COMPARISON OF MANUAL BASEFLOW SEPARATION TECHNIQUES TO A COMPUTER BASEFLOW SEPARATION PROGRAM AND APPLICATION TO SIX DRAINAGE BASINS

By

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PREFACE

The results from a computer baseflow separation program are compared to manual baseflow calculations in six drainage basins. The basins range in size from 19.5 to 287 square miles, are located from Oklahoma to New York, and are characterized by perennial streams. They were chosen to represent differences in drainage area, climate, and geology. Each of the basins, except the one in Oklahoma, have been the subject of baseflow calculations by previous investigators. The author estimated baseflow to the Little Washita River Watershed in February 1984 with seepage measurements.

Estimates of baseflow by the computer program and the manual methods compare favorably. The fixed interval technique is generally not more than 20 percent greater than or less than baseflow calculated by ground-water rating curves, baseflow recession curves, and seepage measurements. The program has many advantages: readily accessible data base, it requires only mean daily stream discharge and basin area, rapid results, the calculations are reproducible, and the program may be run on a variety of microcomputers.

Many previous baseflow studies utilized only one or two years of data or estimates of baseflow from nearby basins. Another purpose of this report is to show the amount of annual variation in baseflow. Ten consecutive years or rainfall and stream flow were analyzed for each basin, except one basin in Illinois which had a seven year data base. It was found that although baseflow as a percent of total runoff does not vary significantly, baseflow expressed as a percent of rainfall or as inches over the drainage basin can change by more than an order of magnitude from year to year. Therefore, baseflow depends upon fluctuations in rainfall, and cannot be expressed as a constant percentage or number of inches annually.

I would like to express my thanks to my major adviser, Dr. Wayne Pettyjohn, and my committee members, Dr. Arthur Hounslow, Dr. Douglas Kent, and James Naney. I am also grateful to those people who helped obtain data for this study that work at the U. S. Department of Agriculture in Chickasha and Durant, Oklahoma, the Illinois State Water Survey, and the U. S. Geological Survey in Syosset, New York. Special thanks are due to Geraghty and Miller, Inc., and members of that company for providing assistance and field equipment. I would also like to thank Kelly Goff and Brad Huffman, Department of Geology, Oklahoma State University, and Peggy Sheldon, Soil Conservation Service, Stillwater, Oklahoma, for their assistance with the computer program and computerized data.

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CHAPTER I

INTRODUCTION

Public awareness of the conservation of ground-water resources has increased dramatically in recent years. The general misconception of ground water as an unlimited source of potable water is quickly becoming a thing of the past. According to a recent editorial by Ward, Durham, and Canter (1984):

> The lay public now knows that ground water accounts for over 90 percent of the fresh water in the United States including all streams and reservoirs. They know that this resource furnishes drinking water to half of the country's population, and that one-third of our largest cities rely totally or in part on underground water supplies. They know that rural America uses ground water almost exclusively for its domestic supply, and that our abundant agriculture would lie fallow if this source of water was unavailable (p. 138).

The sustained quantity of available ground water is related to the amount of recharge an aquifer receives. Many methods have been developed to estimate ground-water recharge, but these are generally time consuming, require a large data base, and do not provide consistent results. This report presents and tests a computer program that determines effective regional ground-water recharge to a drainage basin by means of hydrograph separations. The results of the program are reproducible and the only required inputs are mean daily stream discharge and basin area.

Objectives and Scope

The objectives of this study are to 1) compare the results from a computer baseflow separation program with results obtained by other hydrograph separation techniques, and 2) examine annual fluctuations in baseflow. The computer program, developed by Pettyjohn and Henning (1979) determines baseflow, or effective regional ground-water recharge, from stream hydrographs. According to Pettyjohn and Henning (1979), effective regional ground-water recharge is:

> . . . the total quantity of water that originates from downward infiltration to the water table and upward leakage from deeper zones to the surficial aquifer and then eventually finds its way to a nearby stream. It is synonymous with ground-water runoff. Thus . . . effective ground-water recharge represents only the liquid residual that reaches a stream (p. 2).

The results obtained from the computer program are compared with results of previous baseflow studies in five basins, of which two are in Illinois, one in Pennsylvania, one in Maryland, and one in New York. Results from the computer program are also compared to baseflow estimates for the Little Washita River Basin in Oklahoma, which were calculated specifically for this study. Each of the basins represent a different climate, drainage area, and geology, but they are all located in areas where annual stream flow is sustained by ground-water runoff during years of normal and above normal rainfall.

The second objective of this study is to examine annual fluctuations in the amount of baseflow. The six basins mentioned above are used for this purpose with 10-year data bases of precipitation and mean daily stream discharge. One of the basins, located in Illinois, has a seven-year record of stream discharge.

Previous Work

Quantitative assessment of ground-water runoff has been undertaken by several investigators. Ground-water rating curves have been used by Meinzer and Stearns (1929) for the Pomperaug Basin in Connecticut, Rasmussen and Andreason (1959) for the Beaverdam Creek Basin in Maryland, and Schicht and Walton (1961) for three watersheds in Illinois. Olmstead and Healy (1962) studied Brandywine Creek Basin in Pennsylvania, and La Sala (1967) examined some drainage basins in upstate New York. These workers used ground-water rating curves to aid in the calculation of baseflow. Similar rating curves presently are used in studies by the Connecticut Water Resources Commission. These curves relate ground-water outflow to percent of the drainage basin underlain by stratified drift.

Harder and Drescher (1954) use regional flow nets and the seepage equation to determine ground-water recharge in Langdale County, Wisconsin. Lewis and Burgy (1964), Cohen and others (1965), and Trainer and Watkins (1975) used closely related methods. Pluhowski and Kantrowitz (1964 and

1966) measured ground-water seepage into streams, and hydrograph separation in order to determine baseflow in the Babylon-Islip area of New York.

Many previous studies have been performed along the main reach of the Washita River, Oklahoma. Davis (1950) determined baseflow by hydrograph separation in Pond Creek Basin to be approximately three percent of precipitation. Kent et al. (in press) calculated the maximum allocation of fresh water from the Washita River alluvium through calibration of a computer model. It is important to note that the model used by Kent et al. (in press) is in no way similar to the computer program used throughout this report, and Kent et al. (in press) calculated annual recharge, not baseflow to the alluvium, generally the most porous and permeable unit in a drainage basin in Oklahoma. They determined net annual recharge to the alluvial aquifer between Anadarko and Alex, Oklahoma to be 2.7 inches or 8.0 percent of total precipitation. Kent et al (1973) described a technique for storing and selectively retrieving hydrogeologic data for use in mathmatical modeling and analysis. They use the alluvial aquifer between Anadarko and Alex as an example. The users manual for the computer program presented in Kent et al. (1973) is authored by Naney et al. (1976a). A finite-difference digital model was used by Naney et al. (1980) to simulate drawdown in the Tillman Terrace Deposits, Tillman County, southwestern Oklahoma. Naney et al. (1979) studied surface-water quality within the

Little Washita River Watershed and found that sediment is the major source of pollution. The economic potential for irrigation along the Washita River between Anadarko and Alex is determined through the use of a computer model by Kent et al. (1982). Naney et al. (1976b) compare modeled and measured hydraulic conductivity distribution in the Upper Sugar Creek Watershed, Caddo County, Oklahoma. Levings (1971) correlated aquifer characteristics from Lower Sugar Creek alluvium to the Upper Sugar Creek Watershed. Olmstead (1975) delineated zones of radioactive mineralization in south-central Oklahoma. Silka (1975) described the hydrogeochemistry of the Washita River alluvium in Caddo and Grady counties, and Schipper (1983) and Patterson (1984) presented ground-water management models of the Washita River alluvium upstream of Anadarko and downstream of Alex, respectively.

The computer program used throughout this report has previously been used to estimate effective regional ground-water recharge. Pettyjohn and Miller (1982) applied the method to the Garber-Wellington Aquifer in central Oklahoma and determined that baseflow averages 2.11 inches annually. Pettyjohn and Henning (1979) calculated effective ground-water recharge rates for the entire state of Ohio. They found that during a year of average precipitation (36 inches), baseflow varies from 3.78 inches in bedrock terrain to 8.99 inches in areas covered by extensive, very permeable glacial outwash.

CHAPTER II

SURFACE WATER - GROUND WATER RELATIONSHIPS

The computer program used for this study separates stream hydrographs into two components: ground-water runoff and surface runoff. Ground-water runoff, or baseflow, is that part of stream flow that originates from the seepage of ground water from the geologic formations surrounding the stream channel. Surface runoff occurs during and shortly after precipitation or snowmelt events that exceed the infiltration capacity of a drainage area. Separation of the stream hydrograph by different methods is possible when the relationship between surface runoff and ground-water runoff is established.

Streams can be classified into two general types depending upon the elevation of the water table relative to the level of water in the stream channel. A losing stream (Figure 1A) is one in which the water table is below the level of the stream, and water infiltrates from the stream toward the water table. Discharge per unit area of drainage basin decreases downstream. For this type of stream, streamflow is not sustained by ground-water runoff, and flow may cease shortly after precipitation events. Losing streams are common in arid regions, and losing reaches of

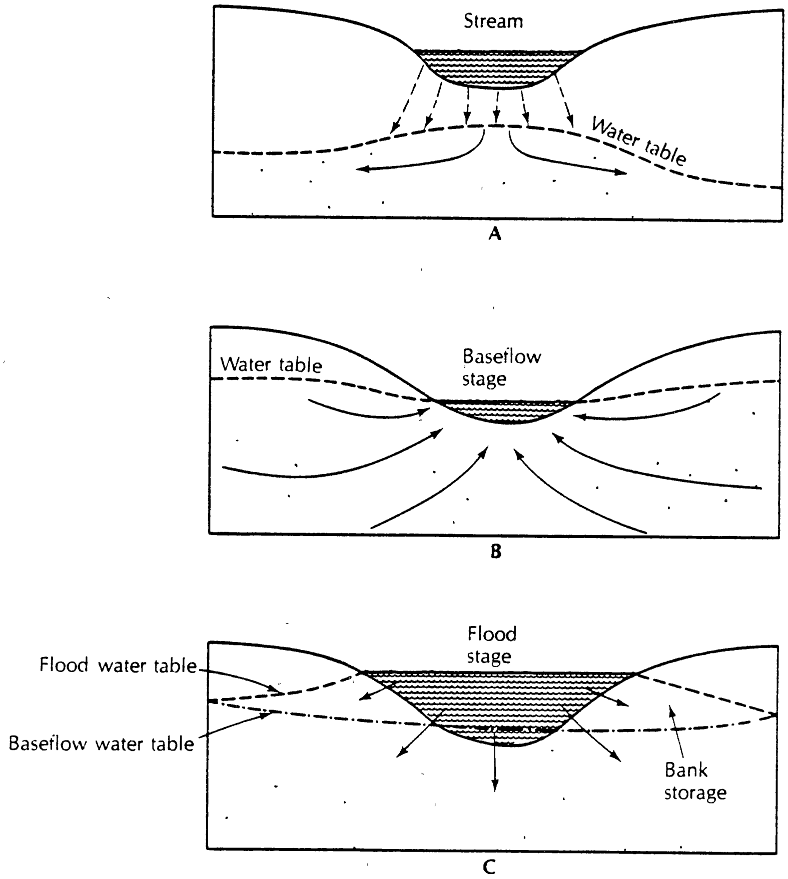


Figure 1. Cross Sections of Gaining and Losing Streams (from Fetter, 1980, p. 42)

streams can occur near pumping centers. A gaining stream (Figure 1B) is one in which the water table slopes toward the stream channel and ground-water discharges into the stream. Streamflow is sustained by ground-water runoff between precipitation events and discharge per unit area of drainage basin increases downstream (Fetter, 1980). This type of stream is commonly found in semi-arid to humid climates. Some losing streams can appear to be gaining if stream flow is regulated or added to by human activities. Each of the streams in this report represent, for the majority of the study periods, unregulated, gaining streams. During very dry periods the Little Washita River and Goose Creek have records of no flow, and thus become losing streams for short periods of time.

During extended dry periods stream flow consists entirely of baseflow and separation techniques are not required, but after a rainfall event the hydrograph includes surface runoff and ground-water runoff. During a flood stage the water level in the stream may rise above the water table (Figure 1C), and reverse the local water-table gradient. This temporarily blocks ground-water runoff, and also allows infiltration of water from the stream channel to the adjacent aquifer. As the stream level declines, the gradient again reverses and ground water flows back into the channel. This temporary increase in aquifer storage is called bank storage (Walton, 1970).

> In the beginning the rate of discharge from bank storage is high because of the steep water-level

> gradient, but as the gradient decreases so also does ground-water runoff, which may eventually cease where the aquifer is depleted. The stream hydrograph gradually tapers off into what is called a depletion curve. To a large extent, the shape of the depletion curve is controlled by the permeability of the stream-side deposit, although soil moisture and evapotranspiration also play important roles (Pettyjohn and Henning, 1979, p. 14).

The division of a stream hydrograph into its two components, surface runoff and ground-water runoff, is a relatively arbitrary process because the point at which surface runoff ends and ground-water runoff begins cannot be precisely identified. Most baseflow separation techniques are based on the N-interval, N being equal to the time, in days, after which surface runoff ceases. It is defined as:

$$N = A^{0.2} \tag{1}$$

where A is the size of the drainage area, in square miles (Linsley et al., 1982, p. 210).

An example of a flood hydrograph and its division into surface runoff and ground-water runoff is shown in Figure 2. The beginning of the flood wave occurs at point A. A straight line, representing baseflow recession if no surface runoff had occurred, is drawn from point A to point B, which is directly below the peak of the flood wave. During the time period from A to B the local water-table gradient reverses and bank storage increases. The point C represents the time when surface runoff ceases and stream flow consists entirely of baseflow. It occurs at a time period equal to the N-interval after the peak discharge. In this example,

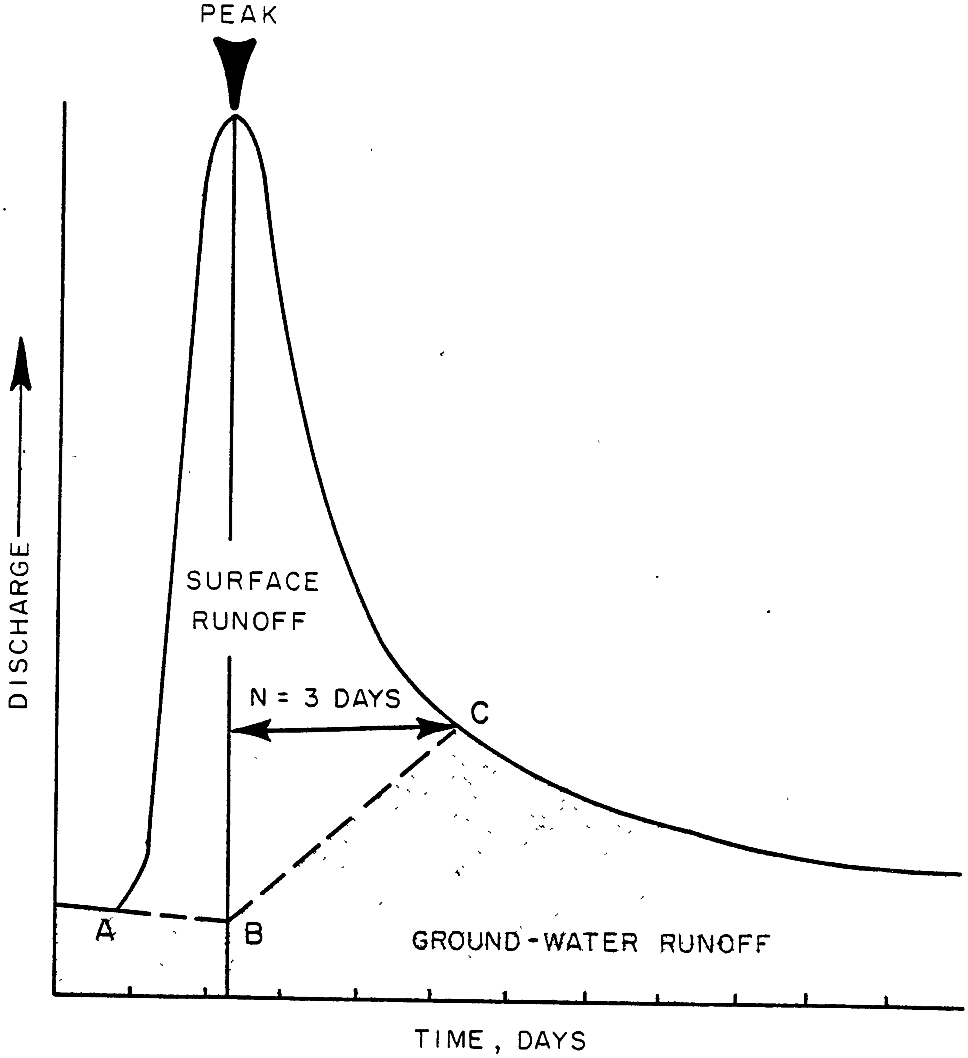
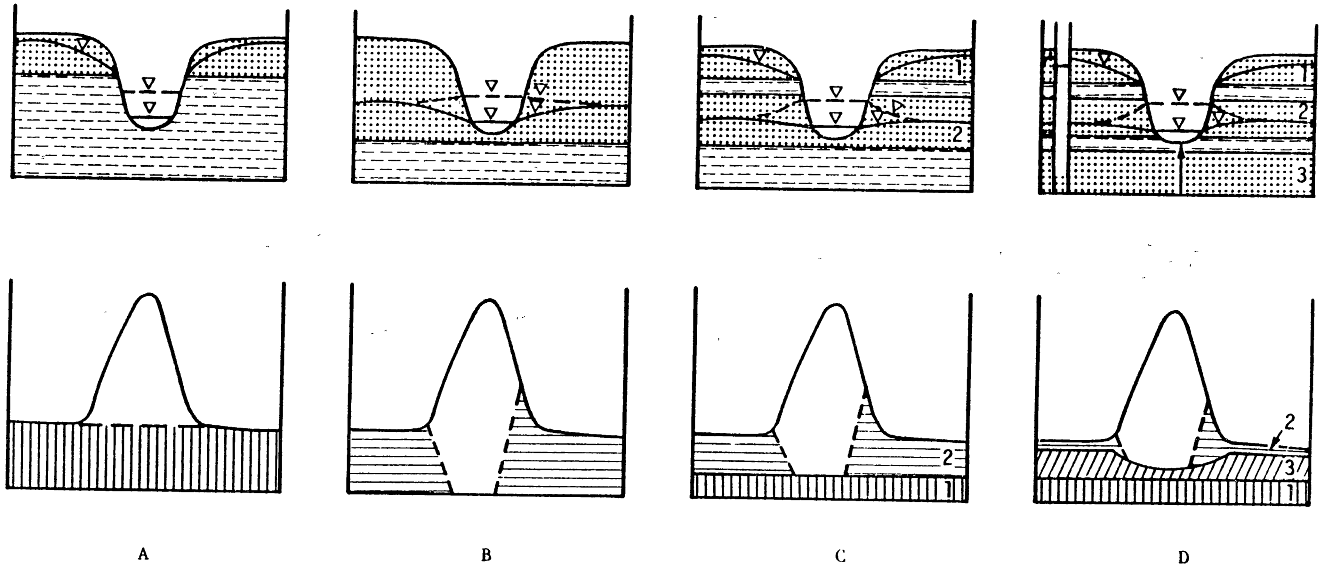


Figure 2. Flood Hydrograph and Separation into Surface and Ground-water Runoff

if the drainage area is assumed to be 243 square miles, N is equal to three days. A straight line is drawn from B to C and the entire shaded area is assumed to consist of groundwater runoff. An increase in the rate of ground-water runoff is assumed from point B to point C due to passage of the flood wave and the draining of bank storage. The time period after point C shows dry weather aquifer depletion, and starts at a point higher than A due to accumulation of ground water behind bank storage.

The hydrograph in Figure 2 demonstrates a relatively simple method of baseflow separation with little regard for the surrounding geologic framework. Cross-sections of four streams running through different geologic settings and the method of baseflow separation for each case is shown in Figure 3. Example A is a stream channel cut into relatively impermeable shale with stream flow sustained by seepage of ground water along the sand-shale contact. As the flood wave passes, stream stage does not rise above the impermeable shale, and no bank storage or change in water-table gradient is created in the sand.

Case B demonstrates the ideal bank storage situation. The stream channel lies in sand above an impermeable shale and baseflow is sustained by ground-water seepage from the sand. As the flood wave is passing, stream stage increases to the pont where the original water-table gradient is reversed and ground-water runoff ceases. Once the flood has passed, accumulated bank storage seeps into the channel



A B C D

Figure 3. Effect of Geologic Setting on Hydrograph Separation
(from Pettyjohn and Henning, 1979, p. 13)

until normal aquifer depletion again resumes.

Two aquifers sustain baseflow in the situation shown in C; the lower aquifer behaves in the same manner as the single unit in example B, but there is an upper, perched aquifer also providing baseflow. As the flood wave passes, ground-water runoff from the lower unit is temporarily blocked, and bank storage is accumulated. Ground-water runoff from the perched aquifer is unaffected if stream stage remains below the impermeable bed.

In case D, three aquifers sustain baseflow in the stream: an upper, perched aquifer, an intermediate water-table aquifer, and a lower artesian aquifer. During passage of a flood wave, the two upper aquifers behave in the same way as the two aquifers in example C; the perched aquifer is unaffected, but unit 2 shows the effects of a reversal of water-table gradient and bank storage. The artesian aquifer, unit 3, is under sufficient pressure to provide baseflow by upward leakage. As the flood wave passes, the difference in head between unit 3 and the stream decreases, resulting in a decrease of upward leakage.

Manual hydrograph separation is a subjective process affected by a number of geologic and environmental factors. Due to a lack of sufficient data and research, hydrograph separation is a somewhat arbitrary process. The computer program presented in this study separates hydrographs based on manual methods, but requires no interpretation and a small, readily available data base.

CHAPTER III

METHODS OF EVALUATING BASEFLOW

Computer Baseflow Separation

A computer program was developed by Pettyjohn and Henning (1979) to determine effective ground-water recharge from stream flow data. They define effective ground-water recharge as ground-water runoff or baseflow. The program separates the baseflow component of runoff by three methods: fixed interval, sliding interval, and local minimum.

Required input for the program is the size of the drainage basin, in square miles (mi^2), and mean daily stream discharge, in cubic feet per second (cfs). The program plots stream hydrographs for the standard water year, which begins October 1, and ends September 30. Each of the methods is based on the "N-interval", which is defined in the previous chapter. The interval actually used in the program is approximately 2N adjusted to the nearest odd integer between 3 and 11.

The fixed interval method moves a bar of 2N width upward from a base line until a part of the bar intersects the hydrograph. The area below the bar is the amount of ground-water discharge for the period of days defined by the interval (2N). The bar is then moved horizontally to the next interval and the process is repeated for a total of 365/2N times (Figure 4).

The first process involved in the sliding interval method is identical to the first part of the fixed interval method; a bar of 2N width is moved upward from a base line until a part of the bar intersects the hydrograph. The point of intersection then becomes the center of the interval. The amount of ground-water discharge for the point of intersection is equal to the lowest value of stream discharge for the interval. The bar is moved over one day and the process is repeated (Figure 4).

The local minima method is similar to the sliding interval method in that ground-water runoff is determined for each day. That particular day becomes the center of the 2N interval. If it is the lowest value in the interval, it becomes the local minimum and is connected by straight lines to other local minima (Figure 4). The area beneath the lines connecting local minima is determined to be the amount of ground-water discharge. A complete listing of the program is included in the Appendix.

Ground-Water Rating Curves

Ground-water rating curves are the basis of a method used by Schict and Walton (1961) to determine baseflow to three small drainage basins in Illinois. The rating curves are prepared by plotting mean ground-water stage against stream flow when stream flow consists entirely of ground-

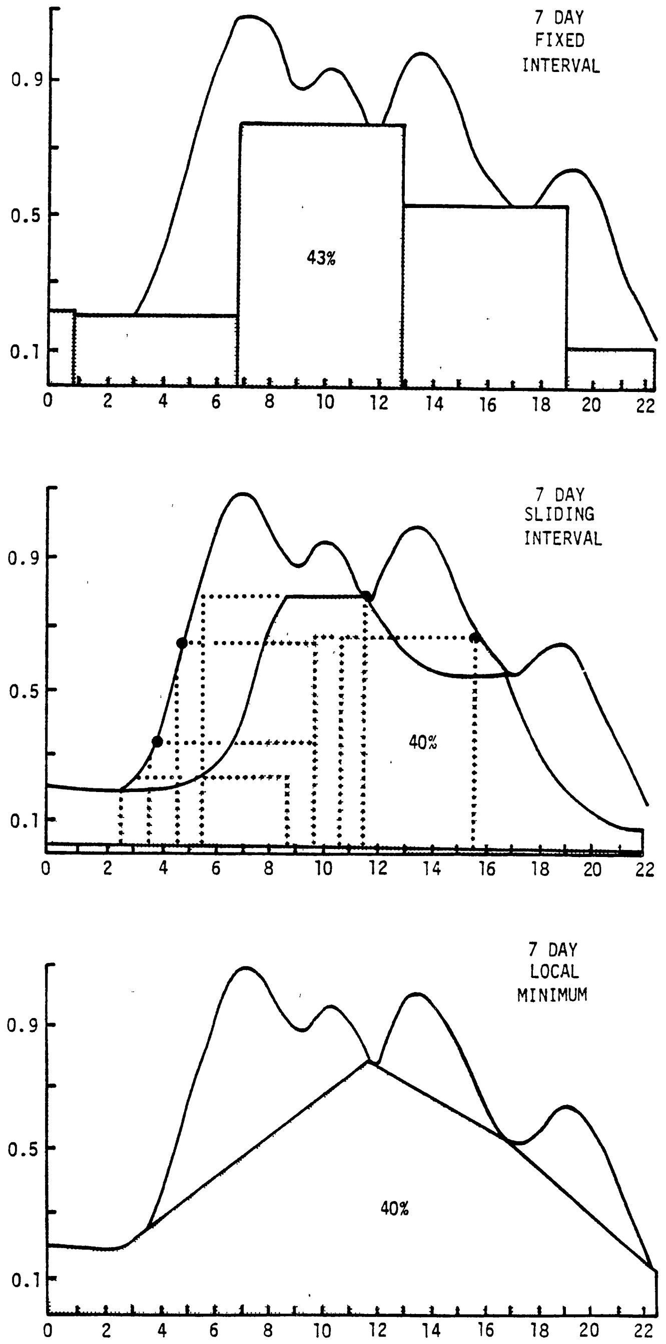


Figure 4. Hydrograph Separation by the Three Computer Techniques (from Pettyjohn and Henning, 1979, p. 35, 36, 37)

water runoff. It must be assumed that surface runoff ceases within a few days to one week after a rainfall event. Therefore, periods during which stream flow is sustained by only ground-water runoff can be chosen by comparing the hydrograph of mean daily streamflow to mean daily precipitation over the basin.

A number of observation wells within the basin must be open to the aquifer or aquifers that discharge water to the stream. Ideally, daily ground-water levels should be used, but weekly or other measurements are satisfactory. Mean ground-water stage is calculated by averaging the depth to water, from a common datum, for all of the wells in the basin.

Two rating curves are prepared in order to assess the effect of evapotranspiration. One rating curve covers the period April through October, when evapotranspiration is high; the other rating curve represents November through March, when evapotranspiration is low. The difference between these two curves is the effective ground-water evapotranspiration. For example, with the same ground-water stage, ground-water runoff is much less in August than in February.

Ground-water runoff is plotted below the stream hydrograph with the aid of the rating curves. Ground-water evapotranspiration is estimated from the difference in the two rating curves. Ground-water recharge occurs when the mean ground-water stage rises, or declines less than is necessary to balance ground-water runoff and evapotranspiration (Schicht and Walton, 1961).

Seepage Measurements

The amount of ground-water runoff originating from different geologic formations is estimated for Wolf Creek Basin, Iowa, through the use of seepage measurements (Kunkle, 1965). Discharge and conductivity were measured along Wolf Creek during a short time interval when there was no surface runoff. Two aquifers were known to be present in the area, each with a distinct water quality. Inflow and conductivity upstream were measured (Q_0, C_0), the conductivity of the water from the two aquifers was known (C_1, C_2), and the outflow and conductivity were measured (Q_3, C_3). Simultaneous solution of the following equations yields the contribution of the two aquifers to stream flow (Q_1, Q_2):

$$Q_0C_0 + Q_1C_1 + Q_2C_2 = Q_3C_3 \qquad (2)$$

$$Q_0 + Q_1 + Q_2 = Q_3 \qquad (3)$$

Seepage measurements can be used to determine total ground-water runoff from a basin if the water quality of contributing aquifers is unknown. Measurements are taken along tributaries and the main stream over a short time interval when stream flow is unaffected by surface runoff. The amount of runoff per unit area is calculated from each measuring station. Areas of high and low ground-water contribution can then be identified or averaged over the basin.

Baseflow Recession Curves

Olmstead and Hely (1962) used baseflow recession curves to calculate ground-water runoff in Brandywine Creek Basin, Pennsylvania. They prepared two curves, one for summer and winter, to compensate for changes in surface and ground-water runoff characteristics. The curves are prepared by tracing a number of recession limbs directly off the stream hydrographs. The hydrograph past point C in Figure 2 is an example of a recession limb. An average curve is drawn through the family of curves traced from the recession limbs, and is considered to represent baseflow recession. This baseflow recession curve is used to extend the hydrograph beneath a flood wave (line AB and CD, Figure 5). This creates an envelope between which a line can be drawn separating surface and ground-water runoff.

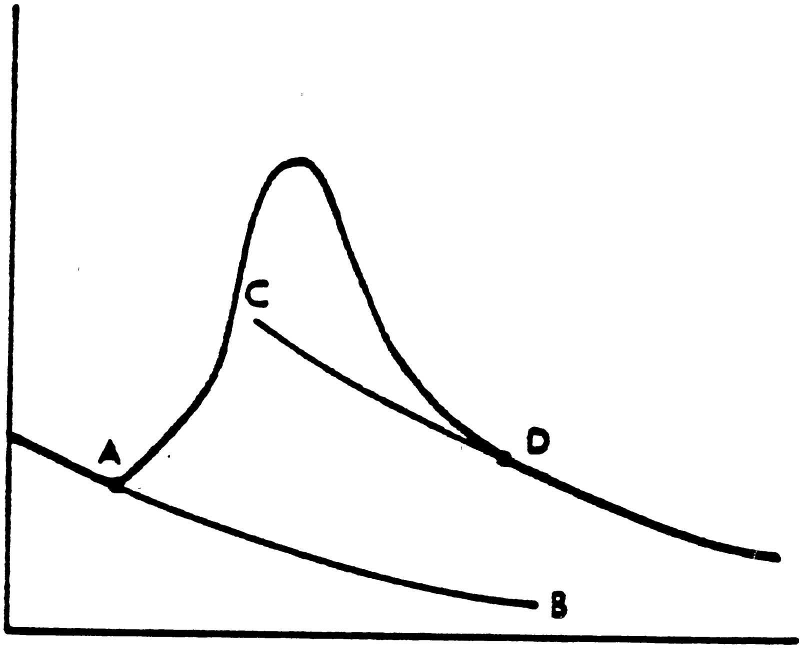


Figure 5. Hydrograph Separation by Baseflow Recession Curves (from Pettyjohn, 1983, p. 33)

CHAPTER IV

LITTLE WASHITA RIVER WATERSHED, OKLAHOMA

Geography

The Little Washita River Watershed above U. S. Department of Agriculture stream gaging station 522 covers approximately 208 square miles in parts of Grady, Caddo, and Comanche counties, southwestern Oklahoma (Figure 6). All or parts of Ranges 7-10 West and Townships 4-6 North are included in the study area. The upper end of the drainage basin lies at an altitude of approximately 1505; the gaging station elevation is approximately 1090 feet.

The basin lies in a moist-subhumid climate zone. Winters are generally moderate with occasional short periods of severe cold and summers are characterized by hot days and cool nights. The average length of the growing season is about 215 days (Davis, 1955). Temperatures less than 32°F can be expected about 65 times a year, and an average temperature of 95-100°F can be expected about 120 days per year. Average annual precipitation is approximately 28 inches (Pettyjohn et al., 1983). Intense precipitation over small areas is common and results in rapid runoff (Tanaka and Davis, 1963). Storms of regional extent are more frequent during the spring and fall, and may cause extensive flooding in the valleys (Davis, 1955).

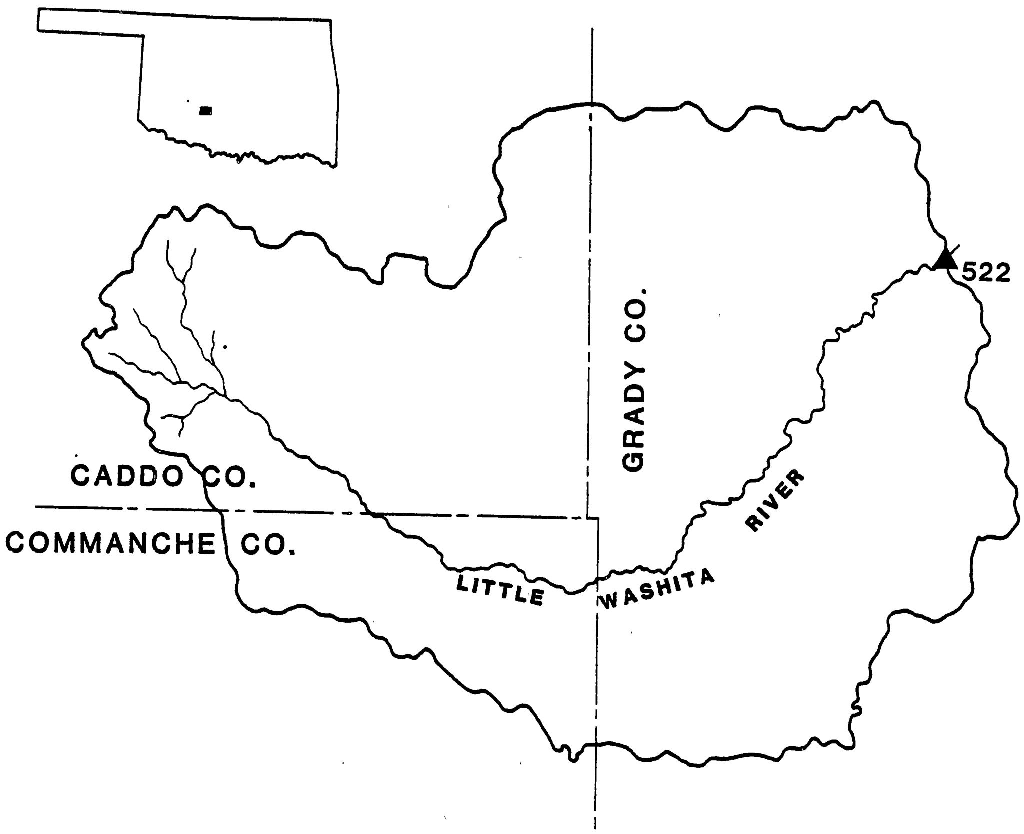


Figure 6. Location of Little Washita River Watershed

No natural ponds existed in the watershed prior to development. At the present time a number of small ponds exist for flood control and recreational purposes. No single pond is larger than about 120 acres, and the density of farm ponds is less than one per square mile.

