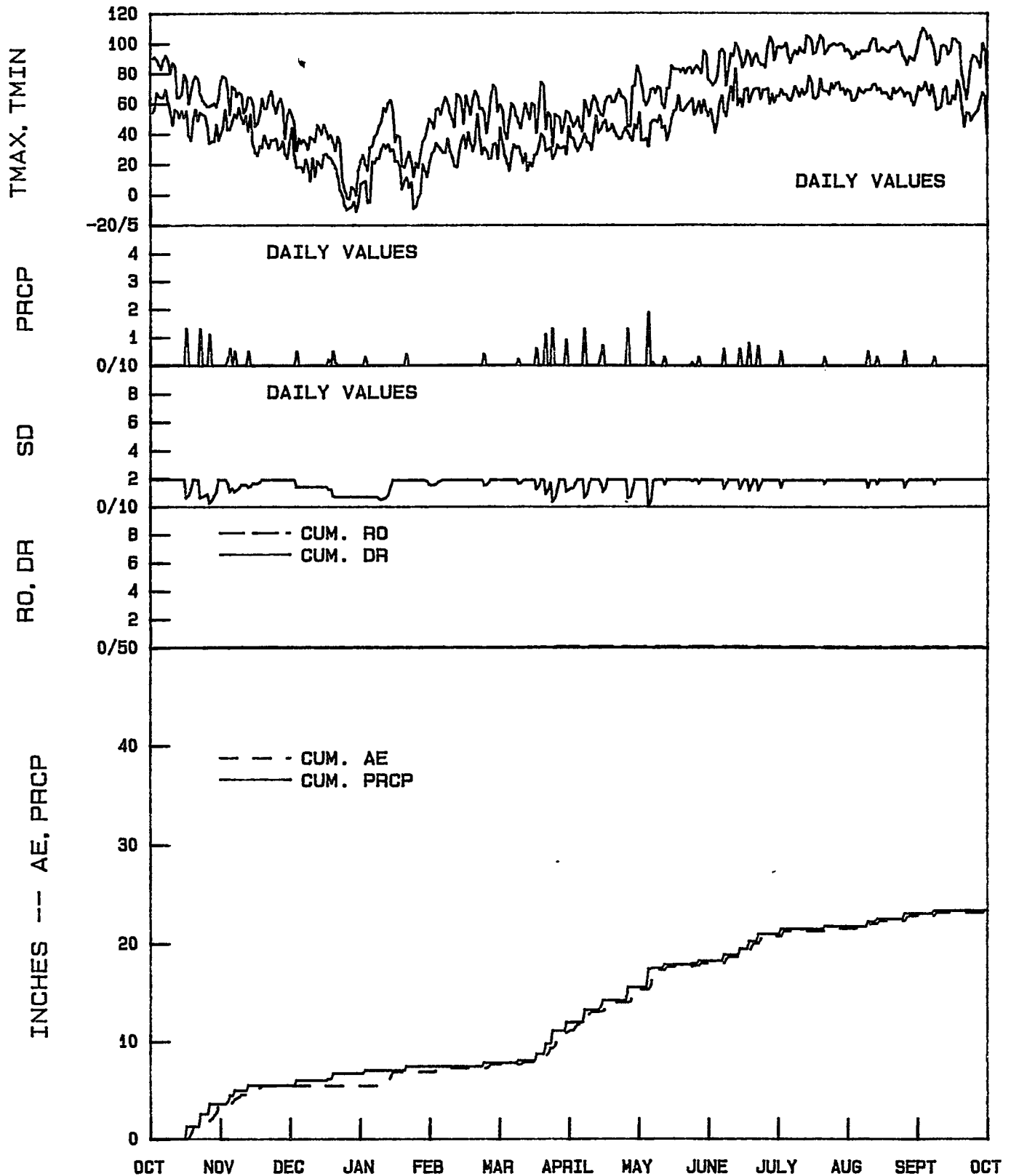


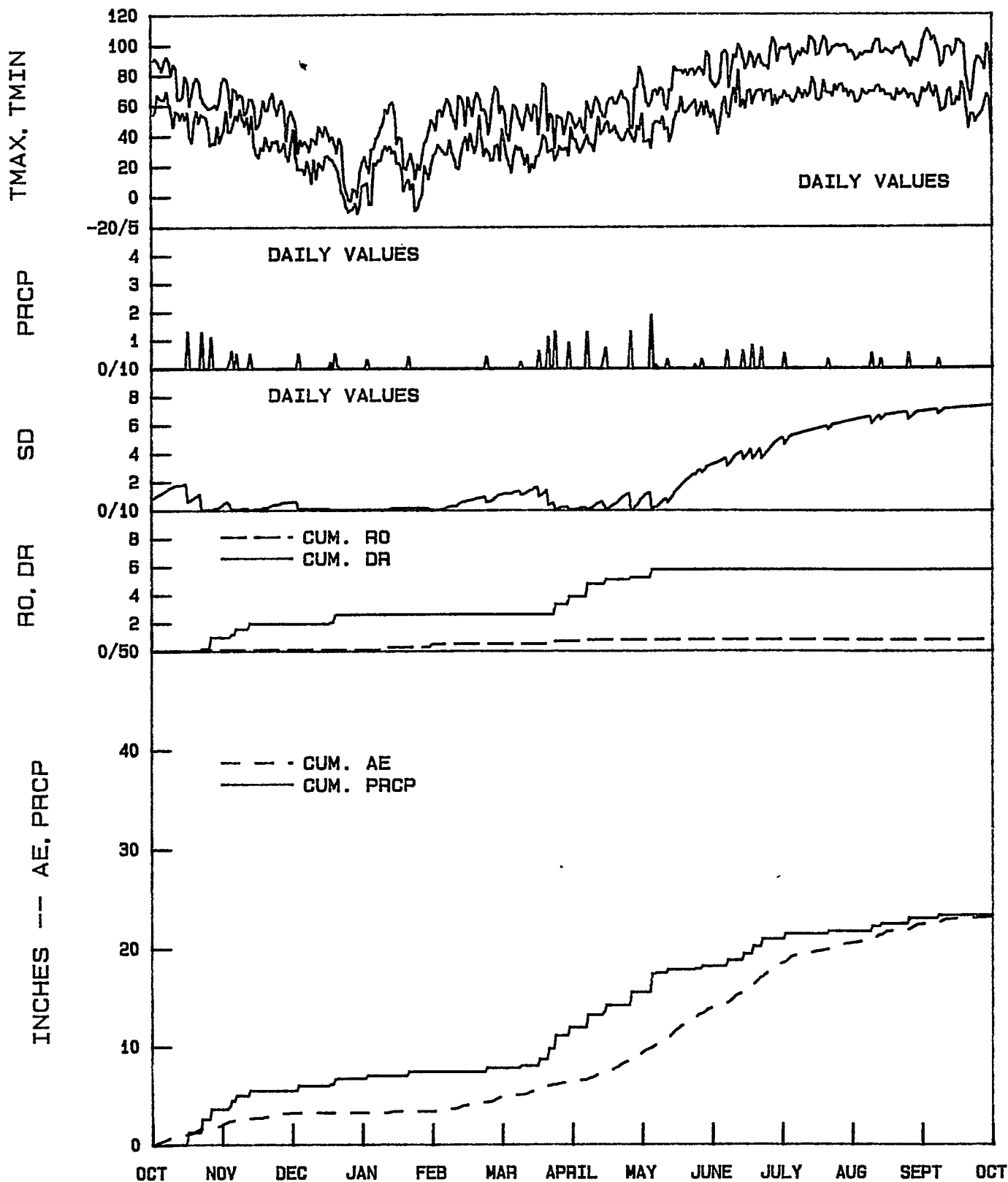
