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BASE-FLOW RECESSION IN ILLINOIS

By

Robert N. Farvolden
Department of Geology
University of Illinois, Urbana-Champaign

Currently at Department of Geology
University of Waterloo
Waterloo, Ontario, Canada

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UNIVERSITY OF ILLINOIS
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2535 Hydrosystems Laboratory
Urbana, Illinois 61801

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ABSTRACT

BASE-FLOW RECESSION IN ILLINOIS

Base-flow recession curves of nineteen Illinois streams were analyzed to determine the most significant factors which affected the base-flow recession rate. The eight most significant factors were (in order): number of days since the last major storm, average minimum daily temperature, average daily temperature, average maximum daily temperature, discharge at beginning of recession, average daily evaporation for one to five days preceeding the beginning of the recession, average daily evaporation for the duration of the recession and total runoff. A regression equation for these variables was derived.

The relationship between base-flow and the water depth in various wells was studied. Significant correlations were obtained for dry weather flow for some wells but the relationships were found to be invalid during periods of storm runoff.

Tritium analyses of eight water samples from two different watersheds were made. The results indicated that a normal gravity flow system exists with shallow groundwater moving toward the streams rather than leaking to underlying aquifers.

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KEYWORDS-- *base-flow/ *groundwater movement/ *hydrograph analysis/ *recession curves/ *surface runoff/ *wells

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I. INTRODUCTION

This project was undertaken to attempt to learn the factors that influence the base-flow of streams in Illinois. Streams were selected for study on the basis of duration of flow record, size of basin, and distribution, and nineteen were finally chosen.

It was originally planned to examine the relationships between base-flow recession and the geological and physiographical characteristics of the basins, but it became apparent that the drainage of the basins is now so strongly influenced by tile and ditch systems that the effects of geology are masked.

It is further discovered that the recession slope of the streams was not constant, and therefore this factor is not a unique characteristic of a stream so that an individual slope recession has little value in appraising the hydrologic characteristics of a stream. Rather, the recession rate varies from one recession to another and the study of this variation for individual streams became the main object of the project.

Project funds were used to support two graduate students in hydrogeology. Darrel Dunn was supported as a Research Assistant during the academic year 1965-66 and worked on the analysis of recession hydrographs of all the basins. David Allman was supported as a Research Assistant for two years beginning July of 1965. His M.S. thesis forms the basis for this report. R. N. Farvolden was supported for one month during the summer of 1966. An invited paper was prepared under the auspices of the

project and delivered at the IUGG General Assembly of Bern, October - November, 1967. The paper, entitled "Methods of Study of the Groundwater Budget in North America", has been published in the Proceedings of the General Assembly.

Panther Creek near El Paso	5-5670	41	--	19.7
Crane Creek near Easton	5-5825	7		53.7
North Fork Mauvaise Terre near Jacksonville	5-5860	9		22.9

2. METHOD OF STUDY

The hydrographs for selected streams were duplicated from the records of the U.S. Geological Survey in Champaign and 19 of these were chosen for recession analysis. Base-flow recession was considered to begin five days after a precipitation event and to end one day before the next precipitation event. In many cases it seemed obvious that strict adherence to these criteria resulted in inclusion of some flow sequences as recessions, when it seemed obvious from appearance of the hydrograph that they were not. This problem was met most often in winter flows, where the effect of snow melt and ice is an unknown factor, in time of drought, where evapotranspiration is a factor and in some cases where it is obvious from visual examination that direct (or indirect) storm runoff and interflow has not ceased five days after the generating storm. However, in order to reduce the bias in drawing recession curves, strict adherence to the criteria for recession was observed.

Recession curves may be described in many ways. In this study they are considered to be straight line segments of the hydrograph when the flow rate (logarithmic scale, base 10) is plotted against time, with the restrictions already mentioned. The number of days required for a tenfold reduction in flow rate (one log cycle) is a clear description of the recession curve, and is referred to in this report as the recession rate.

Appendix A is a list of recession data extracted from the hydrographs.