Land use in the basin is primarily agricultural. Approximately 65 percent is in pasture or range, and 20 percent is cultivated. The remainder is classified as miscellaneous which includes dense timber, roads, and urban development (Burford et al., 1983).

Geology

According to Fenneman (1930), the Washita River Experimental Watershed lies in the Osage Plains of the Central Lowlands Province. Snider (1917) describes the area in more detail, placing the majority of the watershed in the Redbeds Plains and the western portion in the Gypsum Hills physiographic provinces.

The Redbeds Plains region is a slightly rolling to hilly surface underlain by soft red sandy shales interbedded with thin red sandstones. These rocks are soft and pronounced escarpments are not produced. The streams cut shallow, narrow channels between broad, flat-topped ridges. The hills are generally about 100 feet above the streams. The Gypsum Hills region lies immediately west of the Redbeds Plains. The general characteristics are very similar, except for ledges of gypsum, which produce a more pronounced topography. Along the Washita River, distinct alluvial terraces form broad flat plains. Correlative terraces are found along most of the major tributaries (Davis, 1955).

Four soil groups are dominant in the drainage basin. They are mainly sandy loams and silt loams. Forty-five percent of the watershed is covered by soils with rapid permeability, 20 percent with moderately rapid permeability, and 35 percent by moderate permeability (Hobbs and Burford, 1970).

Bedrock formations consisting of sedimentary rocks of the Permian system cropout in the study area. In ascending order, they consist of: the El Reno group, the Whitehorse group, and the Cloud Chief Formation. Deposits younger than Permian in age are absent except for Quaternary alluvium, which is found in the larger stream valleys.

The El Reno Group consist of fluvial and shallow marine deposits of sandstone, siltstone, shale, and gypsum. In ascending order it includes: the Duncan Sandstone, the Chickasha Formation, and the Dog Creek Shale and Blaine Gypsum, undifferentiated. The Whitehorse Group consists of fluvial and shallow marine deposits of sandstone, siltstone, shale, and gypsum. It lies unconformably above the El Reno Group, and, in ascending order, includes the Marlow Formation and Rush Springs Sandstone. The Cloud Chief Formation lies unconformably on top of the Rush Springs Sandstone (Freie, 1930). It consists of irregular, impure gypsum units interbedded with gypsiferous red shales. In the northwestern half of the study area the formation crops out as widely scattered outliers, so that only its lower part is present (Davis, 1955).

In the Little Washita River watershed, alluvium is the only Quaternary deposit represented. Older terrace deposits, where present, are lithologically similar. According to Davis (1955, p. 78): "Practically every stream in the area has alluvium along it, but much of it is thin and not extensive." Alluvium is derived from erosion of the surrounding rocks and reflects their lithology. For example, rocks with a high gypsum content will be associated with alluvium with a large amount of disseminated gypsum. Along the Little Washita River the alluvium is up to 1.5 miles wide and 30 to 40 feet thick (Naney, 1984).

Hydrology

Precipitation

For the study period, 1965-1974, average precipitation on the basin was 28.83 inches. The month of heaviest rainfall was September which had an average of 4.40 inches. January, February, November and December received the least amount of precipitation; about 15 percent of the total. Precipitation was about equally divided between the spring months (March, April, May, June) and the summer months (July, August, September, October). These groups of months received 40 and 45 percent of the total annual rainfall, respectively (Table I).

The period 1965 through 1967 was the driest sequence of years, and includes the year of least precipitation, 1966. That year received only 19.60 inches of precipitation, which was 9.23 inches less than the average (Figure 7). The year

TABLE I

MONTHLY AND ANNUAL PRECIPITATION, IN INCHES, 1965-1974, LITTLE WASHITA RIVER WATERSHED

	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	AVE
J	1.24	0.58	0.15	2.92	0.99	0.10	0.49	0.08	3.31	0.14	1.00
F	0.72	1.31	0.06	1.74	2.33	0.64	1.74	0.50	0.59	1.69	1.13
M	1.05	1.07	2.08	1.85	2.21	3.04	0.07	0.41	5.43	2.28	1.95
A	2.02	4.37	4.90	2.27	1.97	2.86	0.41	5.45	3.11	3.71	3.11
M	3.97	1.44	3.82	6.38	5.96	1.57	4.90	3.39	3.82	3.69	3.89
J	3.56	1.27	1.94	2.02	3.24	1.94	2.59	0.97	5.84	2.92	2.63
J	0.66	1.02	3.18	3.76	0.47	1.08	2.41	0.79	8.50	0.33	2.22
A	6.62	4.43	0.81	0.81	2.75	0.79	4.77	1.21	0.84	5.67	2.87
S	3.26	2.85	4.29	4.25	4.89	5.93	5.42	1.25	7.95	3.95	4.40
O	1.75	0.41	3.72	2.58	1.70	1.64	5.03	9.16	3.25	4.67	3.39
N	0.04	0.58	0.35	4.41	0.19	0.74	0.68	2.23	2.15	1.31	1.27
D	0.81	0.27	1.03	1.03	1.33	0.26	2.79	0.62	0.24	1.33	0.97
TOT	25.70	19.60	26.33	34.02	28.03	20.59	31.30	26.06	45.03	31.69	28.83

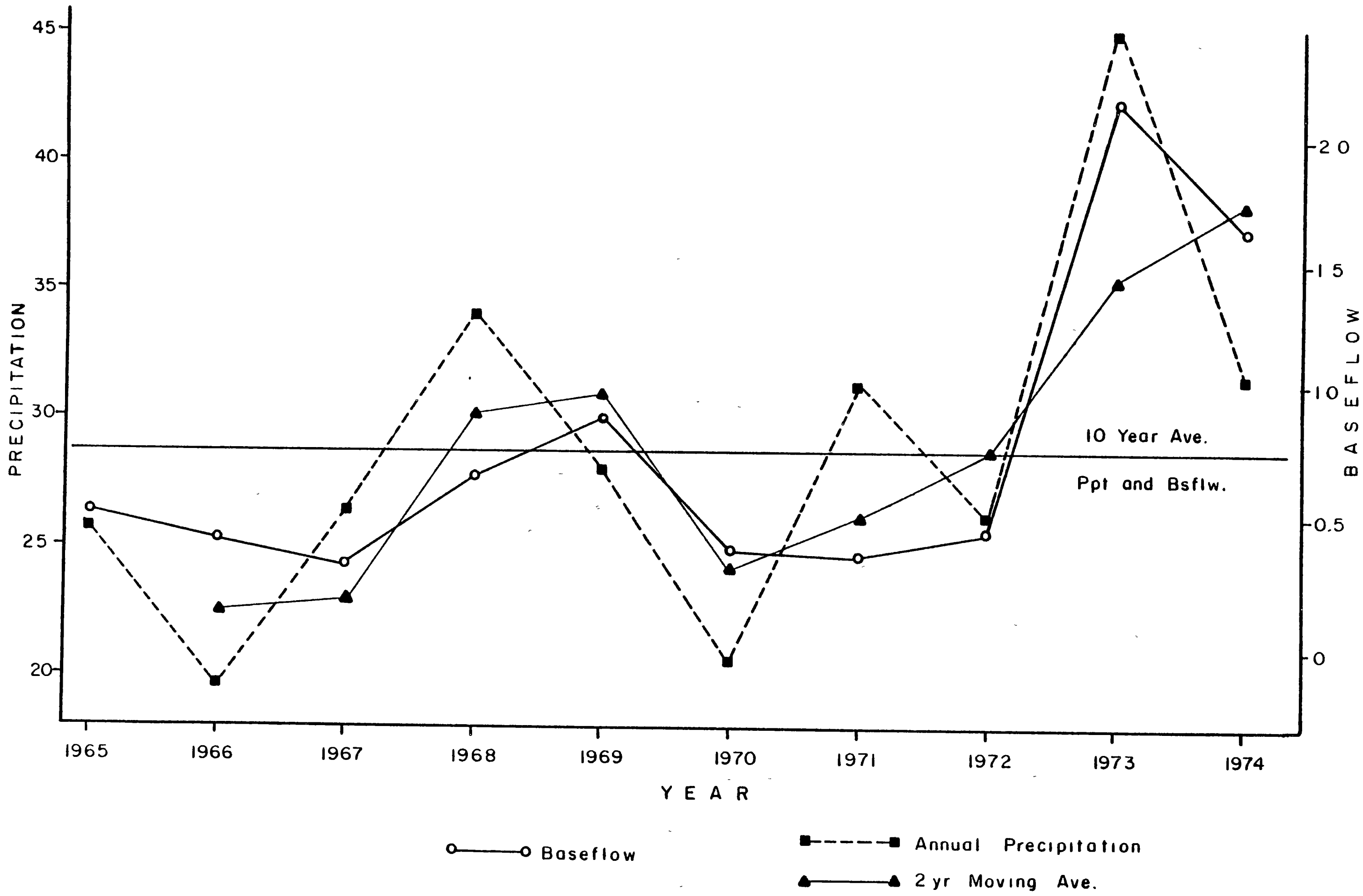


Figure 7. Annual Baseflow (Fixed Interval) and Annual Precipitation, in Inches, 1965-1974, Little Washita River Watershed

with the highest amount of rainfall was 1973 with 45.03 inches, or 16.20 inches greater than the average. The later years of record consist of one or two years of below average rainfall, followed by one or two years of above average rainfall.

Evapotranspiration

Three methods were used to estimate evapotranspiration or consumptive use for the Little Washita River Watershed. These are Blaney-Criddle, soil moisture calculations, and subtracting stream flow from precipitation.

Garton and Criddle (1955) estimate consumptive use of crops in various areas in Oklahoma through the use of a method developed by Blaney and Criddle (1950). This method estimates potential evapotranspiration, which is based on the assumption that the soil is always at field capacity.

Approximately 20 percent of the watershed is cultivated, 65 percent is in pasture or range, and the balance is classified as miscellaneous. Since the Blaney-Criddle method is only an estimate, the percentages of cultivated and pasture or range land areas can be adjusted to 100 percent. This results in 24 percent of the basin area in cultivation, and 76 percent in pasture or range. Visual inspection of the basin revealed, at the present time, that most of the cultivated land is used for cotton and sorghum.

Consumptive use by pasture in the Chickasha area is about 38 inches per year. An average of the consumptive use of cotton and sorghum for the same area is about 25 inches per year. Consumptive use for the entire basin is approximately 35 inches per year.

Soil moisture data for watershed R-1 of the Washita River Experimental Watershed System was obtained from appendices of Annual Research Reports of the Southern Plains Hydrology Research Center. R-1 covers an area of 17.8 acres that is approximately 11 miles north of the Little Washita River Watershed. R-1 was chosen for soil moisture calculations because of its length of record (January 1965 through June 1974), instrumentation (two neutron access tubes to a depth of 51 inches, a rain gauge on the watershed, and a V-notch weir at the outlet of the watershed), and land use. R-1 is classified as range and approximately two-thirds of the Little Washita River Watershed is classified as range during the study period.

Comsumptive use, or evapotranspiration, was calculated by the following equation:

$$cu = ppt + \ sm - Q \qquad (4)$$

where:

cu = consumptive use

ppt = precipitation since last soil moisture measurement

sm = change in soil moisture since last soil moisture measurement

Q = runoff since last soil moisture measurement

The results of these calculations are listed in Table II.

TABLE II

ANNUAL CONSUMPTIVE USE, 1965-1973, LITTLE WASHITA RIVER WATERSHED

YEAR	CU
1965	28.84
1966	24.65
1967	30.26
1968	28.44
1969	34.60
1970	25.69
1971	21.69
1972	21.09
1973	41.73

Consumptive use exceeded precipitation for the period 1965 through 1970, excluding 1968, and was less than precipitation from 1971 through 1973. For all years except 1972, consumptive use is greater than precipitation whenever precipitation is less than the 10 year average. In 1972, precipitation is close to, but below, the 10 year average and consumptive use is less than precipitation.

Evapotranspiration can be estimated by subtracting stream discharge from precipitation if it is assumed that inflow to the basin is limited to precipitation, and outflow is limited to stream flow and evapotranspiration. Using this method, evapotranspiration averaged 27.25 inches or 95 percent of rainfall annually. Years of low rainfall are characterized by the highest percentage of precipitation becoming evapotranspiration (Table III). On a monthly basis, evapotranspiration ranged from 91 to 98 percent of precipitation; the highest values occurring during August, September, and October. September had the highest average monthly evapotranspiration, 4.29 inches, and December and January the lowest, 0.88 and 0.91 inches, respectively.

TABLE III

ANNUAL AND AVERAGE MONTHLY EVAPOTRANSPIRATION IN INCHES, 1965-1974, LITTLE WASHITA RIVER WATERSHED

YEAR	E-T	% PPT	MONTH	E-T	% PPT
1965	24.44	95	J	0.91	91
1966	18.94	97	F	1.04	92
1967	25.65	97	M	1.80	92
1968	32.64	96	A	2.92	94
1969	26.20	93	M	3.68	95
1970	19.89	97	J	2.43	92
1971	30.14	96	J	2.09	94
1972	24.96	96	A	2.80	98
1973	40.50	90	S	4.29	98
1974	29.17	92	O	3.24	96
			N	1.18	93
AVE	27.25	95	D	0.88	91

Surface Water

Stream flow for the study period averaged 1.57 inches annually (Table IV), or five percent of precipitation. The highest stream discharge occurred during 1973 and the lowest in 1966, 4.53 and 0.66 inches, respectively. These years also coincide with the high and low annual rainfalls, respectively. Monthly average stream flow is greater from March through June than other months of the year.

Groundwater

Hydrologic Properties of the Geologic Formations.

Rocks of the El Reno Group, except the Duncan Sandstone, generally yield only a few gallons of water per day to wells. The Duncan Sandstone is under artesian conditions and is capable of yielding over 100 gallons per minute to some wells (Tanaka and Davis, 1963). The Chickasha Formation yields small to moderate amounts of water to wells that penetrate lenticular sandstones and fractures in shale, but in overall character it is relatively impermeable (Davis, 1955). The Dog Creek Shale and Blaine Formation do not generally yield water, although solution cavities may yield water locally (Tanaka and Davis, 1963). In the study area, rocks of the El Reno Group act as a lower confining unit.

The Marlow Formation has a maximum well yield of 1-2 gallons per minute from sandy beds in the formation (Tanaka and Davis, 1963). The Rush Springs Sandstone will yield 100

TABLE IV

MONTHLY AND ANNUAL STREAM DISCHARGE IN INCHES, 1965-1974, LITTLE WASHITA RIVER WATERSHED

	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	AVE
J	0.13	0.06	0.05	0.06	0.08	0.05	0.05	0.07	0.17	0.16	0.09
F	0.08	0.07	0.04	0.09	0.12	0.06	0.06	0.06	0.11	0.19	0.09
M	0.08	0.11	0.06	0.14	0.15	0.12	0.04	0.06	0.39	0.38	0.15
A	0.16	0.12	0.26	0.12	0.18	0.15	0.02	0.23	0.29	0.34	0.19
M	0.15	0.09	0.07	0.22	0.68	0.08	0.04	0.14	0.23	0.40	0.21
J	0.20	0.02	0.03	0.29	0.31	0.04	0.14	0.03	0.88	0.24	0.20
J	0.01	0.01	0.03	0.09	0.03	0.0	0.01	0.01	1.04	0.04	0.13
A	0.22	0.04	0.0	0.01	0.03	0.0	0.10	0.0	0.18	0.13	0.07
S	0.08	0.06	0.02	0.09	0.10	0.11	0.11	0.0	0.43	0.10	0.11
O	0.05	0.02	0.05	0.10	0.04	0.02	0.43	0.29	0.31	0.18	0.15
N	0.04	0.03	0.03	0.09	0.05	0.03	0.05	0.15	0.27	0.20	0.09
D	0.06	0.04	0.04	0.08	0.06	0.04	0.11	0.06	0.23	0.16	0.09
TOT	1.26	0.66	0.68	1.38	1.83	0.70	1.16	1.10	4.53	2.52	1.57

to over 1,000 gallons per minute to properly constructed wells (Tanaka and Davis, 1963). The Rush Springs can be considered to behave as a homogeneous, fine-grained sandstone under water-table conditions (Davis, 1955).

The Cloud Chief Formation is not capable of yielding more than a few gallons of water per day to wells. Almost all existing solution channels and cavities have either collapsed or have been filled with clay and silt (Tanaka and Davis, 1963).

Alluvial deposits are found along almost the entire reach of the Little Washita River and along its major tributaries. The hydrologic properties vary locally as a result of differences in saturated thickness and extent, but these deposits have a pronounced effect on baseflow recession due to their permeability and proximity to stream channels. Alluvial deposits represent sediments with the highest permeability in the basin, allowing rapid infiltration of overland flow and precipitation, seepage of ground water from surrounding bedrock, and infiltration of stream flow when stream stage is higher than the water table than in the alluvium (Naney, 1984).

Recharge and Discharge. The source of recharge to the water-bearing formations in the study area is precipitation on the basin. Ground-water divides are assumed to coincide with drainage divides, therefore underflow into the basin is not considered.

Recharge is below average in the outcrop areas of the

Marlow and younger formations. These rocks are relatively impermeable, their associated soils are clayey and tight, and surface drainage is good (Davis, 1955). The major source of recharge to the Marlow Formation is downward percolation of water from the Rush Springs Sandstone (Tanaka and Davis, 1963). The Rush Springs Sandstone is recharged by direct precipitation on the outcrop and to a lesser extent by water in ponds. Recharge may also occur whenever the water table is higher in streams and alluvium than in the Rush Springs Sandstone. Alluvial deposits are recharged by seepage from surrounding formations, direct precipitation, and infiltration from streams when the level of the water in the channel is above the water table.

Discharge of water from the basin occurs as evapotranspiration, streamflow, underflow, and pumpage. Underflow occurs in the vicinity of the stream gaging station and can be assumed to be negligible because the alluvium is relatively narrow as compared to the size of the drainage basin, and the rocks in that vicinity are fairly impermeable. Discharge from wells can be considered relatively minor due to a low population density and small land area that is irrigated on a regular basis.

Baseflow Evaluation

Instrumentation

A number of observation wells are located within the basin, some are equipped with continuous recorders and others are measured manually about once a month. A continuous recording river stage meter is located on the Little Washita River below approximately 208 square miles of drainage area. This instrument has been in operation since April 1963 and is maintained by the U. S. Department of Agriculture. The U. S. Weather Bureau has installed approximately 36 rain gauges on a 3-mile square grid within the watershed and records are continuous since 1961. Long-term records of evaporation used by Garton and Criddle (1955) are from a Class A Pan located near Chickasha, about 5.5 miles north of the stream gaging station.

Seepage Measurements

Seepage measurements were taken by the author along the main stream of the Little Washita River and its tributaries over a two-day period in February, 1984. No rainfall was observed in the basin at least five days prior to the field work. Stream discharge was recorded at 126 sites within the drainage basin. Each site was chosen at the intersection of a section road and stream, and to obtain good areal coverage of the basin. Of the 126 sites, 44 were observed with stream flow and discharge was recorded. Stream velocity was determined with a Pygmy current meter at the six-tenths depth in the deepest part of the channel. A cross-section of the stream channel at the measuring point was also recorded to calculate channel area. Drainage divides were drawn by the author on 7.5 minute quadrangles and drainage area was determined for each measuring station with an APPLE II microcomputer and APPLE Graphics Tablet.

Drainage basin areas ranged in size from 0.05 to 138 square miles. Basins with areas of less than about two square miles did not contribute to baseflow. This is probably due to their stream channels not intersecting the water table because of their topographically high position. Of the basins that did contribute to baseflow, the average ground-water runoff per unit area was 0.22 cubic feet per second per square mile or 1.42 X 10^6 gallons per day per square mile.

Ground-water Rating Curves

True ground-water rating curves for the basin were not constructed, but periodic water-table measurements were available for three wells in alluvium along the main stream of the Little Washita River from September 1966 through December 1974. General trends of high and low baseflow can be inferred from the well hydrographs (Figures 8, 9, and 10) based on the same principles used in ground-water rating curves. Periods of high ground-water stage are indicative of increased baseflow, but the effects of evapotranspiration must be considered. The water level data were collected and put on magnetic tape by personnel at the U. S. Department of Agriculture Research Station, Chickasha, Oklahoma.

The three hydrographs follow the same general pattern

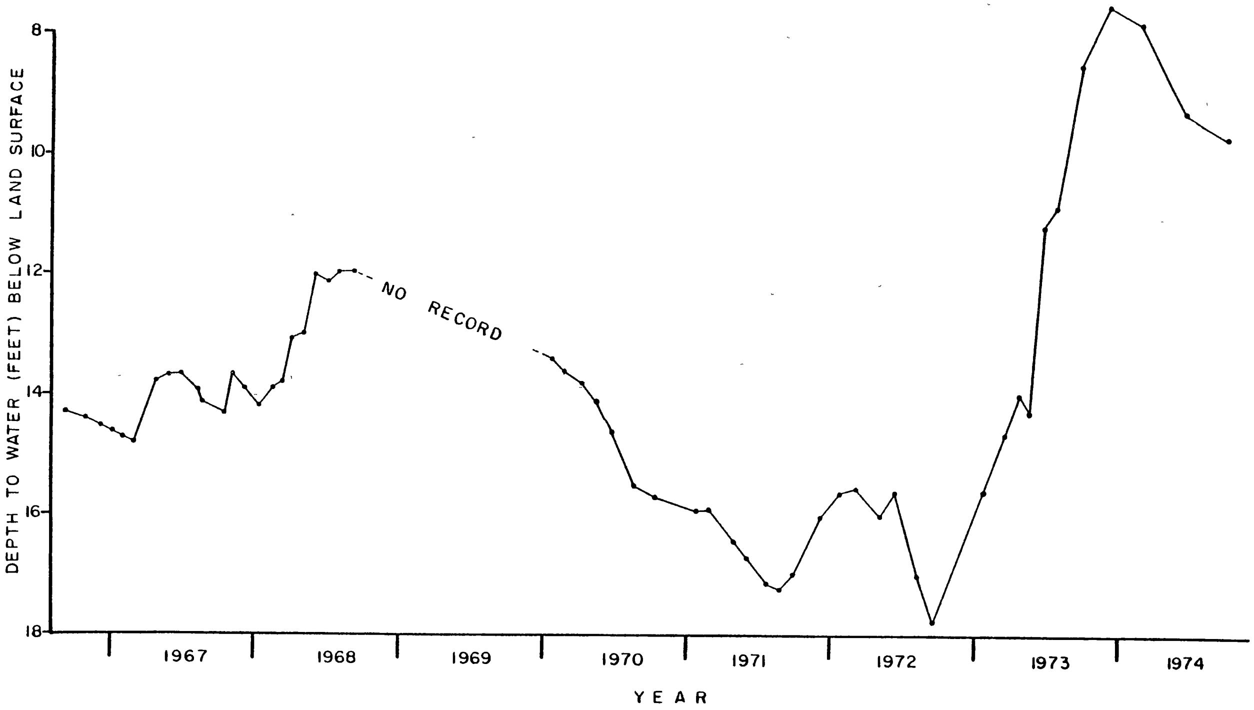


Figure 8. Hydrograph of Well 320, Little Washita River Watershed

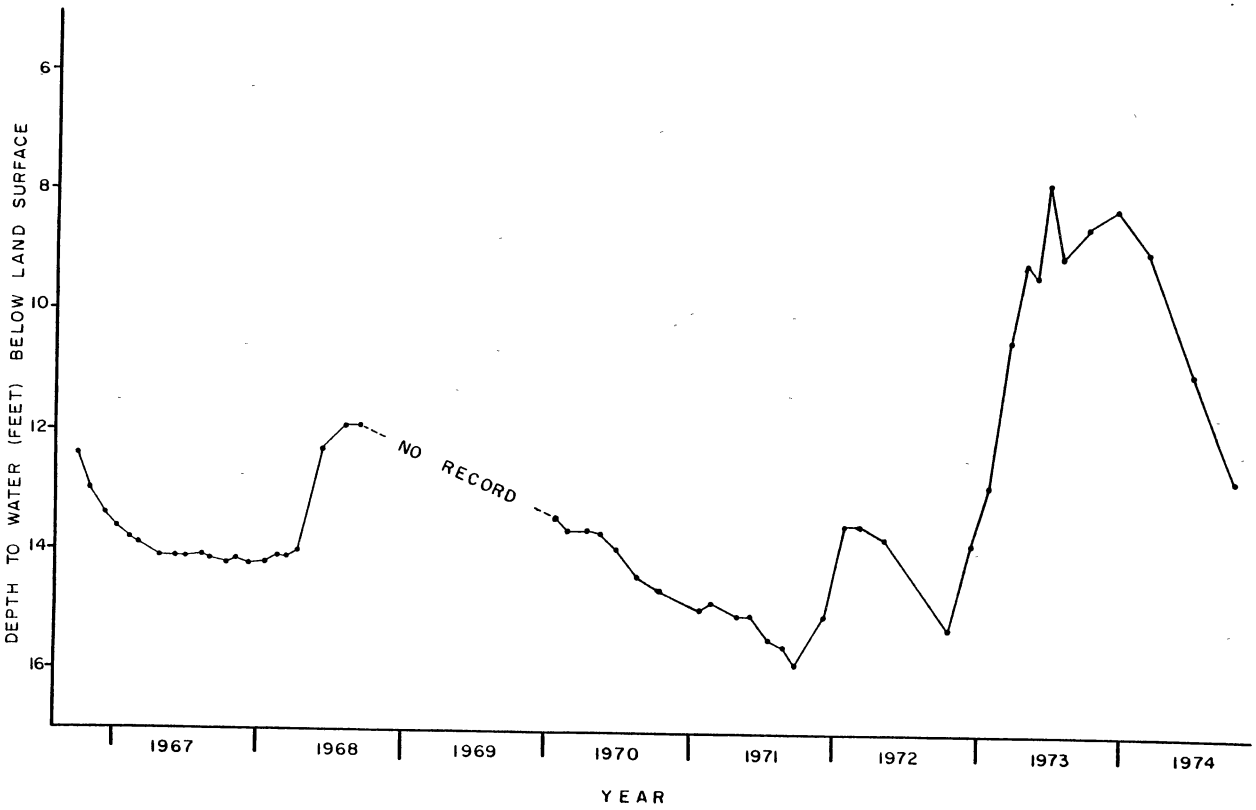


Figure 9. Hydrograph of Well 323, Little Washita River Watershed

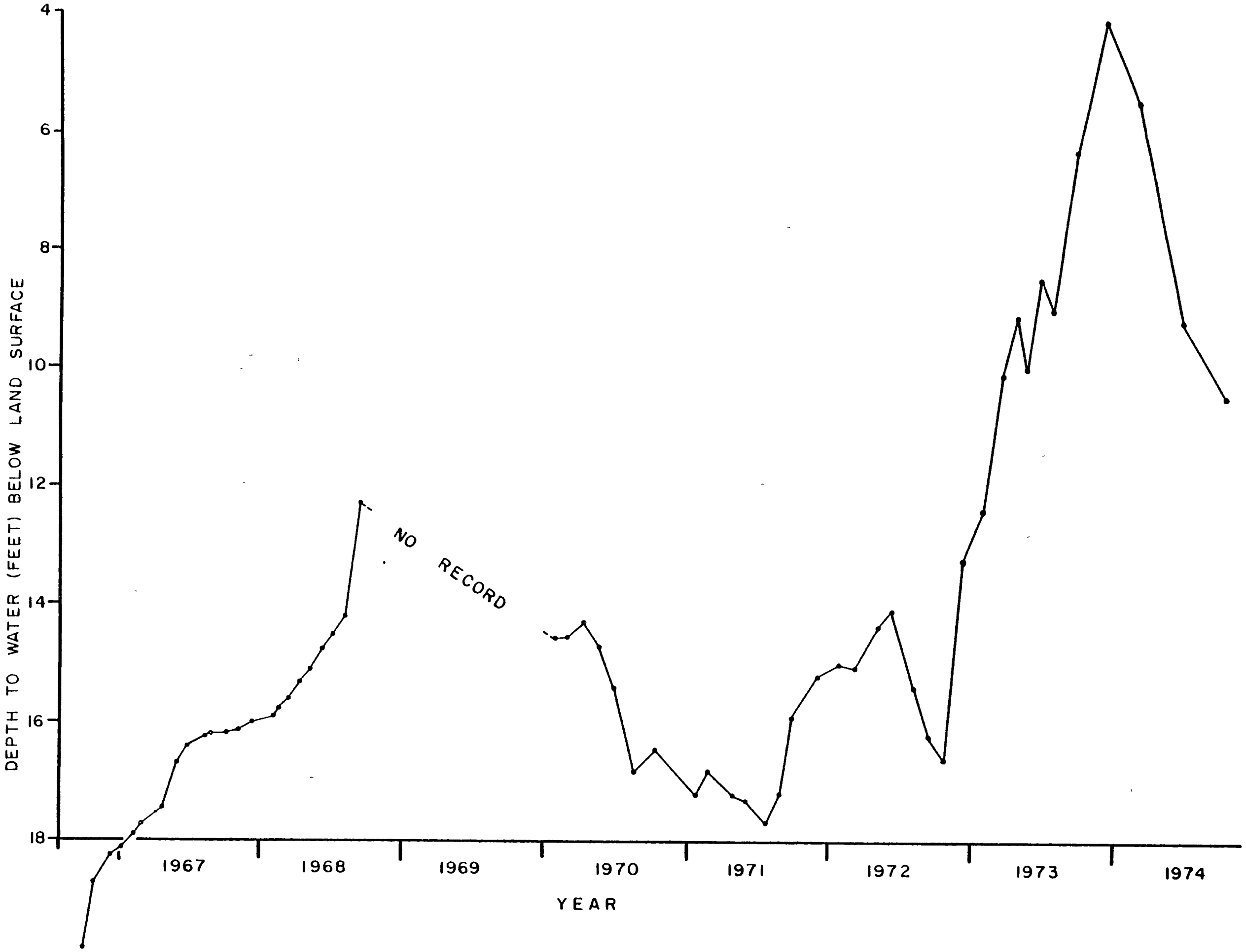


Figure 10. Hydrograph of Well 324, Little Washita River Watershed

for the years of record. On an annual basis, ground-water stage is lowest during the months of August, September, and October. This corresponds with an expected high rate of evapotranspiration and soil moisture deficit for those months. Ground-water stage increases during the winter and spring months in response to a decrease in evapotranspiration and an increase in ground-water storage.

On an overall basis, the period prior to 1970 shows no major trends except an increase in ground-water stage at the end of 1968 through the beginning of 1969. Starting with the beginning of 1970 through the latter part of 1972, the hydrographs show a general decline in water level. Ground-water stage increases dramatically from the end of 1972 through 1973, and begins a sharp decline in 1974.

Ground-water runoff should follow about the same general patterns as ground-water stage, but evapotranspiration and a lag time between ground-water stage and runoff must be accounted for. From the trends exhibited by the well hydrographs, ground-water runoff rates should be low in the latter parts of each year, and higher during the winter and spring months. The annual variations would be expected to be superimposed on a general decline from 1970 through 1972, and a general increase through 1973.

Computer Baseflow Separation

Effective ground-water recharge, or baseflow, for calendar years 1965 through 1974 was determined by computer baseflow separation (Table V). The values obtained by the three methods are within about 10 percent of each other for each year, except 1969 where the local minima value is about 20 percent below the sliding interval and fixed interval values. The local minima method is also associated with the lowest annual value for each of the years studied. The fixed interval and sliding interval methods alternate between the high and middle values for annual baseflow. The fixed interval method was chosen to represent effective ground-water recharge to the Little Washita River Watershed (Table VI).

