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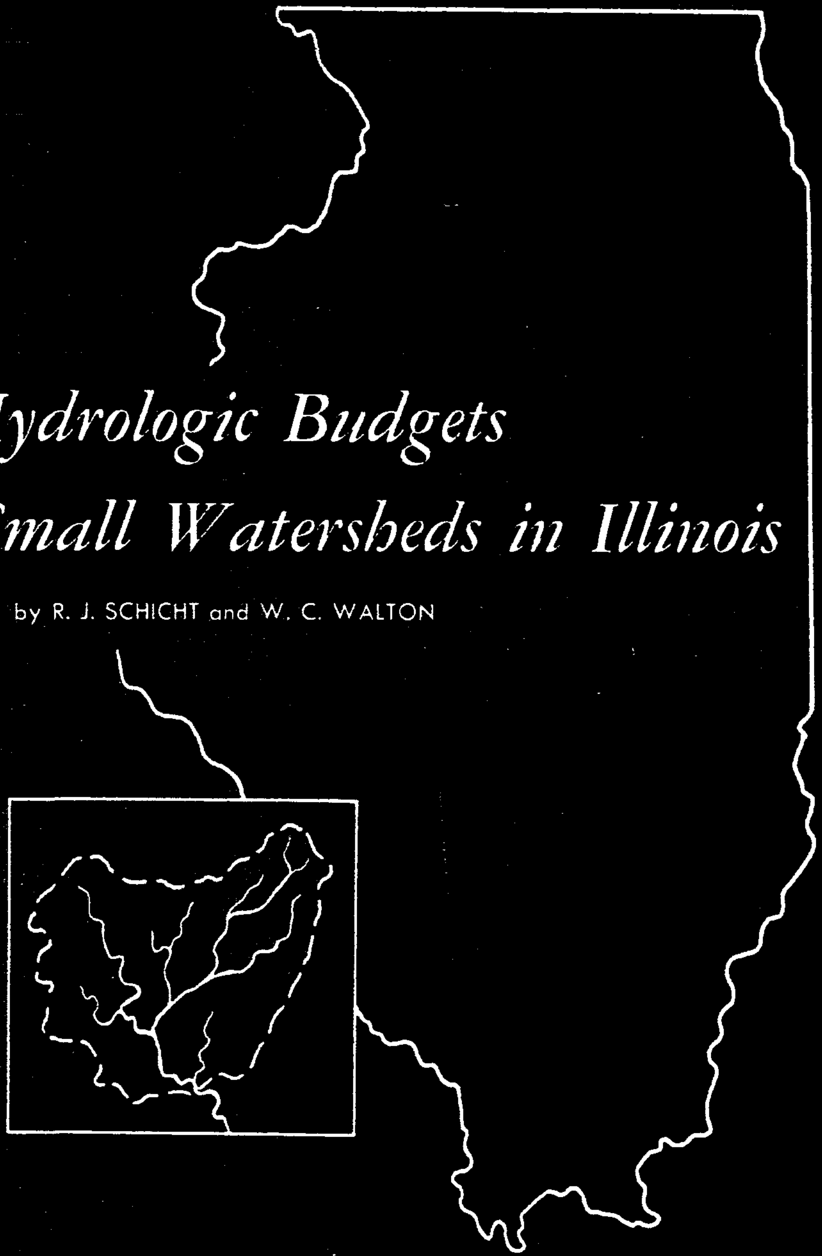

Hydrologic Budgets for Three Small Watersheds in Illinois

by R. J. SCHICHT and W. C. WALTON

ILLINOIS STATE WATER SURVEY
WILLIAM C. ACKERMANN, Chief

URBANA

1961

REPORT OF INVESTIGATION 40

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STATE OF ILLINOIS
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DEPARTMENT OF REGISTRATION AND EDUCATION
WILLIAM SYLVESTER WHITE, Director

STATE WATER SURVEY DIVISION
WILLIAM C. ACKERMANN, Chief

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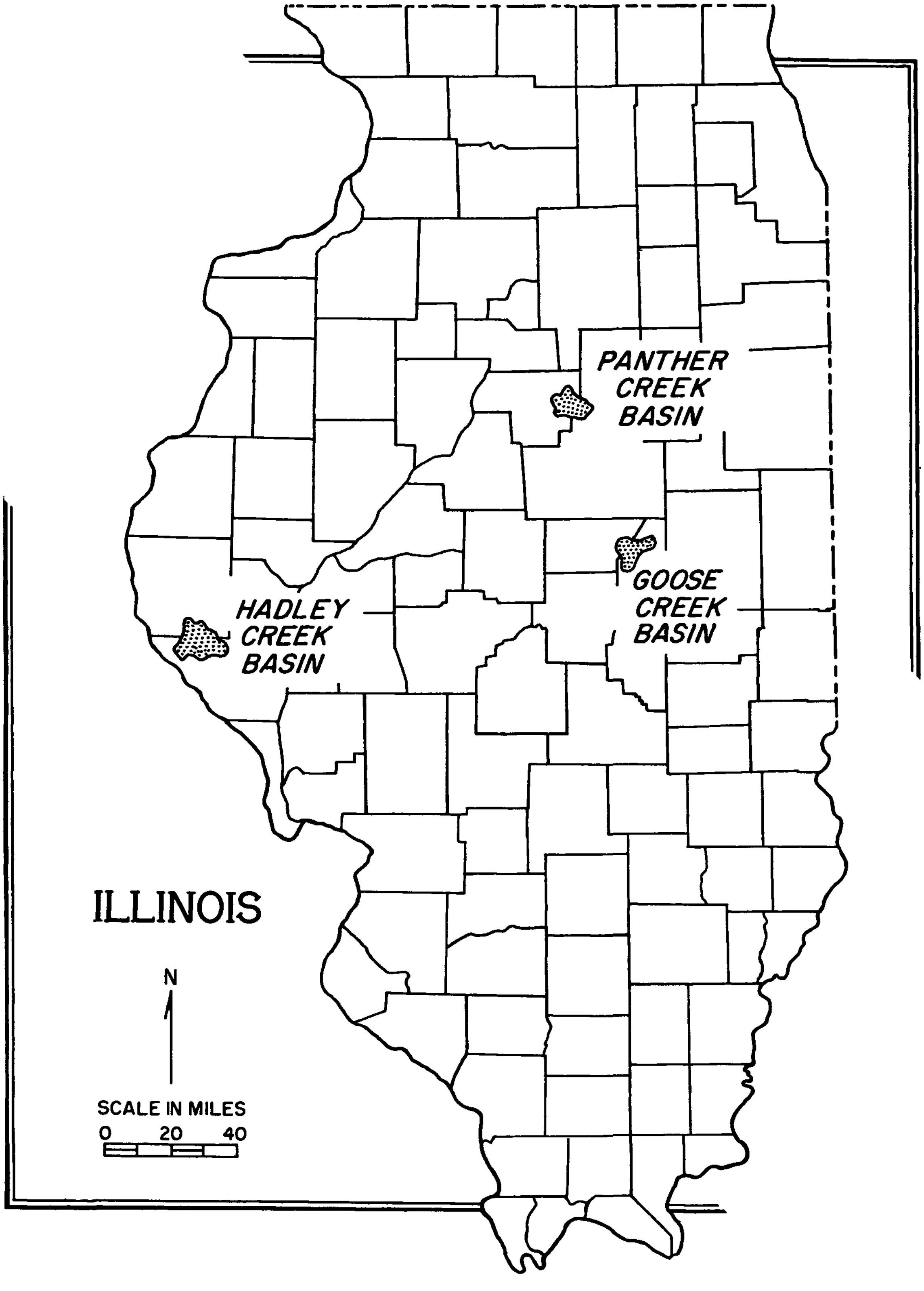

Figure 1. Map showing location of basins

Hydrologic Budgets

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by R. J. Schlcht and W. C. Walton

ABSTRACT

Ground-water recharge, runoff, and evapotranspiration are determined for three basins in Illinois from hydrologic and ground-water budgets using precipitation, stream flow, and ground-water level data. The study basins are in north-central, west-southwestern, and east-central Illinois. The surficial deposits in which the water table fluctuates in the basins are composed largely of glacial till. The hydrologic budget is a quantitative statement of the balance between total water gains and losses of a basin, and the ground-water budget is a quantitative statement of the balance between water gains and losses of the ground-water reservoir.

Ground-water runoff under flood hydrographs and during rainless periods and ground-water e.vapotranspiration are determined from rating curves of mean ground-water stage versus ground-water runoff. Ground-water storage changes are computed from data on changes in mean ground-water stage by using a graph showing the relationship between gravity yield and average time of drainage. The gravity yield-average time of drainage graphs are prepared from the results of hydrologic budget studies made for periods during winter and early spring months when evapotranspiration and soil-moisture change are very small. Annual evapotranspiration is appraised from annual hydrologic budgets and is compared to mean annual potential evapotranspiration and annual water loss.

INTRODUCTION

Purpose and Scope of Investigation

The ground-water reservoir plays an important role in the hydrologic cycle. Some precipitation reaches the water table and is stored temporarily in water-bearing materials. A large part of stream flow is derived from ground-water storage, and measurable amounts of ground water are discharged into the atmosphere by the processes of evapotranspiration. The broad purpose of the studies described in this report was to better understand the role of the ground-water reservoir in the hydrologic cycle and to estimate ground-water factors with greater accuracy than mere expression of concept. The specific aim of the study was to determine the amount of annual precipitation that reaches the water table and to ascertain the quantity of ground water that is discharged annually to streams by subsurface runoff and to the atmosphere by the processes of evapotranspiration.

A method is described for determining the annual recharge to the ground-water reservoir, a factor which must be known before the sustained yield of an aquifer can be quantitatively appraised. The results of this study have significant application because they describe recharge conditions which may be fairly representative of those throughout large areas of the state.

During study periods ranging from 2 1/2 to 8 years the State Water Survey and cooperating state and federal agencies measured precipitation on, stream discharge from, and ground-water levels in parts of the drainage basins of Panther, Hadley, and Goose Creeks. The study areas are in north-central, west-southwestern, and east-central Illinois, respectively, as shown in figure 1. Data on hydrologic phenomena are summarized in hydrologic and ground-water budgets. Ground-water recharge, runoff, evapotranspiration, underflow, and storage are discussed in relation to climatological conditions and physical characteristics of the study areas. Annual evapotranspiration computed from hydrologic budgets is compared to annual potential evapotranspiration determined from meteorological data and to annual water loss determined from precipitation and stream flow records.

Acknowledgments

The geological sections of this report were prepared with the assistance of Dr. R. E. Bergstrom of the Ground-Water and Geophysical Exploration Section of the State Geological Survey. The writers are indebted to members of the Meteorology Section of the State Water Survey, especially F. A. Huff, for collecting, processing, and making

available records of precipitation, and for assisting in the preparation of the climate section of this report. Stream flow data given in this report were provided by the Surface Water Branch of the U. S. Geological Survey.

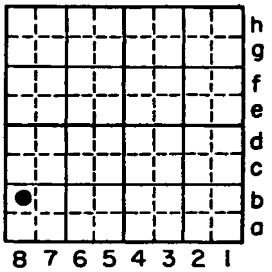
In the course of the studies information was obtained from well drillers, the office of the Woodford County Farm Adviser, Woodford County Clerk's Office, the Soil Conservation Office in Pittsfield, Illinois, the Piatt County Farm Adviser, the University of Illinois Agronomy Department, and residents of the basins. Special acknowledgment is made to well owners who were most cooperative and helpful in making available data on wells.

Many former and present members of the State Water Survey and State Geological Survey assisted in the collection of data in the basins, wrote earlier special reports which have been used as reference material, or aided the writers indirectly in preparing this report. Grateful acknowledgment is made, therefore, to the following: H. F. Smith, G. E. Stout, R. A. Hanson, R. T. Sasman, R. R. Russell, J. P. Dorr, J. W. Brother, W. J. Roberts, Ed Heiken, Bruce Swartz, J. B. Stall, Martin Zulauf, J. E. Hackett. F. A. Huff.

The coauthors of this report participated in the following manner: R. J. Schicht collected and processed much of the data, made most of the computations, and aided in the preparation of the manuscript; W. C. Walton supervised computations, prepared most of the text, and brought the manuscript to final form.

Well-Numbering System

The well-numbering system used in this report is based on the location of the well and uses the township, range, and section for identification. The well number consists of five parts: county abbreviation, township, range, section, and coordinate within the section. Sections are divided into rows of 1/8-mile squares. Each 1/8-mile square contains 10 acres and corresponds to a quarter of a quarter section. A normal section of 1 square mile contains 8 rows or 1/8-mile squares; an odd-size section contains more or fewer rows. Rows are numbered from east to west and lettered from south to north as shown below:



Piatt County
T.20N., R.5E.
sec. 32

The number of the well shown in section 32 above is as follows:

PIA 20N5E-32.8b

Where there is more than one well in a 10-acre square they are identified by arabic numbers after the lower case letter in the well number.

The abbreviations for counties discussed in this report are listed below.

Adams	ADM	Piatt	PIA
DeWitt	DWT	Pike	PKE
Livingston	LIV	Woodford	WDF
McLean	MCL		

HYDROLOGIC BUDGET

A hydrologic budget is a quantitative statement of the balance between the total water gains and losses of a basin for a period of time. The budget considers all waters, surface and subsurface, entering and leaving or stored within a basin. Water entering a basin is equated to water leaving a basin, plus or minus changes in basin storage.

The parts of drainage basins considered herein are contiguous to headwater reaches of streams, and except in the vicinity of stream gaging stations, the boundaries of the basins are reasonably congruous with ground-water and topographic divides. There is no surface or subsurface flow into or out of the basins except subsurface underflow from the basins in the vicinity of stream gaging stations. Water stored on the surface of the basins in ponds is very small, and discharge from wells is mostly for domestic and livestock use and is not significant. Thus, for the basins considered herein, several items of the general hydrologic budget can be eliminated because they do not measurably affect the balance between water gains and losses.

Precipitation, including rain and snow, is the source of water entering the basins and is the only water gain considered in the hydrologic budget. Water leaving the basins includes stream flow, evapotranspiration, and subsurface underflow. Water is stored beneath the surface in soils and in the ground-water reservoir. Changes in storage of water in the soil are reflected in changes in soil moisture, and changes in water levels in wells indicate changes in storage of water in the ground-water reservoir.

For a given period of time, water gain is balanced by water loss, plus or minus changes in basin storage. Stated as an equation, the hydrologic budget is,

$$P = R + ET + U \pm \Delta S_s \pm \Delta S_g \qquad (1)$$

where:

P = precipitation

R = stream flow

ET = evapotranspiration

U = subsurface underflow

ΔS_s = change in soil moisture

ΔS_g = change in ground-water storage

Stream Flow

Stream flow consists of surface runoff, R_s, and ground-water runoff, Rg. Surface runoff is precipitation that finds its way into the stream channel without infiltrating into the soil. Ground-water runoff is precipitation that infiltrates into the soil or to the water table and then percolates into the stream channel. Surface runoff reaches streams rapidly and is discharged from the basins within a few days. Ground water percolates slowly towards and reaches streams gradually. A few (3 to 5) days after precipitation ceases, there is no surface runoff and stream flow is derived entirely from ground-water runoff.

In general, stream flow is high in winter and spring and low in the summer and fall. Streamflow hydrographs have sharp peaks coinciding with heavy rainfall or rapid thaws.

Principles for separating the stream-flow hydrograph into its two components, surface and ground-water runoff, are not well developed. Ground-water runoff (base flow) several days after precipitation ceases is readily determined; however, ground-water runoff under flood hydrographs is the subject of much discussion. The views of two investigators should be noted. Sherman (1942) stated:

"The depletion curve has been applied to the derivation of base flow under flood hydrographs. This is erroneous. Ground-water outflow at flood stages is throttled, and is frequently a negative quantity. After the flood stage recedes, the rate of ground-water outflow is greater than that given by the normal depletion curve until equilibrium takes place."

Wisler and Brater (1959) made the following pertinent remarks concerning ground-water runoff under flood hydrographs.

"Except for the smallest stream rises, the rise in the stage of the river occurs more quickly and is much greater in magnitude than the corresponding rise of the water table. . . . Consequently as quickly as the water surface in the stream rises higher than the adjacent water table, thus creating at any given elevation a greater hydrostatic pressure in the stream than in the banks, ground-water inflow into the stream channel ceases temporarily and the direction of flow reverses, creating bank storage. . . . The volume of this bank storage continues to increase as long as the water level in the stream is higher than the water table..... or until after the stream has passed its peak stage. As soon as the stage starts to fall, the direction of flow again reverses, and for a time, because of the accumulated bank storage, the ground-water contribution to the stream is considerably increased. As soon as the bank storage is drained out, the ground-water flow again follows the normal depletion curve."

Even though ground-water runoff into the stream channel ceases temporarily during periods of flood, ground water continues to percolate towards the stream creating ground-water storage in the lowlands adjacent to the stream channel. As soon as the stream stage starts to fall, ground-water runoff is considerably increased not only because of the accumulated bank storage but also because of the accumulated ground-water storage. When bank and ground-water storage is drained out, ground-water runoff will generally be greater than before precipitation occurred because during most flood periods precipitation infiltrating into the ground-water reservoir causes the water table to rise and the hydraulic gradient towards the stream to increase.

Evapotranspiration

Water is discharged from the basins into the atmosphere through evapotranspiration, a term combining evaporation from land and water surfaces and transpiration from plants. Eva'potranspiration may be subdivided into two parts according to the source of the water discharged into the atmosphere as follows: (1) surface and soil evapotranspiration, ET_S, and (2) ground-water evapotranspiration, ETg. The part of evapotranspiration derived from soilmoisture and by evaporation from the surfaces of water, vegetation, buildings, and other objects is surface and soil evapotranspiration; the part derived from the water table is ground-water evapotranspiration.

Most of the precipitation falling during summer months is evaporated or transpired before it is able to infiltrate to the water table. Thus, a large proportion of the water discharged annually by evapotranspiration processes is not derived from the ground-water reservoir. However, in areas where the water table is shallow and the capillary fringe extends to land surface, large quantities of ground water are discharged into the atmosphere by evaporation. Plant rootlets often extend to the capillary fringe and ground water is discharged into the atmosphere by vegetation through the process of transpiration.

Evapotranspiration depends primarily upon meteorological factors, available soilmoisture and ground water, and type of soil and vegetation. Evapotranspiration is very small during the winter, increases rapidly in the spring, reaches a maximum generally in July, and decreases rapidly as the growing season closes in the autumn. This variation with the time of the year is approximately the same from year to year. Evapotranspiration is often greater than precipitation during the summer months and much less than precipitation during winter and early spring months.

Evapotranspiration can be determined by balancing equation 1. Soil moisture, one of the hydrologic factors, was not measured during investigations described herein; therefore, daily, weekly, and monthly evapotranspiration cannot be appraised. However, soil moisture is near field capacity during January of most years, and annual change in soil moisture is very small. Equation

I can be rewritten for an annual inventory period as follows:

$$ET = P - R - U \pm \Delta S_g \qquad (2)$$

Application of equation 2 requires that the annual change in soil moisture is not significant.

Subsurface Underflow

Subsurface underflow out of the basins occurs in the vicinity of stream gaging stations. Underflow can be estimated from the following modified form of the Darcy equation (see Ferris, in Wisler and Brater, 1959, p. 148):

$$Q = TIL \qquad (3)$$

in which Q is underflow in gallons per day (gpd), T is coefficient of transmissibility of the deposits through which flow is occurring in gallons per day per foot (gpd/ft), I is the hydraulic gradient of the water table in feet per mile (ft/mi), and L is the width of the cross section of the deposits through which flow is occurring in miles.