Fig 6

VERSATILE SOIL MOISTURE BUDGET



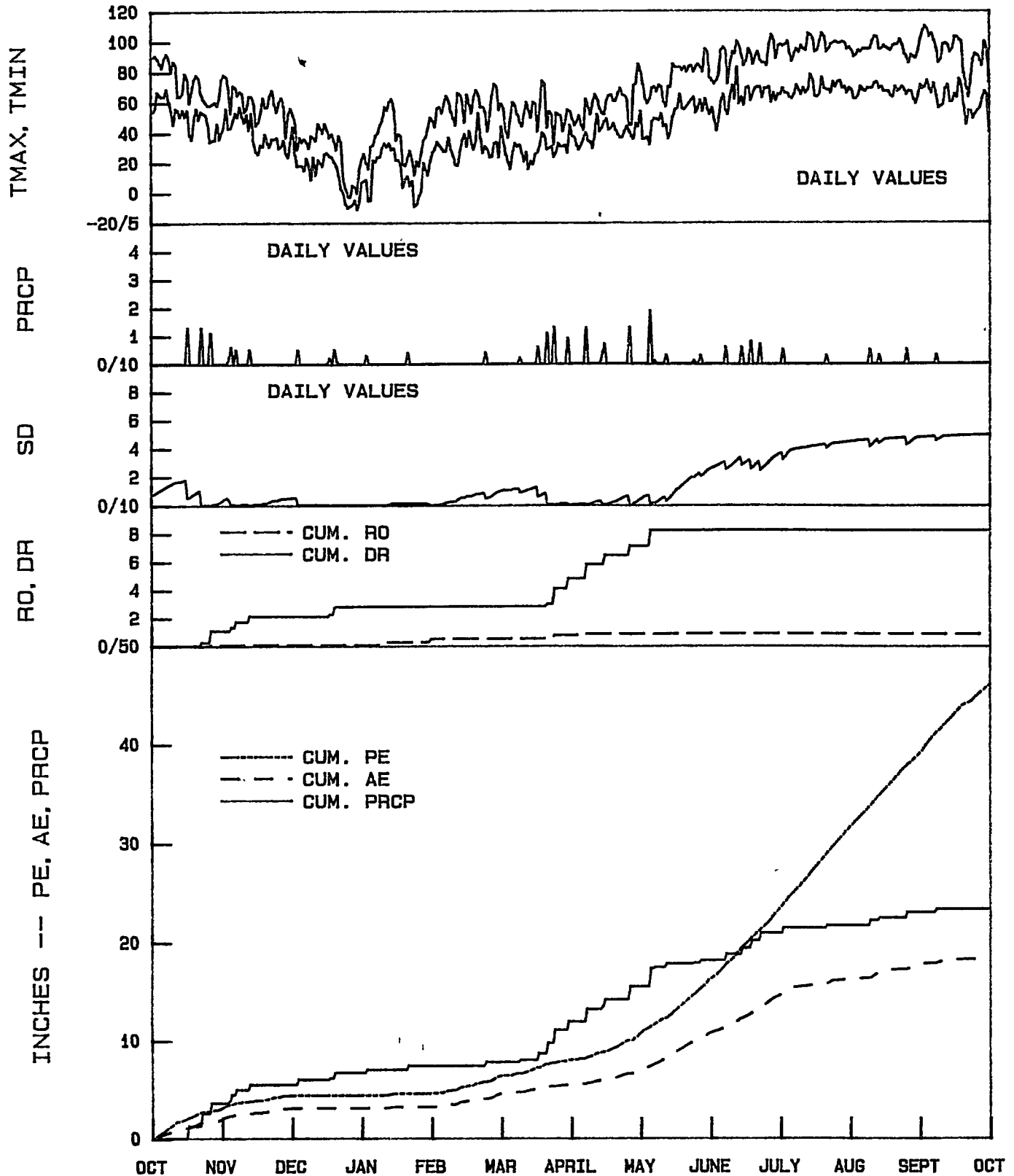
DRUM.TAB.-CLAFLIN-CATTAILS WATER YEAR 1984