TABLE V

BASEFLOW, IN INCHES, BY COMPUTER SEPARATION, 1965-1974, LITTLE WASHITA RIVER WATERSHED

YEAR	F-I	S-I	L-M
1965	0.52	0.53	0.51
1966	0.41	0.40	0.40
1967	0.31	0.29	0.29
1968	0.66	0.65	0.64
1969	0.90	0.86	0.74
1970	0.39	0.40	0.38
1971	0.36	0.39	0.35
1972	0.45	0.42	0.40
1973	2.12	2.14	2.00
1974	1.62	1.61	1.54
TOTAL	7.74	7.69	7.25
AVE	0.77	0.77	0.72

TABLE VI

MONTHLY AND ANNUAL BASEFLOW (FIXED INTERVAL), IN INCHES, 1965-1974, LITTLE WASHITA RIVER WATERSHED

	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	AVE
J	0.08	0.04	0.04	0.04	0.07	0.04	0.04	0.05	0.09	0.15	0.06
F	0.06	0.05	0.04	0.06	0.09	0.05	0.04	0.05	0.10	0.14	0.07
M	0.06	0.06	0.04	0.09	0.11	0.09	0.04	0.06	0.18	0.23	0.10
A	0.07	0.07	0.06	0.08	0.11	0.07	0.02	0.05	0.21	0.20	0.09
M	0.05	0.07	0.03	0.07	0.24	0.05	0.01	0.08	0.12	0.21	0.09
J	0.08	0.02	0.01	0.10	0.09	0.02	0.01	0.02	0.22	0.12	0.07
J	0.0	0.0	0.01	0.05	0.02	0.0	0.0	0.01	0.24	0.04	0.04
A	0.0	0.01	0.0	0.01	0.01	0.0	0.01	0.0	0.17	0.04	0.02
S	0.01	0.02	0.0	0.01	0.02	0.0	0.01	0.0	0.17	0.08	0.03
O	0.02	0.01	0.01	0.03	0.03	0.02	0.06	0.01	0.21	0.09	0.05
N	0.04	0.02	0.03	0.05	0.05	0.02	0.04	0.07	0.20	0.18	0.07
D	0.05	0.04	0.04	0.07	0.06	0.03	0.08	0.05	0.21	0.14	0.08
TOT	0.52	0.41	0.31	0.66	0.90	0.39	0.36	0.45	2.12	1.62	0.77
% Q	42	62	46	47	49	56	31	40	47	64	48
% PPT	2	2	1	2	3	2	1	2	5	5	2.5

Ten year average baseflow was 0.77 inches. The lowest annual baseflow, 0.31 inches, occurred in 1967, a year of near normal rainfall preceded by the driest year (Figure 7). The highest annual baseflow was during 1973, 2.12 inches, which was the year of greatest precipitation. The pattern of annual baseflow closely follows the two year moving average of precipitation, indicating annual baseflow is dependent upon antecedent rainfall.

Figure 11 is a graphical representation of average monthly rainfall and baseflow for the 10-year period, 1965 to 1974. This figure demonstrates the relationship between the time of year and amount of baseflow. November, December, January, and February are months with about equal baseflow, rainfall, and evapotranspiration. March, April, and May have nearly equal baseflow, but rainfall increases greatly from March to May. This indicates an increase in evapotranspiration. Rainfall and baseflow decrease throughout June and July. August receives moderate rainfall, but the smallest baseflow of any month. This could be an indication of soil moisture deficit, increased evapotranspiration and storm characteristics. Summer rainstorms are generally of short duration and high intensity which promotes rapid surface runoff. September receives the highest rainfall of any month, but very little baseflow. The same factors affecting baseflow in August are probably true for September. Rainfall amount decreases from September to October, but baseflow increases. This indicates both decreasing soil moisture deficit and evapotranspiration.

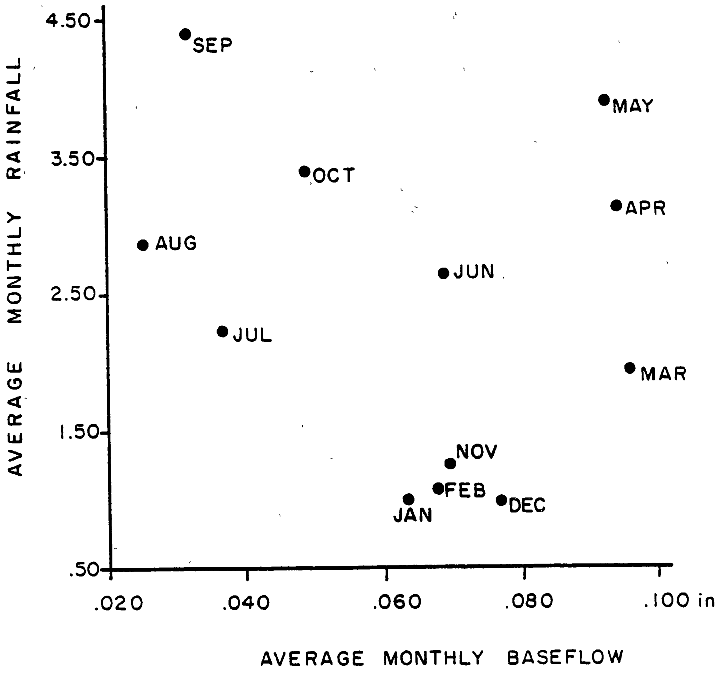


Figure 11. Average Monthly Rainfall and Average Monthly Baseflow (Fixed Interval), 1965-1974, Little Washita River Watershed

Baseflow as a percent of rainfall for the study period is listed in Table VI. This factor averages 2.5 percent and has a range from 1.2 to 5.1 percent. The highest value occurred the year after the largest annual rainfall, indicating an increase in ground-water storage and a two-year relationship between baseflow and precipitation. The two years of least precipitation (1967, 1971) are characterized by the lowest ratios.

Summary

The Little Washita River Watershed covers 208 square miles in the Redbeds Plains of the Central Lowlands Province. Normal annual precipitation is 28 inches with the majority of rainfall occurring during spring and summer. The water-bearing materials consist of sandstone, siltstone, shale, and unconsolidated alluvium.

Baseflow for the watershed was calculated by the computer program for the period 1965 through 1974. The three separation techniques yield values of annual baseflow within about 10 percent. The local minima method consistently gives the lowest amount and the fixed and sliding interval methods alternately generate the high and middle figures. The fixed interval method was chosen to be representative of the basin. Baseflow varied from 0.31 inches to 2.12 inches and averaged 0.77 inches. The average percent of rainfall was 2.5. The pattern of annual baseflow closely follows the two-year moving average of precipitation.

Seepage measurements were made within the drainage basin in February, 1984. The result of the measurements is an average regional baseflow rate of 1.42×10^6 gallons per day per square mile. The two-year rainfall pattern prior to the seepage measurements (1982-1983) is similar to the 1973-1974 rainfall pattern. Baseflow calculations by the computer program for 1973 and 1974 are within 20 percent of the average seepage measurement value.

Fluctuations in the water table for the period September 1966 through December 1974 imply low ground-water runoff during August, September, and October. This pattern holds true for most of that period (Figure 12). The general trend of high rates of baseflow during 1973 and the beginning of 1974 is also evident in Figure 12.

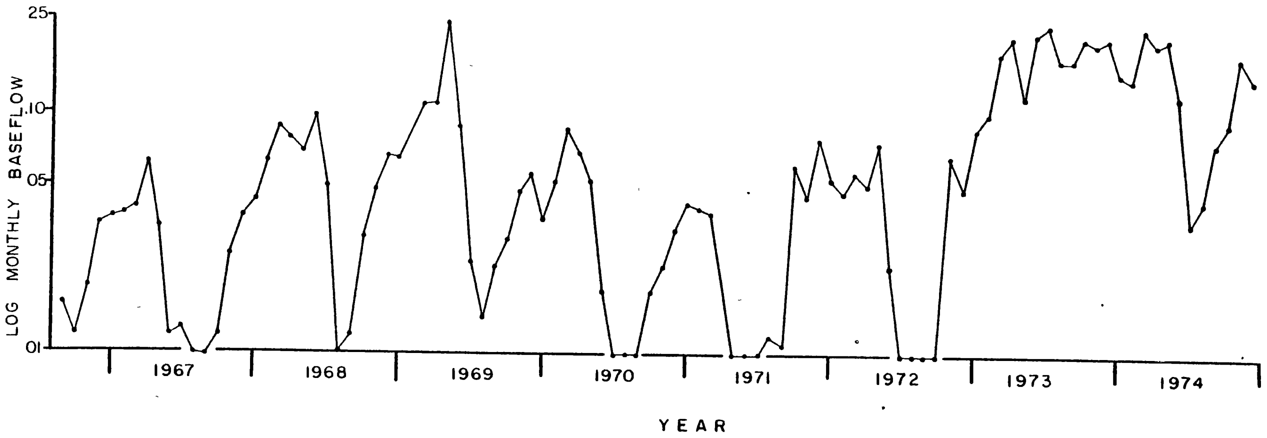


Figure 12. Monthly Baseflow (Fixed Interval), in Inches, 1966-1974, Little Washita River Watershed

CHAPTER V

PANTHER CREEK BASIN, ILLINOIS

The following text is summarized from Schicht and Walton (1961) unless otherwise referenced.

Geography

Panther Creek Basin is located between approximately 40° 44' and 40° 54' north latitude and 88° 52' and 89° 07' west longitude in north-central Illinois (Figure 13). The drainage basin covers about 95 square miles, the majority of its area in Woodford County. The elevation at the upper end is 770 feet; the gaging station is at 660 feet.

North-central Illinois is located in the north temperate zone. The climate is characterized by warm summers and moderately cold winters. Mean annual snowfall is 24 inches, with an average of more than 28 days a year having at least one inch of ground snow cover. The average growing season is about 170 days. Mean annual temperature at the U. S. Weather Bureau station at Minonk is 51°F and normal annual precipitation is 33.6 inches, with the majority of rainfall occurring in April, May, June, August, and September.

Prior to development, the water table was close to land

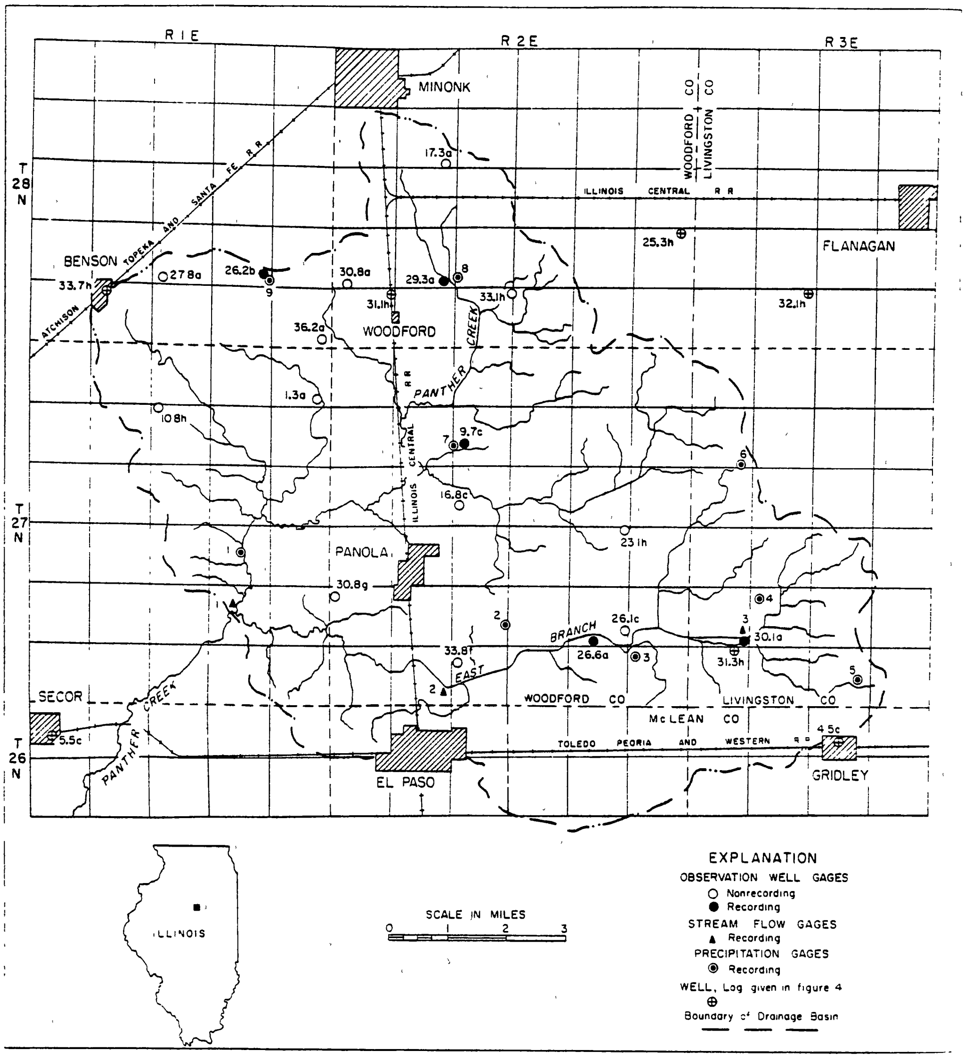


Figure 13. Location of Panther Creek Basin (from Schicht and Walton, 1961, p. 12)

surface and many shallow ponds, swamps, and poorly drained areas were present. Extensive surface and subsurface drainage was necessary to permit agricultural activity. Ponds and low-lying swampy areas were eliminated with the new drainage practices.

Panther Creek Basin is rural and agriculturally oriented. About 80 percent of the basin is cleared and cultivated. The remainder of the land is pasture, woodland, and farm lots.

Geology

The basin lies in the Till Plains Section ot the Central Lowland physiographic province (Fenneman, 1914). Leighton, et al (1948) further divide Illinois into more detailed physiographic divisions and place the basin in the Bloomington Ridged Plain area of the Till Plains Section. This area is characterized by low, broad morainic ridges with intervening wide stretches of relatively flat or gently undulatory ground moraine of Wisconsin age.

Four soil groups are found in Panther Creek Basin: upland prairie, upland timber, swamp and bottomland, and terrace soils. Upland prairie soils are the predominant group and are found throughout the basin except for small areas adjacent to Panther Creek and East Branch.

Upland prairie soils are very dark gray to dark brown silt loams. Surface drainage is moderate and permeability is moderately slow. Artificial drainage is often required for agricultural development. Beneath the subsoils to depths of 40 to 60 inches, the materials are compact calcareous or plastic calcareous glacial tills. The permeability of these materials is moderate to slow.

The stratigraphy of Panther Creek Basin consists of thick glacial deposits lying unconformably on top of Pennsylvanian bedrock. The unconsolidated deposits average 100 feet thick and may reach a thickness of over 290 feet along the eastern edge of the basin. These deposits are mainly unstratified clayey materials (glacial till), but lenses of sand and gravel up to 40 feet thick commonly occur. The bedrock formations consist of shale, with alternating thin beds of limestone, sandstone, siltstone, fire clay, and coal.

Hydrology

Precipitation

Average annual precipitation from 1950 to 1959 was 32.66 inches. April, May, June, July, and August were the months of greatest precipitation, each had an average of more than three inches (Table VII).

The wettest year of the study period, 1951, had an annual rainfall of 44.24 inches, more than 10 inches above average. The year of lowest rainfall, 1956, was about 13 inches below average. Annual rainfall forms a general pattern of one or two years of above average precipitation followed by one or two years of below average precipitation

TABLE VII

MONTHLY AND ANNUAL PRECIPITATION, IN INCHES, 1950-1959, PANTHER CREEK BASIN

	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	AVE
J	4.90	1.41	1.01	1.36	1.23	1.92	0.14	1.51	1.02	2.00	1.65
F	2.71	2.88	1.19	1.19	2.11	1.50	1.45	1.16	0.45	1.76	1.64
M	1.13	3.58	2.73	4.38	3.95	1.55	0.73	1.64	0.33	3.48	2.35
A	5.99	4.20	4.66	1.94	4.46	4.28	2.39	7.47	2.56	4.13	4.21
M	1.07	2.93	3.36	2.06	4.58	3.53	3.24	4.42	2.57	4.00	3.18
J	6.91	7.16	7.07	3.52	2.58	2.81	0.89	4.64	5.67	1.12	4.24
J	6.42	8.40	2.18	6.29	4.42	3.12	3.22	2.28	6.05	3.01	4.54
A	0.62	4.11	4.47	1.22	5.18	4.33	3.23	1.96	4.24	1.96	3.13
S	3.83	2.34	1.43	2.32	0.81	1.86	1.08	1.31	1.82	3.98	2.08
O	0.90	2.99	0.64	0.71	3.42	3.71	0.40	5.14	0.64	4.88	2.34
N	1.81	2.70	2.31	0.72	1.75	0.83	1.54	2.08	2.62	1.91	1.83
D	0.78	1.54	1.57	2.53	1.61	0.35	1.18	2.75	0.49	1.96	1.48
TOT	37.07	44.24	32.62	28.24	36.10	29.79	19.49	36.36	28.46	34.19	32.66

(Figure 14).

Evapotranspiration

The inflow and outflow assumptions made for the Little Washita River Watershed are applied to Panther Creek Basin. Evapotranspiration ranged from 58 to 95 percent and averaged 77 percent of precipitation annually in Panther Creek Basin (Table VIII). Evapotranspiration was the lowest percentage of precipitation during the wettest year, 1951, and the highest percentage of precipitation during the driest year, 1956. On a monthly basis, evapotranspiration was 46 to 98 percent of precipitation, and greatest from August through December.

Schicht and Walton (1961) calculated evapotranspiration for Panther Creek Basin for 1951, 1952, and 1956. They used ground-water rating curves and water budget equations. Their results were 24.71, 23.94, and 18.75 inches, respectively, or 56, 73, and 96 percent of precipitation, respectively.

Surface Water

Stream flow for the study period averaged 7.93 inches annually (Table IX), or 24 percent of precipitation. The highest stream discharge occurred during 1951 and the lowest in 1956, 18.42 and 0.98 inches, respectively. These were also the years of greatest and least precipitation, respectively. Monthly average stream flow was greatest in spring

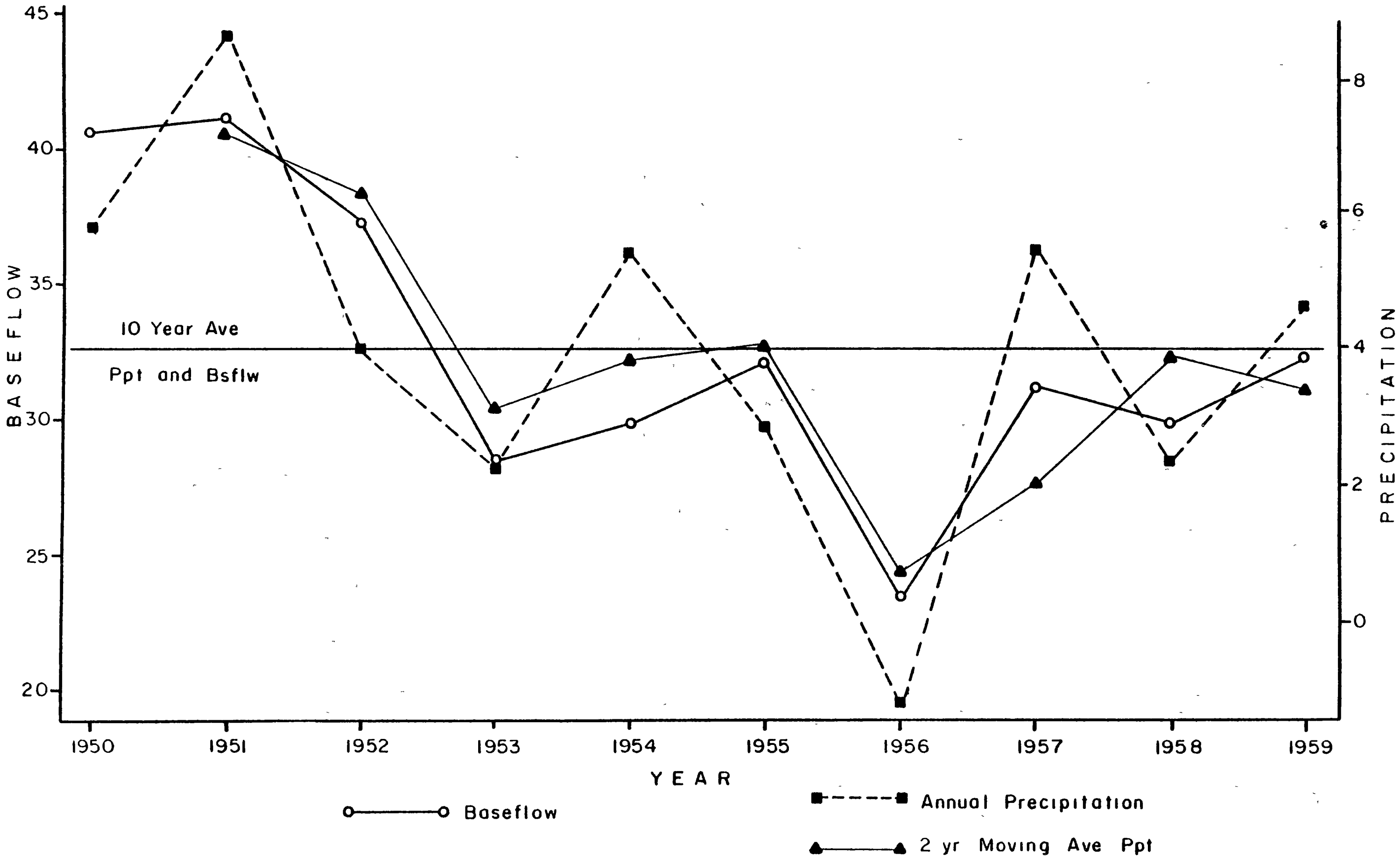


Figure 14. Annual Baseflow (Fixed Interval) and Annual Precipitation, in Inches, 1950-1959, Panther Creek Basin

TABLE VIII

ANNUAL AND AVERAGE MONTHLY EVAPOTRANSPIRATION, IN INCHES, 1950-1959, PANTHER CREEK BASIN

YEAR	E-T	% PPT	MONTH	E-T	% PPT
1950	23.20	62	J	1.01	61
1951	25.82	58	F	0.76	46
1952	22.81	70	M	1.45	62
1953	24.14	85	A	2.57	61
1954	30.04	83	M	2.24	70
1955	23.73	80	J	2.94	69
1956	18.51	95	J	3.54	78
1957	30.41	84	A	2.90	93
1958	22.58	79	S	2.05	98
1959	26.02	76	O	2.28	97
			N	1.64	90
AVE	24.73	77	D	1.36	92

TABLE IX

MONTHLY AND ANNUAL STREAM DISCHARGE, IN INCHES, 1950-1959, PANTHER CREEK BASIN

	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	AVE
J	2.8	0.77	1.2	0.15	0.06	1.1	0.01	0.06	0.20	0.10	0.64
F	1.5	3.0	0.61	0.23	0.06	0.95	0.22	0.04	0.35	1.8	0.88
M	1.5	1.3	2.0	1.0	0.80	0.75	0.05	0.09	0.28	1.2	0.90
A	2.8	2.5	2.6	0.93	1.8	1.5	0.06	2.0	0.40	1.8	1.64
M	0.67	0.94	0.88	0.38	1.1	0.80	0.42	2.0	0.16	2.1	0.94
J	1.5	2.4	2.1	0.56	1.6	0.72	0.11	1.1	2.2	0.66	1.30
J	2.7	4.8	0.27	0.76	0.08	0.13	0.07	0.23	0.83	0.10	1.00
A	0.18	0.39	0.06	0.03	0.23	0.04	0.02	0.02	1.3	0.02	0.23
S	0.10	0.13	0.02	0.01	0.02	0.01	0.0	0.0	0.04	0.01	0.03
O	0.03	0.29	0.01	0.01	0.08	0.02	0.0	0.07	0.02	0.10	0.06
N	0.03	1.5	0.02	0.02	0.09	0.02	0.01	0.10	0.06	0.08	0.19
D	0.06	0.40	0.04	0.02	0.14	0.02	0.01	0.24	0.04	0.20	0.12
TOT	13.87	18.42	9.81	4.10	6.06	6.06	0.98	5.95	5.88	8.17	7.93

and early summer, and lowest in autumn.

Ground Water

Hydrologic Properties of the Geologic Formations.

Due to the complex glacial history of the unconsolidated deposits, the hydrologic character of the till varies greatly both horizontally and vertically. Most wells obtain water from the lenses or layers of sand and gravel that are interbedded in the clayey materials. Locally, ground-water conditions are extremely variable, but small private supplies are available throughout the area (Horberg, 1950). However, considering the basin as a whole, the character of the till in relation to the occurrence and movement of ground water is fairly uniform.

The bedrock formations have low porosities and permeabilities and yield only small amounts of water to wells. Water is transmitted mainly through interconnected fractures, joints, and bedding planes. These rocks act as a lower impermeable boundary.

Recharge and Discharge.

Infiltration ot precipitation is the only source of recharge to Panther Creek Basin. Recharge occurs when the water table rises, or declines less than is necessary to balance ground-water runoff and evapotranspiration. Monthly ground-water recharge is generally largest in spring months of heavy rainfall and least in summer and fall months. Snow cover and frozen ground reduce infiltration rates and therefore recharge during those periods.

Ground-water discharge occurs as underflow, ground-water evapotranspiration, and ground-water runoff. Schicht and Walton (1961) calculated underflow to be about 0.01 cubic feet per second and determined that figure to be low enough to omit it from later calculations. Ground-water evapotranspiration was also calculated by Schicht and Walton (1961) for 1951, 1952, and 1956. It was determined to be 1.19, 2.01, and 0.14 inches, respectively. Ground-water runoff was separated from stream hydrographs through the use of the baseflow separation program.

Baseflow Evaluation

Instrumentation

Five observation wells were equipped with continuous recording gages during the study period. A number of observation wells not equipped with recording gages were measured periodically. All of the wells measure water levels in the glacial till.

Mean daily stream discharge was measured by the U. S. Geological Survey during the study period at a gaging station on Panther Creek, located below 95 square miles of drainage area. The Meteorology Section of the Illinois State Water Survey, in cooperation with the Pfitser Hybrid Corn Company of El Paso, Illinois, measured precipitation in the basin during the study period. Between 1950 and 1958 the density of rain gages was about 10.6 square miles per gage. Figure 13 shows the locations of the instruments.

Ground-water Rating Curves

Ground-water runoff was determined through the use of ground-water rating curves by Schicht and Walton (1961) and is presented in Table X.

Ground-water runoff was highest in 1952, a year of average rainfall preceded by the year of largest annual precipitation. Ground-water runoff during the dry year, 1956, is an order of magnitude less than baseflows during 1951 and 1952.

Computer Baseflow Separation

The program developed by Pettyjohn and Henning (1979) was applied to 10 years of stream flow data for Panther Creek Basin. This period covers the years 1950 through 1959. The computed values of effective ground-water recharge for 1951, 1952, and 1956 are compared to estimates of baseflow determined by Schicht and Walton (1961) for the same time period (Table X). The 10 year study period is used to show long-term relationships between rainfall and baseflow.

For the years 1951, 1952 and 1956, the local minima method yields values of baseflow as much as 42 percent less than either the fixed interval or sliding interval methods. The fixed interval and sliding interval methods are within

TABLE X

MONTHLY AND ANNUAL GROUND-WATER RUNOFF, IN INCHES, 1951, 1952, 1956, PANTHER CREEK BASIN

	S&W	F-I	S-I	L-M
1951				
J	0.16	0.21	0.22	0.11
F	0.15	0.97	1.1	0.87
M	0.30	0.74	0.75	0.63
A	1.44	1.5	1.5	1.3
M	0.82	0.60	0.65	0.54
J	0.56	0.69	0.78	0.59
J	1.13	1.4	1.1	0.57
A	0.22	0.16	0.16	0.16
S	0.10	0.09	0.09	0.06
O	0.22	0.15	0.16	0.11
N	0.55	0.58	0.70	0.44
D	0.35	0.30	0.30	0.32
ANNUAL	6.00	7.39	7.51	5.70
1952				
J	0.77	0.76	0.76	0.63
F	0.57	0.47	0.49	0.48
M	1.57	1.4	1.3	1.1
A	1.94	1.4	1.4	1.2
M	0.82	0.66	0.67	0.56
J	1.10	0.88	0.84	0.59
J	0.27	0.23	0.23	0.20
A	0.04	0.04	0.03	0.03
S	0.02	0.02	0.02	0.01
O	0.01	0.01	0.01	0.01
N	0.02	0.01	0.01	0.01
D	0.03	0.03	0.03	0.02
ANNUAL	7.16	5.91	5.79	4.84

TABLE X (Continued)

	S&W	F-I	S-I	L-M
1956				
J	0.01	0.01	0.01	0.01
F	0.08	0.03	0.04	0.03
M	0.04	0.04	0.04	0.03
A	0.03	0.03	0.02	0.02
M	0.08	0.10	0.12	0.04
J	0.07	0.08	0.07	0.04
J	0.03	0.02	0.02	0.01
A	0.01	0.0	0.0	0.0
S	0.0	0.0	0.0	0.0
O	0.0	0.0	0.0	0.0
N	0.01	0.01	0.0	0.0
D	0.01	0.01	0.01	0.01
ANNUAL	0.37	0.33	0.33	0.19

10 percent of each other for those same years, neither method producing consistently high or low values. The fixed interval method is chosen to represent baseflow for the basin (Table XI).

Annual precipitation and baseflow for 1950 through 1959 are shown graphically in Figure 14. Baseflow varies from a high of 7.39 inches in 1951 to a low of 0.33 inches in 1956; a difference of over one order of magnitude. The years 1951 and 1956 also correspond to the highest and lowest annual rainfalls, respectively.

The preceding year's amount of precipitation has an effect on annual baseflow. This is demonstrated by the line representing the 2-year moving average ot rainfall. This line follows the baseflow pattern more closely than the line representing annual precipitation. For Panther Creek Basin, which is located in a humid region, annual baseflow is a function of the year's and preceding year's amount of rainfall.

The relationship between average monthly baseflow and average monthly rainfall is shown graphically in Figure 15. Groups of months with approximately equal baseflow have varying amounts of rainfall. For example, March, May, and June have about 0.60 inches of baseflow, but rainfall increases from 2.35 inches in March to 4.24 inches in June. This demonstrates an increase in evapotranspiration, which can also be seen with other groups of months.

TABLE XI

MONTHLY AND ANNUAL BASEFLOW (FIXED INTERVAL), IN INCHES, 1950-1959, PANTHER CREEK BASIN

	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	AVE
J	1.3	0.21	0.76	0.10	0.02	0.68	0.01	0.01	0.18	0.06	0.33
F	1.0	0.97	0.47	0.15	0.03	0.53	0.03	0.02	0.19	0.57	0.40
M	1.1	0.74	1.4	0.62	0.39	0.58	0.04	0.04	0.23	0.78	0.59
A	1.3	1.5	1.4	0.56	0.89	0.87	0.03	0.99	0.25	0.52	0.83
M	0.58	0.60	0.66	0.31	0.55	0.58	0.10	1.3	0.12	1.1	0.59
J	0.70	0.69	0.88	0.27	0.72	0.39	0.08	0.57	0.79	0.44	0.55
J	0.96	1.4	0.23	0.22	0.03	0.08	0.02	0.19	0.45	0.06	0.36
A	0.15	0.16	0.04	0.02	0.04	0.01	0.0	0.02	0.56	0.01	0.10
S	0.04	0.09	0.02	0.0	0.01	0.0	0.0	0.0	0.03	0.0	0.02
O	0.03	0.15	0.01	0.0	0.05	0.01	0.0	0.02	0.02	0.06	0.04
N	0.02	0.58	0.01	0.02	0.06	0.02	0.0	0.07	0.04	0.07	0.09
D	0.03	0.30	0.03	0.01	0.10	0.02	0.01	0.16	0.03	0.10	0.08
TOT	7.22	7.39	5.91	2.28	2.89	3.77	0.32	3.39	2.89	3.77	3.98
% Q	52	40	60	56	48	62	32	57	49	46	50
% PPT	19	17	18	8	8	13	2	9	10	11	12

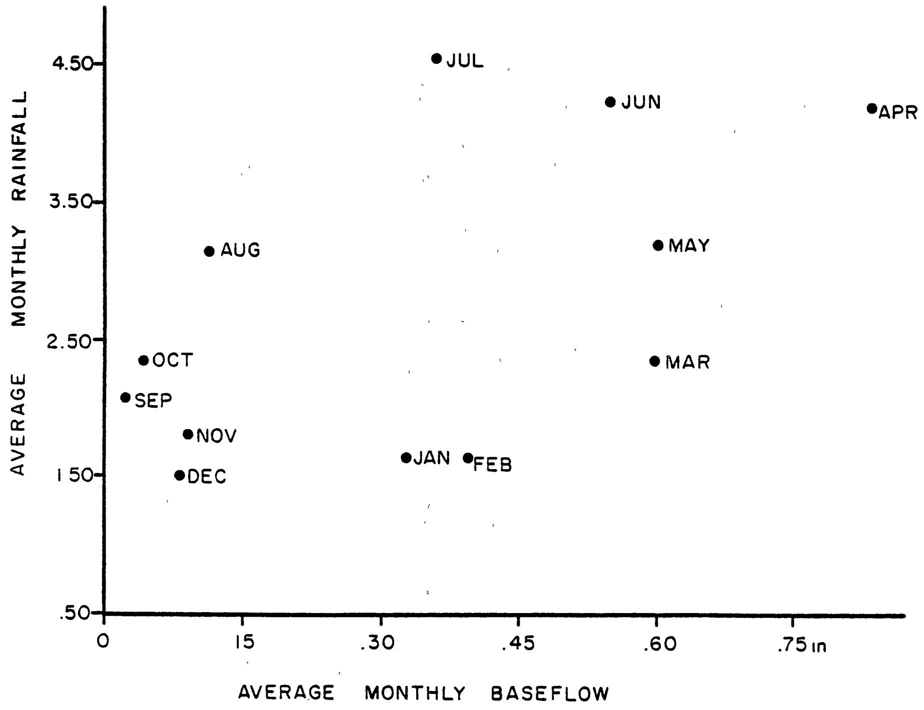


Figure 15. Average Monthly Rainfall and Average Monthly Baseflow (Fixed Interval), 1950-1959, Panther Creek Basin

Baseflow ranges from a high of 19 to a low of 1.6 percent of annual precipitation from 1950 through 1959 (Table XI). The average is 11.5 percent. The highest values occurred during years of above average rainfall and years of near normal rainfall following above average years. The lowest value occurred in 1956, the driest year of the study period.

Baseflow as a percent of stream discharge is also listed in Table XI. The range in this factor, 32 to 62 percent, is not as great as the range in baseflow as a percent of precipitation. The lowest value occurred during 1956, the driest year of the study period, and the average was 50 percent.

Summary

Panther Creek Basin covers 95 square miles in glaciated terrain. Normal annual precipitation is approximately 34 inches, with the majority of rainfall occurring during the growing season. Permeability of the soils is moderate to slow. Unconsolidated glacial till, about 100 feet thick, comprises the water-bearing materials; this is underlain by relatively impermeable bedrock.