Change in Ground-Water Storage

The change in mean ground-water stage during an inventory period, ΔH, multiplied by the gravity yield, Yg, of the deposits within the zone of ground-water fluctuation is equal to the change in ground-water storage, ΔS_g. Stated as an equation

$$\Delta S_g = \Delta H(Y_g) \qquad (4)$$

Gravity yield (Rasmussen and Andreasen, 1959, p. 83) may be defined as the ratio of the volume of water that deposits will yield by gravity drainage to the total volume of deposits drained during a given period of ground-water decline. The gravity drainage of deposits is not immediate and as a result the gravity yield is not constant but increases at a diminishing rate with the time of drainage, gradually approaching the specific yield. The specific yield is the ratio of the volume of water that deposits will yield by complete gravity drainage to the total volume of deposits. Pertinent statements concerning gravity yield made by Rasmussen and Andreasen (1959, p. 83) are:

"However, in a sand that is fairly homogeneous except that a silt or few clay lenses are within the zone of ground-water fluctuation, a rise of the water table from below to above one of these lenses would not result immediately in complete saturation of it. Though the silt or clay might be considerably more porous than the surrounding sand, its permeability might be so low that a rather long time would be required for the water to penetrate the lens, and even then some air would be trapped. Conversely, when the water table receded, leaving a partly or completely saturated silt-clay lens somewhere within the capillary fringe, the lens would not yield its gravity water as readily as the surrounding sand. Rather, there would be a leakage from the silt-clay lens down to the lowered water table. Further, the water table responds quickly to every sizeable rainfall, and a rapidly rising water table entraps air in even the coarser sediments. Trapping of air results in a decrease in porosity and permeability, until the air is dissolved in the water."

These statements suggest that the gravity drainage of clayey materials such as till may be very slow and that the specific yield of till is seldom attained under field conditions. The relationship between gravity yield and time of drainage becomes evident when values of Yg are plotted against the average duration of ground-water decline preceding inventory periods.

The gravity yield of the deposits beneath the basins can be determined from the hydrologic budget. Equation 1 contains two factors, evapotranspiration and change in soil moisture, which were not measured during studies described in this report. However, during winter and early spring months (December, January, February, and early March) evapotranspiration and soil-moisture change are very small (Thornthwaite, Mather, Carter, 1958, p. 20). A reasonable estimate of evapotranspiration for periods during winter and early spring months is 0.3 inch per month. Soil-moisture change can be eliminated and evapotranspiration estimated to average 0.3 inches per month without introducing serious error in the hydrologic budget. Equation 1 may be rewritten for inventory periods during winter and early spring months when the water table is rising as follows:

$$Y_g = \frac{P - R - ET - U}{\Delta H} \qquad (5)$$

Equation 5 is valid for periods when the soil-moisture change is not significant. Values of gravity yield obtained under conditions of a rising water table are probably slightly lower than expected because of entrapped air (see Krul and Liefrinck, 1946, p. 40).

GROUND-WATER BUDGET

A part of precipitation on the basins percolates down through the soil and upon reaching the water table becomes ground water. Some ground water is discharged to streams as ground-water runoff and some is discharged into the atmosphere by the processes of evapotranspiration. For a given period of time, precipitation reaching the water table (ground-water recharge) is balanced by ground-water runoff, underflow, and evapotranspiration, plus or minus changes in ground-water storage. This balance expresses a ground-water budget and may be stated as the following equation:

$$P_g = R_g + ET_g + U \pm \Delta S_g \qquad (6)$$

where:

P_g = ground-water recharge
R_g = ground-water runoff
ET_g = ground-water evapotranspiration

U = subsurface underflow

ΔS_g = change in ground-water storage

Ground-Water Runoff

Ground-water runoff depends in part upon the position of the water table because associated with a particular mean ground-water stage there is a related hydraulic gradient and a consequent discharge of ground water into a stream. The relationship between mean ground-water stage and ground-water runoff can be determined by plotting mean ground-water stages against stream flow on corresponding dates when streamflow consists entirely of ground-water runoff. Periods are selected assuming that surface runoff is complete within five days after rainfall and that in the following protracted period of fair weather stream flow is all ground-water runoff.

In summer months evapotranspiration is very effective in reducing ground-water runoff. With the same ground-water stage, ground-water runoff is much less in August than in February. Separate rating curves of mean ground-water stage versus ground-water runoff must be prepared for dates April through October, when ground-water evapotranspiration is great, and for dates November through March, when ground-water evapotranspiration is very small.

Ground-water runoff under flood hydrographs and during rainless periods can be obtained from the rating curves and plotted beneath the stream flow hydrograph to describe a hydrograph of ground-water runoff. The rating curves give reasonably accurate estimates of ground-water runoff under flood hydrographs because accumulated ground-water storage drained out as the stream stage starts to fall approximately balances the negative ground-water outflow at flood stages.

Ground-water runoff generally is at a maximum during spring and early summer months and is least in late summer and fall months. Ground-water runoff often increases in the fall even though the mean ground-water stage declines because ground-water evapotranspiration decreases rapidly during that period. Annual ground-water runoff depends upon antecedent soil moisture and ground-water stage conditions as well as the amount and distribution of annual precipitation.

Ground-Water Evapotranspiration

Ground water continuously percolates towards streams; however, the roots of plants and soil capillaries intercept and discharge into the atmosphere some of the water which otherwise would become ground-water runoff. Evapotranspiration from the ground-water reservoir is largely afunction of the season and the mean ground-water stage. Ground-water evapotranspiration is very small November to April, increases rapidly in the late spring, reaches a maximum generally in July, and decreases rapidly as the growing season closes in the autumn. The opportunity for evapotranspiration is large at places where the water table is within a few feet of the surface and it generally decreases as the mean ground-water stage declines.

Ground-water evapotranspiration can be estimated from rating curves of mean ground-water stage versus ground-water runoff. Ground-water runoff corresponding to a ground-water stage is read from rating curves prepared for dates April through October, when ground-water evapotranspiration is great, and for dates November through March, when ground-water evapotranspiration is very small. The difference in ground-water runoff between the two curves is the approximate ground-water evapotranspiration.

Ground-Water Recharge

Evapotranspiration and soil-moisture requirements have first priority on precipitation. Rainfall percolates to the water table to recharge the ground-water reservoir during periods when precipitation is in excess of evapotranspiration and soil-moisture requirements and the ground is not frozen. Ground-water recharge is greatest in spring months of heavy rainfall and least in winter, summer, and fall months. In the summer little precipitation reaches the water table except during periods of excessive rainfall. Precipitation cannot infiltrate through frozen soil to recharge the ground-water reservoir. Ground-water recharge is indicated when the mean ground-water stage rises, or declines less than is necessary to balance ground-water runoff and evapotranspiration.

The amount of precipitation which reaches the water table can be estimated from equation 6. Ground-water runoff and evapotranspiration are determined from the mean ground-water stage-runoff rating curves described earlier. To compute changes in ground-water storage, appropriate values of gravity yield must be substituted in equation 4 based on the average period of ground-water decline preceding the inventory period.

Ground-water recharge also can be estimated from data on significant rises in the mean ground-water stage using a method described by Rasmus sen and Andreas en (1959). Recession limbs of the hydrograph of mean ground-water stage are projected to dates on which the following peaks of water-level rise occur, thus taking into consideration ground-water runoff. The amount of recharge occurring during individual rises in the water table is equal to the product of the individual rise and the gravity yield.

PANTHER CREEK BASIN

For a period of 8 years, August 1950 through 1958, the State Water Survey measured precipitation on and ground-water levels in part of the Panther Creek drainage basin. Stream flow was measured during the same period by the Surface Water Branch of the U. S. Geological Survey. The density of precipitation gages varied throughout the study period, as will be explained later, but was 10.6 square miles per gage during much of the time. Ground-water levels were measured continuously in 5 observation wells equipped with recording gages. The number of observation wells was increased from 5 to 16 during the fall of 1958 to determine the adequacy of the observation-well program. The record of stream flow was determined by a recording gage on Panther Creek at the lower end of the study area. Soil moisture was not measured during the investigation.

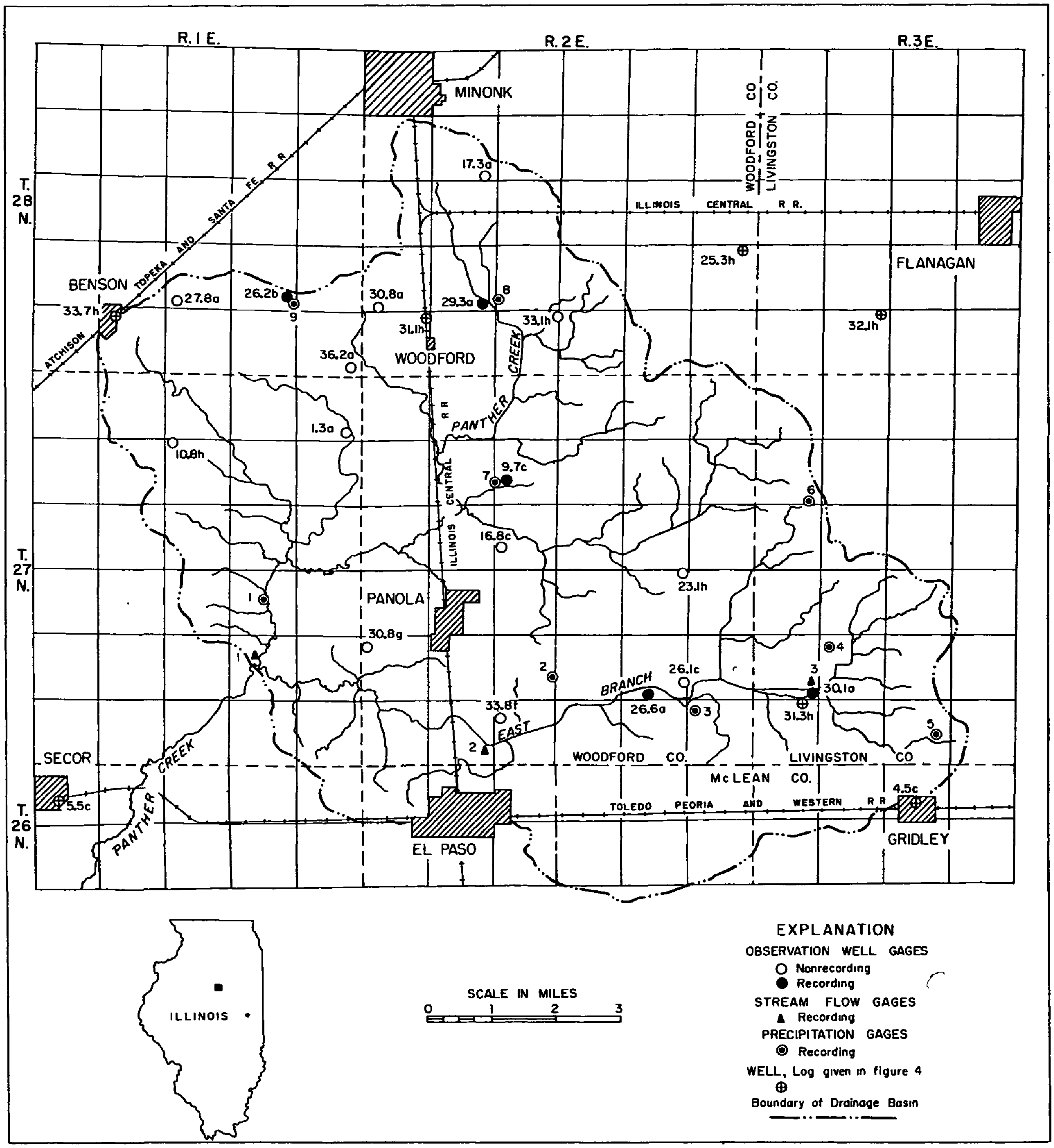


Figure 2. Hydrologic map of Panther Creek drainage basin, Woodford, Livingston, and McLean Counties, Illinois

In an attempt to determine how the various factors of the hydrologic and ground-water budgets are influenced by climatic conditions, emphasis was placed on analysis of data for years of above, near, and below normal precipitation. Critical review of available data indicated that the years 1951, 1952, and 1956 were best for budget studies. Hydrologic and ground-water budgets for these three years are presented and compared. Available information concerning geographic, climatic, and geologic features of Panther Creek basin is given to serve as a background for interpretation of records.

Geography

Location and Extent of the Basin

The Panther Creek basin is in north-central Illinois about 30 miles east of Peoria and about 20 miles north of Bloomington. The part of Panther Creek drainage basin considered, hereafter referred to as "the basin," is approximately between 88°52' and 89°07' west longitude and between 40°44' and 40°54' north latitude as shown in regional setting in figure 1 and in detail in figure 2. The basin covers 95 square miles mostly in Woodford County, however, small parts are in Livingston and McLean Counties. The basin is above a stream gaging station about 4 miles northwest of the city of El Paso and is in T. 26 N. to T. 28 N. and R. 1 E. to R. 3 E.

Topography and Drainage

The basin lies in the Till Plains section of the Central Lowland physiographic province (Fenneman, 1914). The topography consists mostly of gently undulating uplands. Rolling topography is found in belts on moraines along the west, northeast, and east edges of the basin. The uplands are eroded in the immediate vicinity of Panther Creek in the extreme southwest corner where the topography is more diversified.

The elevation of the land surface of the basin declines from 770 feet near the villages of Benson and Gridley to 660 feet at the stream gaging station northwest of El Paso. Except in the southwest corner adjacent to Panther Creek where the elevation of the land surface declines about 50 feet in a distance of one-fourth mile, the relief seldom exceeds 20 feet per mile.

The drainage system is shown in figure 2. Panther Creek is the principal stream, and flows in a generally southwestward course. A small tributary, East Branch Panther Creek, drains the southern quarter of the basin and flows westward to a confluence with Panther Creek 4 miles northwest of El Paso. The average gradients of Panther Creek and East Branch are 4.7 and 5.0 feet per mile, respectively. The water table was very near the surface and shallow ponds, swamps, and poorly drained areas were widespread prior to settlement. Extensive surface and subsurface drainage was necessary to permit agricultural development.

Population and Land Use

The population of the basin is chiefly rural, and according to the U. S. Census of Population, the population density was about 37 persons per square mile in 1950. The populations of incorporated municipalities within or bordering the basin are as follows:

Municipality	Population. 1950
Village of Benson	387
City of El Paso	1818
Village of Gridley	817
City of Minonk	1955
Village of Panola	52

At the time of the study period about 80 per cent of the basin was cleared and cultivated; the remainder was pasture, woodland, and farm lots. The cleared land was devoted to such crops as field corn, oats, soybeans for beans, alfalfa, clover and timothy hay, winter wheat, rye, and sweet corn. Field corn, oats, and soybeans for beans were the major crops.

Table 1

Average monthly and annual temperatures and departures from normal, 1951, 1952, and 1956, Panther Creek basin

	1951		1952		1956	
Month	Temperature °F	Departure (inches)	Temperature °F	Departure (inches)	Temperature °F	Departure (inches)
Jan.	25.2	.4	27.4	2.6	25.9	1.1
Feb.	28.1	.9	33.5	6.3	29.0	1.8
Mar.	35.7	-3.3	36.3	-2.7	38.7	-0.3
Apr.	48.3	-1.8	53.0	2.9	49.5	-0.6
May	64.0	2.7	60.9	-0.4	63.8	2.5
June	68.7	-2.0	76.3	5.6	72.7	2.0
July	73.3	-2.2	77.6	2.1	72.5	-3.0
Aug.	71.7	-1.7	72.6	-0.8	73.0	-0.4
Sept.	63.9	-2.5	65.7	-0.7	65.0	-1.4
Oct.	56.2	1.9	49.1	-5.2	60.7	6.4
Nov.	33.4	-7.2	42.3	1.7	39.5	-1.1
Dec.	26.4	-1.6	31.1	3.1	31.5	3.5
Annual	49.6	-1.3	52.2	1.3	51.8	0.9

Climate

The basin lies in the north temperate zone. Its climate is characterized by warm summers and moderately cold winters. The mean length of the growing season is about 170 days.

Based on records collected by the U. S. Weather Bureau at Minonk, the mean annual temperature is 51 F. June, July, and August are the hottest months with mean temperatures of 71 F, 76 F, and 73 F, respectively; January is the coldest month with a mean temperature of 25 F. Mean monthly temperatures during December, January, and February are below 32 F. Table 1 showing average monthly and annual air temperatures and departures from normal during 1951, 1952, and 1956 was compiled from the records of the U. S. Weather Bureau at Minonk.

Normal annual precipitation based on 1900-44 U. S. Weather Bureau records at Minonk and Gridley is 33.6 inches. The months of greatest precipitation are April, May, June, August, and September, each having an average of more than 3 inches. December, January, and February are the months of least precipitation, each having an average of less than 2 inches. About 59 per cent of the year's precipitation falls during the growing season. Monthly and annual precipitation, 1950-58, computed by averaging arithmetically gage readings, is given in table 2, and the mean daily precipitation during 1952 is shown in figure 3. The occurrence of the annual maximum and minimum precipitation amounts expected on an average of once in 5 and once in 50 years, based on data in the Atlas of Illinois Resources, Section 1, are given below.

	Lowest annual precipitation expected (inches)	Highest annual precipitation expected (inches)
Once in 5 years	30	39
Once in 50 years	24	50

According to the Atlas of Illinois Resources, Section 1, the mean annual snowfall is 24 inches. On the average more than 28 days a year have 1 inch or more ground snow cover; more than 13 days a year have 3 inches or more of ground snow cover. The average depth of maximum frost penetration is 26 inches.

The Meteorology Section of the State Water Survey, in cooperation with the Pfister Hybrid Corn Company of El Paso, Illinois, has measured precipitation within the basin since the spring of 1948. The density of the network has varied. There have been as few as 3 gages in winter months and as many as 34 gages in summer months. Nine gages shown in figure 2 have been continuous in operation since April 1954. During the 1948-49 season there were 14 nonrecording and 6 recording gages corresponding to an average of 1 gage per 4.75 square miles. Within the basin there were 34 gages in 1950, and during 1951-53 a network of 25 recording gages was maintained. The results of rainfall studies during 1948-50 were summarized by Hudson, Stout, and Huff (1952). They conclude that for general climatic purposes concentrated networks, such as employed in 1948-50, are not justifiable. Huff and Neill (1957, p. 11) after analyzing rainfall data collected during 1948-55 imply that the den-

Table 2

Monthly and annual precipitation, 1950-58, Panther Creek basin

Month	Precipitation in inches								
	1950	1951	1952	1953	1954	1955	1956	1957	1958
Jan.	4.90	1.41	1.01	1.36	1.23	1.92	0.14	1.51	1.02
Feb.	2.71	2.88	1.19	1.19	2.11	1.50	1.45	1.16	0.45
Mar.	1.13	3.58	2.73	4.38	3.95	1.55	0.73	1.64	0.33
Apr.	5.99	4.20	4.66	1.94	4.46	4.28	2.39	7.47	2.56
May	1.07	2.93	3.36	2.06	4.58	3.53	3.24	4.42	2.57
June	6.91	7.16	7.07	3.52	2.58	2.81	0.89	4.64	5.67
July	6.42	8.40	2.18	6.29	4.42	3.12	3.22	2.28	6.05
Aug.	0.62	4.11	4.47	1.22	5.18	4.33	3.23	1.96	4.24
Sept.	3.83	2.34	1.43	2.32	0.81	1.86	1.08	1.31	1.82
Oct.	0.90	2.99	0.64	0.71	3.42	3.71	0.40	5.14	0.64
Nov.	1.81	2.70	2.31	0.72	1.75	0.83	1.54	2.08	2.62
Dec.	0.78	1.54	1.57	2.53	1.61	0.35	1.18	2.75	0.49
Annual	37.07	44.24	32.62	28.24	36.10	29.79	19.49	36.36	28.46

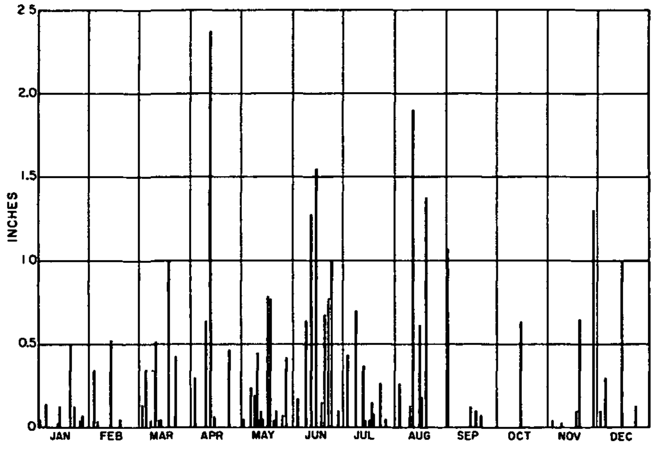


Figure 3. Mean daily precipitation, 1952, Panther Creek basin

sity of gages, 10.6 square miles per gage, in 1954 was sufficient for most purposes.