Table 1 shows the mean value for the recession rate and the number of recessions studied for each stream.

Table 1. Mean Recession Rates

STREAM NAME AND US GEOL.	SURVEY NO.	NO OF RECESSIONS	MEAN RECESSION RATE
Bay Creek at Pittsfield	5-5125	5	15.8
Poplar Creek at Elgin	5-5505	16	14
West Bureau Ck at Wyanet	5-5570	15	20.7
East Bureau Ck near Bureau	5-5575	11	22.4
Crow Creek near Henry	5-5585	13	23.9
Gimlet Creek at Sparland	5-5590	5	22.4
Farm Creek at Farmdale	5-5605	6	25.7
Ackerman Creek at Farmdale	5-5610	2	23
Fond du Lac Ck at East Peoria	5-5615	3	9
Farm Creek at East Peoria	5-5620	4	15
Money Creek near Towanda	5-5644	11	25.1
Money Creek above Lake Bloomington	5-5645	35	18.7
Hickory Creek above Lake Bloomington	5-5650	27	19.5
Indian Creek near Wyoming	5-5688	11	29.4
E. Branch Panther Ck near Gridley	5-5660	18	17.2
E.Branch Panther Ck at El Paso	5-5665	44	20.7

3. RESULTS

Factors Influencing Base-Flow Recession

Analysis of variance indicates that the means of recession rates are significantly different between many of the streams, particularly between those that recede rapidly (Fond du Lac Creek at East Peoria and East Branch Panther Creek near Gridley) and the remainder. However, the recession rate for any stream varies widely and the cause of the variation was investigated.

There is a definite relationship between the rate of recession of a stream and the season of the year (Figure 1). The pattern is clear in spite of a wide variation in recession rates for any month. For this stream (East Branch Panther Creek at El Paso) the recession rate is slowest during the late spring and early summer months (March-April-May) and fastest during the summer months. The same relationship is illustrated in Figure 2.

The relatively low values (days per log cycle of flow decline) during the summer months are easily attributed to evapotranspiration during the growing season, when a considerable portion of the groundwater discharge to some streams is evapotranspired and therefore does not appear as stream flow. One would expect that the highest values for recession would occur in the winter when evapotranspiration is nil, but this is not the case. The higher values for March-April-May must be due to a component of flow entering the system that is not present during the winter.

This observation may be related to precipitation and recharge mechanism in the following way. During the early spring months in central Illinois, the water table is at or near the ground surface. The farmland,