Effective regional ground-water recharge was determined by computer baseflow separation and compared to values of baseflow computed by ground-water rating curves. For the years examined, the fixed and sliding interval methods yielded results 20 percent higher in 1951 and about 20 percent lower in 1952 and 1956 than the rating curve method. Baseflow by the local minima method was consistently lower.

The relationship between annual baseflow and precipitation correlates on a yearly and 2-year basis for the period 1950 through 1959. Years of high rainfall are characterized by years of high baseflow, with the pattern developed by the two-year moving average of precipitation correlating very well with annual baseflow.

Baseflow by the fixed interval method varies from a high of 7.39 inches in 1951 to a low of 0.32 inches in 1956. This represents a difference of over one order of magnitude within a six year period. Average baseflow for the 10 year study period was 3.98 inches. Baseflow averaged 11.5 percent of precipitation and 50 percent of stream flow for the same time period.

CHAPTER VI

GOOSE CREEK BASIN, ILLINOIS

The following text is summarized from Schicht and Walton (1961) unless otherwise referenced.

Geography

Goose Creek Basin is located between approximately 40° 05' and 40° 13' north latitude and 88° 31' and 88° 42' west longitude in east-central Illinois (Figure 16). The basin covers 47.3 square miles in Piatt and DeWitt counties. The elevation of the land surface declines from about 730 feet in the northeast part of the basin to 670 feet at the gaging station.

The basin lies in the north temperate zone and is characterized by warm summers and moderately cold winters. Mean annual temperature is 53°F and mean length of the growing season is 175 days. According to several surrounding U. S. Weather Bureau stations, normal annual precipitation is 37 inches. May and June are the wettest months and December is the month of least precipitation. Mean annual snowfall is 21 inches, and an average of 25 days a year can be expected to have one inch or more ground snow cover.

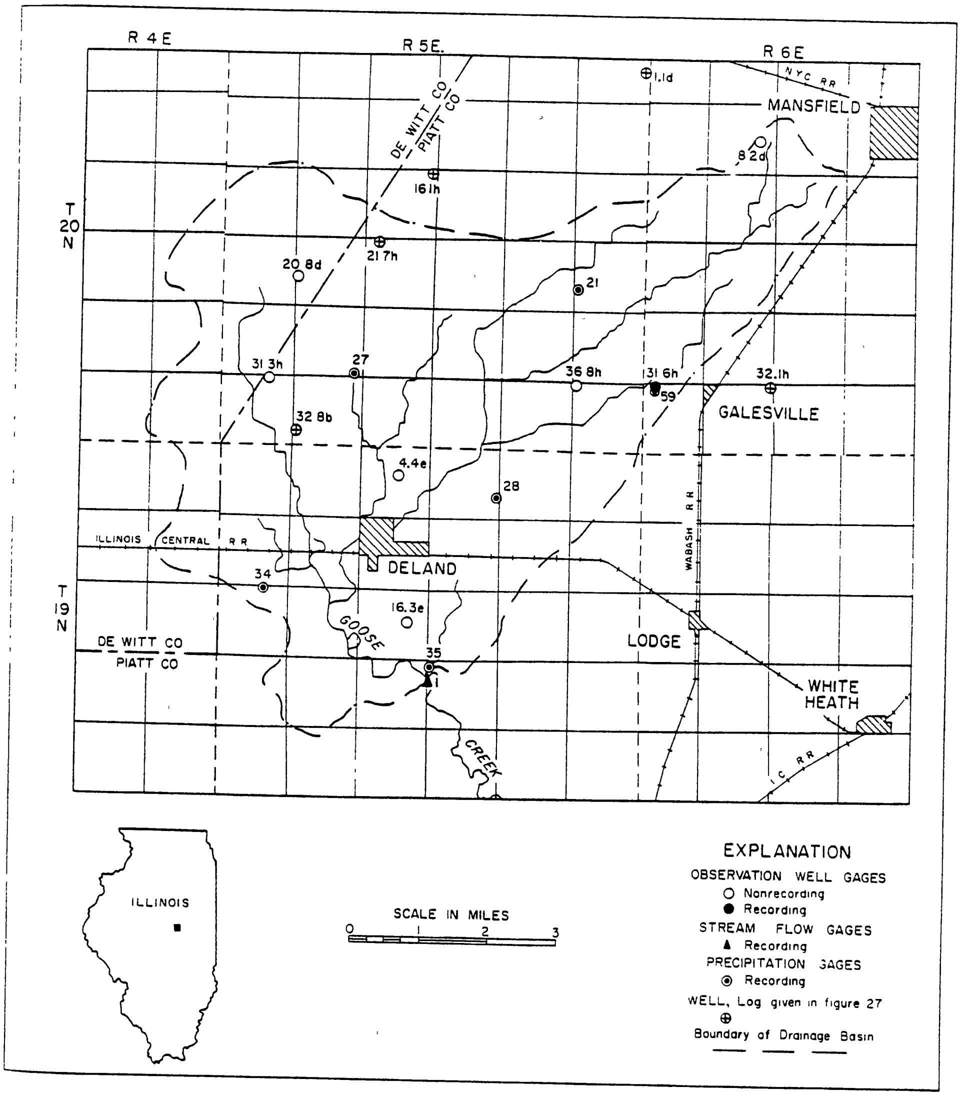


Figure 16. Location of Goose Creek Basin (from Schicht and Walton, 1961, p. 29)

Prior to development for agriculture, the water table was very near the surface throughout the basin. Extensive surface and subsurface drainage was necessary to lower the water table and improve drainage. No ponds are present within the basin at this time.

About 86 percent of the basin is cultivated, the remainder is permanent pasture, woodland, and farm lots. The population is chiefly rural.

Geology

Goose Creek drainage basin lies in the Till Plains section of the Central Lowland Physiographic province. More specifically, it is located in the Bloomington Ridged Plain area of the Till Plains section (Leighton, et al, 1948). The topography consists mostly of nearly level uplands with a slightly rolling surface found adjacent to the creek in the southern quarter of the basin.

Two soil types are dominant in Goose Creek basin: Drummer silty clay loam and Flanagan silt loam. Drummer silty clay loam is characterized by slow surface drainage and moderate permeability which requires underdrainage by tiles prior to development. Flanagan silt loam has moderate surface drainage and permeability which sometimes requires underdrainage by tiles prior to development.

Pleistocene glacial deposits unconformably overlie bedrock of Pennsylvanian age. The bedrock consists mainly of shale, with thin sandstone, limestone, and coal beds.

The glacial deposits consist of about 175 feet of glacial till with some stratified beds of silt, sand, and gravel. These beds occur as irregular lenses and layers in the till to thicknesses of 25 feet.

Hydrology

Precipitation

Average annual precipitation for Goose Creek basin during the seven year study period, 1952-1958, was 32.51 inches (Table XII). June was the month of greatest precipitation, averaging over five inches. January, February, September, and December were the driest months, with an average precipitation less than two inches. April, May, June, July, and August have an average of more than three inches each.

The two driest years during the study period, 1953 and 1956, had rainfalls approximately five inches below the seven year average. The two years of highest rainfall, 1957 and 1958, were about five inches above average. Nineteen hundred fifty two was a wet year, followed by four years of below average precipitation (Figure 17).

Evapotranspiration

The inflow and outflow assumptions made for the Little Washita River Watershed are also applied to Goose Creek Basin. Annual evapotranspiration ranged from 67 to 94 percent, and averaged 80 percent of precipitation (Table XIII).

Average monthly evapotranspiration is the highest percentage of precipitation August through December, up to 99 percent of precipitation, and the lowest percentage of precipitation in May and April.

TABLE XII

MONTHLY AND ANNUAL PRECIPITATION, IN INCHES, 1952-1958, GOOSE CREEK BASIN

	1952	1953	1954	1955	1956	1957	1958	AVE
J	2.97	1.62	1.65	1.97	0.70	1.20	1.53	1.66
F	1.89	1.63	1.41	2.57	2.21	1.86	0.40	1.71
M	3.55	6.75	2.50	1.71	0.69	0.75	0.96	2.42
A	4.67	1.79	4.70	2.50	3.64	7.72	1.95	3.85
M	4.17	2.12	2.58	4.11	2.76	4.53	2.61	3.27
J	5.24	4.52	3.27	4.70	2.64	6.31	8.65	5.05
J	1.66	3.31	2.65	2.19	2.70	2.28	9.80	3.51
A	2.49	1.07	5.89	2.08	7.12	1.67	2.66	3.28
S	2.44	0.71	0.60	3.38	0.64	1.53	3.10	1.77
O	1.32	1.86	4.28	4.31	0.61	2.54	0.67	2.23
N	3.33	0.83	0.44	1.82	2.02	2.67	4.32	2.20
D	1.42	1.40	1.40	0.46	1.53	4.12	0.56	1.56
TOT	35.15	27.61	31.37	31.80	27.26	37.18	37.21	32.51

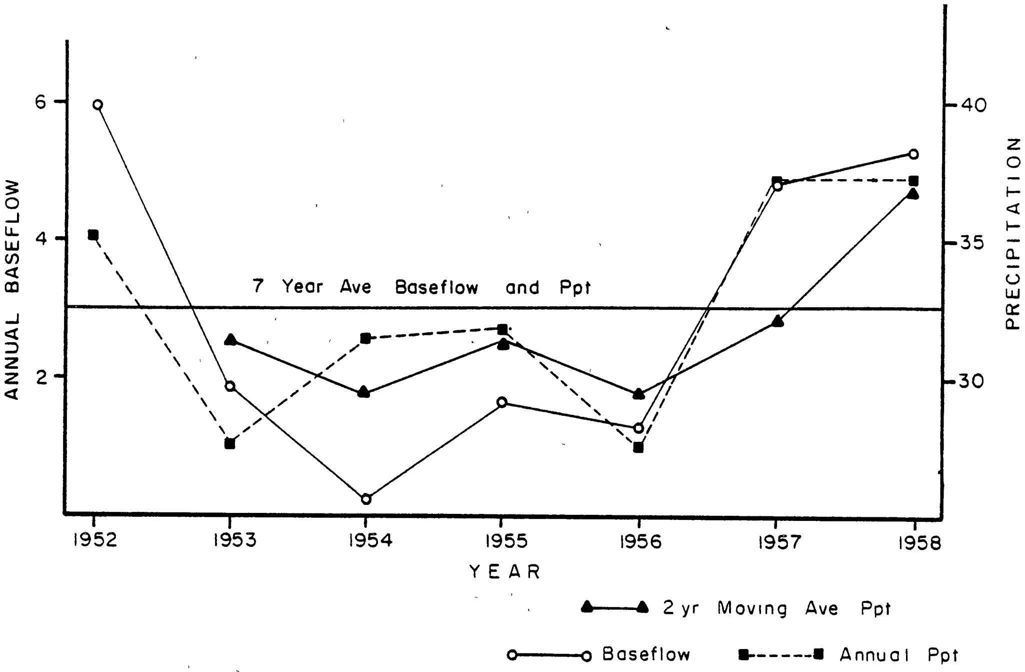


Figure 17. Annual Baseflow (Local Minima) and Annual Precipitation, in Inches, 1952-1958, Goose Creek Basin

TABLE XIII

ANNUAL AND AVERAGE MONTHLY EVAPOTRANSPIRATION, IN INCHES, 1952-1958, GOOSE CREEK BASIN

YEAR	E-T	% PPT	MONTH	E-T	% PPT
1952	24.00	68	J	1.27	76
1953	21.67	78	F	1.26	74
1954	29.56	94	M	1.54	64
1955	27.86	88	A	2.54	66
1956	24.16	89	M	2.45	75
1957	27.68	74	J	3.58	71
1958	24.95	67	J	2.53	72
			A	2.98	91
AVE	25.70	80	S	1.75	99
			O	2.21	99
			N	2.13	97
			D	1.45	93

Schicht and Walton (1961) calculated evapotranspiration for 1955, 1956, and 1957 through the use of ground-water rating curves and water balance equations. Evapotranspiration for those years was 25.76, 24.35, and 24.30 inches, respectively, or 81, 89, and 65 percent of precipitation, respectively.

Surface Water

Average annual stream flow was 6.82 inches and ranged from 1.81 inches to 12.26 inches. The lowest value occurred in 1954, a year of slightly below average precipitation preceded by the lowest annual precipitation. The highest value occurred in 1958, a year of above average rainfall preceded by a year of nearly equal and above average rainfall (Table XIV).

Average monthly stream flow shows that April and June had the highest discharge. These two months also had the greatest amount of rainfall during the study period.

Ground Water

Hydrologic Properties of the Geologic Formations. The hydrologic properties of the glacial deposits and bedrock are very similar to Panther Creek Basin.

Recharge and Discharge. Recharge to Goose Creek Basin occurs in the same manner as recharge to Panther Creek Basin. Ground-water discharge occurs as underflow, ground-water evapotranspiration, and ground-water runoff.

Underflow was calculated by Schicht and Walton (1961) and determined to be 0.002 cubic feet per second. This amount is so small it is omitted from later calculations.

TABLE XIV

MONTHLY AND ANNUAL STREAM DISCHARGE, IN INCHES, 1952-1958, GOOSE CREEK BASIN

	1952	1953	1954	1955	1956	1957	1958	AVE
J	1.7	0.02	0.0	0.10	0.01	0.13	0.75	0.39
F	1.2	0.09	0.0	0.47	0.48	0.68	0.23	0.45
M	2.2	2.4	0.02	0.56	0.35	0.34	0.26	0.88
A	2.7	1.9	0.31	0.47	0.41	3.1	0.28	1.31
M	1.0	0.31	0.05	0.52	0.98	2.5	0.35	0.82
J	2.1	0.43	1.4	1.5	0.56	1.5	2.8	1.47
J	0.24	0.77	0.01	0.11	0.07	0.67	5.0	0.98
A	0.01	0.02	0.02	0.0	0.23	0.02	1.8	0.30
S	0.0	0.0	0.0	0.0	0.0	0.0	0.12	0.02
O	0.0	0.0	0.0	0.11	0.0	0.0	0.04	0.02
N	0.0	0.0	0.0	0.07	0.0	0.02	0.42	0.07
D	0.0	0.0	0.0	0.03	0.0	0.54	0.21	0.11
TOT	11.15	5.94	1.81	3.94	3.09	9.50	12.26	6.82

Baseflow Evaluation

Instrumentation

From January 1955 through September 1958, ground-water levels were continuously measured in three observation wells, of which one was equipped with a recording gage. Periodic measurements were made in other observation wells within the basin. Mean daily stream discharge was measured by the U. S. Geological Survey at a gaging station on Goose Creek, located below approximately 47.3 square miles of drainage area. The Meteorology Section of the Illinois State Water Survey measured precipitation on the basin with a variable density of rain gages during the study period. Instrument locations are shown in Figure 16.

Ground-water Rating Curves

Schicht and Walton (1961) used the same method to determine ground-water runoff to Goose Creek Basin as they did for Panther Creek Basin. Nearly equal ground-water runoff occurred during 1955 and 1956, 1.60 and 1.52 inches, respectively (Table XV). Those years had below average rainfall. Ground-water runoff more than doubled in 1957, 3.80 inches, the year with the second highest precipitation. Schicht and Walton (1961) did not calculate ground-water runoff past September, 1958, but by that month, total ground-water runoff was up to 6.83 inches.

Computer Baseflow Separation

Mean daily stream discharge for Goose Creek Basin from January 1952 through September 1958 was input into the computer program. Monthly and annual values for fixed interval, sliding interval, and local minima methods are presented in Table XV as are the results obtained by Schicht and Walton (1961).

TABLE XV

MONTHLY AND ANNUAL GROUND-WATER RUNOFF, IN INCHES, 1955-1958, GOOSE CREEK BASIN

	S&W	F-I	S-I	L-M
1955				
J	0.03	0.0	0.03	0.0
F	0.08	0.12	0.15	0.12
M	0.31	0.41	0.42	0.32
A	0.26	0.39	0.38	0.33
M	0.29	0.31	0.30	0.29
J	0.44	0.83	0.84	0.44
J	0.07	0.10	0.09	0.09
A	0.01	0.0	0.0	0.0
S	0.0	0.0	0.0	0.0
O	0.04	0.03	0.03	0.01
N	0.05	0.05	0.05	0.04
D	0.02	0.02	0.02	0.02
ANNUAL	1.60	2.26	2.31	1.66
1956				
J	0.01	0.01	0.01	0.01
F	0.21	0.21	0.26	0.26
M	0.28	0.29	0.29	0.31
A	0.14	0.21	0.10	0.10
M	0.40	0.57	0.56	0.18
J	0.40	0.32	0.35	0.30
J	0.05	0.05	0.05	0.06
A	0.03	0.07	0.07	0.03
S	0.0	0.0	0.0	0.0
O	0.0	0.0	0.0	0.0
N	0.0	0.0	0.0	0.0
D	0.0	0.0	0.0	0.0
ANNUAL	1.52	1.73	1.69	1.25

TABLE XV (Continued)

	S&W	F-I	S-I	L-M
1957				
J	0.02	0.05	0.06	0.02
F	0.02	0.27	0.30	0.11
M	0.04	0.27	0.27	0.23
A	0.16	2.0	1.9	1.5
M	2.00	1.8	1.8	1.8
J	0.93	1.0	0.82	0.60
J	0.46	0.51	0.49	0.35
A	0.01	0.01	0.01	0.01
S	0.0	0.0	0.0	0.0
O	0.0	0.0	0.0	0.0
N	0.01	0.01	0.01	0.0
D	0.15	0.30	0.29	0.22
ANNUAL	3.80	6.22	5.95	4.84
1958				
J	0.55	0.38	0.43	0.27
F	0.18	0.20	0.20	0.19
M	0.17	0.23	0.22	0.19
A	0.21	0.24	0.24	0.24
M	0.28	0.23	0.19	0.12
J	1.12	1.3	1.5	1.1
J	2.84	2.1	2.3	1.7
A	1.40	1.0	1.1	1.1
S	0.08	0.09	0.09	0.09

On an annual basis, the fixed interval and local minima methods consistently yield the highest and lowest values of ground-water runoff, respectively. The results from the sliding interval and local minima methods are closer to the amount of ground-water runoff calculated by Schicht and Walton (1961), are alternately higher and lower, but remain within about 20 percent of their values. On a monthly basis, the results of all three methods are within about 20 percent of ground-water runoff as calculated by Schicht and Walton (1961), but consistently high values from the fixed interval method cause a larger cumulative discrepancy over time.

Additional stream data were input to examine fluctuations in baseflow over time. Seven years of daily discharge are available for Goose Creek Basin from 1952 through 1958, after which the station was discontinued. The local minima method was chosen to represent ground-water runoff for the basin (Table XVI).

The highest annual value of baseflow occurred during 1952, 5.99 inches, the lowest during 1954, 0.25 inches, a difference of over one order of magnitude. Average ground-water runoff during the period was 3.03 inches. The line representing annual baseflow closely follows the line representing two year moving average precipitation (Figure 17), indicating annual ground-water runoff depends upon the year's and previous year's rainfall.

Months of approximately equal precipitation but unequal ground-water runoff are evident in Figure 18. December and January through May were months of higher rates of ground-water runoff than June through November. For example, August and May each received about 3.3 inches of rain, but 0.34 and 0.49 inches of baseflow, respectively, and March and October each received about 2.3 inches of precipitation, but 0.42 and 0.01 inches of ground-water runoff, respectively.

TABLE XVI

MONTHLY AND ANNUAL BASEFLOW (LOCAL MINIMA), IN INCHES, 1952-1958, GOOSE CREEK BASIN

	1952	1953	1954	1955	1956	1957	1958	AVE
J	0.96	0.01	0.0	0.0	0.01	0.02	0.27	0.18
F	0.88	0.04	0.0	0.12	0.26	0.11	0.19	0.23
M	1.3	0.57	0.01	0.32	0.31	0.23	0.19	0.42
A	1.5	0.74	0.18	0.33	0.10	1.5	0.24	0.66
M	0.73	0.28	0.04	0.29	0.18	1.8	0.12	0.49
J	0.60	0.08	0.02	0.44	0.30	0.60	1.1	0.45
J	0.02	0.16	0.0	0.09	0.06	0.35	1.7	0.34
A	0.0	0.02	0.0	0.0	0.03	0.01	1.1	0.16
S	0.0	0.0	0.0	0.0	0.0	0.0	0.09	0.01
O	0.0	0.0	0.0	0.01	0.0	0.0	0.03	0.01
N	0.0	0.0	0.0	0.04	0.0	0.0	0.10	0.02
D	0.0	0.0	0.0	0.02	0.0	0.22	0.17	0.06
TOT	5.99	1.90	0.25	1.66	1.25	4.84	5.30	3.03
% Q	54	32	14	42	40	51	43	39
% PPT	17	7	1	5	5	13	14	9

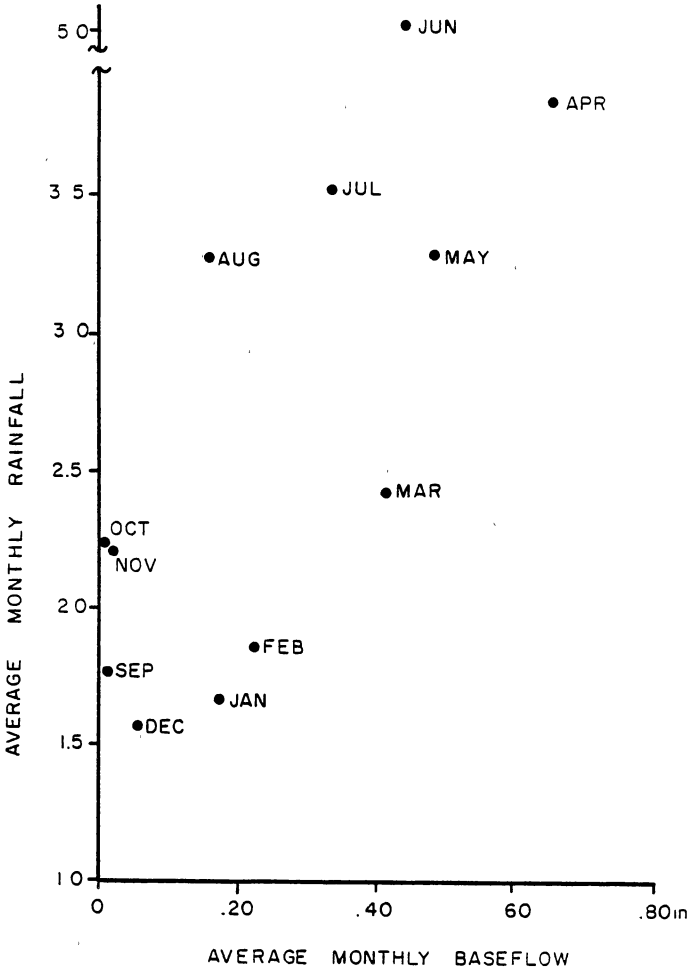


Figure 18. Average Monthly Rainfall and Average Monthly Baseflow (Local Minima), 1952-1958, Goose Creek Basin

Baseflow ranged from one to 17 and averaged nine percent of precipitation (Table XVI). The highest percentage occurred during the wettest year, 1952. The lowest figure occurred during 1954, a year of near normal rainfall preceded by a dry year, further indicating a two year relationship between annual rainfall and annual ground-water runoff.

Annual variation in baseflow as a percent of stream discharge is not as great. It ranged from 14 to 54 percent, the lowest value occurring during the driest year. This factor had an average of 39 percent.

Summary

Goose Creek Basin covers approximately 47 square miles in glaciated terrain. Average annual precipitation is 32.51 inches, with April and June being the wettest months. Permeability of the soils is moderate. The water-bearing materials consist of about 175 feet of glacial till; this is underlain by relatively impermeable bedrock.

Effective ground-water recharge by the sliding interval and local minima methods are about 20 percent greater than ground-water runoff determined by rating curves. On a monthly basis the fixed interval method is also about 20 percent greater, but cumulative differences cause a larger deviation over time.

The local minima method was chosen to represent ground-water runoff for the basin from 1952 through 1958. The largest amount of ground-water runoff occurred during 1952, 5.99 inches, the lowest during 1954, 0.25 inches, a difference of over one order of magnitude. The average was 3.03 inches. The line representing annual baseflow closely resembles the line representing the two year moving average of precipitation. This indicates baseflow is dependent upon antecedent rainfall. Baseflow as a percent of precipitation averaged nine for the study period, and 39 as a percent of stream discharge.

CHAPTER VII

BEAVERDAM CREEK BASIN, MARYLAND

The following text is summarized from Rasmussen and Andreasen (1959) unless otherwise referenced.

Geography

Beaverdam Creek Basin is located in Wicomico County, Maryland, between latitudes 38° 18' and 38° 26' north and longitudes 75° 28' and 75° 34' west (Figure 19). The basin has a drainage area of 19.5 square miles. The upper divide of the basin is 85 feet above mean sea level, the stream gaging station is about 10 feet above mean sea level.

The basin is located in a humid-subtropical climate. The summers are generally hot and humid, and the winters are usually mild. Average annual temperature is 56°F. Mean annual precipitation is 43 inches, and is distributed fairly evenly throughout the year. About 14 inches of snow falls annually, but generally melts shortly after falling. The growing season averages 184 days.

Two ponds, each occupying an area ot about 0.050 square miles, are located within the basin and have formed behind artificial dams. The gaging station is located at the spillway of the lower pond. The upper pond lies about one mile upstream of the lower pond.

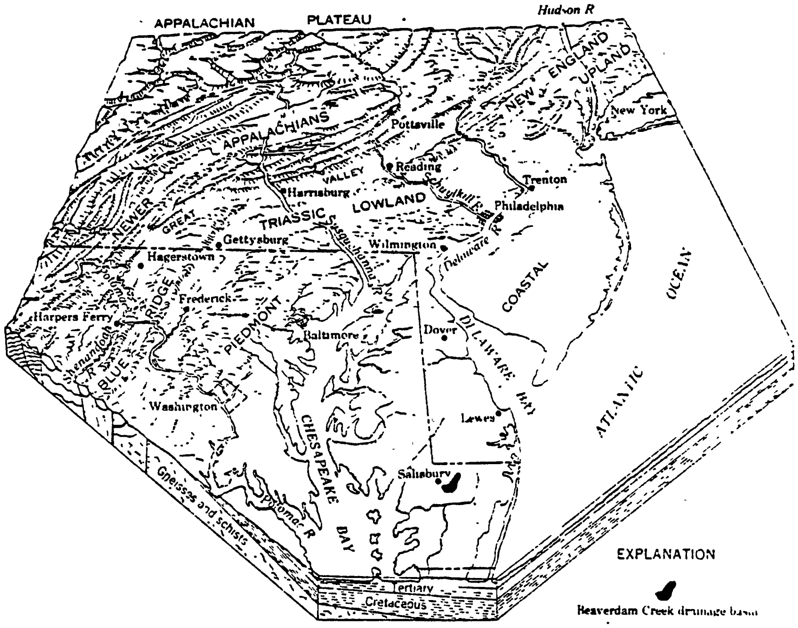


Figure 19. Location of Beaverdam Creek Basin (from Rasmussen and Andreasen, 1959, p. 10)

Beaverdam Creek Basin is chiefly rural. Farming is the major business, with about 60 percent of the land area cleared and cultivated. The remainder of the basin is forested. Cultivated crops are rarely irrigated.

Geology

The basin is located in the Atlantic Coastal Plain province, approximately 90 miles east of the Fall Line. The

Fall Line is defined as the boundary between the coastal Plain and Piedmont provinces. The land forms present in the basin are of low relief and were formed during periods of changing sea level. They consist of: marine terraces, the valleys of Beaverdam Creek and its tributaries, sandy oval depressions called "Maryland basins", and low, stabilized sand dunes.

Maryland basins are oval with an average area of 0.35 square miles. There are approximately 57 of these within the drainage basin. They are poorly drained areas enclosed by sandy rims, which retard surface runoff and promote evapotranspiration.

The sand dunes have a low relief, generally between 5 and 10 feet. These have no preferred orientation, but are widely scattered throughout the drainage basin. High rates of infiltration are possible in the sand dunes. Over 60 percent of the sediments found at the surface to a depth of 20 feet are classified as sand, and therefore have the potential for a rapid infiltration rate.

Beaverdam Creek Basin is underlain by a wedge of unconsolidated and semiconsolidated sediments ranging in age from Triassic to Recent. These sediments consist of sand, silt, and clay, and are about 5,500 feet thick. The shallow ground-water system is contained within the first 250 feet of sediments which consist mainly of fine sand. This is underlain by approximately 100 feet of clayey silt.

Hydrology

Precipitation

Average annual precipitation during the 10 year study period, 1943-1952, was 44.63 inches (Table XVII). Two years of below average rainfall are generally followed by one year of above average rainfall (Figure 20). The wettest year, 1948, had 72.59 inches of rainfall, the years of lowest rainfall were 1943, 1946, 1947, and 1950. Those years received between 35.74 and 37.15 inches of precipitation.

The highest monthly average rainfall occurred between August, 5.21 inches, the lowest during February and April, 2.96 and 2.94 inches, respectively. In general, precipitation is fairly evenly distributed throughout the year.

Evapotranspiration

Total evapotranspiration and ground-water evapotranspiration were determined by Rasmussen and Andreasen (1959) through a series of calculations that include measurements of soil moisture, specific yield, precipitation, and runoff. Ground-water evapotranspiration from April 1950 through March 1952 was 19.45 inches. Total evapotranspiration for the same time period was 49.24 inches.

The assumptions used in calculating evapotranspiration for the Little Washita River Watershed were also applied to Beaverdam Creek Basin. Average annual evapotranspiration was 26.76 inches or 61 percent of precipitation. Evapo-

TABLE XVII

MONTHLY AND ANNUAL PRECIPITATION, IN INCHES, 1943-1952, BEAVERDAM CREEK BASIN

	1943	1944	1945	1946	1947	1948	1949	1950	1951	1952	AVE
J	3.48	3.88	3.13	1.89	5.45	6.67	4.08	1.99	1.63	5.19	3.74
F	2.86	3.66	4.66	2.16	1.14	2.61	4.50	2.62	2.24	3.11	2.96
M	2.96	5.91	2.04	2.71	2.02	3.68	4.50	4.62	2.81	5.16	3.64
A	3.09	3.00	1.84	3.32	4.00	2.66	3.35	2.20	2.69	3.30	2.94
M	4.16	1.19	3.10	6.68	2.71	10.38	3.59	3.73	3.75	2.65	4.19
J	2.03	2.99	5.73	1.37	2.56	7.56	1.27	1.26	5.46	3.30	3.35
J	0.88	1.84	9.81	3.34	2.17	5.15	2.04	4.84	3.46	2.28	3.58
A	3.34	2.26	3.11	4.73	3.27	12.01	6.41	1.77	4.29	10.90	5.21
S	4.21	7.59	4.44	2.96	3.61	4.54	5.70	4.78	3.51	1.24	4.26
O	6.18	3.56	2.86	2.95	2.06	5.59	4.13	1.27	3.00	1.64	3.32
N	1.29	4.09	3.70	2.76	4.63	6.54	3.54	3.48	5.14	5.05	4.02
D	1.26	2.04	8.12	2.28	2.80	5.20	1.16	3.34	4.29	3.75	3.42
TOT	35.74	42.01	52.54	37.15	36.42	72.59	44.27	35.90	42.27	47.57	44.63

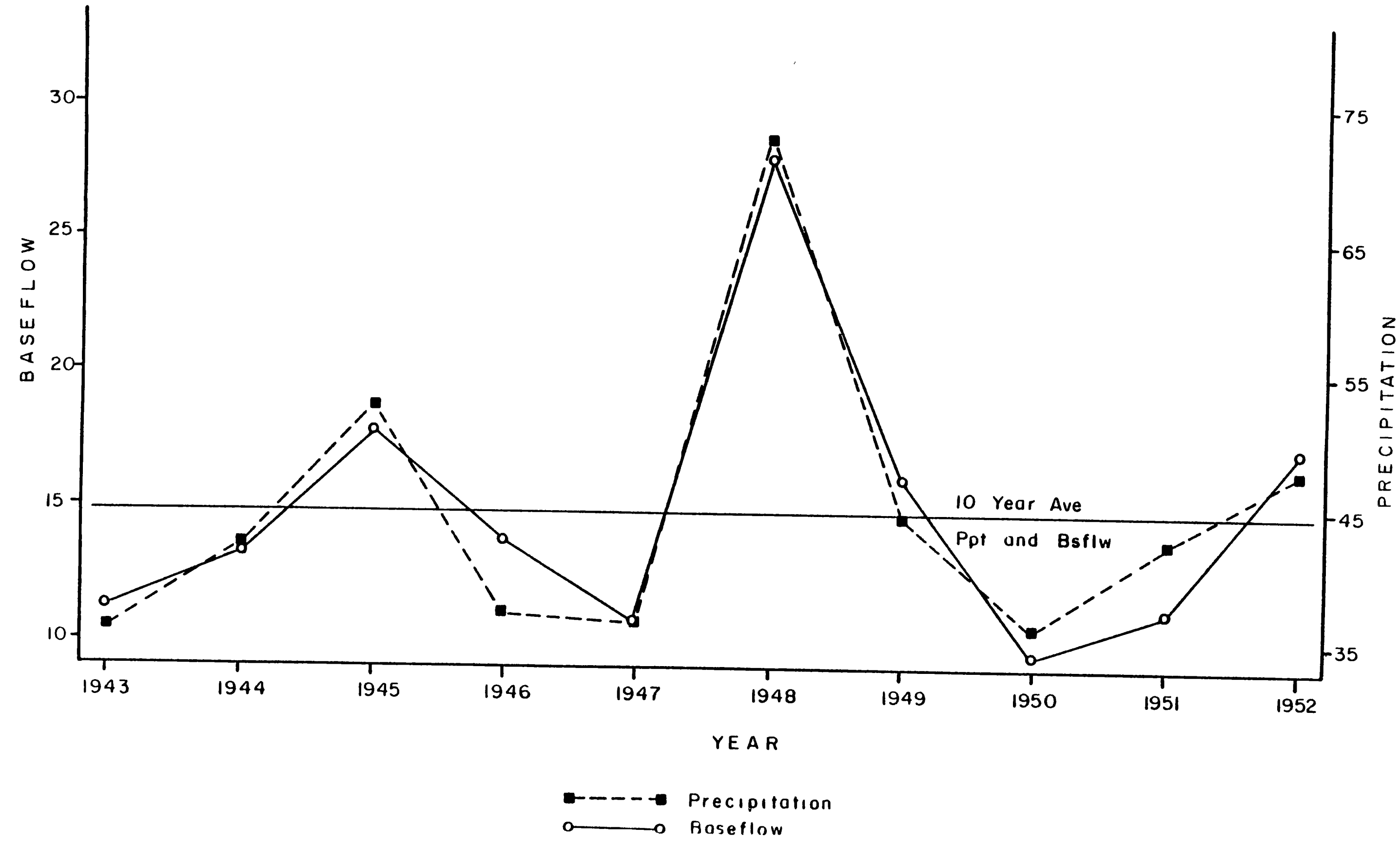


Figure 20. Annual Baseflow (Fixed Interval) and Annual Precipitation, in Inches, 1943-1952, Beaverdam Creek Basin

transpiration was the highest percent of precipitation during 1950, 69 percent, the lowest during 1948, 49 percent. These years correspond with the least and greatest annual rainfalls, respectively. On a monthly basis evapotranspiration as a percent of precipitation is greatest from May through November, and is highest in September, 81 percent (Table XVIII).