A large part of central and southern Illinois, including the basin, experienced a severe drought beginning in the latter part of 1952 (Hudson and Roberts, 1955). For the period 1952 through 1956 cumulative deficiency of precipitation was about 22 inches; cumulative departures below normal from 1950 through 1958 totaled about 20 inches.

An intense rainstorm, exceeding 9 inches in 6 hours at places, occurred on the night of July 8, 1951. The storm and its effects on stream flow are described in detail in Report of Investigation No. 14 (1952).

Geology

Soils

The soils of the basin were divided into four groups by Smith, DeTurk, Bauer, and Smith (1927): upland prairie, upland timber, swamp and bottomland, and terrace soils. Except for small areas adjacent to Panther Creek and East Branch, upland prairie soils predominate.

The upland prairie soils are largely very dark gray to dark brown silt loams formed under prairie vegetation from thin loess (see Wascher, Fahrenbacher, Odell, and Veale, 1950). The surface layer is a very dark gray to dark brown silt loam 6 to 8 inches thick which is medium in organic matter and slightly to medium acid. The subsurface is a very dark grayish brown light silty clay loam 6 to 8 inches thick. The subsoil beginning at a depth of 12 to 16 inches is a brown to dark grayish yellow silty clay.

In a small area in the north central part of the basin the surface layer is a brown to dark brown heavy silt loam 8 to 10 inches thick, or a granular black clay loam to silty clay loam 8 to 10 inches thick (see Wascher, Smith, and Odell, 1949). These materials are high in organic matter and nitrogen and slightly acid to neutral. The subsurface layer is a brown or pale yellowish-brown silt loam, a very dark gray or grayish-black clay loam, or silt clay loam. The subsoil layer which begins at a depth of 14 to 18 inches is a silty clay loam and in color ranges from yellowish brown to dark gray.

The upland prairie soils occur on 1 to 6 per cent slopes. Surface drainage is moderate, artificial drainage is often required for agricultural development. The permeability is moderately slow, underdrainage by tiles is satisfactory under proper farm management.

The materials beneath the subsoils to depths of 40 to 60 inches are compact calcareous or plastic calcareous glacial tills except in a small area in the north central part of the basin where stratified silt and sand or stratified clay, silt, and sand occur. The permeability of the materials beneath the subsoils is moderate to slow.

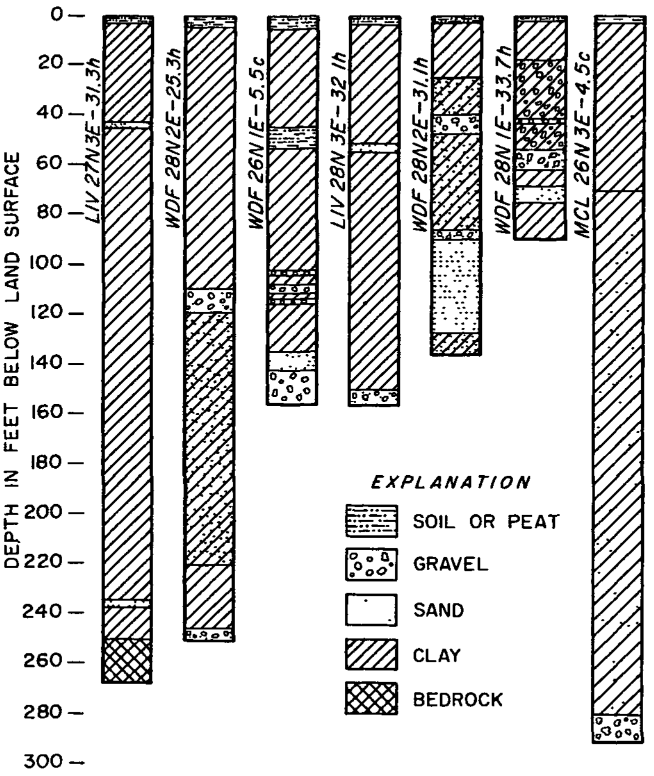


Figure 4. Logs of selected wells. Panther Creek basin (Locations of wells are shown in figure 2)

Glacial Deposits and Their Water-Bearing Properties

Thick deposits of glacial drift chiefly of Wisconsinan age cover the bedrock and constitute the main features of the present land surface. The deposits are composed dominantly of unstratified clayey materials called glacial till, but include some stratified beds of silt, sand, and gravel as shown by logs of wells in figure 4. The average thickness of the glacial drift on the bedrock uplands is about 100 feet. Along the eastern edge of the basin, in Danvers bedrock valley, it may reach a thickness of more than 290 feet (see log of well MCL 26N3E-4.5c in figure 4). Sand and gravel, ranging in thickness from a few inches to more than 40 feet, occur as irregular lenses or layers in the till. These deposits are discontinuous and are limited greatly in areal extent (see Buhle, 1943). In general, because of the complex glacial history, the character of the drift varies greatly both vertically and horizontally. However, considering the basin as" a whole, the character of the drift in relation to the occurrence and movement of ground water is fairly uniform.

There are great variations in the water-bearing openings of till. At places where clayey materials predominate, the till is nearly impervious and yields very little water; a sandy till is somewhat more porous and permeable. Most dug wells in till have small yields and obtain water from the lenses or layers of sand and gravel that are interbedded in the compact clayey materials. The porosity and specific yield of till are not great because the sorting of material is poor and small sediments occupypore spaces between larger fragments of rock (see Dapples, 1959, p. 311 and 411).

Bedrock Formations and Their Water-Bearing Properties

The surficial glacial deposits are immediately underlain by bedrock formations of Pennsylvanian age consisting predominantly of shale with alternating thin beds of limestone, sandstone, siltstone, fire clay, and coal. These formations are situated structurally on the northwest flank of the Illinois basin, and dip regionally south-southeastward at uniform rates less than 15 feet per mile. At Minonk the thickness of the Pennsylvanian rocks is about 515 feet.

The Pennsylvanian rocks generally have low porosities and permeabilities and yield small amounts of water to wells from interconnected cracks, fractures, crevices, joints, and bedding planes. Water-bearing openings are variable from place to place and are best developed near the surface and in the thin limestones and sandstones. Practically speaking, the rocks are important because they act as a barrier to deep percolation.

The bedrock surface topography is relatively flat except for a deep valley (Danvers bedrock valley) whose axis is near the eastern boundary of the basin. The elevation of the bedrock upland averages 625 feet according to Horberg (1957). The bedrock surface slopes eastward along the eastern edge toward Danvers bedrock valley and its elevation declines from about 600 to 450 feet in a distance of 4 miles.

Stream Flow

Daily mean stream flow at gaging station 1 during 1951, 1952, and 1956 plotted on semilogarithmic hydrograph paper is shown on figures 5, 6, and 7. In general, stream flow is high in winter and spring and low in the summer and fall. In the winter accumulated snow often melts producing disproportionately high stream flow for short periods of time.

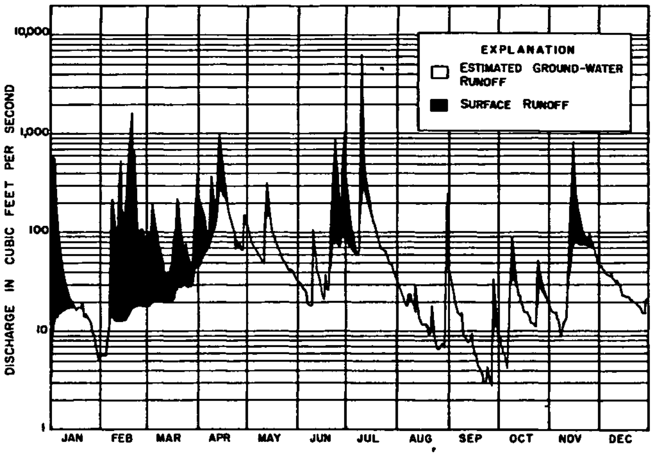


Figure 5. Stream flow at gaging station 1, Panther Creek basin, 1951

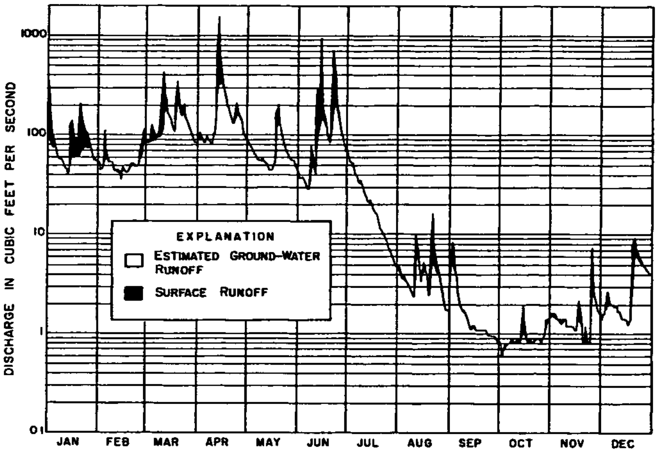


Figure 6. Stream flow at gaging station 1, Panther Creek basin, 1952

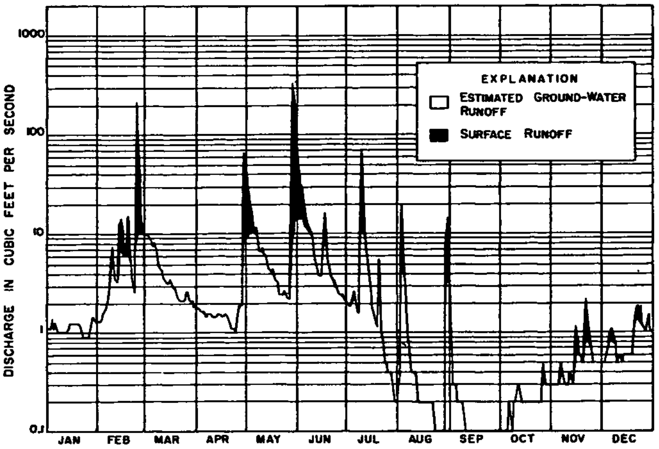


Figure 7. Stream flow at gaging station 1, Panther Creek basin, 1956

Daily mean stream flow exceeded 6000 cubic feet per second (cfs) in July, 1951 and was less than 0.1 cfs during parts of August and September, 1956.

Monthly and annual stream flow during 1951, 1952, and 1956, expressed in inches of water over the basin, are given in table 3. Stream flow was greatest in 1951 largely as a result of above normal precipitation during that year, and was least in 1956 when precipitation was much below normal.

Several conditions were responsible for the low stream flow in 1956. Precipitation was below normal during most of 1955; consequently, the mean ground-water stage was low at the beginning of 1956. Precipitation during 1956 was only slightly in excess of evapotranspiration and soil-moisture requirements. Very little precipitation reached the water table and the mean ground-water stage and ground-water runoff were abnormally low throughout the year.

Ground-Water Runoff

Rating curves were prepared to determine the relationship between mean ground-water stage and

Table 3

Monthly and annual stream flow in inches, 1951, 1952, and 1956, Panther Creek basin

Month	1951			1952			1956		
	R_s	R_g	R	R_s	R_g	R	R_s	R_g	R
Jan.	0.61	0.16	0.77	0.39	0.77	1.16	neg.	0.01	0.01
Feb.	2.85	0.15	3.00	0.08	0.57	0.65	0.14	0.08	0.22
Mar.	0.97	0.30	1.27	0.43	1.57	2.00	0.01	0.04	0.05
Apr.	1.08	1.44	2.52	0.65	1.94	2.59	0.03	0.03	0.06
May-	0.12	0.82	0.94	0.06	0.82	0.88	0.34	0.08	0.42
June	1.80	0.56	2.36	1.03	1.10	2.13	0.04	0.07	0.11
July	3.63	1.13	4.76	neg.*	0.27	0.27	0.04	0.03	0.07
Aug.	0.16	0.22	0.38	0.01	0.04	0.05	0.01	0.01	0.02
Sept.	0.03	0.10	0.13	neg.	0.02	0.02	neg.	neg.	neg.
Oct.	0.07	0.22	0.29	neg.	0.01	0.01	neg.	neg.	neg.
Nov.	0.97	0.55	1.52	neg.	0.02	0.02	neg.	0.01	0.01
Dec.	0.05	0.35	0.40	0.01	0.03	0.04	neg.	0.01	0.01
Annual	12.34	6.00	18.34	2.66	7.16	9.82	0.61	0.37	0.98

* Negligible

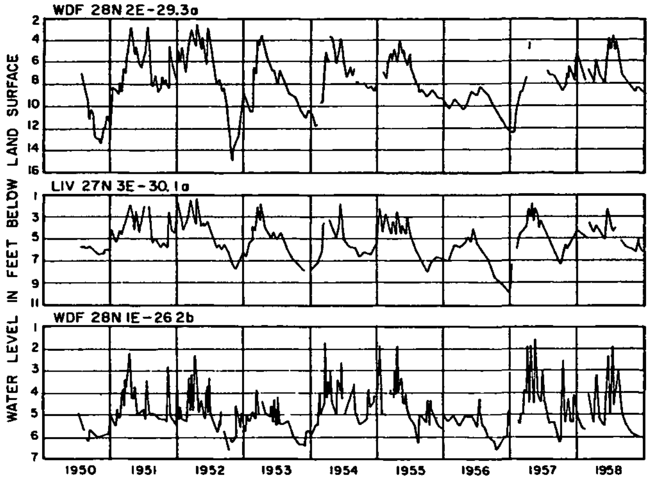


Figure 8. Water levels in observation wells 29.3a, 30.1a, and 26.2b, Panther Creek basin, 1950-58

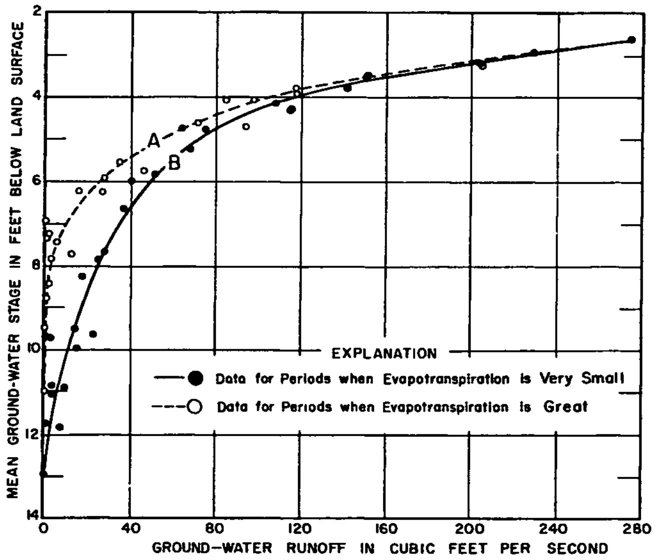


Figure 10. Rating curves of mean ground-water stage versus ground-water runoff at gaging station 1, Panther Creek basin

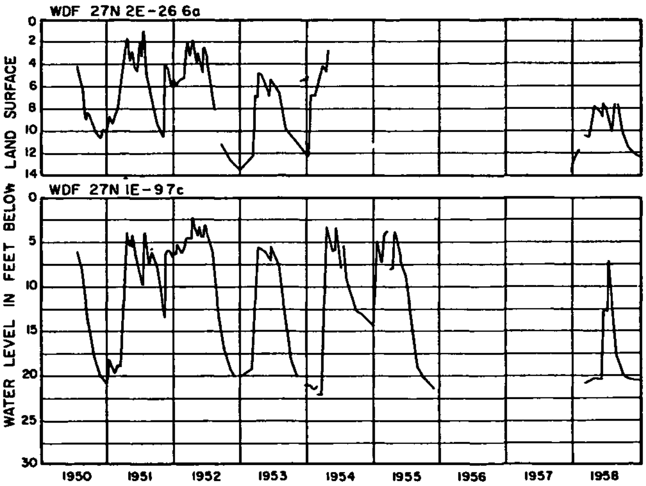


Figure 9. Water levels in observation wells 26.6a and 9.7c, Panther Creek basin, 1950-58

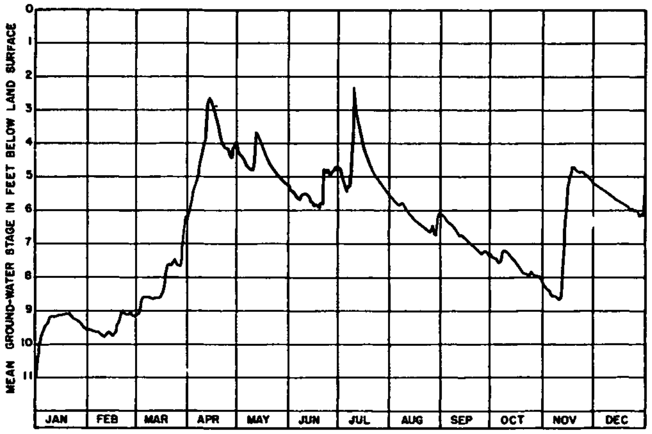


Figure 11. Mean ground-water stage, Panther Creek basin, 1951

ground-water runoff. Fluctuations of the water table in the basin are shown by the hydrographs of wells given in figures 8 and 9. Records of the wells are given in table 4. Daily average.s of ground-water levels measured in wells 29.3a, 30.1a, 26.2b, 26.6a, and 9.7c were computed for selected dates when streamflow consisted entirely of ground-water runoff. Mean ground-water stages were plotted against ground-water runoff on corresponding dates as shown in figure 10. In figure 10 closed circles represent sets of data for dates November to April, when evapotranspiration is at a minimum; open circles represent sets of data for dates April through October, when evapotranspiration is great.

Daily mean ground-water stages were plotted as yearly hydrographs as shown in figures 11, 12 and 13. Ground-water runoff corresponding to each mean ground-water stage was read directly from the rating curves in figure 10. Curve A was used with data for dates April through October and curve B was used with data for the rest of year. During protracted rainless periods actual stream flow is ground-water runoff.

Daily ground-water runoff was plotted beneath stream-flow hydrographs and lines were drawn connecting points to describe ground-water runoff hydrographs as shown in figures 5, 6 and 7. The shaded areas between stream flow and ground-water runoff hydrographs represent surface runoff.