VERSATILE SOIL MOISTURE BUDGET



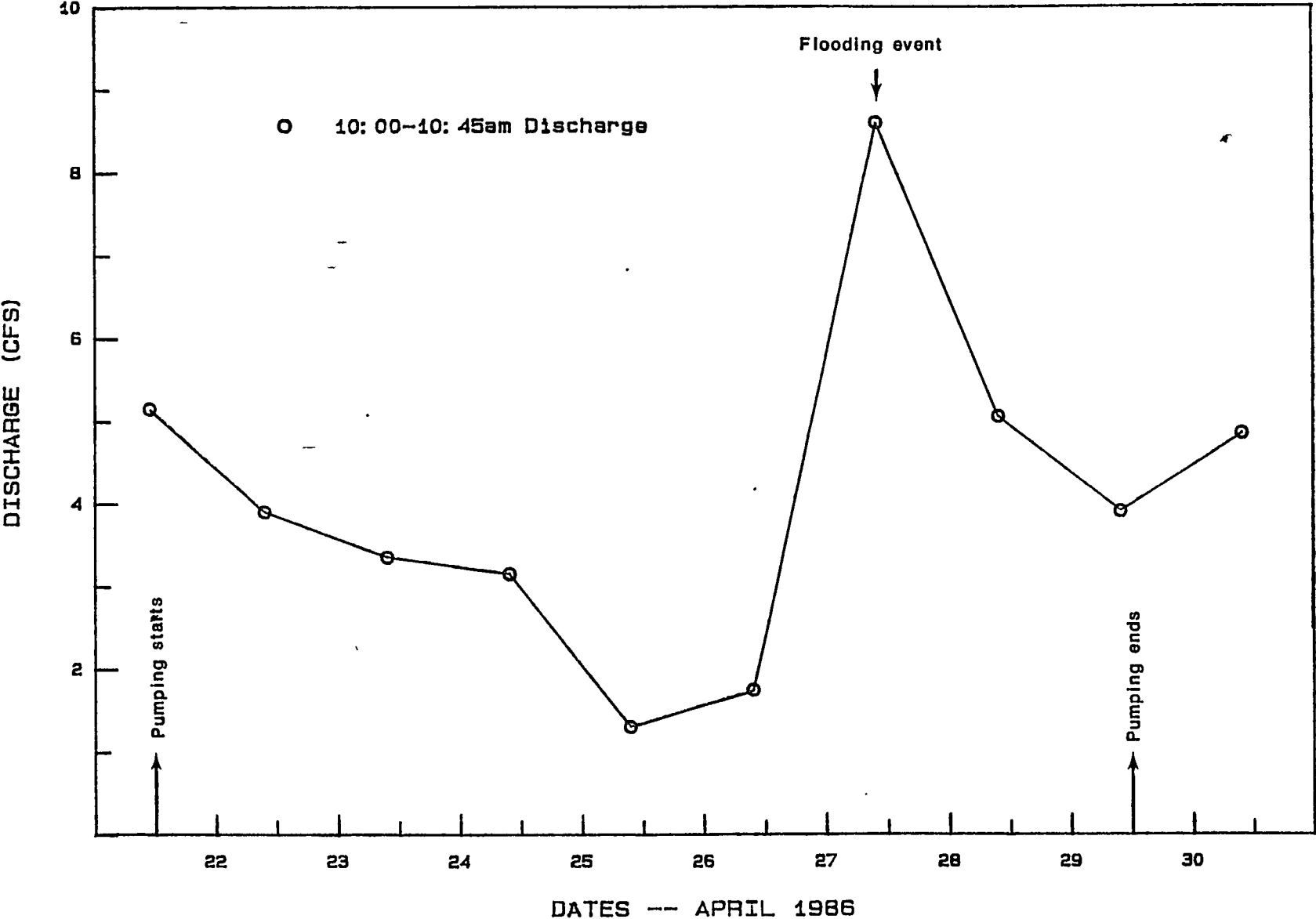
DRUM.TAB.-CLAFLIN-GRASS WATER YEAR 1984

VERSATILE SOIL MOISTURE BUDGET