TABLE XVIII

ANNUAL AND AVERAGE MONTHLY EVAPOTRANSPIRATION, IN INCHES, 1943-1952, BEAVERDAM CREEK BASIN

YEAR	E-T	% PPT	MONTH	E-T	% PPT
1943	22.94	64	J	1.64	44
1944	25.73	61	F	1.18	40
1945	31.28	60	M	1.36	37
1946	22.00	59	A	1.33	45
1947	24.55	67	M	2.76	66
1948	35.29	49	J	2.11	63
1949	25.69	58	J	2.65	74
1950	24.91	69	A	3.70	71
1951	28.80	68	S	3.45	81
1952	26.44	56	O	2.34	70
			N	2.69	67
AVE	26.76	61	D	1.55	45

Surface Water

Average annual stream flow from 1943 through 1952 was 17.87 inches (Table XIX). The highest annual discharge occurred during 1948, the year of greatest rainfall. The

TABLE XIX

MONTHLY AND ANNUAL STREAM DISCHARGE, IN INCHES, 1943-1952, BEAVERDAM CREEK BASIN

	1943	1944	1945	1946	1947	1948	1949	1950	1951	1952	AVE
J	1.3	2.0	2.1	2.6	1.9	3.1	3.6	0.81	0.81	2.8	2.10
F	1.9	1.3	1.9	2.0	1.1	2.1	2.9	1.2	0.95	2.5	1.78
M	1.7	3.6	1.7	1.7	1.2	2.7	3.1	1.7	1.3	4.1	2.28
A	1.5	2.1	1.0	1.3	1.6	1.9	2.3	1.2	1.1	2.1	1.61
M	1.2	1.1	0.81	2.2	0.93	3.2	1.1	1.4	1.1	1.3	1.43
J	0.67	0.76	0.75	0.96	0.60	4.4	0.62	0.83	1.6	1.2	1.24
J	0.53	0.58	1.9	0.98	0.50	1.8	0.49	0.82	1.1	0.60	0.93
A	0.58	0.47	2.1	0.94	0.53	6.2	0.59	0.66	0.87	2.2	1.51
S	0.46	0.98	1.5	0.59	0.59	1.4	0.72	0.53	0.61	0.72	0.81
O	1.0	0.91	1.7	0.57	0.62	2.7	0.74	0.38	0.53	0.61	0.98
N	1.1	0.98	1.4	0.65	1.1	3.3	1.5	0.57	1.4	1.3	1.33
D	0.86	1.5	4.4	0.66	1.2	4.5	0.92	0.89	2.1	1.7	1.87
TOT	12.80	16.28	21.26	15.15	11.87	37.30	18.58	10.99	13.47	21.13	17.87

lowest annual discharges occurred during 1943, 1947, and 1950. These were years of low rainfall also.

The highest average monthly stream discharge occurred during January and March; the lowest during July and September. This probably reflects differences in evapotranspiration and soil moisture since rainfall is about evenly distributed throughout the year.

Ground Water

Hydrologic Properties of the Geologic Formations.

The shallow ground-water reservoir of Beaverdam Creek Basin consists of gravel, sand, silt, and clay to a depth of approximately 250 feet. Underlying these permeable sediments is approximately 100 feet of relatively impermeable silty clay. The water table is located mainly in the Beaverdam sand. The basin as a whole can be considered hydrologically homogeneous, with the Beaverdam sand representative of the water-bearing materials.

Recharge and Discharge.

Direct precipitation on the basin is the major source of recharge. Inflow from adjacent basins is assumed to be negligible because topographic divides nearly coincide with ground-water divides. Recharge from upward leakage is also assumed to be negligible due to the aquitard formed by the lower clay unit.

Discharge from the basin takes the form of runoff and evapotranspiration. Water loss by underflow is assumed to be negligible.

Baseflow Evaluation

Instrumentation

Twenty-five observation wells were installed in the basin to obtain water-level measurements. The wells consisted of 1-inch steel pipe fitted with well points. An automatic water-stage recorder was used on one well, the remainder were periodically measured by steel tape.

Mean daily stream discharge has been measured by the U. S. Geological Survey at the outlet of Schumaker dam since 1929. These data are available in publications of the U.S. Geological Survey.

Records of rainfall for the period January 1943 through March 1950 and April 1952 through December 1952 were obtained from the U.S. Weather Bureau Station at Salisbury, Maryland. From April 1950 through March 1952, precipitation records were calculated from an arithmetic mean of 12 rain gages located within the basin.

Daily measurements of evaporation were made during the 2-year study period at the U. S. Geological Survey Office in Salisbury. A U. S. Weather Bureau class A evaporation pan was used.

Ground-water Rating Curves

Rasmussen and Andreasen (1959) determined ground-water runoff from Beaverdam Creek through the use of a single ground-water rating curve. This curve was prepared by plotting the weekly average of ground-water levels in 25 wells within the basin, when stream flow consisted entirely of baseflow. A close approximation to the true weekly baseflow was obtained and plotted on the stream hydrograph. Ground-water runoff from April 1950 through March 1952 was 21.46 inches (Table XX).

Computer Baseflow Separation

The three computer-separation methods yield results that are within about 10 percent of each other on a monthly basis for the period April 1950 through March 1952 (Table XX). By the end of the 24 month study period the results from the fixed interval and sliding interval methods differ by less than one-half inch. Cumulative differences in the local minima method cause its results to be about 2 inches less than the fixed and sliding interval methods, but it is still within about 10 percent of those values. The computer baseflow separation techniques are 10 to 20 percent greater than the baseflow calculations by Rasmussen and Andreasen (1959).

Additional stream flow data were input to form a 10 year data base from 1943 through 1952. The fixed interval method was chosen to represent ground-water runoff for that period. The results are listed in Table XXI.

Annual ground-water runoff ranged from 28.07 inches in 1948 to 9.51 inches in 1950, and averaged 14.86 inches for the 10 year study period. Baseflow as a percent of precipi-

TABLE XX

GROUND-WATER RUNOFF, IN INCHES, APRIL 1950 - MARCH 1952, BEAVERDAM CREEK BASIN

	BSFL	F-I	S-I	L-M
1950				
A	1.08	1.2	1.1	1.1
M	1.02	1.2	1.3	1.2
J	0.74	0.78	0.78	0.79
J	0.54	0.72	0.70	0.69
A	0.43	0.52	0.50	0.50
S	0.33	0.38	0.41	0.40
O	0.34	0.34	0.35	0.33
N	0.29	0.41	0.44	0.40
D	0.63	0.78	0.79	0.77
1951				
J	0.68	0.73	0.72	0.66
F	0.75	0.82	0.79	0.67
M	0.92	1.0	1.1	0.98
A	0.89	0.95	0.97	0.95
M	0.78	0.88	0.90	0.91
J	1.05	1.3	1.2	0.97
J	0.82	0.90	0.85	0.84
A	0.59	0.72	0.74	0.73
S	0.44	0.44	0.49	0.46
O	0.41	0.46	0.46	0.45
N	0.88	1.1	1.2	1.1
D	1.37	1.9	1.7	1.6
1952				
J	1.83	2.4	2.2	1.9
F	2.06	2.1	2.0	1.8
M	2.59	3.3	3.2	2.4
TOTAL	21.46	25.33	24.89	22.60

TABLE XXI

MONTHLY AND ANNUAL BASEFLOW (FIXED INTERVAL), IN INCHES, 1943-1952, BEAVERDAM CREEK BASIN

	1943	1944	1945	1946	1947	1948	1949	1950	1951	1952	AVE
J	1.2	1.6	1.9	2.4	1.8	2.4	2.9	0.78	0.73	2.4	1.81
F	1.6	1.2	1.6	1.8	1.0	1.8	2.7	1.0	0.82	2.1	1.56
M	1.5	2.5	1.5	1.6	1.2	2.3	2.6	1.4	1.0	3.3	1.89
A	1.4	1.9	0.96	1.2	1.4	1.7	2.0	1.2	0.95	1.6	1.43
M	1.1	1.1	0.74	1.9	0.89	2.7	1.0	1.2	0.88	1.2	1.27
J	0.62	0.64	0.58	0.87	0.55	3.0	0.53	0.78	1.3	1.0	0.99
J	0.45	0.49	1.5	0.85	0.46	1.7	0.45	0.72	0.90	0.50	0.80
A	0.40	0.40	1.8	0.80	0.42	3.3	0.48	0.52	0.72	1.5	1.03
S	0.36	0.45	1.0	0.51	0.43	0.97	0.52	0.38	0.44	0.65	0.57
O	0.74	0.77	1.3	0.53	0.54	2.0	0.63	0.34	0.46	0.58	0.79
N	1.1	0.86	1.3	0.62	0.97	2.8	1.4	0.41	1.1	0.85	1.14
D	0.80	1.4	3.5	0.60	1.0	3.4	0.89	0.78	1.9	1.5	1.58
TOT	11.27	13.31	17.68	13.68	10.66	28.07	16.10	9.51	11.20	17.18	14.86
% Q	88	82	83	90	90	75	87	86	83	81	84
% PPT	32	32	34	37	29	39	36	26	26	36	33

tation was highest in 1948, 39 percent, and lowest in 1950 and 1951, 26 percent. Baseflow as a percent of stream flow varied from 75 to 90 and averaged 84 percent. The lowest value occurred during 1948; the highest during 1946 and 1947. The wettest year on record was 1948; 1950 and 1943 were the two driest years. The line representing annual ground-water runoff closely follows the line representing annual precipitation (Figure 20), indicating a yearly relationship between those factors.

The graph of average monthly rainfall and baseflow (Figure 21) shows months of relatively high and low rates of effective ground-water recharge. December and January through April receive low to moderate amounts of rainfall, but the highest monthly average baseflows. Moderate amounts of rainfall and ground-water runoff are characteristic of May, June, July, October, and November. August and September receive the highest monthly rainfalls, but low amounts of baseflow. The relative quantity of baseflow is related to evapotranspiration, which is highest in August and September, and lowest during the winter and early spring months.

Summary

Beaverdam Creek Basin covers 19.5 square miles on the Atlantic Coastal Plain. Normal annual precipitation is 43 inches and is distributed fairly evenly throughout the year. Permeability of the soils is rapid. The water-bearing materials consist of about 250 feet of mainly sand; this is underlain by an aquitard of thick marine clay.

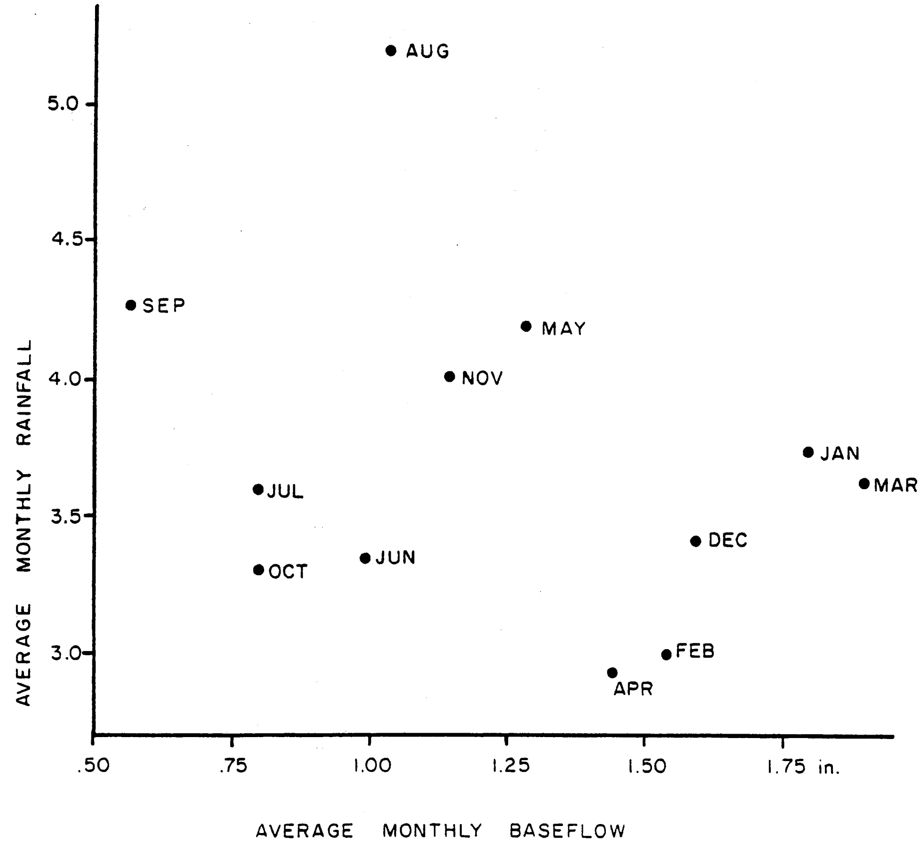


Figure 21. Average Monthly Rainfall and Average Monthly Baseflow (Fixed Interval), 1943-1952, Beaverdam Creek Basin

Effective ground-water recharge by the three computer separation techniques is within 10 to 20 percent of baseflow determined by Rasmussen and Andreasen (1959). The results from the fixed and sliding interval methods are consistently higher, whereas the local minima values are consistently lower. The fixed interval method was chosen to represent ground-water runoff from the basin for a 10 year period.

Extremes in baseflow for the 10 year period ranged from 28.07 inches to 9.51 inches and baseflow averaged 14.86 inches. The line representing annual ground-water runoff closely follows the line representing annual precipitation, indicating a yearly relationship. Baseflow as a percent of rainfall averaged 33 percent, and the ratio of baseflow to stream discharge averaged 84 percent.

CHAPTER VIII

BRANDYWINE CREEK BASIN, PENNSYLVANIA

Geography

Brandywine Creek Basin lies in southeastern Pennsylvania (Figure 22). It has a drainage area of 287 square miles above the gaging station at Chadds Ford. The highest point of the basin lies at approximately 900 feet; the gaging station is at an altitude of about 150 feet above sea level (Wolman, 1955).

Southeastern Pennsylvania is located in the humid continental climate zone. The average precipitation in Brandywine Creek Basin for 1921-1950 was 44.1 inches (Olmstead and Hely, 1962). Rainfall is distributed fairly evenly throughout the year (Wolman, 1955).

Approximately 51 percent of the basin is cropland and pasture, 21 percent is woodland, 21 percent is classified as miscellaneous, and seven percent is occupied by highways, roads, and streams (Olmstead and Hely, 1962). There are no large ponds or lakes in the study area.

Geology

Brandywine Creek Basin is part ot a dissected upland in the Piedmont province of the eastern United States. A

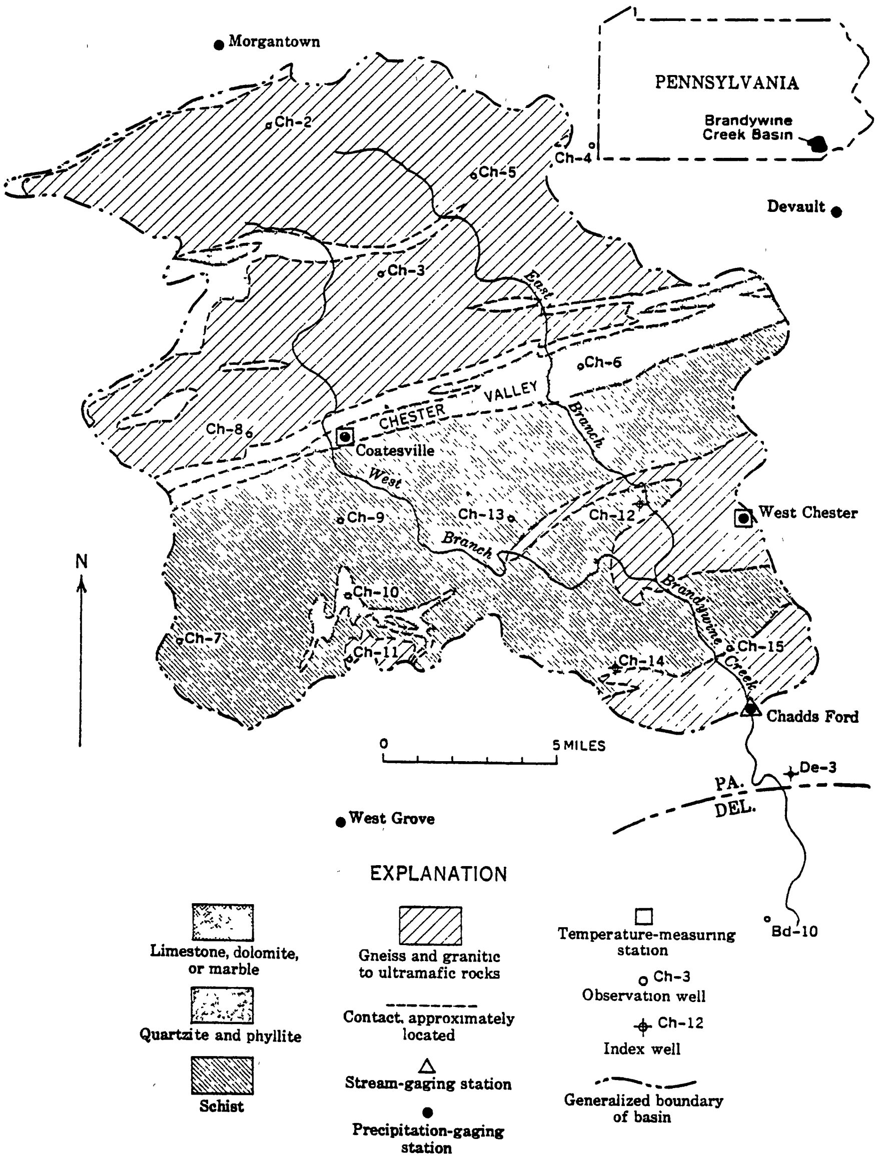


Figure 22. Location of Brandywine Creek Basin (from Olmstead and Healy, 1962, p. 3)

mantle of weathered bedrock of variable thickness covers the entire basin (Olmstead and Hely, 1962). The rivers characteristically flow diagonally across or at right angles to alternating bands of resistant and weak rocks (Wolman, 1955).

Most of the basin is covered by permeable, well drained soils. About 56 percent of the area is underlain by deep, well-drained soils, 21 percent by shallow, well-drained soils, and 23 percent by imperfectly and poorly drained soils. Many of the imperfectly and poorly drained soils are in swampy areas where ground-water discharge occurs (Olmstead and Hely, 1962).

According to Olmstead and Hely (1962):

> The basin is . . . underlain largely by metamorphic and igneous rocks of Precambrian to early Paleozoic age. Chester Valley, a long, narrow lowland underlain by dolomite and limestone, crosses the middle of the basin in a roughly east-west direction. Gneiss and granitic to ultramatic rocks of Precambrian age predominate north of Chester Valley; schist of early Paleozoic age underlies much of the southern half of the basin (p. 2).

Hydrology

Precipitation

Table XXII shows monthly and annual precipitation for Brandywine Creek Basin, 1943-1952. The data are from nearby U. S. Weather Bureau Stations excluding 1952 and 1953. The data for 1952-1953 are from Olmstead and Hely (1962), and were calculated on the basis of a Theissen

TABLE XXII

MONTHLY AND ANNUAL PRECIPITATION, IN INCHES, 1943-1952, BRANDYWINE CREEK BASIN

	1943	1944	1945	1946	1947	1948	1949	1950	1951	1952	AVE
J	2.63	3.66	3.64	1.43	3.63	5.35	6.80	1.45	3.72	5.05	3.74
F	1.92	1.92	3.13	2.46	1.68	2.80	3.19	3.55	3.73	2.13	2.65
M	2.82	5.77	2.21	3.60	2.73	3.71	2.69	5.27	4.39	5.45	3.86
A	3.50	4.67	3.75	1.37	2.69	3.84	3.42	1.49	1.66	7.53	3.39
M	7.66	3.73	4.99	5.31	6.94	7.74	5.08	5.67	3.63	6.39	5.71
J	2.68	3.51	5.66	7.86	3.05	4.42	0.83	2.49	3.42	2.59	3.65
J	2.99	0.69	10.23	4.73	5.04	5.14	6.40	2.22	3.34	6.29	4.71
A	0.91	3.08	3.85	5.83	3.46	7.18	3.19	8.41	3.16	4.65	4.37
S	0.53	6.29	4.98	3.30	3.43	4.16	3.19	5.77	1.03	5.01	3.77
O	7.10	2.11	1.98	2.12	1.08	1.85	3.34	2.79	3.19	0.82	2.64
N	3.14	4.19	5.40	0.94	9.02	4.37	0.93	6.21	7.67	5.51	4.74
D	1.38	3.69	4.49	2.43	1.90	5.57	3.12	2.78	6.30	4.36	3.60
TOT	37.26	43.31	54.31	41.38	44.65	56.13	42.18	48.10	45.24	55.78	46.83

weighted average of six precipitation-gaging stations within the basin.

Average rainfall for the period 1943-1952 was 46.88 inches. The wettest year was 1948, with just over 56 inches, and the driest year was 1943, with a rainfall of 37.26 inches. One or two years of slightly below average rainfall preceded one year of above average rainfall over the 10 year period (Figure 23).

Average monthly rainfall was highest in May, 5.71 inches, and lowest in February and October, 2.65 and 2.64 inches, respectively (Table XXII). Excluding the months of extremes, precipitation is fairly even distributed throughout the year.

Evapotranspiration

Olmstead and Hely (1962) did not calculate total evapotranspiration for the basin, but it can be estimated by subtracting stream flow from precipitation if it is assumed that stream flow and evapotranspiration equal outflow from the basin, and precipitation is the only inflow to the basin. Evapotranspiration averaged 58 percent of precipitation, or 27.17 inches for the study period (Table XXIII). Annual evapotranspiration follows no set pattern except that, in general, years of high rainfall are characterized by a low percentage of evapotranspiration. On a monthly basis, evapotranspiration as a percent of precipitation is highest July through November, and lowest in February.

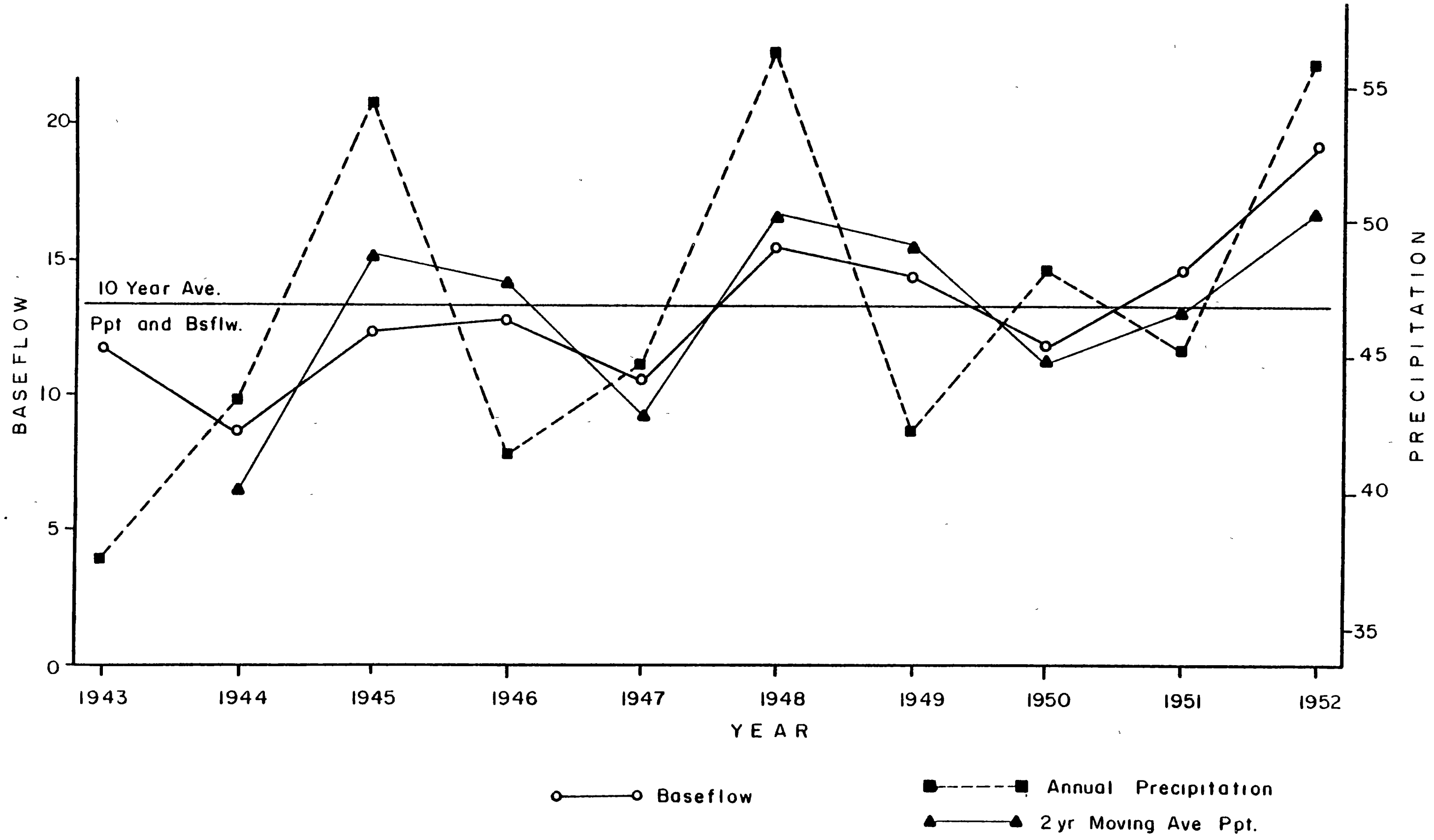


Figure 23. Annual Baseflow (Fixed Interval) and Annual Precipitation, in Inches, 1943-1952, Brandywine Creek Basin

TABLE XXIII

ANNUAL AND AVERAGE MONTHLY EVAPOTRANSPIRATION, IN INCHES, 1943-1952, BRANDYWINE CREEK BASIN

YEAR	E-T	% PPT	MONTH	E-T	% PPT
1943	20.06	54	J	1.72	46
1944	28.98	67	F	0.44	17
1945	34.51	64	M	1.47	38
1946	22.98	56	A	1.37	40
1947	30.24	68	M	3.58	63
1948	32.04	57	J	1.99	54
1949	23.29	55	J	3.29	70
1950	29.44	61	A	3.38	77
1951	23.45	52	S	2.82	75
1952	26.68	48	O	1.86	70
			N	3.31	70
AVE	27.17	58	D	1.93	54

Surface Water

Table XXIV shows monthly and annual stream flow for Brandywine Creek Basin, 1943-1952. Average discharge for the period was 19.67 inches. The highest flows occurred during 1948 and 1952, years with the two largest annual rainfall amounts. The lowest stream flows occurred during 1944 and 1947, years of below average rainfall preceded by one year of even lower rainfall.

TABLE XXIV

MONTHLY AND ANNUAL STREAM DISCHARGE, IN INCHES, 1943-1952, BRANDYWINE CREEK BASIN

	1943	1944	1945	1946	1947	1948	1949	1950	1951	1952	AVE
J	1.9	2.1	1.4	2.0	1.3	1.7	3.7	0.76	2.4	2.9	2.02
F	2.6	0.93	2.4	1.6	0.89	2.5	3.3	1.7	3.5	2.7	2.21
M	2.4	2.4	1.9	1.9	1.7	2.4	2.7	2.2	2.8	3.5	2.39
A	1.9	2.2	1.3	1.2	1.3	2.0	2.3	1.4	2.7	3.9	2.02
M	2.2	1.6	1.5	1.9	1.9	3.3	1.7	1.8	1.6	3.8	2.13
J	1.4	1.0	1.0	3.0	1.5	2.5	0.90	1.3	1.4	2.6	1.66
J	0.91	0.51	2.4	2.1	1.1	2.0	1.1	1.1	1.0	2.0	1.42
A	0.51	0.39	1.4	1.3	0.75	1.6	0.69	1.0	0.83	1.4	0.99
S	0.32	0.74	1.7	0.90	0.63	1.6	0.49	1.2	0.54	1.4	0.95
O	0.90	0.49	1.0	0.87	0.46	0.99	0.56	1.2	0.52	0.80	0.78
N	1.3	0.77	1.6	0.72	1.9	1.3	0.54	2.5	2.0	1.7	1.43
D	0.87	1.2	2.2	0.91	0.98	2.2	0.91	2.5	2.5	2.4	1.67
TOT	17.21	14.33	19.80	18.40	14.41	24.09	18.89	18.66	21.79	29.10	19.67

Ground Water

Hydrologic Properties of the Geologic Formations.

According to Olmstead and Hely (1962):

> Although several types of rocks occur within the basin, the hydrologic characteristics of the rocks, with the possible exception of the dolomite and limestone, are believed to be comparatively uniform for a basin of this size (p. 2).
>
> Furthermore:
>
> A mantle of weathered material of variable thickness has formed on all these rocks. The zone of water-table fluctuation probably lies within the lower part of the weathered material or, locally, within the immediately underlying fractured rock. At most places and at most times the gradient of the water table is toward the streams, which therefore act as ground-water drains (p. 2).

Recharge and Discharge. The source of recharge to the basin is limited to direct precipitation if it is assumed that topographic divides coincide with ground-water divides. Discharge takes the form of surface runoff, ground-water runoff, and evapotranspiration. Ground-water inflow and outflow are assumed to be negligible. Ground-water evapotranspiration is probably highest in stream valleys where the water table is close to the surface, and negligible upslope. Ground-water withdrawals from the basin are considered negligible (Olmstead and Hely, 1962).

Baseflow Evaluation

Instrumentation

Ground-water level data were collected in 16 wells, three of which were equipped with continuous recorders for the period 1952-1953. The data from the three wells were considered to be representative of the entire basin.

Mean daily discharge of Brandywine Creek was measured by a U.S. Geological Survey stream gaging station located at Chadds Ford, Pennsylvania. Publication of the data by the U. S. Geological Survey was discontinued after September 1953.

Precipitation data for 1943-1951 are from the U. S. Weather Bureau station at Chadds Ford, Pennsylvania. The data for 1952 are from a Theissen weighted average of the precipitation-gaging stations in the basin.

Baseflow Recession Curves

Olmstead and Hely (1962) used baseflow recession curves to separate daily stream discharge into direct (surface) runoff and baseflow. Separate curves were prepared for winter and summer, and records of daily precipitation and temperature were used as guides for interpreting slopes of the hydrograph. Baseflow was 18.68 and 16.61 inches in 1952 and 1953, respectively (Table XXV), and greater during the first six months of those years than the last six months.

Computer Baseflow Separation

Mean daily stream discharge for Brandywine Creek Basin from January 1952 through September 1953 was used to determine effective ground-water recharge. The results from the fixed interval, sliding interval, and local minima methods, and the baseflow calculations by Olmstead and Hely (1962) are shown in Table XXV.

TABLE XXV

GROUND-WATER RUNOFF, IN INCHES, 1952-1953, BRANDYWINE CREEK BASIN

	BSFL	F-I	S-I	L-M
1952				
J	1.70	2.0	2.0	2.2
F	2.11	2.1	2.1	2.0
M	2.24	2.3	2.3	2.7
A	2.12	2.1	2.2	2.6
M	2.50	2.6	2.5	2.1
J	1.99	2.0	2.0	1.5
J	1.30	1.3	1.3	0.96
A	1.02	1.0	1.1	0.64
S	0.88	0.85	0.87	0.43
O	0.77	0.75	0.76	0.41
N	0.71	0.73	0.80	0.80
D	1.34	1.4	1.4	1.1
ANNUAL	18.68	19.13	19.33	17.44
1953				
J	1.88	2.1	2.2	2.0
F	2.02	2.0	2.0	2.1
M	2.70	2.8	2.8	2.4
A	2.75	2.9	2.8	2.1
M	2.03	2.1	2.1	2.4
J	1.53	1.6	1.5	2.1
J	0.96	0.94	0.94	1.3
A	0.64	0.63	0.63	1.0
S	0.43	0.41	0.42	0.86
O	0.40			
N	0.53			
D	0.74			
ANNUAL	16.61			

The fixed interval and sliding interval methods yield nearly identical results for the basin. For 1952, effective ground-water recharge by the local-minima method is about 10 percent less than the other two methods. During months of low flow the local minima method deviates the largest amount. In 1953 the method yields larger values for baseflow, again most evident during months of low flow.

Compared with the monthly baseflow calculations by Olmstead and Hely (1962), the fixed and sliding interval methods yield results about 10 percent greater. The local minima results are about 10 percent less for 1952, but about 20 percent greater for the months included in 1953.

The fixed interval method was chosen to represent ground-water runoff from Brandywine Creek Basin for the period 1943 through 1952 (Table XXVI). The highest annual ground-water runoff occurred during 1952, 19.13 inches, the year of the second largest annual rainfall. The lowest annual baseflow occurred in 1944, 8.70 inches, a year of near normal rainfall preceded by the driest year of the study period. The line representing the two year moving average precipitation closely follows the line representing annual baseflow (Figure 23). This indicates the amount of yearly baseflow is dependent upon that year's and the previous year's rainfall. Ten year average baseflow was 13.18 inches.