Monthly and annual ground-water and surface runoff, expressed in inches of water over the basin, are given in table 3. These data indicate that ground-water runoff is at a maximum during spring and early summer months and is least in late summer and fall months. More than half of annual ground-water runoff occurs during the first six months of the year.

Annual ground-water runoff depends upon antecedent ground-water stage conditions as well as the amount and distribution of annual precipitation. Ground-water runoff was less in 1951 than in 1952 although precipitation was much greater in 1951 than in 1952. Ground-water stages and consequently ground-water runoff during the first six months of 1952 were higher than those for the same period in 1951 because of excessive pre-

Table 4

Well records, Panther Creek basin

Well No.	Owner	Type of well	Depth of well (feet)	Diameter of well (inches)	Elevation of land surface (feet above MSL)	Depth to water 5-15-59 (feet below land surface)	Remarks
WDF 28N2E-17.3a		Dug	48		741	31.40	Livestock supply
WDF 28N2E-25.3h	W. Bonk	Drilled	250	4	735		Log available
LIV 28N3E-32.1h	C. Gunden	Drilled	156	4	700		Log available
WDF 28N2E-33.1h	Falk	Dug			720	4.07	Abandoned school well
WDF 28N2E-29.3a	T. Budde	Dug	18	36	720	4.82	Poultry supply
WDF 28N2E-31.1h	Illinois Central R. R.	Drilled	135		730		Log available, test hole
WDF 28N1E-30.8a	Jannsen	Dug	28		725	14.09	Livestock supply
WDF 28N1E-26.2b	C. Kapraun	Dug and drilled	40	36	740	4.73	Poultry supply
WDF 28N1E-27.8a	Jaydyn	Dug	26		750	6.62	Domestic supply
WDF 28N1E-33.7h	Village of Benson	Drilled	73	12	760		Log available (Village well No. 4)
WDF 28N1E-36.2a	McKay Bros.		62		721	4.90	Livestock supply
WDF 27N2E-10.8h	Odel	Dug			731	12.93	Domestic supply
WDF 27N1E-1.3a	Kapraun	Dug	68		721	37.38	Livestock and domestic supply
WDF 27N1E-9.7c	Kelsey	Dug	65		710	5.50	Abandoned
WDF 27N2E-23.1h		Dug	22		738	4.85	Abandoned school well
WDF 27N2E-16.8c	Krug	Dug	30		712	4.38	Abandoned
WDF 27N2E-30.8g	Crump	Dug	44		715		Sealed 10/58
WDF 27N2E-33.8f		Dug			711	5.90	Abandoned
WDF 27N2E-26.6a	J. Kopenstein	Dug	28		712	4.75	Abandoned
WDF 27N2E-26.1c	Bohrer	Dug	48		718	5.30	Domestic supply
LIV 27N3E-31.3h	H. Greenwold	Drilled	266	4	716		Log available
LIV 27N3E-30.1a	J. Murray	Dug	22		719	4.45	Abandoned
LIV 26N1E-5.5c	Village of Secor	Drilled	156		736		Log available
MCL 26N3E-4.5c	Village of Gridley	Drilled	290	8	752		Log available (Village Well No. 2)

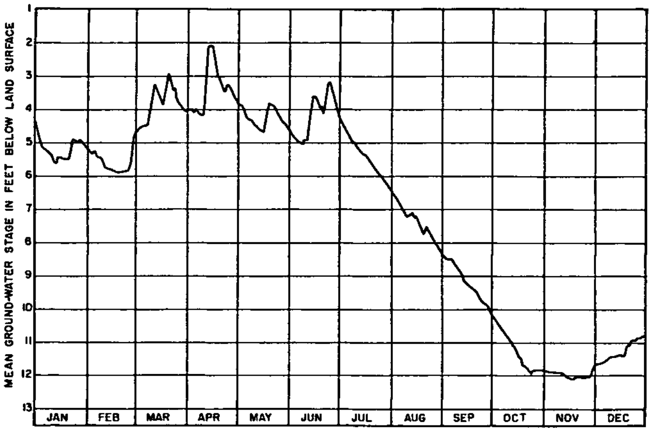


Figure 12. Mean ground-water stage, Panther Creek basin, 1952

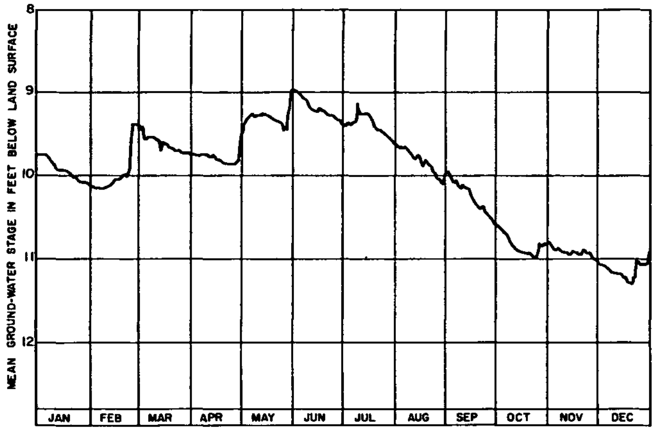


Figure 13. Mean ground-water stage, Panther Creek basin, 1956

cipitation during the summer months of 1951 and near normal precipitation in 1950. During extended dry periods ground-water runoff is reduced greatly. Ground-water runoff was very small during 1956 because precipitation was much below normal in 1955 and 1956.

Ground-water runoff amounted to 33, 73, and 38 per cent of stream flow in 1951, 1952, and 1956, respectively.

Evapotranspiration

Annual values of evapotranspiration in 1951, 1952, and 1956 estimated by balancing equation 2 are given in table 5. Methods used to determine underflow and change in ground-water storage are described later in this report. The range in annual evapotranspiration is much less than the range in annual precipitation. Evapotranspiration was less in 1952, a year of near normal precipitation, than in 1951, a year of above normal precipitation, even though the average temperature during the growing season of 1951 was below normal and the average temperature during the growing season of 1952 was above normal. The ratio of evapotranspiration and precipitation was 56 per cent in 1951, 73 per cent in 1952, and 96 per cent in 1956.

Ground-Water Evapotranspiration

Estimates of daily ground-water evapotranspiration during 1951, 1952, and 1956 were computed from figures 11, 12, and 13 and the ground-water stage-runoff rating curves in figure 10. Monthly and annual ground-water evapotranspiration are given in table 5. These data indicate that monthly ground-water evapotranspiration is greatest generally during July and August and that annual ground-water evapotranspiration is least during dry years. The ratio of ground-water evapotranspiration to total evapotranspiration was 5, 8, and 4 per cent in 1951, 1952, and 1956, respectively.

Table 5

Monthly and annual evapotranspiration in inches, 1951, 1952, and 1956, Panther Creek basin

	1951			1952			1956		
Month	ET_s	ET_g	ET	ET_s	ET_g	ET	ET_s	ET_g	ET
Jan.		neg.*			neg.			neg.	
Feb.		neg.			neg.			neg.	
Mar.		neg.			neg.			neg.	
Apr.		0.08			0.13			0.06	
May		0.27			0.43			0.11	
June		0.18			0.18			0.12	
July		0.05			0.47			0.13	
Aug.		0.34			0.33			0.14	
Sept.		0.23			0.28			0.12	
Oct.		0.04			0.19			0.06	
Nov.		neg.			neg.			neg.	
Dec.		neg.			neg.			neg.	
Annual	23.52	1.19	24.71	21.93	2.01	23.94	18.01	0.74	18.75

* Negligible

Underflow

The width of the lowlands adjacent to Panther Creek through which underflow occurs is about 500 feet. Based on the bedrock surface and topographic maps, the thickness of the glacial drift is estimated to be less than 25 feet and the hydraulic gradient of the water table in the vicinity of stream gaging station 1 is estimated to be less than 50 feet per mile. The coefficient of transmissibility of the deposits through which underflow occurs is low and is probably in the magnitude of 500 gpd/ft. Underflow was computed by substituting the above data in equation 3 to be about 0.01 cfs and is so small that it was omitted from budget computations.

Changes in Ground-Water Storage

To compute changes in ground-water storage appropriate values of Yg must be substituted in equation 4 based on the average period of ground-water stage decline preceding the selected inventory period. Because the gravity yield of till varies greatly with time of drainage, it is impossible to use the method of convergent approximations described by Rasmussen and Andreasen (1959, p. 86) to determine gravity yield.

Computations of gravity yield were made using equation 5 and data for nine inventory periods during winter and early spring months, 1951-58. Values of Yg were plotted against the average time of drainage preceding the inventory periods as shown in figure 14. These data indicate that the average gravity yield of the glacial deposits increases at a diminishing rate from about 1 per cent for a drainage period of 10 days to about 8 per cent for a drainage period of 140 days. Extrapolation of the curve in figure 14 suggests that the average specific yield of glacial deposits beneath the basin is about 12 per cent.

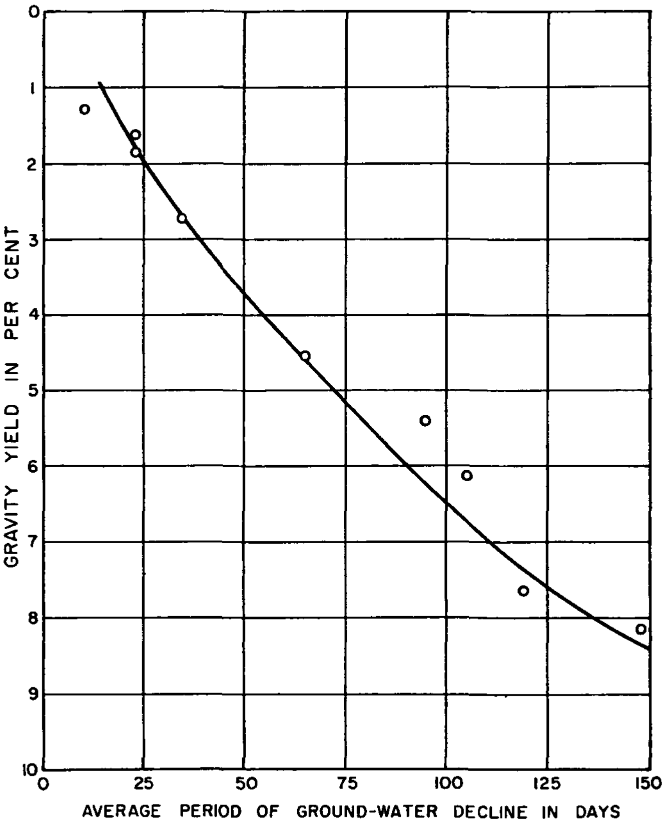


Figure 14. Graph showing relation of gravity yield and average period of drainage, Panther Creek basin

Monthly increases or decreases in ground-water storage during 1951, 1952, and 1956 were estimated from figures 11, 12, and 13 by multiplying mean ground-water stage changes by appropriate values of Y_g given in figure 14. The data on changes in ground-water storage appear in table 6.

Table 6

Monthly and annual ground-water recharge in inches, 1951, 1952, and 1956, Panther Creek basin

	1951		1952		1956	
Month	P_g	ΔS_g	P_g	ΔS_g	P_g	ΔS_g
Jan.	0.44	+ 0.28	0.69	-0.08	neg.	-0.01
Feb.	0.20	+ 0.05	0.57	neg.*	0.29	+ 0.21
Mar.	1.16	+ 0.86	1.71	+0.14	neg.	-0.04
Apr.	2.20	+ 0.68	1.92	-0.15	0.11	+ 0.02
May	0.89	-0.20	1.11	-0.14	0.20	+ 0.01
June	0.79	+0.05	1.36	+0.08	0.09	-0.10
July	1.03	-0.15	0.15	-0.59	0.06	-0.10
Aug.	0.41	-0.15	0.18	-0.19	0.06	-0.09
Sept.	0.12	-0.21	0.03	-0.27	0.02	-0.10
Oct.	0.03	-0.23	0.02	-0.18	0.02	-0.04
Nov.	0.88	+0.33	0.02	neg.	0.01	neg.
Dec.	0.23	-0.12	0.27	+ 0.24	0.01	neg.
Annual	8.38	+ 1.19	8.03	-1.14	0.87	-0.24

* Negligible

Ground-Water Recharge

With a few possible exceptions the water table rose, or declined less than was necessary to balance ground-water runoff and evapotranspiration, during portions of every month of 1951, 1952, and 1956. There was, therefore, some ground-water recharge in most months of these years.

Monthly and annual ground-water recharge estimated by balancing equation 6 are given in table 6. Ground-water recharge during the three years ranged from 8.38 inches in 1951 to 0.87 inch in 1956 and was 8.03 inches in 1952. Ground-water recharge was 19 per cent of precipitation during a year of above normal precipitation, 4.5 per cent of precipitation during a year of below normal precipitation, and 25 per cent of precipitation during a year of near normal precipitation. Data in table 6 show the pronounced adverse effects of extended dry periods on ground-water recharge.

Monthly ground-water recharge is largest in spring months of heavy rainfall and least in summer and fall months. As shown in figure 12 most ordinary summer rains have little or no effect on the water table. The water table, however, rose conspicuously August 11, 15, and 20, 1952 indicating appreciable ground-water recharge on these dates. As shown in figure 3 precipitation exceeded 0.5 inch on these dates and was in excess of evapotranspiration and soil-moisture requirements.

In February, March, and the early part of April, 1951, precipitation was above normal; however, ground-water recharge was only moderate. Temperatures during part of November and December of 1950 and March and the early part of April of 1951 were below normal. As a result, there was a snow cover over frozen ground much of February and March which impeded the infiltration of precipitation to the water table. As shown in figure 5 most precipitation in February and March was discharged from the basin by surface runoff.

HADLEY CREEK BASIN

For a period of 2 1/2 years, April 1956 through September 1958, daily measurements of precipitation, stream flow, and ground-water levels were made in part of the Hadley Creek drainage basin. Instrumentation consisted of 11 rain gages, a stream gaging station, and 5 observation wells equipped with recording gages. The number of observation wells was increased from 5 to 21 during the summer of 1959 to determine the adequacy of the observation-well program. The U. S. Weather Bureau established and maintained the rain gages, and stream-flow data were collected, processed, and analyzed by the Surface Water Branch of the U. S. Geological Survey. Soil moisture was not measured during the investigation.

Hydrologic and ground-water budgets for the period April 1956 through September 1958 are presented. Information concerning the geographic, climatic, and geologic features of Hadley Creek basin is given to serve as a background for the interpretation of records.

Geography

Location and Extent of the Basin

The Hadley Creek basin is in west-southwestern Illinois about 20 miles northwest of the city of Pittsfield and about 20 miles southeast of the city of Quincy. The part of Hadley Creek drainage basin considered, hereafter referred to as "the basin," is situated approximately between 90°54' and 91°11' west longitude and between 39°41' and 39°50' north latitude as shown in figures 1 and 15. The basin covers 72.7 square miles in Pike and Adams Counties in T. 3 S. to T. 4 S. and R. 4 W. to R. 7 W. About one-third of the basin is in Adams County. The basin is above a stream gaging station about 1 mile south-southeast of the village of Kinder hook.

Topography and Drainage

The northern half of the basin lies in the Till Plains and Dissected Till Plains sections of the Central Lowland physiographic province, and the southern half lies in the Lincoln Hills section of the Ozark Plateaus province (Fenneman, 1914; and Leighton, Ekblaw, and Horberg, 1948). The topography consists mostly of rather rugged uplands. Along Hadley Creek and its major tributaries, lowlands average about one-third mile in width. Gully and sheet erosion were severe before soil conservation practices were introduced.

The elevation of the land surface of the basin declines from about 870 feet near the village of Baylis to about 480 feet at the stream gaging station near Kinderhook. The topography is highly diversified with the relief of the land surface in many places exceeding 160 feet in a distance of 700 feet.

The drainage system is shown in figure 15. Hadley Creek is the principal stream and flows in a generally westward course. Beebe Creek and North Fork Hadley Creek trend north to south and are the main tributaries draining most of the northern half of the basin. The average gradients of Hadley Creek, Beebe Creek, and North Fork Hadley Creek are 16.6, 34.9, and 37.6 feet per mile, respectively. The valleys of the main tributaries are narrow and have steep sides. Surface runoff from the basin is rapid because of the rugged relief of the land surface.

Population and Land Use

The population of the basin is chiefly rural. According to the U. S. Census of Population, the population density was about 40 persons per square mile in 1950. The populations of incorporated municipalities within or bordering the basin are as follows:

Municipality	Population, 1950
City of Barry	1529
Village of Baylis	307
Village of Kinderhook	299

During the study period, about 40 per cent of the land was devoted to row crops, small grain, hay, and rotation pasture. The remainder of the basin was permanent pasture, woodland, and farm lots.

Climate

The basin lies in the north temperate zone. Its climate is characterized by warm summers and moderately cold winters. The mean length of the growing season is about 188 days.

Based on records collected by the U. S. Weather Bureau at Quincy, the mean annual temperature is 55 F. June, July, and August are the hottest months with mean temperatures of 75 ,

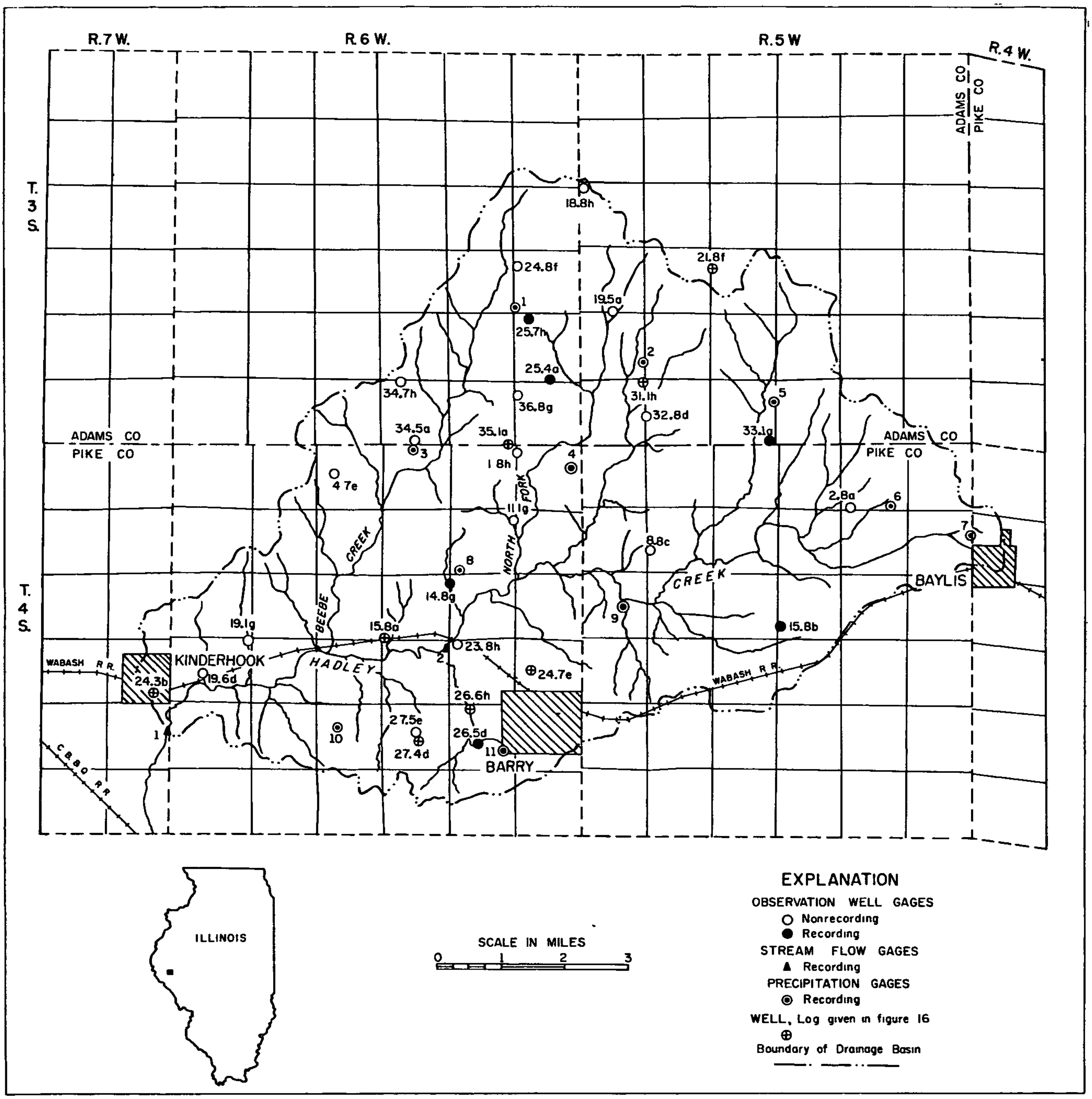


Figure 15. Hydrologic map of Hadley Creek drainage basin, Adams and Pike Counties, Illinois

80°, and 78°F, respectively; January is the coldest month with a mean temperature of 30 F and is the only month with a mean monthly temperature below freezing. Table 7 showing average monthly and annual air temperatures and departures from normal, 1956-58, was compiled from the records of the U. S. Weather Bureau at Quincy.