DRUM.TAB.-CLAF LIN-SMALL GRAINS WATER YEAR 1984

WELLER'S DOWNSTREAM STATION



DATES -- APRIL 1986

Fig 10

Piezometer Level vs. Time

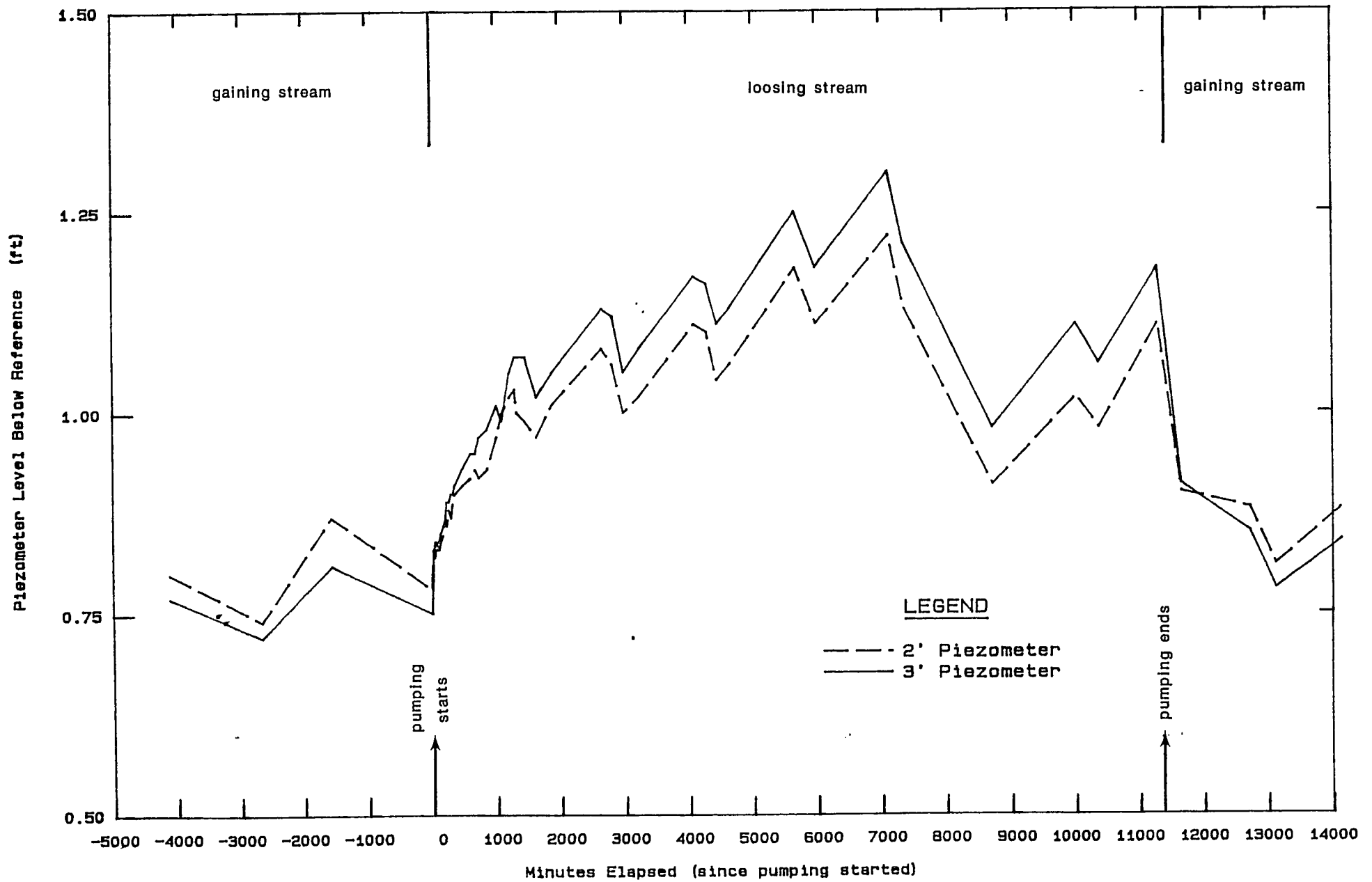


Fig. 11