Figure 24 shows months of variable rainfall but about equal baseflow. Baseflow for February, April, and May was

TABLE XXVI

MONTHLY AND ANNUAL BASEFLOW (FIXED INTERVAL), IN INCHES, 1943-1952, BRANDYWINE CREEK BASIN

	1943	1944	1945	1946	1947	1948	1949	1950	1951	1952	AVE
J	1.5	0.66	0.77	1.7	1.0	0.95	2.3	0.68	1.6	2.0	1.32
F	1.4	0.56	1.3	1.1	0.72	1.1	2.8	0.91	2.2	2.1	1.42
M	1.7	1.3	1.6	1.5	1.3	1.9	2.2	1.2	2.1	2.3	1.71
A	1.3	1.4	1.1	1.1	1.1	1.5	1.8	1.2	2.1	2.1	1.47
M	1.5	1.3	1.1	1.1	1.3	2.0	1.3	1.3	1.4	2.6	1.49
J	1.2	0.76	0.63	1.5	1.1	1.7	0.83	1.1	1.0	2.0	1.18
J	0.77	0.47	1.1	1.1	0.77	1.4	0.73	0.76	0.75	1.3	0.92
A	0.47	0.31	1.0	0.92	0.62	1.1	0.55	0.61	0.57	1.0	0.72
S	0.29	0.33	0.81	0.68	0.50	0.86	0.42	0.65	0.44	0.85	0.58
O	0.43	0.42	0.91	0.74	0.42	0.89	0.47	0.80	0.43	0.75	0.63
N	0.74	0.42	0.87	0.66	0.89	0.87	0.48	1.0	0.78	0.73	0.74
D	0.58	0.77	1.2	0.65	0.80	1.2	0.52	1.7	1.2	1.4	1.0
TOT	11.88	8.70	12.39	12.75	10.52	15.47	14.40	11.91	14.57	19.13	13.18
% Q	69	61	62	69	73	64	76	64	67	66	67
% PPT	32	20	23	31	24	28	34	25	32	34	28

approximately 1.45 inches, but average rainfall increased from 2.65 inches in February to 5.71 inches in May. Months with similar relationships are September and October, and August and November. This indicates changes in evapotranspiration and soil moisture deficit; those factors are higher in May and September than February and October, respectively.

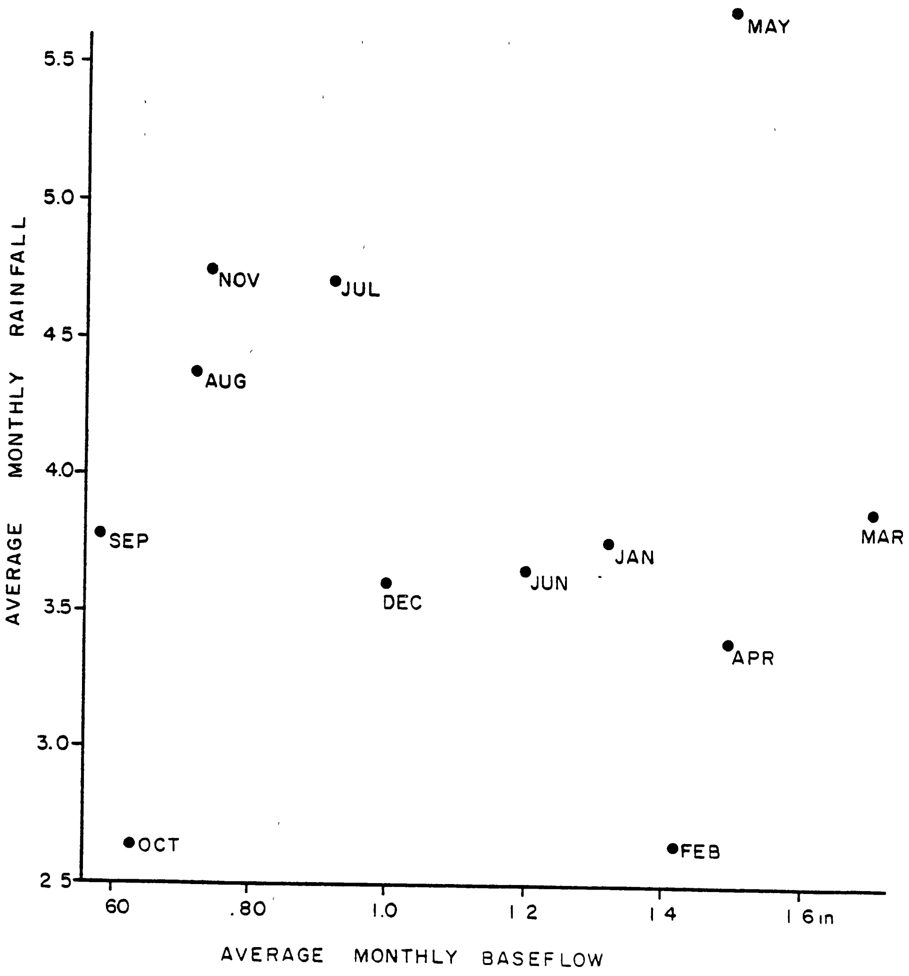


Figure 24. Average Monthly Rainfall and Average Monthly Baseflow (Fixed Interval), 1943-1952, Brandywine Creek Basin

The ratio of baseflow to precipitation ranged from 20 to 34 percent and averaged 28 percent. The highest and lowest values generally occurred during years of high and low rainfall and runoff, respectively. Brandywine Creek Basin is characterized by the least variation of baseflow as a percent of precipitation for each of the basins studied. Baseflow as a percent of stream discharge does not vary substantially either. It had a high at 76 percent in 1949, and a low of 61 percent in 1944. The average was 67 percent.

Summary

Brandywine Creek basin covers 287 square miles in the Peidmont province. Normal annual precipitation is 44 inches, which is distributed fairly evenly throughout the year. Most of the basin is covered by permeable, well-drained soils. The water-bearing materials consist of weathered and fractured bedrock.

Baseflow calculated by the fixed interval and sliding interval methods are about 10 percent greater than ground-water runoff determined by baseflow recession curves. The local minima method values were 20 percent greater one year, and 10 percent less another, than those calculated by Olmstead and Hely (1962).

Extremes in baseflow ranged from 8.70 inches in 1944 to 19.13 inches in 1952. The pattern of annual baseflow closely follows the pattern of two year moving average precipitation, indicating baseflow is a function of that year and the previous year's amount of rainfall. Baseflow as a percent of precipitation, and stream discharge averaged 28 and 67, respectively.

CHAPTER IX

CONNETQUOT RIVER BASIN, NEW YORK

Geography

Connetquot River Basin is located between approximately 40° 45' and 40° 53' north latitude and 73° 04' and 73° 14' west longitude in south central Suffolk County, Long Island, New York. It covers an area of 24 square miles. The basin has a maximum elevation of 115 feet, and the gaging station is located at 1.56 feet above mean sea level (Figure 25).

Long Island is located in the temperate-climate belt and has a mean annual temperature of 51°F (Franke and McClymonds, 1972). The average growing season is about 190 days. Precipitation averages 44 inches annually and is fairly evenly distributed throughout the year. Snowfall averages 25 inches per year and rarely remains on the ground for more than a week (Pluhowski and Kantrowitz, 1964).

Lake Ronkonkoma is located in the northeast corner of the drainage basin. It occupies a kettle hole whose bottom is approximately 60 feet below the water table. According to historical records researched by Pluhowski and Kantrowitz (1964), Lake Ronkonkoma is the only natural lake in the basin. A number of small ponds were constructed and are

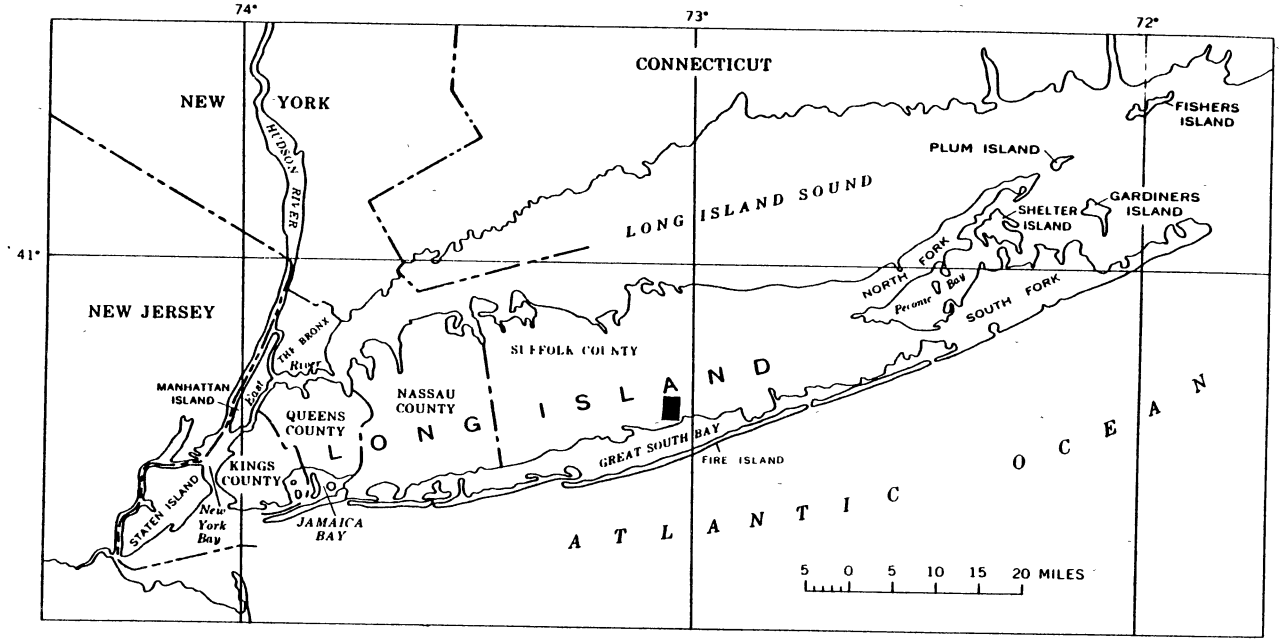


Figure 25. Location of Connetquot River Basin (modifed from Franke and McClymonds, 1972, p. 2)

used for recreational purposes.

Approximately half the drainage basin is urbanized, the majority of this area is covered by private residences. The basin encloses the town of Ronkonkoma and East Hauppauge as well as parts of East Brentwood and Central Islip. No heavy industry is present in the area. The low-lying parts of the basin are undeveloped and marshy in spots.

Geology

Most of the major topographic features of Long Island are related to Pleistocene glaciation. North of the study area lies the Ronkonkoma Moraine which is a set of east-trending hills. This marks the southern-most extension of glacial ice sheets. It has a maximum altitude of about 400 feet in western Suffolk County (McClymonds and Franke, 1972).

A moderately even, gently sloping surface of glacial outwash deposits extends from the Ronkonkoma Moraine to Great South Bay. The surface has an altitude of about 100 to 150 feet along its inland border and slopes southward at about 20 feet per mile (McClymonds and Franke, 1972). Marine action has reworked some of these deposits to form barrier beaches along the south shore of Long Island.

Loam and sandy loam soils are characteristic of south central Suffolk county. They are thin, contain little or no clay, highly permeable, and generally underlain by coarse sand and gravel. Gentle surface slopes cover most of the area, further increasing the potential for rapid infiltration (Pluhowski and Kantrowitz, 1964).

Long Island is underlain by consolidated bedrock of Pre-cambrian age, which in turn is overlain by a wedge-shaped mass of unconsolidated sediments (McClymonds and Franke, 1972). The top of the bedrock is at or near the surface in the northwestern part of the island and slopes to the southeast at a rate of about 65 feet per mile. It is at a depth of around 1,600 feet below sea level in southwestern Suffolk County.

The Raritan Formation is of Late Cretaceous age and directly overlies the bedrock. It consists of the Lloyd Sand Member and an unnamed clay member. The Lloyd Sand lies directly on the bedrock surface and consists of sand and gravel with lenses of clay and silty clay. It is 150 to 300 feet thick and the top has an altitude between 800 and 1,500 feet below sea level. the unnamed clay member consists of 170 to 300 feet of clay, silt, and some very fine to fine sand.

Directly overlying the clay member of the Raritan is the Magothy Formation of Late Cretaceous age. It consists of beds and lenses of sand, clayey and silty sand, and clay. Gravel units may occur in the lower (basal) portions of the Magothy. It is 700 to 1,200 feet thick and the altitude of the top of the formation ranges from 200 feet above to more than 100 feet below sea level. During late Pliocene and Pleistocene time, the surface of the Magothy was eroded by streams.

Pleistocene deposits comprise the uppermost 50 to 150 feet of sediments. The oldest Pleistocene formation is the Gardiners clay; 20 to 40 feet of clay with lenses of silt and very fine sand, and thin layers of fine gravel. It is a marine interglacial deposit.

The upper Pleistocene deposits consist of glacial outwash and till. The outwash deposits are stratified medium to coarse sand and gravel, and cover the majority of the area. The glacial till is composed of unstratified clay, sand, gravel, and boulders.

Hydrology

Precipitation

The 10 year study period, 1964 through 1973, was chosen because concurrent streamflow and precipitation data were available. The U. S. Geological Survey in Syosset, New York provided these data through written communication. The streamflow data are also published in water-supply papers.

During the study period, precipitation ranged from 57.83 inches in 1972 to 25.87 inches in 1965 (Table XXVII and Figure 26). Average precipitation was 43.08 inches during the same period. January was the driest month, receiving 2.59 inches of precipitation, and December was the wettest, with slightly over five inches of rainfall.

TABLE XXVII

MONTHLY AND ANNUAL PRECIPITATION, IN INCHES, 1964-1973, CONNETQUOT RIVER BASIN

	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	AVE
J	3.79	3.35	3.38	1.34	2.56	1.26	0.66	2.68	2.93	3.98	2.59
F	3.48	3.41	3.74	3.43	1.62	3.40	4.10	5.33	5.89	3.60	3.80
M	3.21	3.08	1.93	5.70	7.19	2.77	5.07	2.81	5.39	4.07	4.12
A	7.56	3.08	2.16	3.21	1.17	4.55	3.83	3.32	4.33	7.88	4.11
M	0.55	0.70	5.87	5.56	4.43	1.64	3.78	3.11	5.87	4.84	3.64
J	1.50	1.93	0.76	4.29	4.61	2.38	1.93	1.94	7.49	4.95	3.18
J	3.83	2.05	0.59	6.01	0.48	8.21	2.66	4.44	1.06	3.70	3.30
A	0.28	3.33	2.56	5.33	3.03	4.75	5.14	4.33	1.65	2.92	3.33
S	3.45	1.16	7.50	1.53	1.77	3.46	1.55	2.85	3.53	2.11	2.89
O	3.36	1.20	3.39	1.29	2.40	4.32	1.09	3.40	6.93	3.63	3.10
N	3.23	1.08	1.99	2.77	6.13	3.73	4.92	6.93	6.63	2.72	4.01
D	5.77	1.50	2.88	5.99	6.30	7.86	3.34	2.24	6.13	8.06	5.01
TOT	40.04	25.87	36.75	46.45	41.69	48.33	38.07	43.38	57.83	52.46	43.08

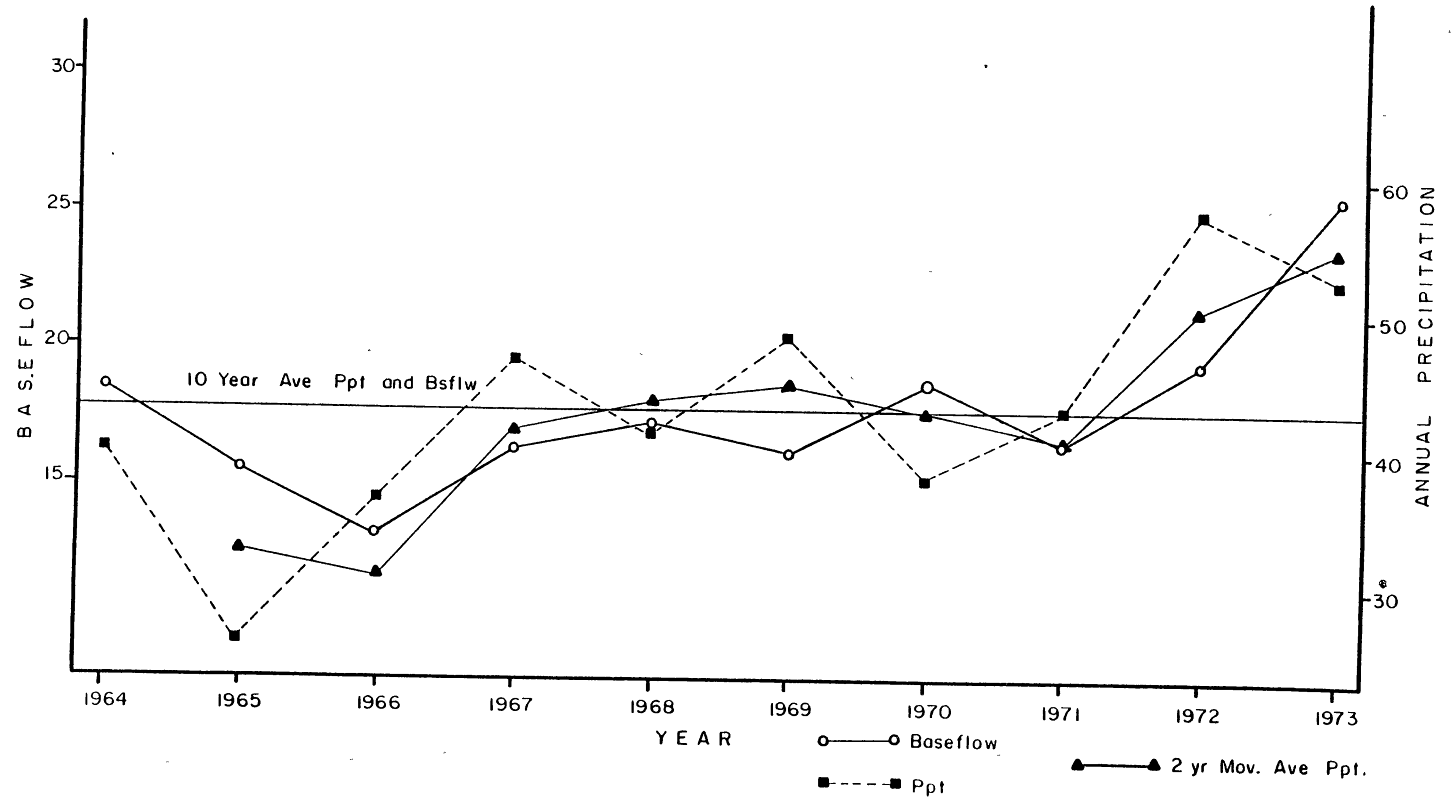


Figure 26. Annual Baseflow (Fixed Interval) and Annual Precipitation, in Inches, 1964-1973, Connetquot RIver Basin

Evapotranspiration

Pluhowski and Kantrowitz (1964) estimate annual evapotranspiration to be about 21 inches, based on nearby pan evaporation and precipitation-runoff studies made in areas adjacent to Long Island. Evapotranspiration can also be estimated by subtracting stream discharge from precipitation, using the same assumptions as those for Brandywine Creek Basin. Evapotranspiration during the study period averaged 24.26 inches, or 55 percent of precipitation (Table XXVIII). As a percent of precipitation, it was lowest in 1965, the year of least rainfall, and highest in 1969 and 1972, years of above average rainfall. On a monthly basis, the ratio of evapotranspiration to precipitation is fairly equal throughout the year, except January, when it was significantly lower.

Surface Water

Stream flow for the study period averaged 18.9 inches annually (Table XXIX), or 44 percent of precipitation. The lowest stream discharge occurred during 1966 and the highest in 1973, 19.7 and 27.0 inches, respectively. These years are also one year after the low and high annual rainfalls, respectively, indicating a two year relationship between stream flow and precipitation. Monthly average stream flow is distributed fairly evenly throughout the year, ranging from a low of 1.3 inches in September to a high of 1.8 inches in March, April, and May.

TABLE XXVIII

ANNUAL AND AVERAGE MONTHLY EVAPOTRANSPIRATION, IN INCHES, 1964-1973, CONNETQUOT RIVER BASIN

YEAR	E-T	% PPT	MONTH	E-T	% PPT
1964	20.34	51	J	0.99	38
1965	9.47	37	F	2.30	60
1966	22.85	62	M	2.32	56
1967	28.95	62	A	2.31	56
1968	23.19	56	M	1.84	50
1969	31.13	64	J	1.58	50
1970	18.37	48	J	1.80	54
1971	25.88	60	A	1.83	55
1972	36.93	64	S	1.59	55
1973	25.46	48	O	1.70	55
			N	2.61	65
AVE	24.26	55	D	3.31	66

TABLE XXIX

MONTHLY AND ANNUAL STREAM DISCHARGE, IN INCHES, 1964-1973, CONNETQUOT RIVER BASIN

	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	AVE
J	1.8	1.7	1.3	1.2	1.7	1.5	1.7	1.5	1.5	2.2	1.6
F	1.6	1.7	1.3	1.0	1.4	1.3	1.7	1.5	1.5	2.3	1.5
M	1.6	1.6	1.4	1.6	1.9	1.5	1.8	1.8	1.8	2.5	1.8
A	2.1	1.6	1.2	1.5	1.6	1.5	2.1	1.7	1.7	2.8	1.8
M	1.9	1.6	1.4	1.6	1.6	1.4	1.9	1.7	1.8	2.7	1.8
J	1.5	1.4	1.2	1.7	1.8	1.2	1.7	1.4	1.9	2.4	1.6
J	1.6	1.2	0.96	1.7	1.5	1.3	1.6	1.2	1.7	2.5	1.5
A	1.5	1.2	0.97	1.6	1.3	1.5	1.6	1.4	1.5	2.1	1.5
S	1.2	1.0	1.1	1.3	1.3	1.3	1.4	1.3	1.3	1.8	1.3
O	1.6	1.1	1.1	1.3	1.2	1.4	1.3	1.1	1.7	1.8	1.4
N	1.5	1.1	1.0	1.3	1.5	1.5	1.4	1.3	2.1	1.7	1.4
D	1.8	1.2	1.0	1.7	1.7	1.8	1.5	1.6	2.4	2.2	1.7
TOT	19.7	16.4	13.9	17.5	18.5	17.2	19.7	17.5	20.9	27.0	18.9

Ground-Water

Hydrologic Properties of the Geologic Formations.

The ground-water reservoir of Long Island consists of the saturated unconsolidated sand and gravel deposits. The bedrock is poorly permeable to virtually impermeable and forms the lower boundary of the ground-water reservoir. The unconsolidated sediments can be divided into three aquifers: a shallow water-table aquifer, an intermediate artesian aquifer, and a deep artesian aquifer.

The shallow water-table aquifer consists of saturated permeable Pleistocene deposits. Average thickness of the aquifer is 75 feet (Pluhowski and Kantrowitz, 1964). The lower boundary of the aquifer is defined by beds of low permeability in the upper part of the Magothy Formation. In places where the uppermost parts of the Magothy are permeable, the water-table aquifer extends to the first zone of low permeability. The Gardiners clay forms the lower boundary in the southern-most part of the study area. The water-table aquifer is hydraulically connected to Connetquot River and provides a substantial sustained base flow.

The intermediate artesian aquifer is composed of permeable deposits of the Magothy Formation. Clayey and silty lenses in the upper part of the magothy, and the Gardiners Clay, where present, form the upper boundary. The lower boundary is formed by the Raritan clay. Vertical leakage to or from the overlying water-table aquifer is minimal due to very small differences in head in each of the aquifers (McClymonds and Franke, 1972).

The deep artesian aquifer consists of the Lloyd Sand Member of the Raritan Formation. It is the lower-most water producing zone. The aquifer is well-confined, but receives recharge from vertical leakage through the Raritan Clay (McClymonds and Franke, 1972).

Recharge and Discharge. Recharge to Connetquot River Basin is from direct precipitation. Drainage divides are assumed to coincide with topographic divides, therefore underflow into the basin is not considered. Discharge takes the form of ground-water runoff, evapotranspiration, and ground-water outflow. A small percentage of discharge from the ground-water reservoir leaves the basin as underflow to the Atlantic Ocean because of a horizontal gradient in the lower part of the water-table aquifer (Pluhowski and Kantrowitz, 1962). Vertical leakage in the vicinity of the basin is considered negligible due to approximately equal heads in the upper and lower aquifers (Pluhowski and Kantrowitz, 1962).

Baseflow Evaluation

Instrumentation

Mean daily stream discharge was measured by the U. S. Geological Survey during the study period at a gaging station on Connetquot River below 24 square miles of drainage area. Rainfall and evaporation were measured at nearby stations also maintained by the U. S. Geological Survey.

Hydrograph Separation

Pluhowski and Kantrowitz (1964) determined baseflow to Connetquot River by hydrograph separation. They calculated ground-water runoff to be 94 to 98 percent of total discharge. In another investigation at a nearby stream (Pluhowski and Kantrowitz, 1962), they determined baseflow to be 95 percent of total stream discharge, by hydrograph separation and seepage measurements.

Computer Baseflow Separation

The computer program was applied to 10 years of consecutive stream flow data. The fixed interval method was used to represent ground-water runoff from the basin. Results of the separation technique are presented in Figure 26 and Table XXX.

Ground-water runoff for the period 1964 through 1973 accounted for 94 to 96 percent of total runoff, and averaged 95 percent. Baseflow as a percent of total stream discharge is a fairly constant factor from year to year. This compares favorably with the previous estimates by Pluhowski and Kantrowitz (1964 and 1962) of 94 to 98 percent and 95 percent, respectively.

Annual baseflow varied from 13.2 inches in 1966 to 25.6 inches in 1973. These were years following the lowest and

TABLE XXX

MONTHLY AND ANNUAL BASEFLOW, IN INCHES, 1964-1973, CONNETQUOT RIVER BASIN

	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	AVE
J	1.6	1.6	1.2	1.1	1.6	1.4	1.7	1.4	1.4	2.1	1.5
F	1.5	1.6	1.2	0.99	1.3	1.3	1.6	1.4	1.4	2.2	1.4
M	1.5	1.5	1.4	1.5	1.7	1.4	1.7	1.8	1.8	2.4	1.7
A	2.0	1.6	1.2	1.5	1.5	1.4	2.0	1.7	1.6	2.7	1.7
M	1.9	1.5	1.3	1.6	1.6	1.3	1.9	1.7	1.7	2.6	1.7
J	1.5	1.3	1.2	1.5	1.7	1.2	1.6	1.3	1.7	2.3	1.5
J	1.4	1.1	0.91	1.6	1.4	1.3	1.6	1.1	1.6	2.3	1.4
A	1.4	1.2	0.93	1.5	1.3	1.5	1.5	1.3	1.5	2.1	1.4
S	1.1	0.95	0.86	1.2	1.2	1.2	1.3	1.1	1.1	1.6	1.2
O	1.5	1.1	1.0	1.2	1.2	1.3	1.2	1.1	1.6	1.7	1.3
N	1.4	1.1	1.0	1.2	1.3	1.4	1.4	1.2	1.9	1.6	1.4
D	1.7	1.1	0.98	1.6	1.6	1.6	1.4	1.6	2.3	2.0	1.6
TOT	18.5	15.6	13.2	16.5	17.4	16.3	18.9	16.7	19.6	25.6	17.8
% Q	94	95	95	94	94	95	96	95	94	95	95
% PPT	46	60	36	36	42	34	50	38	34	49	42

highest annual rainfalls, respectively. Also, the line representing two year moving average precipitation follows the line representing annual baseflow more closely than the line representing annual precipitation. This is an indication that the amount of ground-water runoff is dependent upon the year's and previous year's quantity of rainfall. Baseflow as a percentage of precipitation varied from 34 percent in 1969 and 1972 to 60 percent in 1965. The 10 year average was 42 percent.

The amount of baseflow does not vary significantly from month to month. September had the lowest average baseflow, 1.2 inches; March, April, and May are months of highest average baseflow, 1.7 inches. Average monthly baseflow and precipitation are shown graphically in Figure 27. Months of equal baseflow but increasing amounts of rainfall, such as July, August, February, and November are evident. The winter and early spring months receive relatively larger amounts of ground-water runoff due to lower evapotranspiration.

Summary

Connetquot River Basin covers 24 square miles in glacial outwash. Normal annual precipitation is 44 inches and is nearly evenly distributed throughout the year. Permeability of the soils is rapid. Unconsolidated sand and gravel, about 75 feet thick, comprises the aquifer in direct connection with Connetquot River.

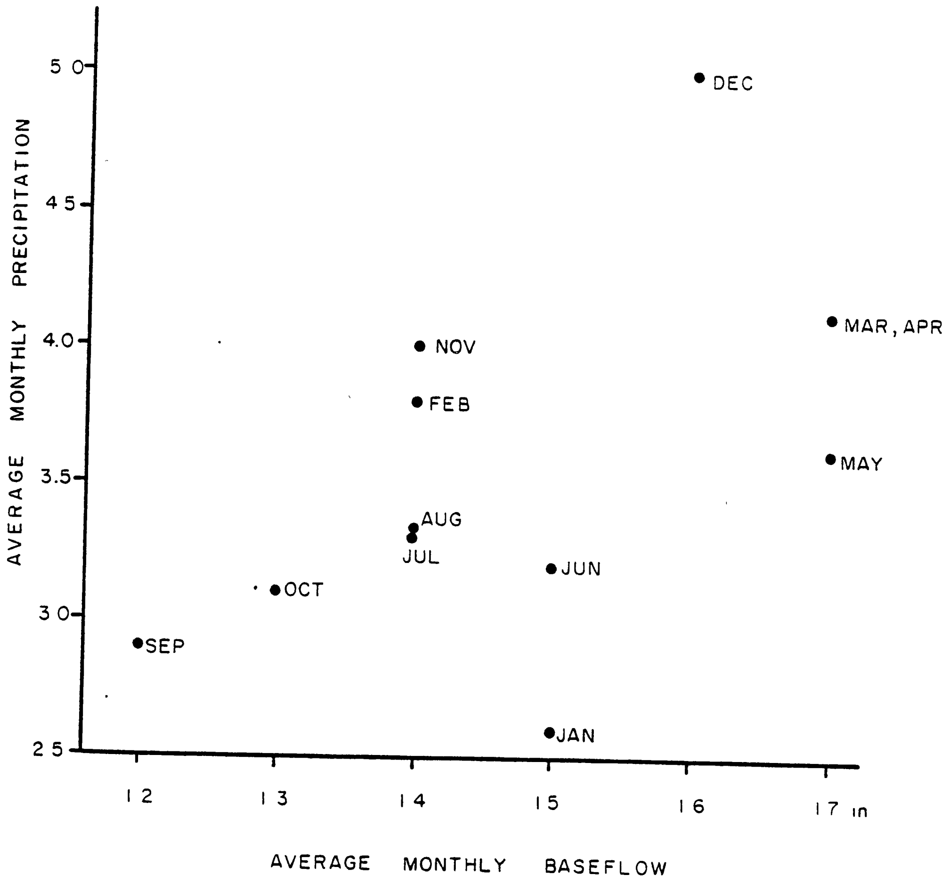


Figure 27. Average Monthly Rainfall and Average Monthly Baseflow (Fixed Interval), 1964-1973, Connetquot River Basin

Ten consecutive years of stream flow data were used to determine baseflow from the basin by computer separation techniques. The fixed interval method was chosen to represent the basin. Baseflow as a percent of stream discharge averaged 95 percent over the 10 year study period. This coincides with estimates by Pluhowski and Kantrowitz (1964, 1962) of 94 to 98 percent and 95 percent.

The relationship between annual baseflow and precipitation correlates closely on a two year basis. The year of least rainfall is followed by the year of lowest stream discharge and baseflow, as well as the year of highest rainfall followed by the greatest annual discharge and baseflow. A lag time between rainfall and baseflow is characteristic of humid regions.

Ground-water runoff ranged from 25.6 to 13.2 inches and averaged 17.8 inches for the period 1964 through 1973. As a percent of precipitation, the range was from 34 to 60 percent, with an average of 42 percent.

CHAPTER X

SUMMARY AND CONCLUSIONS

The results from a computer program developed by Pettyjohn and Henning (1979) to determine baseflow by hydrograph separation was compared with data provided by previous baseflow studies. Six drainage basins, ranging in size from 19.5 to 287 square miles, located from Oklahoma to New York, were chosen. Each of the streams is perennial.

The computer program separates the hydrograph by three methods: fixed interval, sliding interval, and local minima. Each method is based on the N-interval, N being equal to the time, in days, surface runoff ceases after a rainfall or snowmelt event. The N-interval is commonly used to estimate the period of time surface runoff ceases. Required input for the program consists of mean daily stream discharge, which is used to create the hydrograph, and drainage area of the basin, which is used to calculate the N-interval. These data are readily available in publications of the U. S. Geological Survey and the U. S. Department of Agriculture.

Pettyjohn and Henning (1979) estimated that manual separation techniques require 4.5 hours per gaging station per year of data. One year of discharge data can be input and the computer program run in approximately three-fourths of an hour. The computer program presented in this report can be used as a substitute for time consuming, manual baseflow separation techniques.

The results obtained by the previous investigators were compared to baseflow calculations by computer hydrograph separation for the same time periods in order to check the accuracy of the computer separation program. The previous investigators used ground-water rating curves, baseflow recession curves, or seepage measurements. The fixed interval method was generally within 20 percent (higher or lower) of the manual techniques.

Seepage measurements with a Pygmy current meter were made along the Little Washita River, Oklahoma, and its tributaries during a two day period in February, 1984 by the author. The Little Washita River Basin has an area of 287 square miles and a mean annual rainfall of 28 inches. No rainfall events had been observed within the basin at least five days prior to the measurements, therefore, stream flow consisted entirely of ground-water runoff. Discharge was recorded at 44 sites, and drainage areas were determined on 7.5 minute quadrangles. The average ground-water runoff per unit area was 1.42×10^6 gallons per day per square mile, which is within 20 percent of the computer techniques during a similar two year rainfall pattern. Well hydrographs were also available for three wells within the basin. Water-table fluctuations imply low ground-water runoff during

August, September, and October, and higher than average rates of baseflow during 1973 and the early part of 1974. These patterns are also reflected by the computer separation program during the same time period.