Normal annual precipitation based on U. S. Weather Bureau records at Quincy, Barry, and Griggsville is 36 inches. An average of more than 3 inches of rain falls during each of the months March through October. February is the month of least precipitation having an average of less than 2 inches. About 67 per cent of the year's precipitation falls during the growing season.

The U. S. Weather Bureau with the cooperation of the Soil Conservation Service measured precipitation within the basin 1956 through July 1959 with 11 recording rain gages. The locations of the rain gages are shown in figure 15. The density of the network was 6.61 square miles per gage. Monthly and annual precipitation, 1956 through 1958, computed by averaging arithmetically

Table 7

Average monthly and annual temperatures and departures from normal, 1956-58, Hadley Creek basin

Month	1956 Temperature °F	1956 Departure (inches)	1957 Temperature °F	1957 Departure (inches)	1958 Temperature °F	1958 Departure (inches)
Jan.	26.1	-2.5	23.4	-6.3	26.9	- 2.8
Feb.	31.4	0	37.2	4.2	21.8	-11.2
Mar.	42.1	-1.2	41.1	-1.2	36.9	- 5.4
Apr.	51.4	-2.7	54.1	-0.5	53.6	- 1.0
May	68.1	4.0	65.4	0.3	64.9	- 0.2
June	77.4	3.9	74.4	-0.9	70.6	- 4.7
July	78.7	0.3	81.3	1.3	74.5	- 5.5
Aug.	77.5	0.7	78.1	0.4	77.3	- 0.4
Sept.	69.7	0.4	67.1	-2.7	68.0	- 1.8
Oct.	62.5	5.8	53.7	-4.6	58.3	0
Nov.	42.7	-1.0	41.7	-1.4	47.1	4.0
Dec.	34.1	2.3	36.9	4.4	28.3	- 4.2
Annual	55.1	0.8	54.5	-0.6	52.3	- 2.8

gage readings, is given in table 8. The occurrence of the annual maximum and minimum precipitation amounts expected on an average of once in 5 and once in 50 years based on data in the Atlas of Illinois Resources, Section 1 are given below.

	Lowest annual precipitation expected (inches)	Highest annual precipitation expected (inches)
Once in 5 years	30	42
Once in 50 years	24	54

According to the Atlas of Illinois Resources, Section 1, the mean annual snowfall is 18 inches. On the average, 25 days a year have 1 inch or more ground snow cover; 12 days a year have 3 inches or more of ground snow cover. The average depth of maximum frost penetration is 21 inches.

Table 8

Monthly and annual precipitation, 1956-58, Hadley Creek basin

Month	Precipitation in inches 1956	1957	1958
Jan.	0.31	2.11	1.07
Feb.	0.89	1.57	0.79
Mar.	0.50	2.95	0.70
Apr.	4.64	7.75	3.28
May	3.29	6.40	4.05
June	4.81	5.48	3.86
July	2.76	2.79	9.32
Aug.	3.18	2.25	4.10
Sept.	0.06	0.96	2.56
Oct.	0.82	3.25	1.05
Nov.	2.37	1.48	4.09
Dec.	2.00	2.74	0.24
Annual	25.63	39.73	35.11

Geology

Soils

The soils of the basin were divided into five groups by Hopkins, Mosier, Van Alstine, and Garrett (1915) and Mosier, Wascher, Leighty, and Snider (1922), as follows: upland prairie, upland timber, old bottomland, late swamp and bottomland, and residual soils. The residual soil group represents only very small areas of rock outcrop. Timber and upland prairie soils predominate; however, bottomland soils extend along wide stretches of Hadley Creek and its tributaries.

The timber soils are largely grayish yellow to brownish gray silt loams formed under deciduous forest from moderately thick to deep loess (see Wascher, Fahrenbacher, Odell, and Veale, 1950). The surface layer is a grayish yellow to brownish gray silt loam 0 to 8 inches thick and is low in organic matter and ranges in acidity from slight to strong. The subsoil beginning at a depth of 12 to 16 inches is generally a silty clay loam to silty clay varying in color from brownish yellow to yellowish brown. Surface drainage is generally rapid, thus artificial drainage is not required. The permeability is moderate and underdrainage by tiles is not required.

The upland prairie soils are largely grayish brown to brown silt loams formed under prairie vegetation from varying thicknesses of loess. The surface layer is from 3 to 10 inches thick and ranges in acidity from slightly medium to medium. The subsoil beginning at a depth of 6 to 14 inches is generally a silty clay loam varying in color from a mottled brownish yellow to yellowishbrown. Surface drainage is seldom required; however, underdrainage is needed where the permeability is slow or moderately slow.

The bottomland soils are brown to yellowish brown silt to sand loams formed under grass from water-laid sediments. The surface layer is from 6 to 15 inches thick, is medium to high in organic matter and ranges in acidity from slightly acid to neutral. The subsoils are highly variable in texture and color and are generally greater than 3 feet in thickness. Surface drainage and permeabilities are variable; subsurface and surface drainage sometimes is required.

The substrata immediately beneath the loess is Kansan till, Illinoian till, bedrock, or sandy outwash.

Glacial Deposits and Their Water-Bearing Properties

Deposits of silt and clay (loess) reaching 25 feet in thickness constitute the main features of the land surface throughout much of the basin. Thin deposits of glacial drift chiefly of the Kansan stage cover the bedrock surface and occur beneath the loess. During the Illinoian stage a glacier advanced into the extreme northeastern part of the basin. In its advance the Illinoian glacier overlapped the older Kansan glacial drift.

The drift deposits on the uplands are composed dominantly of unstratified clayey materials called till. Sand, ranging in thickness from a few inches to more than 50 feet, occurs at places as irregular lenses or layers in the till as shown by the logs of wells given in figure 16. These deposits are discontinuous and are limited greatly in areal extent. The thickness of the drift varies from a feather edge near bedrock outcrops to a maximum of more than 100 feet at Baylis.

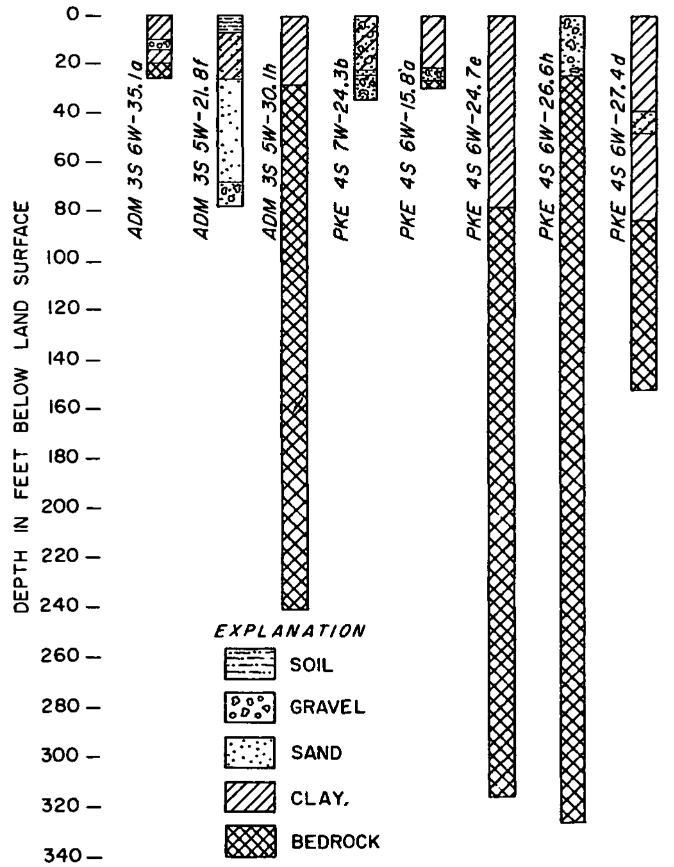


Figure 16. Logs of selected wells, Hadley Creek basin (Locations of wells are shown in figure 15)

Water-bearing properties of the till vary greatly as described previously.

Glacial outwash deposits of sand and gravel and fine-grained alluvial materials occur in the valley lowlands. The permeability and yield of the outwash deposits are relatively high at some places. Extensive deposits of highly permeable glacial outwash and alluvial materials occur along the Mississippi flood plain immediately west of stream gaging station 1.

Bedrock Formations and Their Water-Bearing Properties

The glacial deposits are immediately underlain by bedrock formations of Mississippian age except in the northeastern half of the basin where bedrock of Pennsylvanian age occurs beneath the drift. These formations are situated structurally on the west-southwest flank of the Illinois basin. The bedrock layers dip regionally eastward or northeastward at rates ranging from 15 to 50 feet per mile. There are numerous local anticlines and synclines that modify or reverse the regional dip (Bergstrom and Zeizel, 1957). For example, local anticlinal structures extend from Pittsfield to Hadley and east-west between Baylis and Fishhook.

The bedrock formations of Pennsylvanian age consist mostly of shale with thin sandstone, limestone, and coal beds. The Pennsylvanian rocks generally have low porosities and permeabilities and yield only small amounts of water to wells. The bedrock of Mississippian age contains thicker beds of limestone which are cracked and creviced at most locations yielding enough water for domestic and farm supplies and small municipal supplies (Bergstrom and Zeizel, 1957). Practically speaking, the rocks are important because they act as a barrier to deep percolation.

The bedrock surface has considerable relief and is similar to that of the land surface. Valleys in the bedrock are generally beneath Hadley Creek and its tributaries. According to Horberg (1957), the bedrock surface declines from an elevation of about 775 feet near Baylis to about 425 feet near Kinderhook. The bedrock crops out at the surface locally on the glaciated uplands and along valley walls.

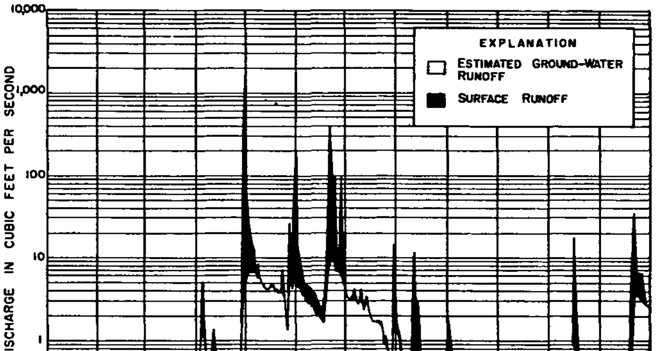


Figure 17. Stream flow at gaging station 1, Hadley Creek basin, 1956

Stream Flow

Daily mean stream flow at gaging station 1 for the period April 1956 through September 1958 is shown on figures 17, 18, and 19. Daily mean stream flow exceeded 3000 cfs in May 1957; there was no measureable stream flow during several periods in the fall months of 1956 and 1957. Monthly stream flow, expressed in inches of water over the basin, is given in table 9.

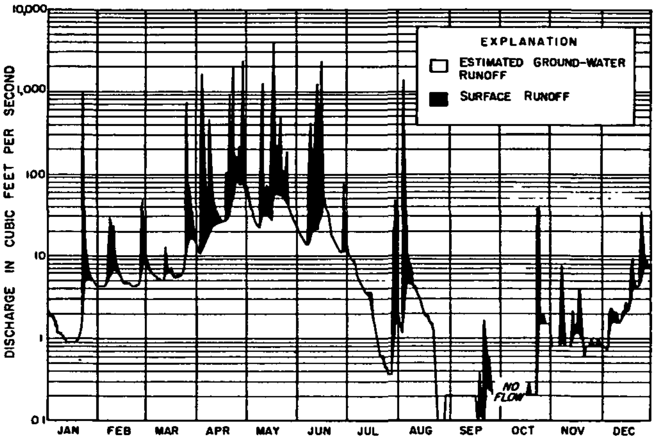


Figure 18. Stream flow at gaging station 1, Hadley Creek Basin, 1957

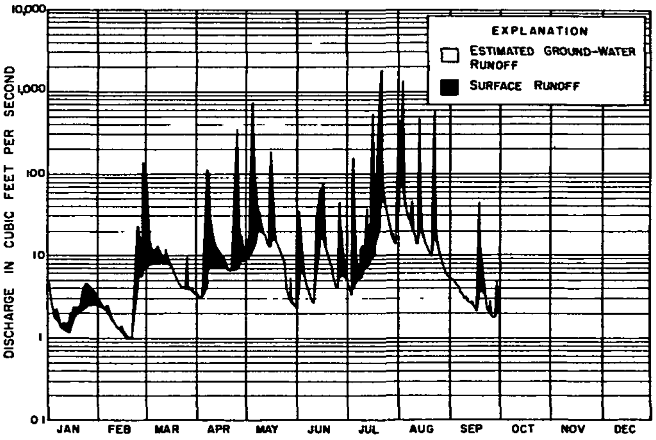


Figure 19. Stream flow at gaging station 1, Hadley Creek basin, 1958

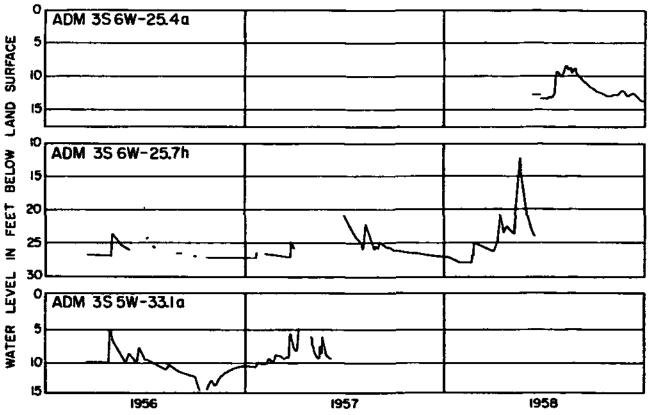


Figure 20. Water levels in observation wells 25.4a, 25.7h, and 33.1a, Hadley Creek basin, 1956-58

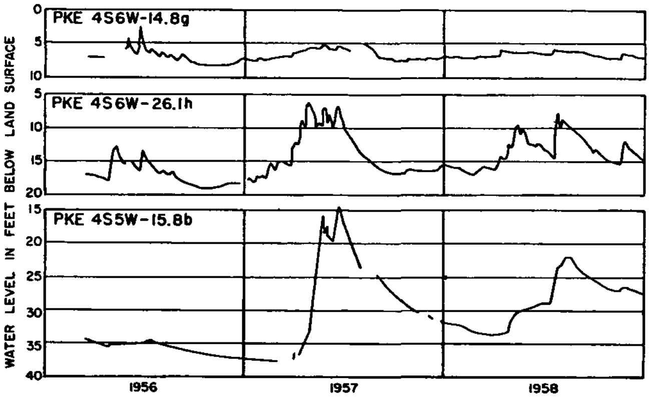


Figure 21. Water levels in observation wells 14.8g, 26.1h, and 15.8b, Hadley Creek basin, 1956-58

Table 9

Monthly and annual stream flow in inches, 1956-58, Hadley Creek basin

Month	1956			1957			1958		
	R_s	R_g	R	R_s	R_g	R	R_s	R_g	R
Jan.				0.50	0.04	0.54	0.01	0.03	0.04
Feb.				0.07	0.08	0.15	0.13	0.04	0.17
Mar.				0.46	0.13	0.59	0.04	0.10	0.14
Apr.	0.56	0.08	0.64	4.29	0.56	4.85	0.32	0.08	0.40
May	0.05	0.01	0.06	3.37	0.56	3.93	0.65	0.18	0.83
June	0.17	0.06	0.23	2.47	0.36	2.83	0.19	0.08	0.27
July	0.04	0.03	0.07	0.03	0.06	0.09	3.23	0.25	3.48
Aug.	0.09	0.01	0.10	0.77	0.03	0.80	1.22	0.39	1.61
Sept.	0.01	neg.	0.01	neg.	neg.	neg.	0.03	0.06	0.09
Oct.	neg.*	neg.	neg.	0.04	neg.	0.04			
Nov.	0.01	neg.	0.01	0.01	0.01	0.02			
Dec.	0.03	0.02	0.05	0.03	0.06	0.09			
Annual				12.04	1.89	13.93			

* Negligible

Ground-Water Runoff

Rating curves were prepared to determine the relationship between mean ground-water stage and ground-water runoff. Fluctuations of the water table in the basin are shown by the hydrographs of wells given in figures 20 and 21. Records of the wells are given in table 10. Two observation wells, PKE 4S6W-14.8g and PKE 4S6W-26.1h, were chosen as representative of the mean ground-water stage in the basin based on the water-level data obtained July 21 and November 5, 1959 from the 21 wells shown in figure 15.

Daily averages of ground-water levels measured in wells PKE 4S6W-14.8g and PKE 4S6W-26.1h were computed for selected dates when stream flow consisted entirely of ground-water runoff. Mean ground-water stages were plotted against ground-water runoff on corresponding dates as shown in figure 22.