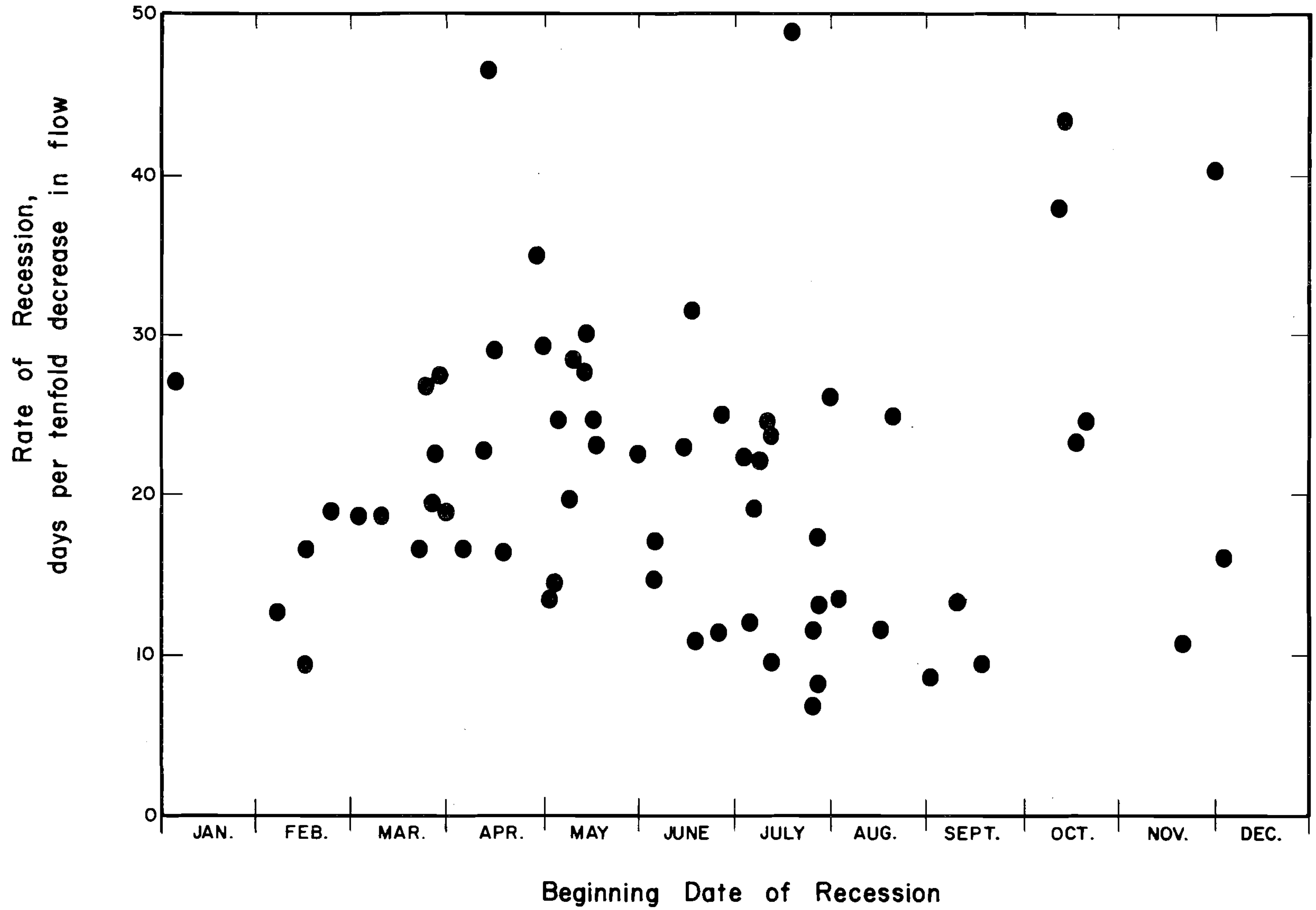

Figure 1. Rate of Recession vs. Date of Beginning of Recession for East Branch of Panther Creek at El Paso.