Schicht and Walton (1961) used ground-water rating curves to determine baseflow in Panther Creek Basin, Illinois. The basin has an area of 95 square miles and an average annual precipitation of 34 inches. They determined ground-water runoff for 1951, 1952, and 1956 as 6.00, 7.16, and 0.37 inches, respectively. The fixed interval computer hydrograph separation results were consistently closer to the values calculated by Schicht and Walton (1961) than either the sliding interval or local minima methods. The results for the same years were 7.39, 5.91, and 0.33 inches, respectively.

Schicht and Walton (1961) also calculated ground-water runoff for Goose Creek Basin, Illinois, using ground-water rating curves. Goose Creek Basin has an area ot 47 square miles and receives an average of 37 inches of precipitation annually. Their results for 1955, 1956, and 1957 were 1.60, 1.52, and 3.80 inches, respectively. Of the three computer separation methods, the local minima method yielded results closest to those values, and were 1.66, 1.25, and 4.84 inches, respectively.

Baseflow from Beaverdam Creek Basin, Maryland, was determined by ground-water rating curves by Rasmussen and Andreasen (1959). The basin has an area of 19.5 square miles and an average annual precipitation of 43 inches. From April, 1950 through March, 1952, they calculated ground-water runoff to be 21.46 inches. Hydrograph separation by the fixed interval computer method calculated ground-water runoff as 25.33 inches for the same time period.

Olmstead and Hely (1962) used baseflow recession curves to calculate ground-water runoff from Brandywine Creek Basin, Pennsylvania. The basin has an area of 287 square miles and an average annual rainfall of 44 inches. For 1952 they determined baseflow to be 18.68 inches; baseflow by the fixed interval computer method was 19.13 inches for the same year. From January through September, 1953, Olmstead and Hely (1962) calculated baseflow as 14.94 inches, for the same time period the fixed interval method yielded 15.48 inches.

Ground-water runoff from the Connetquot River Basin, New York, was determined by Pluhowski and Kantrowitz (1964) by hydrograph separation and seepage measurements to be between 94 and 98 percent of total discharge. The basin covers an area of 24 square miles and precipitation averages 44 inches annually. A 10 year average, by the fixed interval computer separation method, determined that ground-water runoff accounted for 94 to 96 percent of total runoff, and averaged 95 percent.

The results from the computer hydrograph separation program were compared to manual techniques of hydrograph separation and seepage measurements to determine the accuracy of the computer method. Six drainage basins were chosen where manual techniques were previously used by other investigators. Ground-water rating curves were used in Panther Creek, Goose Creek, and Beaverdam Creek Basins. Baseflow recession curves were used in Brandywine Creek Basin, and seepage measurements were used in the Connetquot River Basin and the Little Washita River Basin. The computer hydrograph separation program yielded results within 20 percent (higher or lower) of the previous investigators' calculations. It is important to note that no method of calculating baseflow has been proven more accurate than another, but the computer technique uses readily available data, its results are reproducible, and are comparable to those obtained by other, more time consuming procedures.

Ten consecutive years of stream flow data for each basin were chosen except for Goose Creek Basin, where a seven year data base was available, to determine long-term baseflow characteristics. The results of this part of the study show that annual baseflow within each basin can vary as much as an order of magnitude, and annual baseflow is dependent upon antecedent rainfall conditions. Also, for each basin, the percent of stream discharge that is baseflow does not change as significantly from year to year, but, as a percentage of rainfall, baseflow can differ by over an order of magnitude (Table XXXI). It should be noted that

TABLE XXXI

SUMMARY OF BASIN CHARACTERISTICS, 10 YEAR RANGES

DRAINAGE BASIN	PPT (IN/YR)	Q (IN/YR)	IN/YR	% PPT	% Q
Little Washita River Watershed	19.60-45.03	0.66- 4.53	0.31- 2.12	1- 5	31-64
Panther Creek Basin	19.49-44.24	0.98-18.42	0.32- 7.39	2-19	32-62
Goose Creek Basin	27.26-37.21	1.81-12.26	0.25- 5.99	1-17	14-54
Beaverdam Creek Basin	35.74-72.59	10.99-37.30	9.51-28.07	26-37	75-90
Brandywine Creek Basin	37.26-56.13	14.33-29.10	8.70-19.13	20-34	61-76
Connetquot River Basin	25.87-57.83	13.9 -27.0	13.2 -25.6	34-60	94-96

years of the highest and lowest rainfalls do not always coincide with the years of greatest and least stream flow and baseflow due to a two year relationship between discharge and precipitation.

The long-term averages of precipitation, stream discharge, and baseflow, expressed as inches over each basin, are presented in Table XXXII. The lowest stream discharge, Little Washita Watershed, and the highest stream discharge, Brandywine Creek Basin, are associated with the least and greatest amounts of precipitation, respectively. Baseflow as a percent of stream flow is lowest in Goose Creek Basin, 39, and highest in Connetquot River Basin, 95. Goose Creek is a relatively small stream in a basin with moderate to low permeability, whereas Connetquot River Basin is characterized by highly permeable soils and an upper water-bearing zone. Baseflow as a percent of precipitation is lowest in the driest basin, Little Washita River Watershed, 2.5 percent, due to high rates of evapotranspiration. The highest percentage of precipitation that becomes baseflow, 42 percent, occurs in Connetquot River Basin.

The computer program gives fast and reasonable estimates of baseflow from readily available mean daily stream discharge data and drainage area. The fixed interval computer method compares favorably with the manual techniques of determining baseflow. It is important to note that no method of calculating baseflow has been proven more accurate than another, but the computer program uses readily

TABLE XXXII

SUMMARY OF BASIN CHARACTERISTICS, 10 YEAR AVERAGES

Drainage Basin	Area(mi^2)	Ppt(in)/ yr	Q(in)/ yr	inches/ yr	Baseflow %Ppt	%Q
Little Washita River Watershed	208	28.84	1.58	0.77	2.5	48
Panther Creek Basin	95	32.66	7.93	3.98	12	50
Goose Creek Basin	47.3	32.51	6.82	3.03	9	39
Beaverdam Creek Basin	19.5	44.65	17.87	14.86	33	84
Brandywine Creek Basin	287	46.83	19.67	13.18	28	67
Connetquot River Basin	24	43.08	18.9	17.8	42	95

available data, and its results are reproducible. Many previous investigators have ignored the large differences in baseflow possible from year to year. Ideally, baseflow studies should include a number of consecutive years of high and low rainfall. Previous investigators using manual methods may have been hesitant to analyze more than a few years due to the large data base and number of calculations required.