Daily mean ground-water stages were plotted as yearly hydrographs as shown in figures 23, 24, and 25. Ground-water runoff corresponding to each mean ground-water stage was read directly from the rating curves in figure 22. Curve

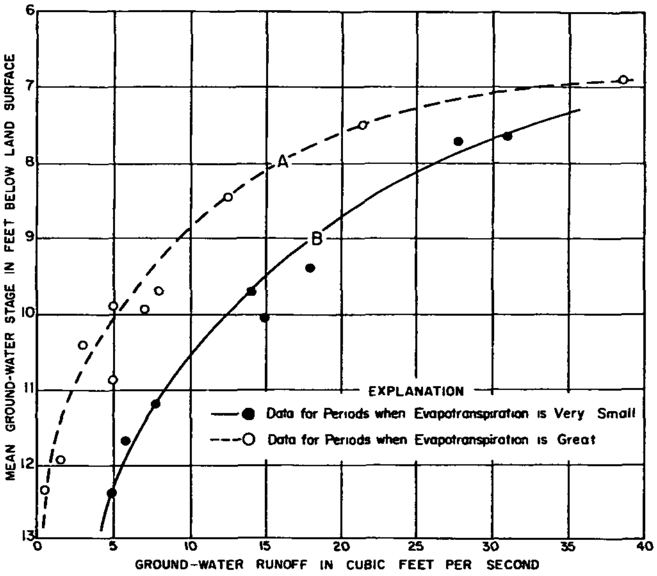


Figure 22. Rating curves of mean ground-water stage versus ground-water runoff at gaging station 1, Hadley Creek basin

Table 10

Well records, Hadley Creek basin

Well No.	Owner	Type of well	Depth of well (feet)	Diameter of well (inches)	Elevation of land surface (feet above MSL)	Depth to water 11-5-59 (feet below land surface)	Remarks
ADM 3S6W-24.8f		Dug			700	5.81	Livestock supply
ADM 3S6W-25.4g	J. Robinson	Dug			740	16.09	Abandoned
ADM 3S6W-25.7h	R. Smith	Dug	32		745	24.11	Abandoned
ADM 3S6W-34.5a	A. Martin	Dug	57		664	17.43	Domestic supply
ADM 3S6W-34.7h	E. Hendricks	Dug			702	10.41	Abandoned
ADM 3S6W-35.1g	J. M. Doran	Drilled	56		658		Log available
ADM 3S6W-36.8g		Dug			745	21.92	Abandoned
ADM 3S5W-18.8h		Dug			665	9.66	Livestock supply
ADM 3S5W-19.5a	R. Watts	Dug			724	39.66	Domestic supply
ADM 3S5W-21.8f	Village of Beverly	Drilled	78	5 5/8	790		Log available
ADM 3S5W-31.1h	G. N. Redman	Drilled	242	5 5/8	705		Log available
ADM 3S5W-32.8d		Dug			708	32.91	Domestic supply
ADM 3S5W-33.1a	H. Robinson	Dug	18		748		Abandoned
PKE 4S7W-24.3b	Village of Kinderhook	Drilled	44	8	480		Log available
PKE 4S6W-1.8h		Dug			660	20.19	Abandoned
PKE 4S6W-4.7e	C. McCarl	Dug	9		660	5.29	Livestock supply
PKE 4S6W-9.6d		Dug			500	28.32	Abandoned
PKE 4S6W-11.1g		Dug			600	18.18	Abandoned
PKE 4S6W-14.8g	R. Metcalf	Dug	14		580	6.48	Abandoned
PKE 4S6W-15.8a	E. O. Blake	Drilled	32		560		Log available
PKE 4S6W-18.1g		Dug			640		Abandoned
PKE 4S6W-23.8h		Dug			650	6.88	Domestic supply
PKE 4S6W-24.7e	L. A. Flick	Drilled	318	5 5/8	675		Log available
PKE 4S6W-26.1h	T. Coffman	Dug	28		624	16.25	Abandoned
PKE 4S6W-26.6h	Village of Barry	Drilled	325	8	590		Log available
PKE 4S6W-27.4d	R. Hart	Drilled	155		700		Log available
PKE 4S6W-27.5e		Dug			690	17.46	Abandoned
PKE 4S5W-2.8a		Dug			750	51.01	Domestic supply
PKE 4S5W-8.8c	J. Redshaw	Dug			685	43.07	Domestic supply
PKE 4S5W-15.8b	B. Erke	Dug	53		745	26.82	Abandoned

A was used with data for dates April through October and curve B was used with data for the rest of the year.

Daily ground-water runoff was plotted beneath stream-flow hydrographs and lines were drawn connecting points to describe ground-water runoff hydrographs as shown in figures 17, 18, and 19. The shaded areas between the stream flow and ground-water runoff hydrographs represent surface runoff.

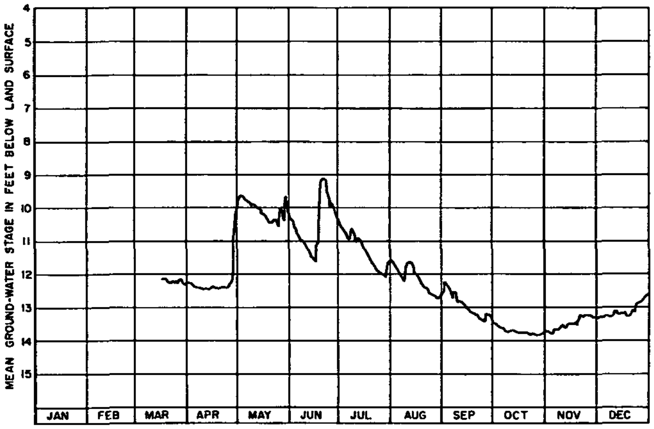


Figure 23. Mean ground-water stage, Hadley Creek basin, 1956

Monthly and annual ground-water and surface runoff, expressed in inches of water over the basin, are given in table 9. In 1957 ground-water runoff was 14 per cent of stream flow. The data in table 9 indicate that ground-water runoff was at a maximum during spring and early summer months of 1956 and 1957 and the late summer months of 1958. The mean ground-water stage during July and August 1958 was slightly higher than it was during April and May 1957. However, ground-water runoff during April and May 1957 was greater than it was during July and August 1958 largely because ground-water evapotranspiration was greater.

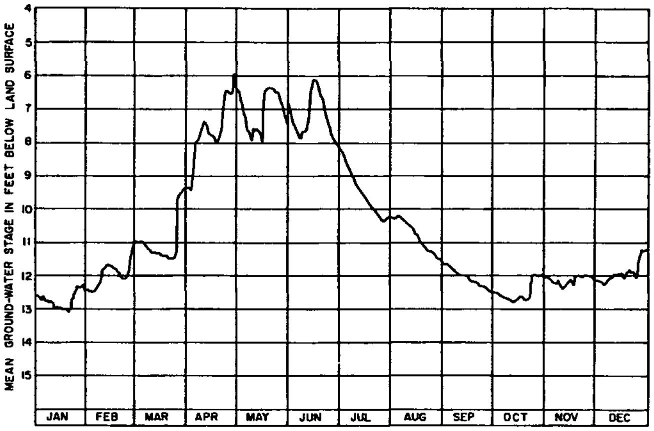


Figure 24. Mean ground-water stage, Hadley Creek basin, 1957

Evapotranspiration

Annual evapotranspiration in 1957 estimated by substituting data on P, R, U, and ΔSg in equation 2 is given in table 11. Underflow and change in ground-water storage are discussed later in this report. Evapotranspiration during 1957 totaled 24.68 inches or 62 per cent of precipitation.

Ground-Water Evapotranspiration

Estimates of daily ground-water evapotranspiration during 1956, 1957, and 1958 were computed from figures 23, 24, and 25 and the ground-water stage-runoff rating curves in figure 22. Monthly and annual ground-water evapotranspiration are given in table 11. These data indicate that monthly ground-water evapotranspiration is greatest generally during June, July, and August. In 1957, ground-water evapotranspiration was about 4 per cent of the total evapotranspiration.

Underflow

The width of the lowlands adjacent to Hadley

Table 11

Monthly and annual evapotranspiration in inches, 1956-58, Hadley Creek basin

	1956			1957			1958		
Month	ET_s	ET_g	ET	ET_s	ET_g	ET	ET_s	ET_g	ET
Jan.					neg.			neg.	
Feb.					neg.			neg.	
Mar.					neg.			neg.	
Apr.		0.12			0.09			0.11	
May		0.08			0.11			0.17	
June		0.11			0.23			0.14	
July		0.10			0.18			0.14	
Aug.		0.08			0.12			0.33	
Sept.		0.06			0.08			0.18	
Oct.		0.03			0.07				
Nov.		neg.*			neg.				
Dec.		neg.			neg.				
Annual				23.80	0.88	24.68			

* Negligible

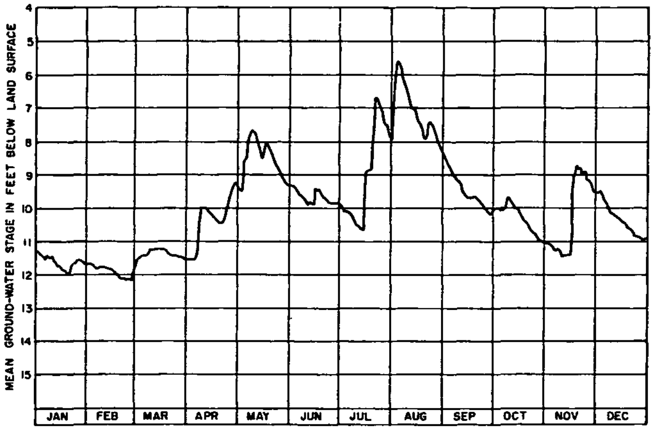


Figure 25. Mean ground-water stage, Hadley Creek basin, 1958

Creek through which underflow occurs is about 3000 feet. Based on the bedrock surface and topographic maps, and resistivity surveys (Buhle, 1940), the thickness of the unconsolidated deposits is estimated to be about 30 feet and the hydraulic gradient of the water table in the vicinity of gaging station 1 is estimated to be 15 ft/mi. The coefficient of transmissibility of the deposits through which underflow occurs is estimated to be in the magnitude of 30,000 gpd/ft. Using the data given above, the underflow was estimated from equation 3 to average about 0.40 cfs or 0.07 inches per year. The underflow, although small, was included in budget computations.

Changes in Ground-Water Storage

Computations of gravity yield were made with equation 5 using data for two inventory periods, March 25 to April 5, 1957 and March 1 to April 7, 1958. The average value of Yg is 6.3 per cent.

Inventory periods were limited to two because of the lack of significant rises in the water table during winter and early spring months and because the study period was short. Because gravity yield varies with the time of drainage it is erroneous to assume that 6.3 per cent will approximate Yg under all conditions at all times.

Ground-water storage change during 1957 was estimated by substituting data on the annual change in mean ground-water stage as indicated in figure 24 and a gravity yield of 6.3 per cent in equation 4. Ground-water storage was increased 1.05 inches during 1957.

Ground-Water Recharge

The amount of precipitation reaching the water table in 1957 was estimated by balancing on an annual basis equation 6. In 1957, ground-water recharge was 3.89 inches or about 10 per cent of precipitation.

Monthly ground-water recharge cannot be estimated with any degree of accuracy because the relationship between gravity yield and average time of drainage is unknown.

GOOSE CREEK BASIN

For a period of 3 1/2 years, January 1955 through September 1958, the State Water Survey measured precipitation on and ground-water levels in part of the Goose Creek drainage basin. Stream flow was measured during the same period by the Surface Water Branch of the U. S. Geological Survey. The density of precipitation gages varied throughout the study period, as is explained later, but was 7.8 square miles per gage during much of the time. Ground-water levels were continuously measured in 3 observation wells. One observation well was equipped with a recording gage. The record of stream flow was determined by a recording gage on Goose Creek at the lower end of the study area. Soil moisture was not measured during the investigation.

Hydrologic and ground-water budgets for the period January 1955 through September 1958 are presented. Information concerning geographic, climatic, and geologic features of Goose Creek basin is given to serve as a background for the interpretation of records.

Geography

Location and Extent of the Basin

The Goose Creek basin is in east-central Illinois about 20 miles west of the city of Champaign and about 30 miles southeast of the city of Bloomington. The part of Goose Creek drainage basin considered, hereafter referred to as "the basin."

is situated approximately between 88° 31' and 88°42' west longitude and between 40°05' and 40°13' north latitude as shown in figures 1 and 26. The basin covers 47.3 square miles in Piatt and DeWitt Counties in T. 18 N. to T. 20 N. and R. 4 E. to R. 6 E. Only a small part of the basin is in DeWitt County. The basin is above a stream gaging station about 2 miles south-southeast of the village of DeLand.

Topography and Drainage

The basin lies in the Till Plains section of the Central Lowland Physiographic province (Fenneman, 1914). The topography consists mostly of nearly level uplands. Slightly rolling topography is found adjacent to Goose Creek in the southern quarter of the basin.

The elevation of the land surface of the basin declines from about 730 feet near the village of Mansfield to about 670 feet at the stream gaging station near DeLand. Except in the southern part of the basin along Goose Creek where the elevation of the land surface declines about 30 feet in a distance of one-half mile, the relief seldom exceeds 10 feet per mile.

The drainage system is shown in figure 26. Goose Creek is the principal system, and flows

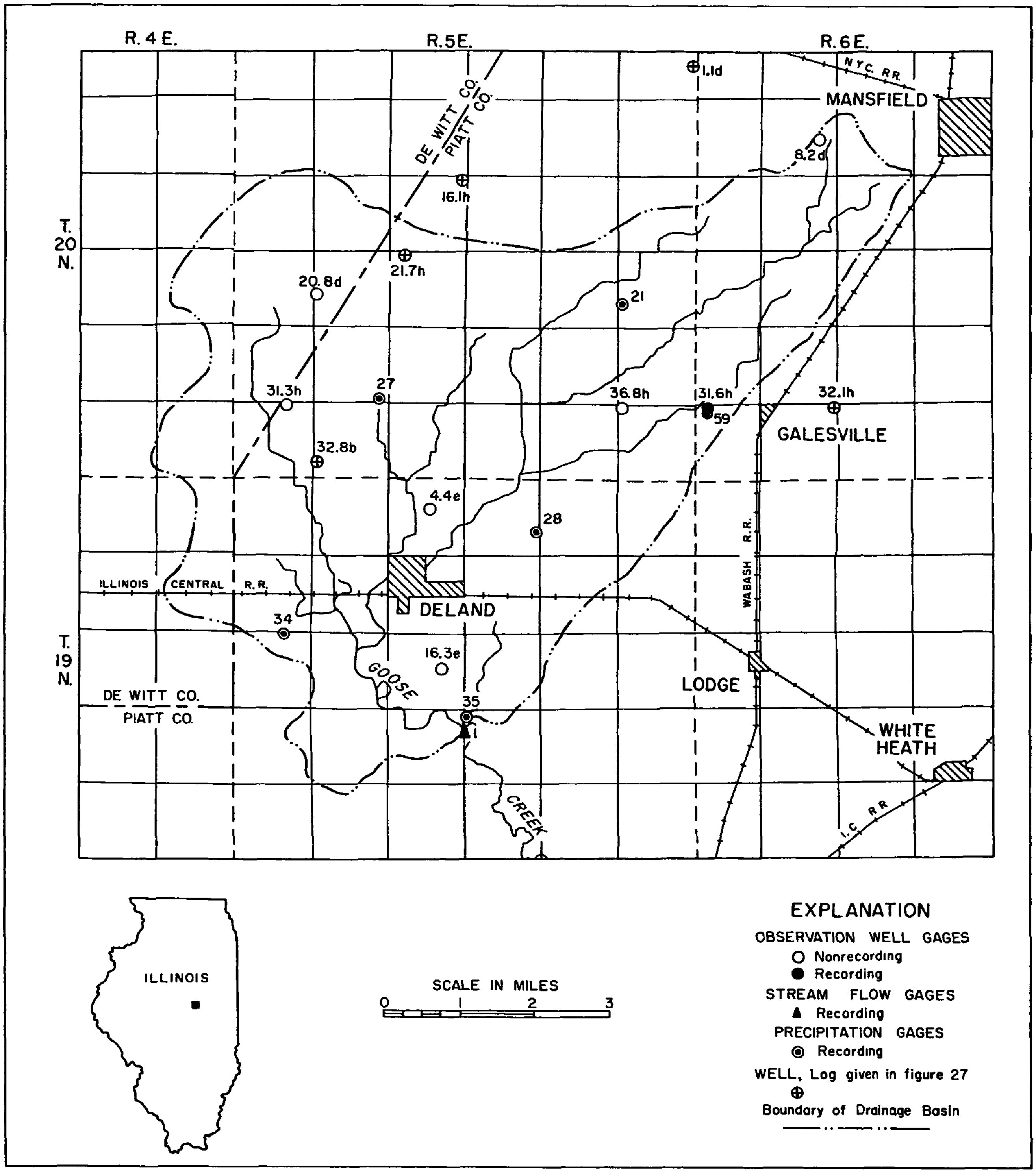


Figure 26. Hydrologic map of Goose Creek drainage basin, DeWitr and Piatt Counties, Illinois

in a generally southward course. The average gradient of Goose Creek is 3.9 feet per mile. The water table was very near the surface and poorly drained areas were widespread prior to settlement. Extensive surface and subsurface drainage was necessary to permit agricultural development.

Population and Land Use

The population of the basin is chiefly rural. According to the U. S. Census of Population, the population density was about 25 persons per square mile in 1950. The populations of incorporated municipalities within or bordering the basin are as follows:

Municipality	Population, 1950
Village of DeLand	416
Village of Mansfield	665

At the time of the study period about 86 per cent of the basin was cultivated; the remainder was permanent pasture, woodland, and farm lots. The cleared land was devoted to such crops as field corn, oats, soybeans for beans, alfalfa, clover and timothy hay, winter wheat, and rye. Field corn, oats, and soybeans for beans were the major crops.

Climate

The basin lies in the north temperate zone. Its climate is characterized by warm summers and moderately cold winters. The mean length of the growing season is 175 days.

Based on records collected by the U. S. Weather Bureau at Urbana, the mean annual temperature is 53 F. June, July, and August are the hottest months with mean temperatures of 73, 77, and 74 F, respectively; January is the coldest month with a mean temperature of 29 F. Mean monthly temperatures during December, January, and February are below 32°F. Table 12 showing average monthly and annual temperatures and departures from normal, 1955 through 1958, was compiled from the records of the U. S. Weather Bureau at Urbana.

Normal annual precipitation based on U. S. Weather Bureau records at Bloomington, Normal, Clinton, Decatur, and Urbana is 37 inches. The months of greatest precipitation are May and June, each having an average of more than 4 inches. March, April, July, August, September, and October have an average of more than 3 inches. December is the month of least precipitation having an average of slightly less than 2 inches. About 68 per cent of the year's precipitation falls during the growing season.

The Meteorology Section of the State Water Survey has measured precipitation within the basin and in the vicinity of the basin since the spring of 1951. Thirty-three recording rain gages were installed over a 50-square-mile area in 1951 (Huff and Neill, 1957). During July, 1952 the area of the network was enlarged to 100 square miles and 50 recording rain gages were in operation. The network was reorganized in 1954; however, the area of the network remained at 100 square miles with 48 recording rain gages. During the spring of 1955 the network was expanded to include an area of 400 square miles with 49 recording gages.

The density of the network within the basin has varied. During the periods January to May 1955 and November 1955 to April 1956, there was 1 gage in operation; from October 1956 to March 1957, and from December 1957 to March 1958, there were 4 gages in operation. During the remainder of the study period 6 gages were in operation.

Monthly and annual precipitation, 1955 through 1958, computed by averaging arithmetically gage readings, is given in table 13, Precipitation during 1955 and 1956 was much below normal; precipitation was near normal in 1957. A large part of central and southern Illinois, including the

Table 13

Monthly and annual precipitation, 1955-58, Goose Creek basin

Month	Precipitation in inches			
	1955	1956	1957	1958
Jan.	1.97	0.70	1.20	1.53
Feb.	2.57	2.21	1.86	0.40
Mar.	1.71	0.69	0.75	0.96
Apr.	2.50	3.64	7.72	1.95
May	4.11	2.76	4.53	2.61
June	4.70	2.64	6.31	8.65
July	2.19	2.70	2.28	9.80
Aug.	2.08	7.12	1.67	2.66
Sept.	3.38	0.64	1.53	3.10
Oct.	4.31	0.61	2.54	0.67
Nov.	1.82	2.02	2.67	4.32
Dec.	0.46	1.53	4.12	0.56
Annual	31.80	27.26	37.18	37.21

Table 12

Average monthly and annual temperatures and departures from normal, 1955-58, Goose Creek basin

	1955		1956		1957		1958	
Month	Temperature °F	Departure (inches)	Temperature °F	Departure (inches)	Temperature °F	Departure (inches)	Temperature °F	Departure (inches)
Jan.	27.7	0.9	27.4	0.6	21.7	-7.6	27.8	-1.5
Feb.	31.4	2.4	31.6	2.6	35.6	4.3	23.2	-8.1
Mar.	40.8	0.6	40.1	-0.1	40.2	0.1	36.4	-3.7
Apr.	58.5	7.9	49.5	-1.1	52.1	0.3	52.7	0.9
May	64.8	3.2	63.6	2.0	61.8	-0.6	63.3	0.9
June	67.9	-3.0	73.9	3.0	72.1	-0.5	66.4	-6.2
July	79.8	4.1	72.8	-2.9	76.7	0.1	73.1	-3.5
Aug.	76.9	3.5	73.3	-0.1	74.2	-0.1	73.6	-0.7
Sept.	69.6	3.0	65.5	-1.1	64.7	-2.6	66.4	-0.9
Oct.	56.1	1.2	61.7	6.8	52.3	-4.4	56.4	-0.3
Nov.	37.1	-3.8	40.5	-1.0	40.6	-0.8	44.2	2.8
Dec.	28.7	-0.9	35.5	5.9	35.5	4.5	24.2	-6.8
Annual	53.3	1.6	52.9	1.2	52.3	-0.6	50.7	-2.2

basin, experienced a severe drought beginning in the latter part of 1952 and ending early in 1957 (see Hudson and Roberts, 1955). The occurrence of the annual maximum and minimum precipitation amounts expected on an average of once in 5 and once in 50 years based on data in the Atlas of Illinois Resources, Section 1, are given below.

	Lowest annual precipitation expected (inches)	Highest annual precipitation expected (inches)
Once in 5 years	32	43
Once in 50 years	26	54

According to the Atlas of Illinois Resources, Section 1, the mean annual snowfall is 21 inches. On the average, 25 days a year have 1 inch or more ground snow cover; 12 days a year have 3 inches or more of ground snow cover. The average depth of maximum frost penetration is 20 inches.

Geology

Soils

Two types of soils are dominant in the basin (Soil Association Areas of Piatt County, 1957). They are Drummer silty clay loam and Flanagan silt loam. These soil types are described in detail by Wascher, Fehrenbacher, Odell, and Veale (1950). The descriptions of the soil types are summarized in the following paragraphs.

Drummer silty clay loam was formed from moderately heavy water-deposited sediments under sedges and slough grasses on nearly level to depressional topography. The surface layer is a black clay loam to silty clay loam 10 to 16 inches thick and is high in organic matter and ranges in acidity from slightly acid to neutral. The subsoil beginning at a depth of 16 to 26 inches is a brownish gray mottled, with yellowish brown, clay loam to silty clay loam. Surface drainage is slow and permeability is moderate requiring under drainage by tiles.

Flanagan silt loam was formed from 40 to 60 inches of loess on calcareous loam till under prairie vegetation on gently sloping topography. The surface layer is a brown to very dark grayish brown silt loam from 6 to 10 inches thick and is high in organic matter and is medium in acidity. The subsoil beginning at a depth of 11 to 18 inches is a yellowish brown, mottled with brownish gray, silty clay loam. Surface drainage is moderate and permeability is moderate; tile drainage is helpful.

Glacial Deposits and Their Water-Bearing Properties

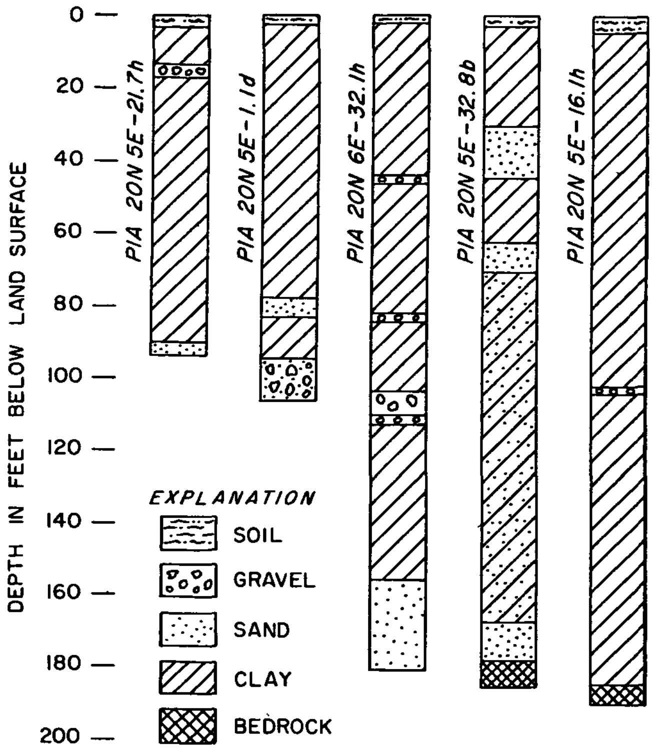


Figure 27. Logs of selected wells, Goose Creek basin (Locations of wells are shown in figure 26)

Thick deposits of glacial drift of Wisconsinan age and older cover the bedrock and constitute the main features of the present land surface. The deposits are composed dominantly of unstratified clayey materials called glacial till, but include some stratified beds of silt, sand, and gravel as shown by logs of wells in figure 27. The average thickness of the glacial drift on the bedrock is about 175 feet. Sand and gravel, ranging in thickness from a few inches to more than 25 feet, occur as irregular lenses or layers in the till. These deposits are discontinuous and are limited greatly in areal extent. Water-bearing properties of the glacial deposits were described previously.

Bedrock Formations and Their Water-Bearing Properties

The glacial deposits are immediately underlain by bedrock formations of Pennsylvanian age. The bedrock formations consist mostly of shale with thin sandstone, limestone, and coal beds. The Pennsylvanian rocks generally have low porosities and permeabilities and yield only small amounts of water to wells. Practically speaking, the rocks are important because they act as a barrier to deep percolation. The bedrock formations are situated structurally on the north-northwest flank of the Illinois basin; the regional dip is modified by the LaSalle anticlinal belt.

The bedrock surface slopes gently toward the buried Mahomet Valley in a south-southwesterly direction from an elevation of about 530 feet near Mansfield to an elevation of about 500 feet near stream gaging station 1 (Horberg, 1957). The floor of the Mahomet Valley lies about 6 miles south of gaging station 1. A few miles south of the basin the bedrock surface slopes from an elevation of about 500 feet to less than 300 fect in a distance of 4 miles.

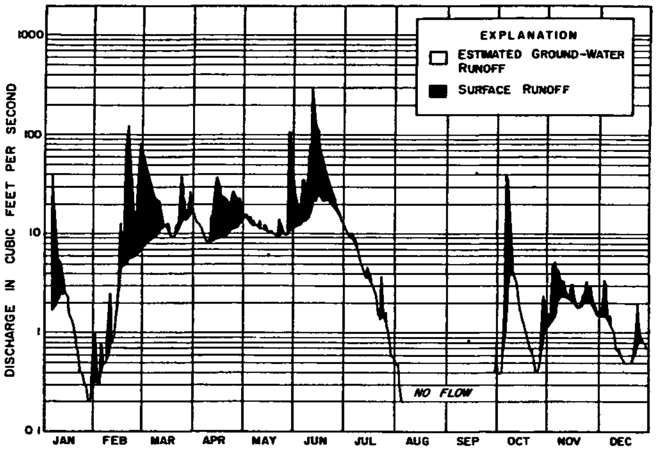


Figure 28. Stream flow at gaging station 1, Goose Creek basin, 1955

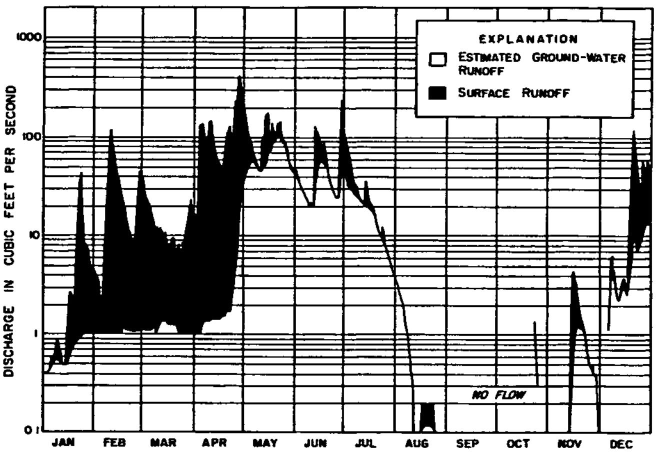


Figure 30. Stream flow at gaging station 1, Goose Creek basin, 1957

Stream Flow

Daily mean stream flow at gaging station 1 for the period January 1955 through September 1958 is shown on figures 28, 29, 30 and 31. Daily mean stream flow exceeded 1000 cfs in July 1958 and was less than 0.1 cfs during the fall months of 1955, 1956, and 1957. Monthly and annual stream flow, expressed in inches of water over the basin, are given in table 14. Stream flow was greatest in 1957 as a result of above normal precipitation during that year, and was least in 1956.

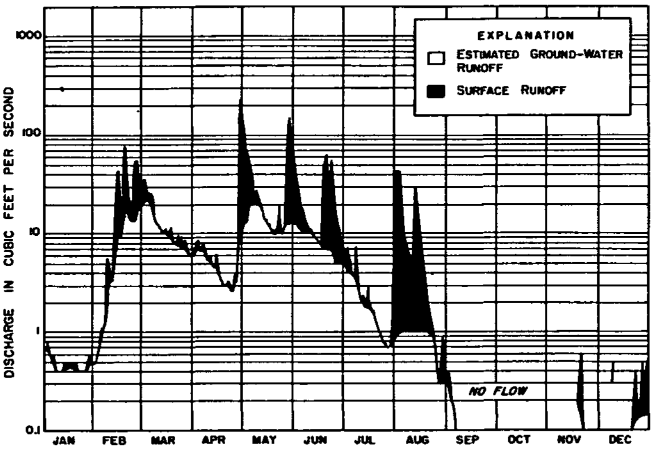


Figure 29. Stream flow at gaging station 1, Goose Creek Basin, 1956

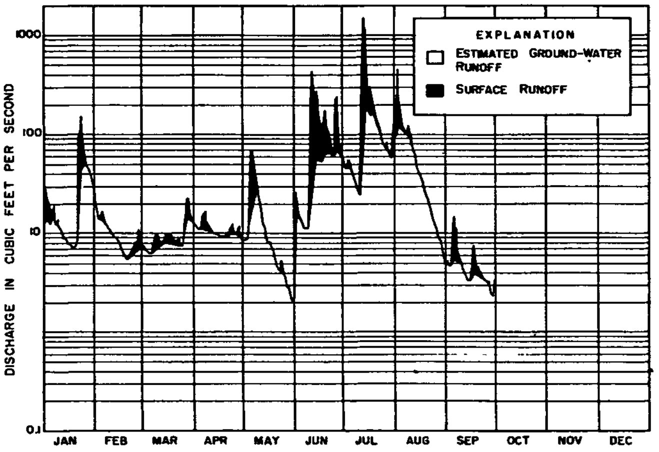


Figure 31. Stream flow at gaging station 1, Goose Creek basin, 1958

Table 14
Monthly and annual stream flow in inches, 1955-58, Goose Creek basin

	1955			1956			1957			1958		
Month	R_s	R_g	R	R_s	R_g	R	R_s	R_g	R	R_s	R_g	R
Jan.	0.07	0.03	0.10	neg.	0.01	0.01	0.11	0.02	0.13	0.20	0.55	0.75
Feb.	0.39	0.08	0.47	0.30	0.21	0.51	0.66	0.02	0.68	0.05	0.18	0.23
Mar.	0.25	0.31	0.56	0.07	0.28	0.35	0.30	0.04	0.34	0.11	0.17	0.28
Apr.	0.21	0.26	0.47	0.27	0.14	0.41	2.91	0.16	3.07	0.07	0.21	0.28
May-	0.23	0.29	0.52	0.58	0.40	0.98	0.47	2.00	2.47	0.07	0.28	0.35
June	1.01	0.44	1.45	0.16	0.40	0.56	0.61	0.93	1.54	1.65	1.12	2.77
July	0.04	0.07	0.11	0.02	0.05	0.07	0.21	0.46	0.67	2.14	2.84	4.98
Aug.	neg.*	0.01	0.01	0.20	0.03	0.23	0.01	0.01	0.02	0.30	1.40	1.70
Sept.	neg.	neg.	neg.	neg.	neg.	neg.	neg.	neg.	neg.	0.04	0.08	0.12
Oct.	0.07	0.04	0.11	neg.	neg.	neg.	neg.	neg.	neg.			
Nov.	0.02	0.05	0.07	neg.	neg.	neg.	0.01	0.01	0.02			
Dec.	0.01	0.02	0.03	neg.	neg.	neg.	0.39	0.15	0.54			
Annual	2.30	1.60	3.90	1.60	1.52	3.12	5.68	3.80	9.48			

* Negligible

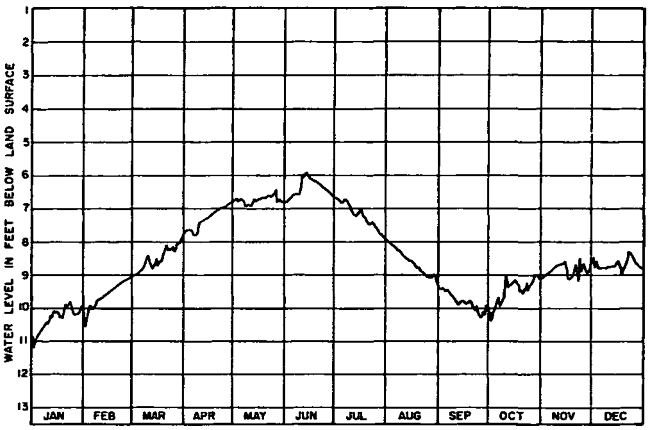


Figure 32. Water levels in observation well 31.6h, Goose Creek basin, 1955

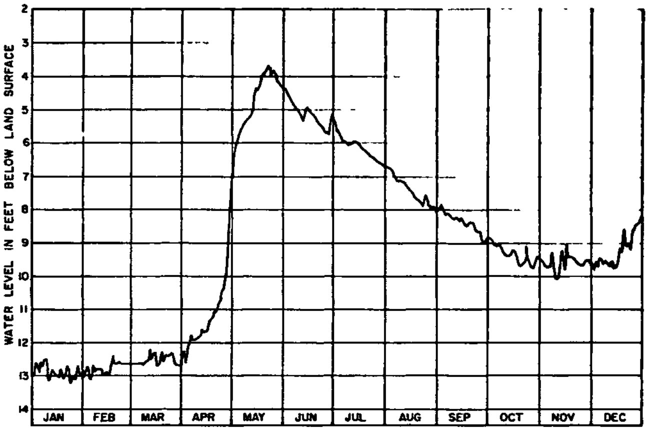


Figure 34. Water levels in observation well 31.6h, Goose Creek basin, 1957

Ground-Water Runoff

Rating curves were prepared to determine the relationship between mean ground-water stage and ground-water runoff. Fluctuations of the water table in the basin are shown by the hydrographs of well 31.6h in figures 32, 33, 34, and 35. Observation well 31.6h was chosen as representative of the mean ground-water stage in the basin based on the water-level data obtained May 16, 1960 and June 17, 1960 in the seven wells shown in figure 26. Records of wells for which water-

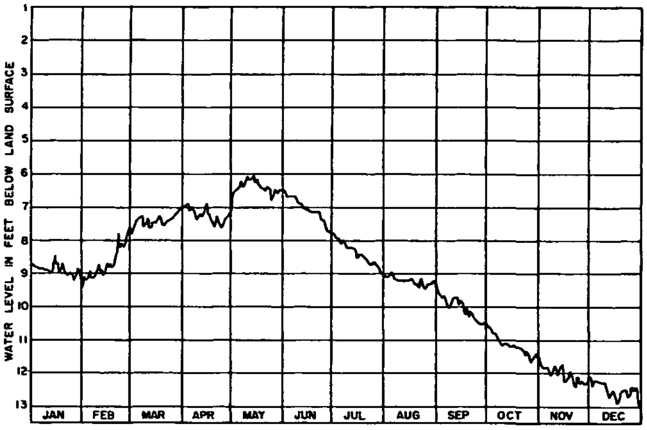


Figure 33. Water levels in observation well 31.6h, Goose Creek basin, 1956

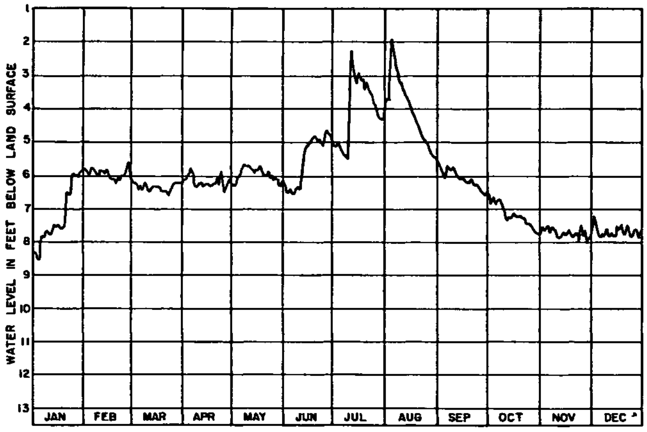


Figure 35. Water levels in observation well 31.6h, Goose Creek basin, 1958

Table 15

Well records, Goose Creek basin

Well No.	Owner	Type of well	Depth of well (feet)	Diameter of well (inches)	Elevation of land surface (feet above MSL)	Depth to water 6-17-60 (feet below land surface)	Remarks
PIA 20N5E-11d	K. Troxel	Drilled	106	4	721		Log available
PIA 20N5E-16.1h		Drilled	190	4	721		Log available
PIA 20N6E-8.2d	C. Mosgrove	Dug	23		730	4.08	Abandoned
DWT 20N5E-20.8d	R. Fehrnback	Dug	56		721	4.28	Abandoned
PIA 20N5E-21.7h	A. King	Drilled	94	4	720		Log available
PIA 20N5E-31.3h	R. Wisegarver	Dug	34		711	7.89	Abandoned
PIA 20N5E-32.8b	H. Fahrnkopf	Drilled	185	3	710		Log available
PIA 20N5E-36.8h		Dug	56		712	4.47	Abandoned
PIA 20N6E-31.6h	B. Swartz	Dug	37		714	5.17	Abandoned
PIA 20N6E-32.1h	W. Copen	Drilled	181	4	710		Log available
PIA 19N5E-4.4e		Dug			701	4.13	Abandoned
PIA 19N5E-16.3e	G. Smith	Dug	40		701	5.52	Abandoned

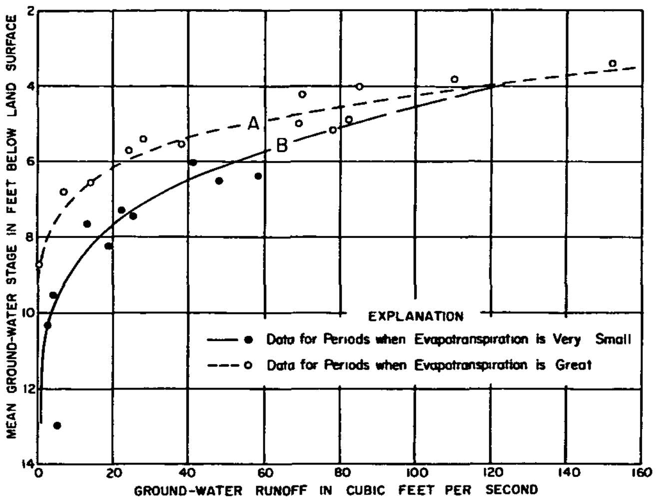


Figure 36. Rating curves of mean ground-water stage versus ground-water runoff at gaging station 1, Goose Creek basin

level data are available are shown in table 15.