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APPENDIX

LISTING OF COMPUTER PROGRAM

```
1 REM ************************************************************
2 REM *
3 REM *      FOLLOWING ARE THE SPECIAL CONTROL CODES FOR THE PRINTER     *
4 REM *         AND THE SCREEN. CHR$(27) IS NOT INCLUDED BECAUSE IT IS   *
5 REM *         PROGRAMMING CONTROL FUNCTION FOR A IDS PAPER TIGER 460.  *
6 REM *         HOWEVER IT IS USED TO CONTROL THE LINE SPACING.          *
7 REM *                                                                  *
10 REM ***************************************************************
20 ENHANCED.PRINT$=CHR$(27)+CHR$(33)
30 UNENHANCE.PRINT$=CHR$(27)+CHR$(34)
40 FINE.SPACE$=CHR$(27)+CHR$(84)+"10"
50 REVERSE.VIDEO$=CHR$(7)
60 CLEAR.SCREEN$=CHR$(26)
70 FORM.FEED$=CHR$(12)
80 SMALL.PRINT$=CHR$(27)+CHR$(81)
90 MEDIUM.PRINT$=CHR$(27)+CHR$(69)
100 LARGE.PRINT$=CHR$(27)+CHR$(78)
110 PRINT CLEAR.SCREEN$
120 DEFINT I-N
130 DIM DD(365),DSS(365),GDIS(365)
140  REM This generates the input menu ***********************************
150  PRINT CLEAR.SCREEN$
160  PRINT:PRINT:PRINT:PRINT:PRINT
170  PRINT SPC(35)"INPUT MENU"
180  PRINT
190  PRINT SPC(20)"A."SPC(5)"INPUT DISCHARGE DATA"
200  PRINT SPC(20)"B."SPC(5)"LIST DISCHARGE DATA AND EDIT IT"
210  PRINT SPC(20)"C."SPC(5)"SAVE DISCHARGE DATA ON DISK"
220  PRINT SPC(20)"D."SPC(5)"LOAD DISCHARGE DATA FROM DISK"
230  PRINT SPC(20)"E."SPC(5)"EXIT THE PROGRAM"
240  PRINT SPC(20)"F."SPC(5)"ENTER THE CALCULATION MENU"
250  PRINT SPC(20)"G."SPC(5)"DELETE YOUR FILE ON DISK"
260  PRINT SPC(20)"H."SPC(5)"PRINT THE DISCHARGE DATA"
270  PRINT SPC(20)"I.     LIST THE DATA FILES ON THE DISK"
280  PRINT
290  PRINT SPC(23)"ENTER THE LETTER OF THE DESIRED FUNCTION"
300 INPUT "                              ==>",M$
310 IF M$="a" OR M$="A" THEN GOTO 440
320 IF M$="b" OR M$="B" THEN GOTO 740
330 IF M$="c" OR M$="C" THEN GOTO 1760
340 IF M$="d" OR M$="D" THEN GOTO 1950
350 IF M$="e" OR M$="E" THEN SYSTEM
360 IF M$="f" OR M$="F" THEN CHAIN "CALC.BAS",10,ALL
370 IF M$="g" OR M$="G" THEN GOTO 2090
380 IF M$="h" OR M$="H" THEN GOTO 2160
390 IF M$="I" OR M$="i" THEN GOTO 2580
410 PRINT "That is not a valid command"
420 GOTO 300
430 REM  input subroutine ***********************************************
440 DMAX=0
450 NMISS=0
460 PRINT CLEAR.SCREEN$
470 INPUT "In what year was the data taken ",YR
480 INPUT "What was the USGS station number ",SN
490 LINE INPUT "What was the station's title ",ST$
500 INPUT "What was the drainage basin area",DRAINAGE
510 PRINT "Please enter the discharge data"
520 FOR DDP=1 TO 365 STEP 1
530     IF DDP <= 31 THEN MONTH$="OCTOBER":DAY=DDP
540     IF DDP > 31 AND DDP<=61 THEN MONTH$="NOVEMBER":DAY=DDP-31
550     IF DDP > 61 AND DDP<=92 THEN MONTH$="DECEMBER":DAY=DDP-61
560     IF DDP > 92 AND DDP<=123 THEN MONTH$="JANUARY":DAY=DDP-92
570     IF DDP > 123 AND DDP<=151 THEN MONTH$="FEBURARY":DAY=DDP-123
580     IF DDP > 151 AND DDP<=182 THEN MONTH$="MARCH":DAY=DDP-151
590     IF DDP > 182 AND DDP<=212 THEN MONTH$="APRIL":DAY=DDP-182
600     IF DDP > 212 AND DDP<=243 THEN MONTH$="MAY":DAY=DDP-212
610     IF DDP > 243 AND DDP<=273 THEN MONTH$="JUNE":DAY=DDP-243
620     IF DDP > 273 AND DDP<=304 THEN MONTH$="JULY":DAY=DDP-273
630     IF DDP > 304 AND DDP<=336 THEN MONTH$="AUGUST":DAY=DDP-304
640     IF DDP >= 336 AND DDP<=365 THEN MONTH$="SEPTEMBER":DAY=DDP-335
650     IF DDP < 93 THEN YEAR=YR-1 ELSE YEAR=YR
660     PRINT "Enter the data for "MONTH$", "DAY" "YEAR;
```

```
670     INPUT DD(DDP)
680     IF DMAX<DD(DDP) THEN DMAX=DD(DDP)
690     IF DD(DDP)<0! THEN NMISS=NMISS+1
700     IF DD(DDP)<0! THEN DSS(DDP)=DSS(DDP-1) ELSE DSS(DDP)=DD(DDP)
710     NEXT DDP
720 REM go to menu 1
730 GOTO 150
740 REM subroutine to list the data ************************************
750 DMAX=0!
760 NMISS=0
770 PRINT "The year for the data is "YR" (y or n)";
780 INPUT ANS$
790 IF ANS$="N" OR ANS$="n" THEN INPUT "ENTER THE CORRECT YEAR ==>";YR
800 PRINT "The station's name is "ST$" (y or n)";
810 INPUT ANS$
820 IF ANS$="N" OR ANS$="n" THEN LINE INPUT "ENTER THE CORRECT STATION NAME ==>"
;ST$
830 IF INSTR(ST$,CHR$(34))<>0 THEN PRINT "DOUBLE QUOTATION MARKS ARE NOT VALID":
GOTO 820
840 PRINT "The station's USGS number is ";SN" (y or n)";
850 INPUT ANS$
860 IF ANS$="N" OR ANS$="n" THEN INPUT "ENTER THE CORRECT USGS NUMBER ==>";SN
870 PRINT "The drainage basin area is "DRAINAGE" (y or n)";
880 INPUT ANS$
890 IF ANS$="N" OR ANS$="n" THEN INPUT "ENTER THE CORRECT DRAINAGE BASIN AREA ==
>";DRAINAGE
900 FOR DDP=1 TO 365 STEP 1
910     IF DDP <= 31 THEN MONTH$="OCTOBER":DAY=DDP
920     IF DDP > 31 AND DDP<=61 THEN MONTH$="NOVEMBER":DAY=DDP-31
930     IF DDP > 61 AND DDP<=92 THEN MONTH$="DECEMBER":DAY=DDP-61
940     IF DDP > 92 AND DDP<=123 THEN MONTH$="JANUARY":DAY=DDP-92
950     IF DDP > 123 AND DDP<=151 THEN MONTH$="FEBURARY":DAY=DDP-123
960     IF DDP > 151 AND DDP<=182 THEN MONTH$="MARCH":DAY=DDP-151
970     IF DDP > 182 AND DDP<=212 THEN MONTH$="APRIL":DAY=DDP-182
980     IF DDP > 212 AND DDP<=243 THEN MONTH$="MAY":DAY=DDP-212
990     IF DDP > 243 AND DDP<=273 THEN MONTH$="JUNE":DAY=DDP-243
1000     IF DDP > 273 AND DDP<=304 THEN MONTH$="JULY":DAY=DDP-273
1010     IF DDP > 304 AND DDP<=336 THEN MONTH$="AUGUST":DAY=DDP-304
1020     IF DDP >= 336 AND DDP<=365 THEN MONTH$="SEPTEMBER":DAY=DDP-335
1030     IF DDP < 93 THEN YEAR=YR-1 ELSE YEAR=YR
1040     PRINT "The discharge for "MONTH$", "DAY" "YEAR" IS "DD(DDP)
1050     TST$="y"
1060     IF DDP MOD 22 < 1 OR DDP=365 THEN PRINT "Enter E to edit, Y to view more
 data, or N to return to the input menu."
1070     IF DDP MOD 22 <1 OR DDP=365   THEN INPUT " ",TST$
1080     IF TST$="n" OR TST$="N" THEN GOTO 140
1090     IF TST$="y" OR TST$="Y"THEN GOTO 1740
1100     IF TST$="e" OR TST$="E"THEN GOTO 1120
1110     GOTO 1070
1120     PRINT "In what month does your change occur";
1130     INPUT MONTHS$
1140     MONTH$=MID$(MONTHS$,1,3)
1150     IF MONTH$="jan" OR MONTH$="JAN"  THEN DATE=92
1160     IF MONTH$="feb" OR MONTH$="FEB"  THEN DATE=123
1170     IF MONTH$="mar" OR MONTH$="MAR"  THEN DATE=151
1180     IF MONTH$="apr" OR MONTH$="APR"  THEN DATE=182
1190     IF MONTH$="may" OR MONTH$="MAY"  THEN DATE=212
1200     IF MONTH$="jun" OR MONTH$="JUN"  THEN DATE=243
1210     IF MONTH$="jul" OR MONTH$="JUL"  THEN DATE=273
1220     IF MONTH$="aug" OR MONTH$="AUG"  THEN DATE=304
1230     IF MONTH$="sep" OR MONTH$="SEP"  THEN DATE=335
1240     IF MONTH$="oct" OR MONTH$="OCT"  THEN DATE=0
1250     IF MONTH$="nov" OR MONTH$="NOV"  THEN DATE=31
1260     IF MONTH$="dec" OR MONTH$="DEC"  THEN DATE=61
1270     IF DATE<1 AND DATE=92 THEN PRINT "THERE IS NO SUCH MONTH, TRY AGAIN"
1280     IF DATE<1 AND DATE=92 THEN GOTO 1130
1290     PRINT "Which day's discharge do you wish to change";
1300     INPUT DAY
1310     IF DAY < 1 THEN PRINT "That is not a valid day, try again"
```

```
1320     IF DAY < 1 THEN GOTO 1300
1330     IF DATE=92 AND DAY > 31 THEN PRINT "There are only 31 days in January"
1340     IF DATE=92 AND DAY > 31 THEN GOTO 1290
1350     IF DATE=123 AND DAY =29 THEN PRINT "Leap year is not implemented"
1360     IF DATE=123 AND DAY > 29 THEN PRINT "There are only 28 days in Feburary"
1370     IF DATE=123 AND DAY > 28 THEN GOTO 1290
1380     IF DATE=151 AND DAY > 31 THEN PRINT "There are only 31 days in March"
1390     IF DATE=151 AND DAY > 31 THEN GOTO 1290
1400     IF DATE=182 AND DAY > 30 THEN PRINT "There are only 30 days in April"
1410     IF DATE=182 AND DAY > 30 THEN GOTO 1290
1420     IF DATE=212 AND DAY > 31 THEN PRINT "There are only 31 days in May"
1430     IF DATE=212 AND DAY > 31 THEN GOTO 1290
1440     IF DATE=243 AND DAY > 30 THEN PRINT "There are only 30 days in June"
1450     IF DATE=243 AND DAY > 30 THEN GOTO 1290
1460     IF DATE=273 AND DAY > 31 THEN PRINT "There are only 31 days in july"
1470     IF DATE=273 AND DAY > 31 THEN GOTO 1290
1480     IF DATE=304 AND DAY > 31 THEN PRINT "There are only 31 days in August"
1490     IF DATE=304 AND DAY > 31 THEN GOTO 1290
1500     IF DATE=335 AND DAY > 30 THEN PRINT "There are only 30 days in September
"
1510     IF DATE=335 AND DAY > 30 THEN GOTO 1290
1520     IF DATE=0 AND DAY > 31 THEN PRINT "There are only 31 days in October"
1530     IF DATE=0 AND DAY > 31 THEN GOTO 1290
1540     IF DATE=31 AND DAY > 30 THEN PRINT "There are only 30 days in November"
1550     IF DATE=31 AND DAY > 30 THEN GOTO 1290
1560     IF DATE=61 AND DAY > 31 THEN PRINT "There are only 31 days in December
1570     IF DATE=61 AND DAY > 31 THEN GOTO 1290
1580     DATE = DATE + DAY
1590     PRINT "The discharge presently is "DD(DATE)
1600     PRINT "Enter C if you wish to change this data, enter N if you do not."
1610     INPUT " ",ANS$
1620     IF ANS$="c" OR ANS$="C" THEN INPUT "Enter the new value",DD(DATE)
1630     IF ANS$="c" OR ANS$="C" THEN GOTO 1660
1640     IF ANS$="n" OR ANS$="N" THEN GOTO 1690
1650     GOTO 1610
1660     IF DD(DATE) > DMAX THEN DMAX=DD(DATE)
1670     IF DD(DATE) < 0! THEN DSS(DATE)=DSS(DATE - 1) ELSE DSS(DATE)=DD(DATE)
1680     IF DD(DATE) < 0! THEN NMISS=NMISS + 1
1690     PRINT "Do you wish to change any more data?"
1700     INPUT " ",ANS$
1710     IF ANS$="n" OR ANS$="N" THEN GOTO 1740
1720     IF ANS$="y" OR ANS$="Y" THEN GOTO 1120
1730     GOTO 1700
1740     NEXT DDP
1750 GOTO 140
1760 REM THIS SAVES THE DISCHARGE DATA ON A FILE ON DISK *****************
1770 INPUT "PLEASE ENTER A NAME FOR YOUR FILE THE DATA ARE TO BE STORED IN ==>",
FILENAME$
1780 IF INSTR(FILENAME$," ")<>0 THEN PRINT "ILLEGAL FILE NAME, BLANKS ARE NOT AL
LOWED":GOTO 1770
1790 IF LEN(FILENAME$)>8 THEN PRINT "ILLEGAL FILE NAME, NO MORE THAN 8 CHARACTER
S ARE ALLOWED":GOTO 1770
1800 IF "Z"<LEFT$(FILENAME$,1) OR "A">LEFT$(FILENAME$,1) THEN PRINT "ILLEGAL FIL
E NAME, THE FIRST CHARACTER MUST BE AN ALPHABETIC CHARACTER":GOTO 1770
1810 FOR I=1 TO LEN(FILENAME$) STEP 1
1820      IF MID$(FILENAME$,I,1)<"0" OR MID$(FILENAME$,I,1)>"[" THEN PRINT "ILLEG
AL FILENAME, ILLEGAL CHARACTER IN POSITION ";I:GOTO 1770
1830      IF MID$(FILENAME$,I,1)<"A" AND MID$(FILENAME$,I,1)>"9" THEN PRINT "ILLE
GAL FILENAME, ILLEGAL CHARACTER IN POSITION ";I:GOTO 1770
1840      NEXT I
1850 PRINT "NOW SAVING YOUR DATA ON DISK UNDER THE FILENAME "FILENAME$
1860 OPEN "o",1,FILENAME$
1870 PRINT# 1,YR;SN;CHR$(34);ST$;CHR$(34);DRAINAGE
1880 PRINT# 1,DMAX,NMISS
1890 FOR I=1 TO 365 STEP 1
1900      PRINT# 1,DD(I),DSS(I)
1910      NEXT I
1920 PRINT# 1,DD(365),DSS(365)
1930 CLOSE 1
1940 GOTO 150
1950 REM THIS LOADS THE DISCHARGE DATA FROM A DISK FILE ******************
1960 INPUT "PLEASE ENTER THE NAME OF YOUR FILE THE DATA ARE IN ==>",FILENAME$
```

```
1970 PRINT "NOW LOADING DATA FROM FILENAME "FILENAME$
1980 OPEN "I",2,FILENAME$
1990 INPUT# 2,YR,SN,ST$,DRAINAGE
2000 INPUT# 2,DMAX,NMISS
2010 FOR I=1 TO 365 STEP 1
2020     IF EOF(2) THEN CLOSE 2
2030     IF EOF(2) THEN GOTO 140
2040     INPUT# 2,DD(I),DSS(I)
2050     NEXT I
2060 CLOSE 2
2070 PRINT "THE DATA HAS BEEN LOADED FROM DISK"
2080 GOTO 150
2090 REM THIS IS TO KILL A FILE
2100 INPUT "ENTER THE NAME OF THE FILE YOU WISH TO DELETE ==>",FILENAME$
2110 PRINT "YOU ARE ABOUT TO DELETE THE FILE NAMED "FILENAME$" DO YOU WISH TO CO
NTINUE (Y/N) ?";
2120 INPUT ANS$
2130 IF ANS$="N" OR ANS$="n" THEN GOTO 140
2140 KILL FILENAME$
2150 GOTO 150
2160 REM ************* PRINT THE DATA ******************************
2170 LPRINT:LPRINT:LPRINT:LPRINT:LPRINT
2180 LPRINT LARGE.PRINT$
2190 LPRINT SPC(10)"The water year that the data were taken is ";YR
2200 LPRINT SPC(10)"The USGS station number is ";SN
2210 LPRINT SPC(10)"The station's title is ";ST$
2220 LPRINT SPC(10)"The station's drainage area is ";DRAINAGE;" sq. mi."
2230 LPRINT:LPRINT
2240 LPRINT ENHANCED.PRINT$;SPC(6)"MEAN DAILY DISCHARGE, IN CFS";UNENHANCE.PRINT
$
2250 LPRINT "___________________________________________________________________
____________"
2260 LPRINT SMALL.PRINT$
2270 LPRINT "    OCTOBER";
2280 LPRINT "  NOVEMBER";
2290 LPRINT "  DECEMBER";
2300 LPRINT "   JANUARY";
2310 LPRINT "  FEBURARY";
2320 LPRINT "     MARCH";
2330 LPRINT "     APRIL";
2340 LPRINT "       MAY";
2350 LPRINT "      JUNE";
2360 LPRINT "      JULY";
2370 LPRINT "    AUGUST";
2380 LPRINT " SEPTEMBER"
2390 LPRINT "-------------------------------------------------------------------
---------------------------------------------------------------";SMALL.PRINT$
2400 FOR DYP=1 TO 31
2410     LPRINT USING "##";DYP;
2420     LPRINT ")";
2430     LPRINT USING "#####.##";DD(DYP);
2440     IF DYP<31 THEN LPRINT USING "  #####.##";DD(DYP+31);  ELSE LPRINT "
   ";
2450     LPRINT USING "  #####.##";DD(DYP+61);
2460     LPRINT USING "  #####.##";DD(DYP+92);
2470     IF DYP<29 THEN LPRINT USING "  #####.##";DD(DYP+123); ELSE LPRINT "
   ";
2480     LPRINT USING "  #####.##";DD(DYP+151);
2490     IF DYP<31 THEN LPRINT USING "  #####.##";DD(DYP+182); ELSE LPRINT "
   ";
2500     LPRINT USING "  #####.##";DD(DYP+212);
2510     IF DYP<31 THEN LPRINT USING "  #####.##";DD(DYP+243); ELSE LPRINT "
   ";
2520     LPRINT USING "  #####.##";DD(DYP+273);
2530     LPRINT USING "  #####.##";DD(DYP+304);
2540     IF DYP<31 THEN LPRINT USING "  #####.##";DD(DYP+335) ELSE LPRINT "
  "
2550     NEXT DYP
2560 LPRINT FORM.FEED$;LARGE.PRINT$
2570 GOTO 140
2580 REM **************** LIST THE DATA FILES ON THIS DISK ***********
2590 PRINT CLEAR.SCREEN$:PRINT:PRINT:PRINT
```

```
2600 FILES "*.   "
2610 PRINT
2620 INPUT "HIT RETURN TO RETURN TO THE INPUT MENU";JNK$
2630 GOTO 150
 10 REM ==== THIS GENERATES THE OUTPUT MENU ====================
 20 PRINT CLEAR.SCREEN$
 30 PRINT:PRINT:PRINT:PRINT
 40 PRINT SPC(30)"OUTPUT MENU"
 50 PRINT
 60 PRINT SPC(20)"A. LIST YEARLY STATISTICS"
 70 PRINT SPC(20)"B. LIST MONTHLY STATISTICS"
 80 PRINT SPC(20)"C. PRINT A HYDROGRAPH"
 90 PRINT SPC(20)"D. PRINT A FLOW DURATION CURVE"
 100 PRINT SPC(20)"E. EXIT THE PROGRAM"
 110 PRINT SPC(20)"F. PLOT A HYDROGRAPH"
 120 PRINT SPC(20)"G. PLOT A FLOW DURATION CURVE"
 130 PRINT SPC(20)"H. RETURN TO THE CALCULATION MENU"
 140 PRINT SPC(20)"I. RETURN TO THE INPUT MENU"
 150 PRINT
 160 PRINT SPC(23)"ENTER THE LETTER OF THE DESIRED FUCTION"
 170 INPUT "                              ==>",M$
 180 IF M$="A" OR M$="a" THEN GOTO 300
 190 IF M$="B" OR M$="b" THEN GOTO 840
 200 IF M$="C" OR M$="c" THEN GOTO 3260
 210 IF M$="D" OR M$="d" THEN GOTO 3770
 220 IF M$="E" OR M$="e" THEN SYSTEM
 230 IF M$="F" OR M$="f" THEN PRINT "GRAPHICS NOT IMPLEMENTED"
 240 IF M$="G" OR M$="g" THEN PRINT "GRAPHICS NOT IMPLEMENTED"
 250 IF M$="H" OR M$="h" THEN CHAIN "CALC.BAS",10,ALL
 260 IF M$="I" OR M$="i" THEN CHAIN "RECHARGE.BAS",50,ALL
 280 PRINT "THAT IS NOT A VALID COMMAND"
 290 GOTO 170
 300 REM THIS PRINTS OUT THE SUMMARY INFORMATION ABOUT THE SEPERATION
 301 PRINT CLEAR.SCREEN$;"CALCULATING THE YEARLY STATISTICS"
 310 DAYS=0!
 320 XMIN=100000!
 330 XMAX=0!
 340 TOTDIS=0!
 350 TOTGW=0!
 360 FOR I=1 TO 365
 370      IF DSS(I)<0! THEN GOTO 430
 380      DAYS=DAYS+1
 390      TOTDIS=TOTDIS+DSS(I)
 400      TOTGW=TOTGW+GDIS(I)
 410      IF DSS(I)<XMIN THEN XMIN=DSS(I)
 420      IF DSS(I)>XMAX THEN XMAX=DSS(I)
 430      NEXT I
 440 TOTGW=TOTGW*1
 450 TOQUAN=86400!*TOTDIS
 460 TOQUGW=86400!*TOTGW
 470 TOTGWI=.03719*(TOTGW/DRAINAGE)
 480 TOTOIN=.03719*(TOTDIS/DRAINAGE)
 490 XDSS=TOTDIS/DAYS
 500 PRINT CLEAR.SCREEN$
 510 PRINT "TOTAL DISCHARGE FOR THE WATER YEAR "TOQUAN" FT OR "TOTQIN" INCHES"
 520 PRINT "MINIMUM DISCHARGE "XMIN" CFS"
 530 PRINT "MEAN DISCHARGE "XDSS" CFS"
 540 PRINT "MAXIMUM DISCHARGE "XMAX" CFS"
 550 TDSSMI=TOQUAN/DRAINAGE
 560 TDGWSM=TOQUGW/DRAINAGE
 570 PRINT "TOTAL DISCHARGE/YR/BASIN AREA "TDSSMI" CF/SQ. MI."
 580 PRINT "THE TOTAL GROUND WATER DISCHARGE FOR A YEAR "TOQUGW" CF OR "TOTGWI  "
 INCHES"
 590 PRINT "TOTAL GROUND WATER DISCHARGE/YR/BASIC AREA "TDGWSM" CF/SQ. MI."
 600 PERCENT=(TOQUGW/TOQUAN)*100!
 610 PRINT "THE PERCENT OF TOTAL DISCHARGE DUE TO GROUND WATER RUNOFF "PERCENT
 620 RECH=TDGWSM*7.48/DAYS
 630 IRECH=INT(RECH/1000!)
 640 RECHG=IRECH*1000!
 650 IF RECH<10000! THEN RECHG=RECH
 660 PRINT "THE RECHARGE RATE = "RECHG" GPD/SQ. MI."
 670 PRINT
 680 PRINT "HIT ANY KEY TO RETURN TO THE OUTPUT MENU OR ";REVERSE.VIDEO$;"P TO PR
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```
INT";REVERSE.VIDEO$
690 JUNK$=INKEY$
700 IF JUNK$="" THEN GOTO 690
710 IF JUNK$<>"P" AND JUNK$<>"p" THEN GOTO 20
720 GOSUB 4890
730 LPRINT "TOTAL DISCHARGE FOR THE WATER YEAR "TOQUAN" FT OR "TOTQIN" INCHES"
740 LPRINT "MINIMUM DISCHARGE "XMIN" CFS"
750 LPRINT "MEAN DISCHARGE "XDSS" CFS"
760 LPRINT "MAXIMUM DISCHARGE "XMAX" CFS"
770 LPRINT "TOTAL DISCHARGE/YR/BASIN AREA "TDSSMI" CF/SQ. MI."
780 LPRINT "THE TOTAL GROUND WATER DISCHARGE FOR A YEAR "TOQUGW" CF OR "TOTGWI
" INCHES"
790 LPRINT "TOTAL GROUND WATER DISCHARGE/YR/BASIC AREA "TDGWSM" CF/SQ. MI."
800 LPRINT "THE PERCENT OF TOTAL DISCHARGE DUE TO GROUND WATER RUNOFF "PERCENT
810 LPRINT "THE RECHARGE RATE = "RECHG" GPD/SQ. MI."
830 GOTO 20
840 REM ==== THIS PRODUCES THE MONTHLY STATISTICS ========================
845 PRINT CLEAR.SCREEN$;"CALCULATING THE MONTHLY STATISTICS"
850 DEFDBL T
860 DIM RMONTH(12,6)
870 REM ===================OCTOBER==============================
880 TOTALQ=1E-15
890 TOTLGW=0!
900 FOR I=1 TO 12
910     FOR J=1 TO 6
920         RMONTH(I,J)=0!
930         NEXT J
940     NEXT I
950 FOR I=1 TO 31
960     IF DSS(I)>=0! THEN TOTALQ=TOTALQ+DSS(I):TOTLGW=TOTLGW+GDIS(I)
970     NEXT I
980 RMONTH(1,1)=TOTALQ*86400!
990 RMONTH(1,2)=.03719*(TOTALQ/DRAINAGE)
1000 RMONTH(1,3)=TOTLGW*86400!
1010 RMONTH(1,4)=.03719*(TOTLGW/DRAINAGE)
1020 RMONTH(1,5)=(TOTLGW/TOTALQ)*100
1030 RECH=(TOTLGW/DRAINAGE)*7.48/31!*86400!
1040 IRECH=FIX(RECH/1000!)
1050 RMONTH(1,6)=IRECH*1000
1060 IF RECH<=1000! THEN RMONTH(1,6)=RECH
1070 REM ==============================NOVEMBER===============
1080 TOTALQ=1E-15
1090 TOTLGW=0!
1100 FOR I=32 TO 61
1110     IF DSS(I)>=0! THEN TOTALQ=TOTALQ+DSS(I):TOTLGW=TOTLGW+GDIS(I)
1120     NEXT I
1130 RMONTH(2,1)=TOTALQ*86400!
1140 RMONTH(2,2)=.03719*(TOTALQ/DRAINAGE)
1150 RMONTH(2,3)=TOTLGW*86400!
1160 RMONTH(2,4)=.03719*(TOTLGW/DRAINAGE)
1170 RMONTH(2,5)=(TOTLGW/TOTALQ)*100
1180 RECH=(TOTLGW/DRAINAGE)*7.48/31!*86400!
1190 IRECH=FIX(RECH/1000!)
1200 RMONTH(2,6)=IRECH*1000
1210 IF RECH<=1000! THEN RMONTH(2,6)=RECH
1220 REM ==============================DECEMBER================
1230 TOTALQ=1E-15
1240 TOTLGW=0!
1250 FOR I=62 TO 92
1260     IF DSS(I)>=0! THEN TOTALQ=TOTALQ+DSS(I):TOTLGW=TOTLGW+GDIS(I)
1270     NEXT I
1280 RMONTH(3,1)=TOTALQ*86400!
1290 RMONTH(3,2)=.03719*(TOTALQ/DRAINAGE)
1300 RMONTH(3,3)=TOTLGW*86400!
1310 RMONTH(3,4)=.03719*(TOTLGW/DRAINAGE)
1320 RMONTH(3,5)=(TOTLGW/TOTALQ)*100
1330 RECH=(TOTLGW/DRAINAGE)*7.48/31!*86400!
1340 IRECH=FIX(RECH/1000!)
1350 RMONTH(3,6)=IRECH*1000
1360 IF RECH<=1000! THEN RMONTH(3,6)=RECH
1370 REM ==============================JANUARY================
1380 TOTALQ=1E-15
1390 TOTLGW=0!
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```
1400 FOR I=93 TO 123
1410      IF DSS(I)>=0! THEN TOTALQ=TOTALQ+DSS(I):TOTLGW=TOTLGW+GDIS(I)
1420      NEXT I
1430 RMONTH(4,1)=TOTALQ*86400!
1440 RMONTH(4,2)=.03719*(TOTALQ/DRAINAGE)
1450 RMONTH(4,3)=TOTLGW*86400!
1460 RMONTH(4,4)=.03719*(TOTLGW/DRAINAGE)
1470 RMONTH(4,5)=(TOTLGW/TOTALQ)*100
1480 RECH=(TOTLGW/DRAINAGE)*7.48/31!*86400!
1490 IRECH=FIX(RECH/1000!)
1500 RMONTH(4,6)=IRECH*1000
1510 IF RECH<=1000! THEN RMONTH(4,6)=RECH
1520 REM =================================FEBURARY==============
1530 TOTALQ=1E-15
1540 TOTLGW=0!
1550 FOR I=124 TO 151
1560      IF DSS(I)>=0! THEN TOTALQ=TOTALQ+DSS(I):TOTLGW=TOTLGW+GDIS(I)
1570      NEXT I
1580 RMONTH(5,1)=TOTALQ*86400!
1590 RMONTH(5,2)=.03719*(TOTALQ/DRAINAGE)
1600 RMONTH(5,3)=TOTLGW*86400!
1610 RMONTH(5,4)=.03719*(TOTLGW/DRAINAGE)
1620 RMONTH(5,5)=(TOTLGW/TOTALQ)*100
1630 RECH=(TOTLGW/DRAINAGE)*7.48/31!*86400!
1640 IRECH=FIX(RECH/1000!)
1650 RMONTH(5,6)=IRECH*1000
1660 IF RECH<=1000! THEN RMONTH(5,6)=RECH
1670 REM =================================MARCH===============
1680 TOTALQ=1E-15
1690 TOTLGW=0!
1700 FOR I=152 TO 182
1710      IF DSS(I)>=0! THEN TOTALQ=TOTALQ+DSS(I):TOTLGW=TOTLGW+GDIS(I)
1720      NEXT I
1730 RMONTH(6,1)=TOTALQ*86400!
1740 RMONTH(6,2)=.03719*(TOTALQ/DRAINAGE)
1750 RMONTH(6,3)=TOTLGW*86400!
1760 RMONTH(6,4)=.03719*(TOTLGW/DRAINAGE)
1770 RMONTH(6,5)=(TOTLGW/TOTALQ)*100
1780 RECH=(TOTLGW/DRAINAGE)*7.48/31!*86400!
1790 IRECH=FIX(RECH/1000!)
1800 RMONTH(6,6)=IRECH*1000
1810 IF RECH<=1000! THEN RMONTH(6,6)=RECH
1820 REM =================================APRIL==============
1830 TOTALQ=1E-15
1840 TOTLGW=0!
1850 FOR I=183 TO 212
1860      IF DSS(I)>=0! THEN TOTALQ=TOTALQ+DSS(I):TOTLGW=TOTLGW+GDIS(I)
1870      NEXT I
1880 RMONTH(7,1)=TOTALQ*86400!
1890 RMONTH(7,2)=.03719*(TOTALQ/DRAINAGE)
1900 RMONTH(7,3)=TOTLGW*86400!
1910 RMONTH(7,4)=.03719*(TOTLGW/DRAINAGE)
1920 RMONTH(7,5)=(TOTLGW/TOTALQ)*100
1930 RECH=(TOTLGW/DRAINAGE)*7.48/31!*86400!
1940 IRECH=FIX(RECH/1000!)
1950 RMONTH(7,6)=IRECH*1000
1960 IF RECH<=1000! THEN RMONTH(7,6)=RECH
1970 REM =================================MAY==================
1980 TOTALQ=1E-15
1990 TOTLGW=0!
2000 FOR I=213 TO 243
2010      IF DSS(I)>=0! THEN TOTALQ=TOTALQ+DSS(I):TOTLGW=TOTLGW+GDIS(I)
2020      NEXT I
2030 RMONTH(8,1)=TOTALQ*86400!
2040 RMONTH(8,2)=.03719*(TOTALQ/DRAINAGE)
2050 RMONTH(8,3)=TOTLGW*86400!
2060 RMONTH(8,4)=.03719*(TOTLGW/DRAINAGE)
2070 RMONTH(8,5)=(TOTLGW/TOTALQ)*100
2080 RECH=(TOTLGW/DRAINAGE)*7.48/31!*86400!
2090 IRECH=FIX(RECH/1000!)
2100 RMONTH(8,6)=IRECH*1000
2110 IF RECH<=1000! THEN RMONTH(8,6)=RECH
```

```
2120 REM ================================JUNE=================
2130 TOTALQ=1E-15
2140 TOTLGW=0!
2150 FOR I=244 TO 273
2160     IF DSS(I)>=0! THEN TOTALQ=TOTALQ+DSS(I):TOTLGW=TOTLGW+GDIS(I)
2170     NEXT I
2180 RMONTH(9,1)=TOTALQ*86400!
2190 RMONTH(9,2)=.03719*(TOTALQ/DRAINAGE)
2200 RMONTH(9,3)=TOTLGW*86400!
2210 RMONTH(9,4)=.03719*(TOTLGW/DRAINAGE)
2220 RMONTH(9,5)=(TOTLGW/TOTALQ)*100
2230 RECH=(TOTLGW/DRAINAGE)*7.48/31!*86400!
2240 IRECH=FIX(RECH/1000!)
2250 RMONTH(9,6)=IRECH*1000
2260 IF RECH<=1000! THEN RMONTH(9,6)=RECH
2270 REM ================================JULY=================
2280 TOTALQ=1E-15
2290 TOTLGW=0!
2300 FOR I=274 TO 304
2310     IF DSS(I)>=0! THEN TOTALQ=TOTALQ+DSS(I):TOTLGW=TOTLGW+GDIS(I)
2320     NEXT I
2330 RMONTH(10,1)=TOTALQ*86400!
2340 RMONTH(10,2)=.03719*(TOTALQ/DRAINAGE)
2350 RMONTH(10,3)=TOTLGW*86400!
2360 RMONTH(10,4)=.03719*(TOTLGW/DRAINAGE)
2370 RMONTH(10,5)=(TOTLGW/TOTALQ)*100
2380 RECH=(TOTLGW/DRAINAGE)*7.48/31!*86400!
2390 IRECH=FIX(RECH/1000!)
2400 RMONTH(10,6)=IRECH*1000
2410 IF RECH<=1000! THEN RMONTH(10,6)=RECH
2420 REM ================================AUGUST===============
2430 TOTALQ=1E-15
2440 TOTLGW=0!
2450 FOR I=304 TO 335
2460     IF DSS(I)>=0! THEN TOTALQ=TOTALQ+DSS(I):TOTLGW=TOTLGW+GDIS(I)
2470     NEXT I
2480 RMONTH(11,1)=TOTALQ*86400!
2490 RMONTH(11,2)=.03719*(TOTALQ/DRAINAGE)
2500 RMONTH(11,3)=TOTLGW*86400!
2510 RMONTH(11,4)=.03719*(TOTLGW/DRAINAGE)
2520 RMONTH(11,5)=(TOTLGW/TOTALQ)*100
2530 RECH=(TOTLGW/DRAINAGE)*7.48/31!*86400!
2540 IRECH=FIX(RECH/1000!)
2550 RMONTH(11,6)=IRECH*1000
2560 IF RECH<=1000! THEN RMONTH(11,6)=RECH
2570 REM ================================SEPTEMBER============
2580 TOTALQ=1E-15
2590 TOTLGW=0!
2600 FOR I=336 TO 365
2610     IF DSS(I)>=0! THEN TOTALQ=TOTALQ+DSS(I):TOTLGW=TOTLGW+GDIS(I)
2620     NEXT I
2630 RMONTH(12,1)=TOTALQ*86400!
2640 RMONTH(12,2)=.03719*(TOTALQ/DRAINAGE)
2650 RMONTH(12,3)=TOTLGW*86400!
2660 RMONTH(12,4)=.03719*(TOTLGW/DRAINAGE)
2670 RMONTH(12,5)=(TOTLGW/TOTALQ)*100
2680 RECH=(TOTLGW/DRAINAGE)*7.48/31!*86400!
2690 IRECH=FIX(RECH/1000!)
2700 RMONTH(12,6)=IRECH*1000
2710 IF RECH<=1000! THEN RMONTH(12,6)=RECH
2720 PRINT CLEAR.SCREEN$
2730 PRINT "      TOTAL Q(CF)   TOTAL Q(IN)   GW (CF)    GW (IN)    % GW       RR GP
/M12"
2740 FOR MN=1 TO 12
2750     IF MN=1 THEN PRINT "OCT.   ";
2760     IF MN=2 THEN PRINT "NOV.   ";
2770     IF MN=3 THEN PRINT "DEC.   ";
2780     IF MN=4 THEN PRINT "JAN.   ";
2790     IF MN=5 THEN PRINT "FEB.   ";
2800     IF MN=6 THEN PRINT "MAR.   ";
2810     IF MN=7 THEN PRINT "APR.   ";
2820     IF MN=8 THEN PRINT "MAY    ";
2830     IF MN=9 THEN PRINT "JUN.   ";
```

```
2850      IF MN=11 THEN PRINT "AUG.  ";
2860      IF MN=12 THEN PRINT "SEPT. ";
2870      PRINT USING "#.##^^^^"; RMONTH(MN,1);
2880      PRINT USING "      #.##^^^^"; RMONTH(MN,2);
2890      PRINT USING "      #.##^^^^"; RMONTH(MN,3);
2900      PRINT USING "  #.##^^^^"; RMONTH(MN,4);
2910      PRINT USING "  ##.#     "; RMONTH(MN,5);
2920      PRINT USING "  #.##^^^^"; RMONTH(MN,6)
2930      NEXT MN
2940 PRINT
2950 PRINT "HIT ANY KEY TO RETURN TO THE OUTPUT MENU OR ";REVERSE.VIDEO$;"P TO P
RINT";REVERSE.VIDEO$
2960 JUNK$=INKEY$
2970 IF JUNK$="" THEN GOTO 2960
2990 IF JUNK$<>"P" AND JUNK$<>"p" THEN ERASE RMONTH:GOTO 20
3000 GOSUB 4890
3010 LPRINT "       TOTAL Q(CF)  TOTAL Q(IN)  GW (CF)   GW (IN)   % GW       RR GP
D/M12"
3020 FOR MN=1 TO 12
3030      IF MN=1 THEN LPRINT "OCT.  ";
3040      IF MN=2 THEN LPRINT "NOV.  ";
3050      IF MN=3 THEN LPRINT "DEC.  ";
3060      IF MN=4 THEN LPRINT "JAN.  ";
3070      IF MN=5 THEN LPRINT "FEB.  ";
3080      IF MN=6 THEN LPRINT "MAR.  ";
3090      IF MN=7 THEN LPRINT "APR.  ";
3100      IF MN=8 THEN LPRINT "MAY   ";
3110      IF MN=9 THEN LPRINT "JUN.  ";
3120      IF MN=10 THEN LPRINT "JUL.  ";
3130      IF MN=11 THEN LPRINT "AUG.  ";
3140      IF MN=12 THEN LPRINT "SEPT. ";
3150      LPRINT USING "#.##^^^^"; RMONTH(MN,1);
3160      LPRINT USING "      #.##^^^^"; RMONTH(MN,2);
3170      LPRINT USING "      #.##^^^^"; RMONTH(MN,3);
3180      LPRINT USING "  #.##^^^^"; RMONTH(MN,4);
3190      LPRINT USING "  ##.#     "; RMONTH(MN,5);
3200      LPRINT USING "  #.##^^^^"; RMONTH(MN,6)
3210      NEXT MN
3220 ERASE RMONTH
3240 GOTO 20
3250 REM THIS IS THE HYDROGRAPH PRINTING ROUTINE ===============
3260 XMIN=100000'
3280 PRINT CLEAR.SCREEN$:PRINT:PRINT:PRINT:PRINT "PRINTING OUT THE GRAPH "
3290 GOSUB 4890
3300 FOR GRAPH=1 TO 365
3310      IF GDIS(GRAPH)<XMIN THEN XMIN=GDIS(GRAPH)
3320      IF DSS(GRAPH)>XMAX THEN XMAX=DSS(GPAPH)
3330      NEXT GRAPH
3350 LPRINT SMALL.PRINT$
3355 LPRINT FINE.SPACE$
3360 IF XMIN>0 THEN BTM=INT(.434295*LOG(XMIN)) ELSE BTM=0
3370 IF XMAX>0 THEN TOP=INT(.434295*LOG(XMAX))+1 ELSE TOP=0
3380 SCALE=(TOP - BTM)/100
3390 IF SCALE=0 THEN PRINT "ALL DISCHARGE VALUES ARE ZERO ":GOTO 30
3400 NOW=1
3401 LPRINT SPC(40);"FLOW IN CFS"
3410 FOR I=BTM TO TOP
3420      PT=FIX((.434295*LOG(10^I))/SCALE)-FIX((BTM)/SCALE) ELSE PT=FIX(.434295*
LOG(10^I)/SCALE)
3440      IF NOW>PT THEN GOTO 3480
3450      FOR J=NOW+1 TO PT-1
3460          LPRINT " ";
3470          NEXT J
3480      LPPINT 10^I;
3490      NOW=PT+I+1
3500      NEXT I
3510 LPRINT:LPRINT:LPRINT:LPRINT
3520 FOR GRAPH=1 TO 130
3530      LPRINT "=";
3540      NEXT GRAPH
3550 LPRINT "="
3560 LPRINT
3570 FOP GRAPH=1 TO 365
```

```
3571       MG$="   "
3572       IF GRAPH=15 THEN MG$="OCT"
3573       IF GRAPH=46 THEN MG$="NOV"
3574       IF GRAPH=76 THEN MG$="DEC"
3575       IF GRAPH=107 THEN MG$="JAN"
3576       IF GRAPH=137 THEN MG$="FEB"
3577       IF GRAPH=166 THEN MG$="MAR"
3578       IF GRAPH=197 THEN MG$="APR"
3579       IF GRAPH=227 THEN MG$="MAY"
3580       IF GRAPH=258 THEN MG$="JUN"
3581       IF GRAPH=288 THEN MG$="JUL"
3582       IF GRAPH=319 THEN MG$="AUG"
3583       IF GRAPH=351 THEN MG$="SEP"
3584       IF GRAPH=31 THEN MG$=">>>"
3585       IF GRAPH=61 THEN MG$=">>>"
3586       IF GRAPH=92 THEN MG$=">>>"
3587       IF GRAPH=123 THEN MG$=">>>"
3588       IF GRAPH=151 THEN MG$=">>>"
3589       IF GRAPH=182 THEN MG$=">>>"
3590       IF GRAPH=212 THEN MG$=">>>"
3591       IF GRAPH=243 THEN MG$=">>>"
3592       IF GRAPH=273 THEN MG$=">>>"
3593       IF GRAPH=304 THEN MG$=">>>"
3594       IF GRAPH=336 THEN MG$=">>>"
3595       IF GRAPH=365 THEN MG$=">>>"
3596       LPRINT MG$;"I*";
3597       IF DSS(GRAPH)=0 THEN GOTO 3610
3600       IF XMIN>0 THEN IDIS=FIX((.434295*LOG(DSS(GRAPH)))/SCALE)-FIX((BTM)/SCAL
E) ELSE IDIS=FIX((.434295*LOG(DSS(GRAPH)))/SCALE)
3610       IF GDIS(GRAPH)=0 THEN GOTO 3630
3620       IF XMIN>0 THEN IGW=FIX((.434295*LOG(GDIS(GRAPH)))/SCALE)-FIX((BTM)/SCAL
E) ELSE IGW=FIX((.434295*LOG(GDIS(GRAPH)))/SCALE)
3630       IF GDIS(GRAPH)=0 THEN GOTO 3670
3640       FOR GW=1 TO IGW
3650           LPRINT "*";
3660           NEXT GW
3670       IF DSS(GRAPH)=0 THEN LPRINT:GOTO 3720
3680       FOR DISCH=IGW TO IDIS
3690           LPRINT ".";
3700           NEXT DISCH
3710       LPRINT "."
3720       NEXT GRAPH
3730 LPRINT LINE.FEED$
3731 LPRINT SPC(20);"* - GROUND WATER"
3732 LPRINT SPC(20);". - SURFACE RUNOFF"
3740 LPRINT LARGE.PRINT$,FORM.FEED$
3750 GOTO 20
3760 REM THIS ROUTINE CALCULATES THE FLOW DURATION CURVE ====
3770 DIM PLOT$(120)
3780 GOSUB 4890
3790 PRINT CLEAR.SCREEN$:PRINT:PRINT:PRINT:PRINT:PRINT "I AM WORKING ON IT"
3800 JUMP%=365
3810 WHILE JUMP%-1
3820       JUMP%=JUMP%/2
3830       NOTDONE%=1:NOTDONEG%=1
3840       WHILE NOTDONE% OR NOTDONEG%
3850             NOTDONE%=0:NOTDONEG%=0
3860             FOR M%=1 TO 365-JUMP%
3870                 N%=M%+JUMP%
3880                 IF DSS(M%)<DSS(N%) THEN X=DSS(M%):DSS(M%)=DSS(N%):DSS(N%)=
:NOTDONE%=1
3890                 IF GDIS(M%)<GDIS(N%) THEN Y=GDIS(M%):GDIS(M%)=GDIS(N%):GDI
(N%)=Y:NOTDONEG%=1
3900                 NEXT M%
3910             WEND
3920       WEND
3930 XMAX=DSS(1)
3940 XMIN=DSS(365)
3950 ONEPERCENT=(XMAX-XMIN)/100
3960 LPRINT
```

```
3970 LPRINT SMALL.PRINT$
3990 LPRINT "PERCENT"SPC(38)"FLOW CFS/SQ.MI"
4000 LPRINT
4010 LPRINT "TIME .1"SPC(16)".2"SPC(16)".4"SPC(16)".8    1.0"SPC(16)"2"SPC(17)"4
SPC(17)"8    10"
4020 FOR I=1 TO 125
4030      LPPINT "_";
4040      NEXT I
4050 LPRINT "_"
4060 PT=1
4070 FOR I=1 TO 101
4080      IF (I-1) MOD 10 <> 0 THEN GOTO 4140
4090      FOR J=1 TO 120
4100           PLOT$(J)="."
4110           NEXT J
4120      PLOT$(120)="|"
4130      GOTO 4250
4140      FOR J=1 TO 120
4150           PLOT$(J)=" "
4160           NEXT J
4170      PLOT$(120)="|"
4180      PLOT$(18)="."
4190      PLOT$(36)="."
4200      PLOT$(54)="."
4210      PLOT$(60)="."
4220      PLOT$(78)="."
4230      PLOT$(96)="."
4240      PLOT$(114)="."
4250      FOR PT=(I-1)*3.61386+1 TO I*3.61386
4260              GDISDEN=GDIS(PT)/DRAINAGE
4270              DISDEN=DSS(PT)/DRAINAGE
4280              IF GDISDEN<.1 THEN GINDX=0:GOTO 4300
4290              GINDX=FIX(60*.434295*LOG(GDISDEN)+60.5)
4300              IF DISDEN<.1 THEN INDX=0:GOTO 4320
4310              INDX=FIX(60*.434295*LOG(DISDEN)+60.5)
4320              IF GINDX>120 THEN GINDX=120
4330              IF INDX>120 THEN INDX=120
4340              IF GINDX<1 THEN GINDX=0
4350              IF INDX<1 THEN INDX=0
4360              IF GINDX<>0 THEN PLOT$(GINDX)="#"
4370              IF INDX<>0 THEN PLOT$(INDX)="+"
4380           NEXT PT
4390      IF I>1 THEN GOTO 4470
4400      LPRINT "+";
4410      LPRINT USING "###";I-1;
4420      LPRINT " I";
4430      FOR J=1 TO 120
4440           LPRINT PLOT$(J);
4450           NEXT J
4460      LPRINT " ":GOTO 4540
4470      LPRINT " ";
4480      LPRINT USING "###";I-1;
4490      LPRINT " I";
4500      FOR J=1 TO 120
4510           LPRINT PLOT$(J);
4520           NEXT J
4530      LPRINT " "
4540      NEXT I
4550 LPRINT
4551 LPRINT SPC(20);"# - GROUND WATER FLOW"
4552 LPRINT
4553 LPRINT SPC(20);"+ - TOTAL FLOW"
4560 DELTA1=DSS(37)/DRAINAGE-DSS(36)/DRAINAGE
4570 DELTA2=DSS(329)/DRAINAGE-DSS(328)/DRAINAGE
4580 DELTA3=DSS(92)/DRAINAGE-DSS(91)/DRAINAGE
4590 DELTA4=DSS(274)/DRAINAGE-DSS(273)/DRAINAGE
4600 Q90=DSS(36)/DRAINAGE-DELTA1/2
4610 Q10=DSS(328)/DRAINAGE-DELTA2/2
4620 Q75=DSS(91)/DRAINAGE-DELTA3/4
4630 Q25=DSS(274)/DRAINAGE-DELTA4/4
4640 IF Q90<=0 THEN LPRINT "Q90 IS LESS THAN OR EQUAL TO ZERO, RATIO IS MEANINGL
ESS":Q90=.001
4650 IF Q75<=0 THEN LPRINT "Q75 IS LESS THAN OR EQUAL TO ZERO, RATIO IS MEANINGL
```

```
ESS":Q75=.001
4660 RT1090=SQR(Q10/Q90)
4670 RT2575=SQR(Q25/Q75)
4680 LPRINT SPC(7)"THE RATIO (Q10/Q90)**1/2 = "RT1090"   (Q25/Q75)**1/2 = "RT257
5
4685 GOSUB 4890
4690 LPRINT SMALL.PRINT$
4700 FOR I=1 TO 353 STEP 8
4710     II=I+7
4720     FOR N=I TO II
4730         LPRINT USING " ####.##";(366-N)*100/365;
4740         LPRINT "  ";
4750         LPRINT USING "##.###";DSS(366-N)/DRAINAGE;
4760         NEXT N
4770     LPRINT
4780     NEXT I
4790 FOR N=361 TO 365
4800     LPRINT USING " ####.##";(366-N)*100/365;
4810     LPRINT "  ";
4820     LPRINT USING "##.###";DSS(366-N)/DRAINAGE;
4830     NEXT N
4840 LPRINT
4850 ERASE PLOT$
4860 LPRINT LINE.FEED$
4870 RUN "RECHARGE"
4880 REM ******************************** PAGE HEADER ***************
4890 LPRINT FORM.FEED$;LARGE.PRINT$
4900 LPRINT "THE STATION'S TITLE IS "ST$
4910 LPRINT "THE STATION'S USGS NUMBER IS",SN
4920 LPRINT "THE YEAR OF THE DATA IS",YR
4930 LPRINT "THE STATION'S DRAINAGE AREA IS ";DRAINAGE;" SQ. MI."
4935 LPRINT
4940 IF METHOD=1 THEN LPRINT "          FIXED INTERVAL CALCULATION METHOD":LPRINT
4950 IF METHOD=2 THEN LPRINT "          SLIDING INTERVAL CALCULATION METHOD":LPRI
NT
4960 IF METHOD=3 THEN LPRINT "          LOCAL MINIMA CALCULATION METHOD":LPRINT
4970 RETURN
 10 REM THIS IS THE WHERE THE MISSING DATA IS APPROXIMATED *************
 20 PRINT CLEAR.SCREEN$
 30 RINTR=DRAINAGE^.2:RINTR=RINTR*2!
 40 IF RINTR<4 THEN INTERVAL=3
 50 IF RINTR<6 AND RINTR>4 THEN INTERVAL=5
 60 IF RINTR<8 AND RINTR>6 THEN INTERVAL=7
 70 IF RINTR<10 AND RINTP>8 THEN INTERVAL=9
 80 IF RINTR>10 THEN INTERVAL=11
 90 PRINT CLEAR.SCREEN$
 100 PRINT:PRINT:PRINT:PRINT
 110 PRINT SPC(32)"CALCULATION MENU"
 120 PRINT
 130 PRINT SPC(20)"A. "SPC(5)"FIXED INTERVAL METHOD"
 140 PRINT SPC(20)"B. "SPC(5)"SLIDING INTERVAL METHOD"
 150 PPINT SPC(20)"C. "SPC(5)"LOCAL MINIMA METHOD"
 160 PRINT SPC(20)"D. "SPC(5)"RETURN TO THE INPUT MENU"
 170 PRINT SPC(20)"E. "SPC(5)"EXIT THE PROGRAM"
 180 PRINT
 190 PRINT SPC(25)"ENTER THE LETTER OF THE DESIPED FUNCTION"
 200 INPUT "                              ==>",TST$
 210 IF TST$="a" OR TST$="A" THEN GOTO 300
 220 IF TST$="b" OR TST$="B" THEN GOTO 560
 230 IF TST$="c" OR TST$="C" THEN GOTO 880
 240 IF TST$="d" OR TST$="D" THEN CHAIN "RECHARGE.BAS",50,ALL
 250 IF TST$="e" OR TST$="E" THEN SYSTEM
 260 IF TST$="t" THEN PRINT FRE(JUNK)
 280 GOTO 200
 290 REM This performs the fixed interval method of calculation *********
 300 K=365/INTEPVAL
 310 PRINT CLEAR.SCPEEN$:PRINT:PRINT:PRINT:PRINT
 320 PPINT "CALCULATING USING THE FIXED INTERVAL METHOD":METHOD=1
 330 FOR I=1 TO K
 340     PMIN=100000!
 350     L1=((I-1)*INTERVAL)+1
 360     L2=I*INTEPVAL
```

```
370      FOR J=L1 TO L2
380          IF DSS(J)<PMIN THEN PMIN=DSS(J)
390          NEXT J
400      FOR J=L1 TO L2
410          GDIS(J)=PMIN
420          NEXT J
430      NEXT I
440 M1=(K*INTERVAL)+1
450 IF K*INTERVAL=365 THEN CHAIN "OUTPUT.BAS",10,ALL
460 PMIN=100000!
470 FOR J=M1 TO 365
480      IF DSS(J)<0! THEN GOTO 500
490      IF DSS(J)<PMIN THEN PMIN=DSS(J)
500      NEXT J
510 FOR J=M1 TO 365
520      IF DSS(J)<0! THEN GOTO 540
530      GDIS(J)=PMIN
540      NEXT J
550 CHAIN "OUTPUT.BAS",10,ALL
560 REM This performs the sliding interval method of calculation ********
570 PRINT CLEAR.SCREEN$:PRINT:PRINT:PRINT:PRINT
580 PRINT "CALCULATING USING THE SLIDING INTERVAL METHOD":METHOD=2
590 INTER=(INTERVAL-1)/2
600 FOR I=1 TO 365 STEP 1
610      IF DSS(I)<0! THEN GOTO 850
620      IF (I-(INTER+1))<0! THEN GOTO 720
630      IF ((365-I)-(INTER+1))<0! THEN GOTO 790
640      PMIN=100000!
650      K1=I-INTER
660      K2=I+INTER
670      FOR J=K1 TO K2 STEP 1
680          IF DSS(J)<PMIN THEN PMIN=DSS(J)
690          NEXT J
700      GDIS(I)=PMIN
710      GOTO 850
720      PMIN=100000!
730      K2=I+INTER
740      FOR J=1 TO K2 STEP 1
750          IF DSS(J)<PMIN THEN PMIN=DSS(J)
760          NEXT J
770      GDIS(I)=PMIN
780      GOTO 850
790      PMIN=100000!
800      K1=I-INTER
810      FOR J=K1 TO 365 STEP 1
820          IF DSS(J)<PMIN THEN PMIN=DSS(J)
830          NEXT J
840      GDIS(I)=PMIN
850      NEXT I
860 CHAIN "OUTPUT.BAS",10,ALL
870 REM THIS IS THE LOCAL MINIMA METHOD OF CALCULATION IS PERFORMED *****
880 INTER=INTERVAL
890 DIM IPOINT(400)
895 PRINT CLEAR.SCREEN$
900 PRINT "CALCULATING USING THE LOCAL MINIMA METHOD":METHOD=3
910 NUMPT=0
920 IF INTER=3 THEN GOTO 970
930 IF INTER=5 THEN GOTO 1020
940 IF INTER=7 THEN GOTO 1070
950 IF INTER=9 THEN GOTO 1120
960 IF INTER>=11 THEN GOTO 1170
970 L=365-1
980 FOR I=2 TO L
990  IF DSS(I)<=DSS(I+1) AND DSS(I)<=DSS(I-1) THEN NUMPT=NUMPT+1:IPOINT(NUMPT)=
1000  NEXT I
1010 GOTO 1210
1020 L=365-2
1030 FOR I=3 TO L
1040  IF DSS(I)<=DSS(I+1) AND DSS(I)<=DSS(I-1) AND DSS(I)<=DSS(I+2) AND DSS(I)<=
DSS(I-2) THEN NUMPT=NUMPT+1:IPOINT(NUMPT)=I
1050  NEXT I
1060 GOTO 1210
1070 L=365-3
```

```
1080 FOR I=4 TO L
1090  IF DSS(I)<=DSS(I-1) AND DSS(I)<=DSS(I+1) AND DSS(I)<=DSS(I-2) AND DSS(I)<=
DSS(I+2) AND DSS(I)<=DSS(I-3) AND DSS(I)<=DSS(I+3) THEN NUMPT=NUMPT+1:IPOINT(NUM
PT)=I
1100  NEXT I
1110 GOTO 1210
1120 L=365-4
1130 FOR I=5 TO L
1140  IF DSS(I)<=DSS(I-1) AND DSS(I)<=DSS(I+1) AND DSS(I)<=DSS(I-2) AND DSS(I)<=
DSS(I+2) AND DSS(I)<=DSS(I-3) AND DSS(I)<=DSS(I+3) AND DSS(I)<=DSS(I-4) AND DSS(
I)<=DSS(I+4) THEN NUMPT+NUMPT+1:IPOINT(NUMPT)=I
1150  NEXT I
1160 GOTO 1210
1170 L=365-5
1180 FOR I=6 TO L
1190  IF DSS(I)<=DSS(I-1) AND DSS(I)<=DSS(I+1) AND DSS(I)<=DSS(I-2) AND DSS(I)<=
DSS(I+2) AND DSS(I)<=DSS(I-3) AND DSS(I)<=DSS(I+3) AND DSS(I)<=DSS(I+4) AND DSS(
I)<=DSS(I-4) AND DSS(I)<=DSS(I-5) AND DSS(I)<==DSS(I+5) THEN NUMPT=NUMPT+1:IPOIN
T(NUMPT)=1
1200  NEXT I
1210 J=IPOINT(1)
1220 K=NUMPT-1
1230 L=IPOINT(NUMPT)
1240 FOR IJ=1 TO J
1250      GDIS(IJ)=DSS(J)
1260      NEXT IJ
1270 FOR IJ=L TO 365
1280      GDIS(IJ)=DSS(L)
1290      NEXT IJ
1300 FOR I=1 TO K
1310      IP1=IPOINT(I)
1320      IP2=IPOINT(I+1)
1330      GDIS(IP1)=DSS(IP1)
1340      GDIS(IP2)=DSS(IP2)
1350      ISTART=IP1
1360      IEND=IP2
1370      FOR J=ISTART TO IEND
1380           X=J-IP1
1390           Y=IP2-IP1
1400           IF GDIS(IP1)=0! THEN GDIS(IP1)=.01
1410           IF GDIS(IP2)=0! THEN GDIS(IP2)=.01
1420           GDIS(J)=(GDIS(IP2)^(X/Y)*(GDIS(IP1)^(1-X/Y)))
1430           NEXT J
1440      NEXT I
1450 FOR IJK=1 TO 365
1460      IF GDIS(IJK)>DSS(IJK) THEN GDIS(IJK)=DSS(IJK)
1470      NEXT IJK
1480 ERASE IPOINT
1490 CHAIN "OUTPUT.BAS",10,ALL
```

VITA

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Candidate for the Degree of

Master of Science

Thesis: COMPARISON OF MANUAL BASEFLOW SEPARATION TECHNIQUES TO A COMPUTER BASEFLOW SEPARATION PROGRAM AND APPLICATION TO SIX DRAINAGE BASINS

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