Daily ground-water levels measured in well 31.6h were computed for selected dates when stream flow consisted entirely of ground-water runoff. Mean ground-water stages were plotted against ground-water runoff on corresponding dates as shown in figure 36.

Daily mean ground-water stages, as indicated by the records of well 31.6h, were plotted as yearly hydrographs as shown in figures 33, 34, and 35. Ground-water runoff corresponding to each mean ground-water stage was read directly from the rating curves in figure 36. Curve A was used with data for dates April through October and curve B was used with data for the rest of the year.

Daily ground-water runoff was plotted beneath stream-flow hydrographs and lines were drawn connecting points to describe ground-water runoff hydrographs as shown in figures 28, 29, 30, and 31. The shaded areas between the stream flow and ground-water runoff hydrographs represent surface runoff.

Monthly and annual ground-water and surface runoff, expressed in inches of water over the basin, are given in table 14. Ground-water runoff amounted to 41, 50, and 40 per cent of stream flow in 1955, 1956, and 1957. During 1957 ground-water runoff was small until late April and early May when the water table rose sharply. Ground-water runoff during May, June, and July was about 89 per cent of the total ground-water runoff in 1957.

Evapotranspiration

Annual evapotranspiration in 1955, 1956, and 1957 estimated by substituting available data on P, R, U, and ΔSg in equation 2 are given in table 16. Underflow and change in ground-water storage are discussed later in this report. The ratio of evapotranspiration to precipitation was 81 per cent in 1955, 89 per cent in 1956,. and 65 per cent in 1957.

Evapotranspiration during 1956 was about the same as it was in 1957 although precipitation was below normal in 1956 and near normal in 1957. Evapotranspiration was high in 1955 largely because the mean annual temperature in 1955 was 53.3 F or 1.6 F above normal. Temperatures in 1955 during April, May, July, August, and September were 7.9, 3.2, 4.1, 3.5, 3.0, and 1.2 F above normal, respectively. Evapotranspiration was comparatively low in 1957 largely because the mean annual temperature in 1957 was 52.3 F or 0.6 F below normal.

Ground-Water Evapotranspiration

Estimates of daily ground-water evapotranspiration 1955-58 were computed from figures 32, 33, 34, and 35 and the ground-water stage-runoff rating curves in figure 36. Monthly and annual ground-water evapotranspiration are given in table 16. The ratio of ground-water evapotranspiration

Table 16

Monthly and annual evapotranspiration in inches, 1955-58, Goose Creek basin

Month	1955			1956			1957			1958		
	ET_s	ET_g	ET	ET_s	ET_g	ET	ET_s	ET_g	ET	ET_s	ET_g	ET
Jan.		neg.*			neg.			neg.			neg.	
Feb.		neg.			neg.			neg.			neg.	
Mar.		neg.			0.26			neg.			0.30	
Apr.		0.33			0.55			neg.			1.01	
May		0.64			0.64			0.26			1.16	
June		0.66			0.28			1.04			0.13	
July		0.64			0.24			0.78			0.31	
Aug.		0.28			0.13			0.62			0.66	
Sept.		0.10			0.13			0.40			1.23	
Oct.		0.01			0.03			0.10				
Nov.		neg.			neg.			neg.				
Dec.		neg.			neg.			neg.				
Annual	23.10	2.66	25.76	22.09	2.26	24.35	21.10	3.20	24.30			

* Negligible

and total evapotranspiration was 10 per cent in 1955, 9 per cent in 1956, and 13 per cent in 1957.

Underflow

The width of the lowlands adjacent to Goose Creek through which underflow occurs is about 400 feet. Based on the bedrock surface and topographic maps, the thickness of the glacial drift is estimated to be 170 feet and the hydraulic gradient of the water table in the vicinity of stream gaging station 1 is estimated to be less than 10 feet per mile. The coefficient of transmissibility of the deposits through which underflow occurs is low and is probably in the magnitude of 2000 gpd/ft.

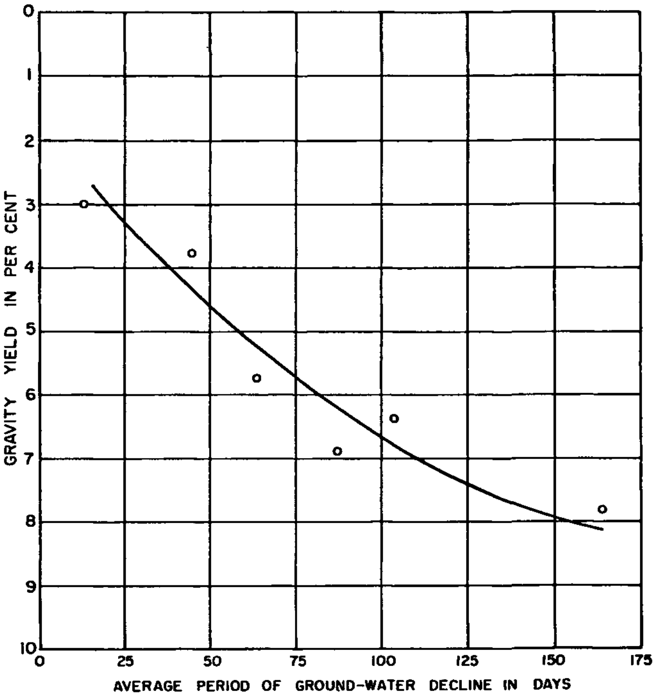


Figure 37. Graph showing relation of gravity yield and average period of drainage, Goose Creek basin

Using the data given above, the underflow was estimated from equation 3 to average about 0.002 cfs. Underflow is so small that it was omitted from budget computations.

Changes in Ground-Water Storage

Computations of gravity yield were made using equation 5 and data for six inventory periods during winter and early spring months, 1955-58. Values of Yg were plotted against the average time of drainage preceding the inventory periods as shown in figure 37. These data indicate that the average gravity yield of the glacial deposits increases at a diminishing rate from about 3 per cent for an average drainage period of 12 days to about 8 per cent for an average drainage period of 160 days. Extrapolation of the curve in figure 37 suggests that the average specific yield of the glacial deposits beneath the basin is about 9 per cent.

Monthly increases or decreases in ground-water storage, 1955-58, were estimated from figures 32, 33, 34, and 35, by multiplying mean ground-water stage changes by appropriate values of Yg given in figure 37. The data on changes in ground-water storage appear in table 17.

Ground-Water Recharge

Ground-water recharge, 1955-58, estimated by balancing equation 6 are given in table 17. Annual ground-water recharge during the three years ranged from 3.57 inches in 1956 to 10.40 inches in 1957 and was 6.40 inches in 1955. Ground-water recharge was 20 per cent of precipitation during 1955 and 13 per cent during 1956. Precipitation was below normal in both years. Ground-water recharge was 28 per cent of precipitation in 1957, a year of near normal precipitation.

Table 17

Monthly and annual ground-water recharge in inches, 1955-58, Goose Creek basin

	1955		1956		1957		1958	
Month	P_g	ΔS_g	P_g	ΔS_g	P_g	ΔS_g	P_g	ΔS_g
Jan.	0.50	+ 0.47	0.01	neg.	0.02	neg.	1.39	+0.84
Feb.	0.73	+ 0.65	0.78	+0.57	0.20	+ 0.18	0.08	-0.10
Mar.	1.01	+ 0.70	0.67	+0.13	0.22	+ 0.18	0.34	-0.13
Apr.	1.21	+ 0.62	0.64	-0.05	3.04	+2.88	1.17	-0.05
May-	0.95	+ 0.02	1.23	+0.19	4.16	+ 1.90	1.32	-0.12
June	1.14	+ 0.04	0.24	-0.44	1.67	-0.30	1.73	+0.48
July	0.19	-0.52	neg.	-0.29	0.34	-0.90	3.32	+0.17
Aug.	0.01	-0.28	neg.	-0.16	0.03	-0.60	1.67	-0.39
Sept.	neg.*	-0.10	neg.	-0.13	neg.	-0.40	0.91	-0.40
Oct.	0.46	+0.41	neg.	-0.03	neg.	-0.10		
Nov.	0.18	+0.13	neg.	neg.	0.01	neg.		
Dec.	0.02	neg.	neg.	neg.	0.71	+0.56		
Annual	6.40	+2.14	3.57	-0.21	10.40	+3.40		

* Negligible

COMPARISON OF BUDGETS FOR BASINS

Comparative results of annual hydrologic and ground-water budgets for Panther, Hadley, and Goose Creek basins are given in table 18. Data for years during which precipitation was near normal are presented. The comparison shows that surface runoff is greatest in the Hadley Creek basin. Surface runoff varies from basin to basin probably because of differences in the amount and distribution of precipitation, in soils, and in land use. A comparison of characteristics of the basins is given in table 19. Only about 14 per cent of stream flow is ground-water runoff in the Hadley

Table 18

Comparison of budget factors for basins

Budeet factors	Basin		
	Panther Creek	Goose Creek	Hadley Creek
Year	1952	1957	1957
		Inches	
Precipitation	32.62	37.18	39.73
Stream flow	9.82	9.48	13.93
Surface runoff	2.66	5.68	12.04
Ground-water runoff	7.16	3.80	1.89
Evapotranspiration	23.94	24.30	24.68
Surface and soil evapotranspiration	21.93	21.10	23.80
Ground-water evapotranspiration	2.01	3.20	0.88
Ground-water recharge	8.03	10.40	3.89
Change in ground-water storage	-1.14	+3.40	+1.05
Underflow	neg.*	neg.	0.07

* Negligible

Table 19

Comparison of characteristics of basins

Characteristics	Basin		
	Panther Creek	Goose Creek	Hadley Creek
Topography	Gently undulating uplands	Level uplands	Rugged uplands
Average stream gradient in feet per mile	4.7	3.9	16.4
Vegetal cover	80% corn, oats, and soybeans; 20% pasture, woodland, and farm lots	86% corn, oats, soybeans, alfalfa, hay, wheat, rye; 14% pasture, woodland, and farm lots	40% row crops, small grain, and hay; 60% pasture, woodland, and farm lots
Soil	Upland prairie silt loams	Drummer silty clay loam and Flanagan silt loam	Upland prairie and timber silt loams
Unconsolidated deposits	100 feet of glacial till	175 feet ot glacial till	25 feet of loess and 50 feet of glacial till
Bedrock formations	Shale of Pennsylvanian age	Shale of Pennsylvanian age	Shale of Mississippian and Pennsylvanian age
Average depth to water table in feet below land surface	7	8	20
North Latitude	40°44'-40°54'	40°05'-40°13'	39°41'-39°50'
Mean annual temperature in F	51	53	55
Mean annual precipitation, inches	33.6	37.0	36.0

Creek basin, whereas, in the Panther Creek basin ground-water runoff is 73 per cent of stream flow and in the Goose Creek basin ground-water runoff is 40 per cent of stream flow.

Evapotranspiration varies less than 1 inch from basin to basin probably because differences in mean air temperatures and water requirements of vegetal cover are slight. Ground-water evapotranspiration is least in Hadley Creek basin and is consistent with the greater depth to the water table in Hadley Creek basin.

Ground-water recharge is much greater in Panther and Goose Creek basins than in Hadley Creek basin. The lower ground-water recharge in Hadley Creek basin is probably due to differences in the amount and distribution of precipitation. in soils, and in land use.

ANNUAL EVAPOTRANSPIRATION, POTENTIAL EVAPOTRANSPIRATION, AND WATER LOSS

The measurement of actual evapotranspiration is extremely difficult. Direct determinations are made from lysimeters or evapotranspirometers but they may be misleading because of dissimilarities between evapotranspirometers and natural conditions in the field. Indirect determinations of evapotranspiration are often made from meteorological data with methods devised by Thornthwaite (1948), Penman (1956), Blaney and Griddle (1950), and Hamon (1960). These methods use different meteorological parameters and coefficients for considering vegetation and water conditions and yield differing results.

Evapotranspiration is limited by the availability of moisture. To circumvent deficit moisture conditions, Thornthwaite (1948) introduced the term potential evapotranspiration which may be defined as the evapotranspiration that would occur under a condition of adequate moisture supply. Several investigators have devised methods for estimating potential evapotranspiration from meteorological data. Comparable estimates on a yearly basis are obtained; however, on a daily, weekly, and monthly basis estimates made by available methods differ significantly.

Annual evapotranspiration computed from hydrologic budgets for Panther, Hadley, and Goose Creek basins and mean annual potential evapotranspiration computed by the Hamon (1960) formula are given in table 20. Normal monthly meteorological data were used to estimate mean annual potential evapotranspiration. Except for a dry year, the ratio of annual evapotranspiration and mean annual potential evapotranspiration ranged from year to year and from basin to basin between 77 and 87 per cent. Evapotranspiration from Panther Creek basin in 1956 when precipitation was much below normal was only 66 per cent of mean annual potential evapotranspiration. During years of near or above normal precipitation the annual evapotranspiration from Panther and Goose Creek basins averaged 84 per cent of mean annual potential evapotranspiration. Annual evapotranspiration from Hadley Creek basin was 77 per cent of mean annual potential evapotranspiration during a year of near normal precipitation. Annual potential evapotranspiration based on monthly meteorological data and computed by the Hamon formula is also given in table 20. The ratios of annual evapotranspiration and annual potential evapotranspiration range within a few per cent of the range of ratios of annual evapotranspiration and mean annual evapotranspiration.

Williams (1940) defined the water loss of a drainage basin as the difference between the average precipitation over the basin and the stream flow from the basin for a given period. Many

Table 20

Annual evapotranspiration as compared with mean annual Potential evapotranspiration

Basin	Year	Annual evapotranspiration, ET (inches)	Mean annual potential evapotranspiration, ETmp (inches)	Ratio $\frac{ET}{ETmp}$ (per cent)	Annual potential evapotranspiration, ETp (inches)	Ratio $\frac{ET}{ETp}$ (per cent)
Panther Creek	1951	24.71	28.24	87.5	26.96	91.7
Panther Creek	1952	23.94	28.24	84.7	29.37	81.5
Panther Creek	1956	18.75	28.24	66.4	28.43	66.0
Goose Creek	1955	25.76	29.56	87.1	30.44	84.5
Goose Creek	1956	24.35	29.56	82.4	28.89	84.1
Goose Creek	1957	24.30	29.56	82.2	28.72	84.6
Hadley Creek	1957	24.68	31.97	77.2	29.57	83.7

factors cause yearly variations in the annual water loss from a given basin. The hydrologic budget stated as equation 1 shows that the water loss depends upon subsurface underflow and changes in soil moisture and ground-water storage, in addition to amount and distribution of precipitation and stream flow. By using mean annual precipitation and mean annual stream flow for several years the effects of changes in soil moisture and ground-water storage are reduced to a minimum and the mean annual water loss is essentially the mean annual evapotranspiration.

Annual water loss computed from precipitation and stream flow records for Panther, Hadley, and Goose Creek basins and annual evapotranspiration computed from hydrologic budgets are given in table 21. The ratio of evapotranspiration to water loss ranged from year to year and from basin to basin between 88 and 105 per cent. Evapotranspiration averaged 97 per cent of water loss.

Table 21

Annual evapotranspiration as compared with water loss

Basin	Year	Annual evapotranspiration, ET (inches)	Annual water loss (inches)	Ratio $\frac{ET}{\text{Water loss}}$ (per cent)	Change in ground-water storage, ΔS_g (inches)
Panther Creek	1951	24.71	25.90	95.4	+ 1.19
Panther Creek	1952	23.94	22.80	105.0	-1.14
Panther Creek	1956	18.75	18.51	101.3	-0.24
Goose Creek	1955	25.76	27.90	92.3	+ 2.14
Goose Creek	1956	24.35	24.14	100.9	-0.21
Goose Creek	1957	24.30	27.70	87.7	+3.40
Hadley Creek	1957	24.68	25.80	95.7	+ 1.05

CONCLUSIONS

Ground-water recharge, runoff, and evapotranspiration can be readily determined from ground-water budgets using data on precipitation, stream flow, and ground-water levels. An important factor of the ground-water budget is the change in ground-water storage which depends upon the gravity yield of deposits. Before a ground-water budget can be prepared the relationship between gravity yield and average time of drainage must be determined from hydrologic budgets for periods during winter and early spring months when evapotranspiration and soil-moisture change are very small.

In summer months evapotranspiration is very effective in reducing ground-water runoff. Separate rating curves of mean ground-water stage versus ground-water runoff prepared for dates April through October and November through March can be used to estimate the magnitude of ground-water evapotranspiration and ground-water runoff.

Annual evapotranspiration can be appraised from hydrologic budgets using data on precipitation, stream flow, and ground-water levels if annual change in soil moisture is not significant. Weekly and daily evapotranspiration cannot be determined unless changes in soil moisture are quantitatively appraised. Soil-moisture storage plays a very important role in weekly or daily hydrologic budgets, especially during periods of high evapotranspiration losses. Future studies must place emphasis on accurate determination of soil moisture. The most promising method for measuring soil moisture is one involving neutron emission (Sharpe, 1953). Hydrologic and ground-water budgets on a daily basis would permit an understanding of hydrologic factor relationships not yet fully understood.

The results of the budget studies which represent a small sample of conditions in Illinois indicate that annual evapotranspiration during years of near and above normal precipitation can be estimated within 2 or 3 inches by multiplying mean annual potential evapotranspiration by a ratio of 0.84. Studies made in Panther Creek basin indicate that the ratio reduces to 0.66 during a year of much below normal precipitation.

Annual water loss, the difference between the average precipitation over the basin and the stream flow from the basin, ranged from 88 to 105 per cent of annual evapotranspiration. Annual evapotranspiration can be estimated within 2 or 3 inches by computing annual water loss from precipitation and stream flow records.

It is probable that a 5-year study period would give sufficient data to determine the influence of climatological factors on ground-water recharge, runoff, and evapotranspiration. A density of precipitation gages of about 10 square miles per gage is adequate. Studies made in the three basins indicate that a density of observation wells of about 2 square miles per gage would be desirable to define changes in ground-water storage. Recording gages should be used to measure ground-water levels and stream flow.

Ground-water underflow from the basins was not important and detailed quantitative studies were not justified. In some cases ground-water underflow may be important and accurate methods of evaluation will be necessary. In this event, the hydraulic gradient of the water table in the vicinity of stream gaging stations should be defined with several observation wells. The thickness and character of the deposits near the outlets of the basins and the permeability of the materials through which underflow occurs should be appraised by means of test-well drilling and a pumping test.

Based on existing geohydrologic data, ground-water divides were assumed to coincide with surface-water divides and the boundaries of the basins. In future hydrologic investigations, similar to this one, the records of observation wells outside of the basin should be obtained to detect any migration of the ground-water divide and to accurately determine the position of the ground-water divides. Observation wells should be measured in at least a 2-mile strip area outside basins.

Based on a critical review of available data, computed values of ground-water recharge are estimated to be accurate within 1 or 2 inches. It is recognized that extensive surface and subsurface drainage in Panther and Goose Creek basins may appreciably affect the rate of ground-water recharge and that computed values of recharge should be extended with reservation to other basins with characteristics unlike those of the study basins. Although ground-water recharge to only three basins in Illinois has been computed, the results of studies described in this report permit a better understanding of recharge to glacial deposits and will aid greatly in the quantitative appraisal of the state's water resources.

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