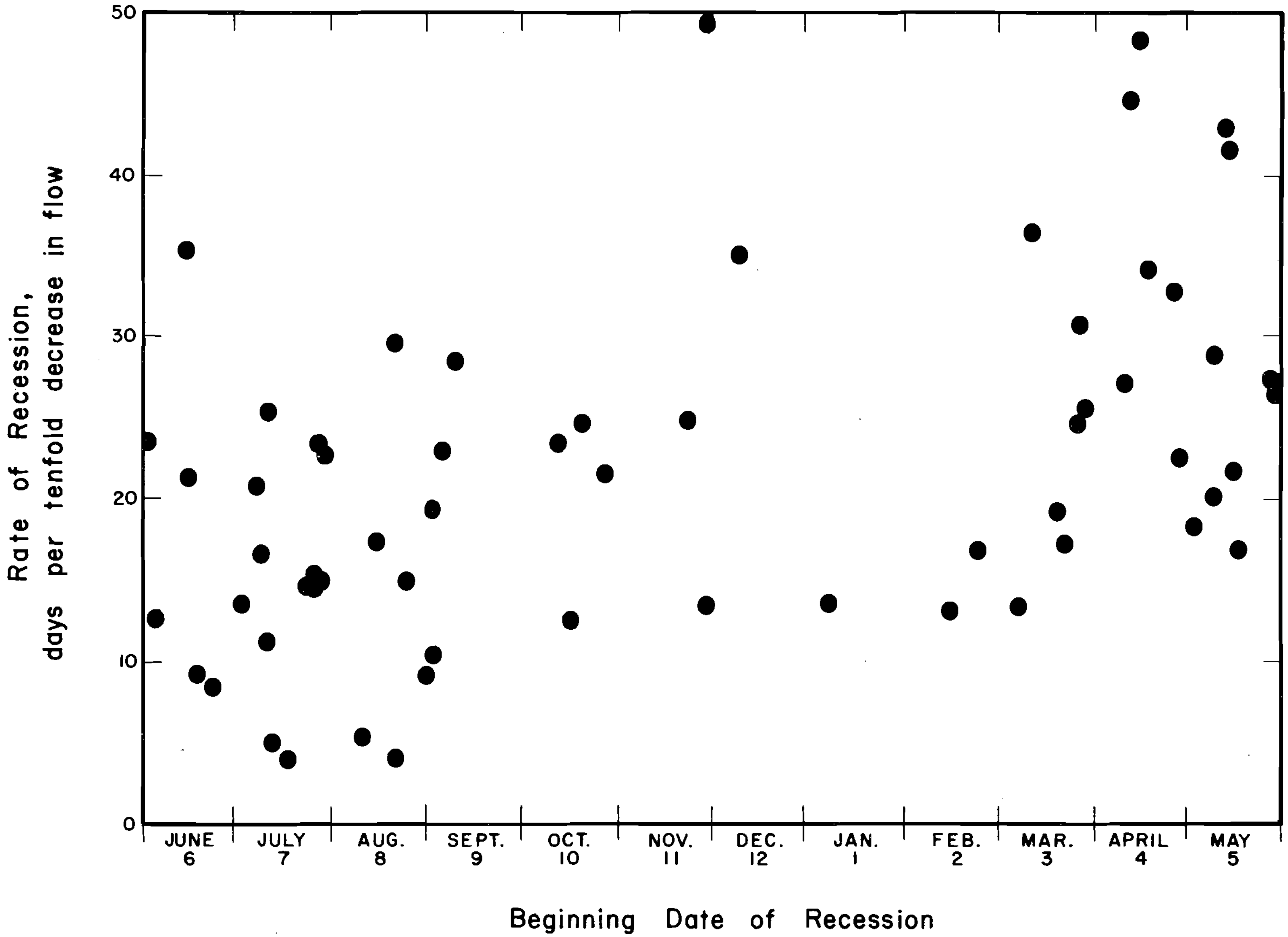

Figure 2. Rate of Recession vs. Beginning Date of Recession for Panther Creek near El Paso.

cultivated the previous autumn after the harvest, has the appearance of a sea of mud. Drainage and evaporation will produce only small soil-moisture deficiencies, so that any precipitation may produce infiltration and groundwater recharge.

The influence of recent precipitation on the hydrograph was examined. Figure 3 is a scatter diagram of the recession rate for Money Creek above Lake Bloomington (5-5645) and the number of days since one inch of rain had been recorded. A better correlation seems to be present between the recession rate and the number of days since there had been one inch of rain, if only the months May to October inclusive are considered (Figure 4 and Figure 5).

The influence of the rate of flow at the beginning of a recession on the rate of recession was also examined. Figure 6 is a scatter diagram of this relationship for Panther Creek near El Paso. The recession rate after high flood peaks almost certainly reflects the influence of inter-flow or direct runoff, or both. These obvious cases where the hydrograph does not reflect groundwater discharge alone, could easily be eliminated from consideration, but in order to do this by strictly objective criteria, most of the true recessions would then also be excluded.

The complex relationships among the factors that influence base-flow recession rate can be evaluated to provide the sort of data amenable to statistical analysis. Streamflow records for Panther Creek near El Paso and its sub-basins, East Branch Panther Creek at El Paso and East Branch Panther Creek near Gridley, were chosen for these analyses. Figure 7 shows the location of the basin and the hydrologic network. The pertinent factors and all other factors likely to influence base-flow recession have been described by Allman (1967) in some detail. It is clear that bank

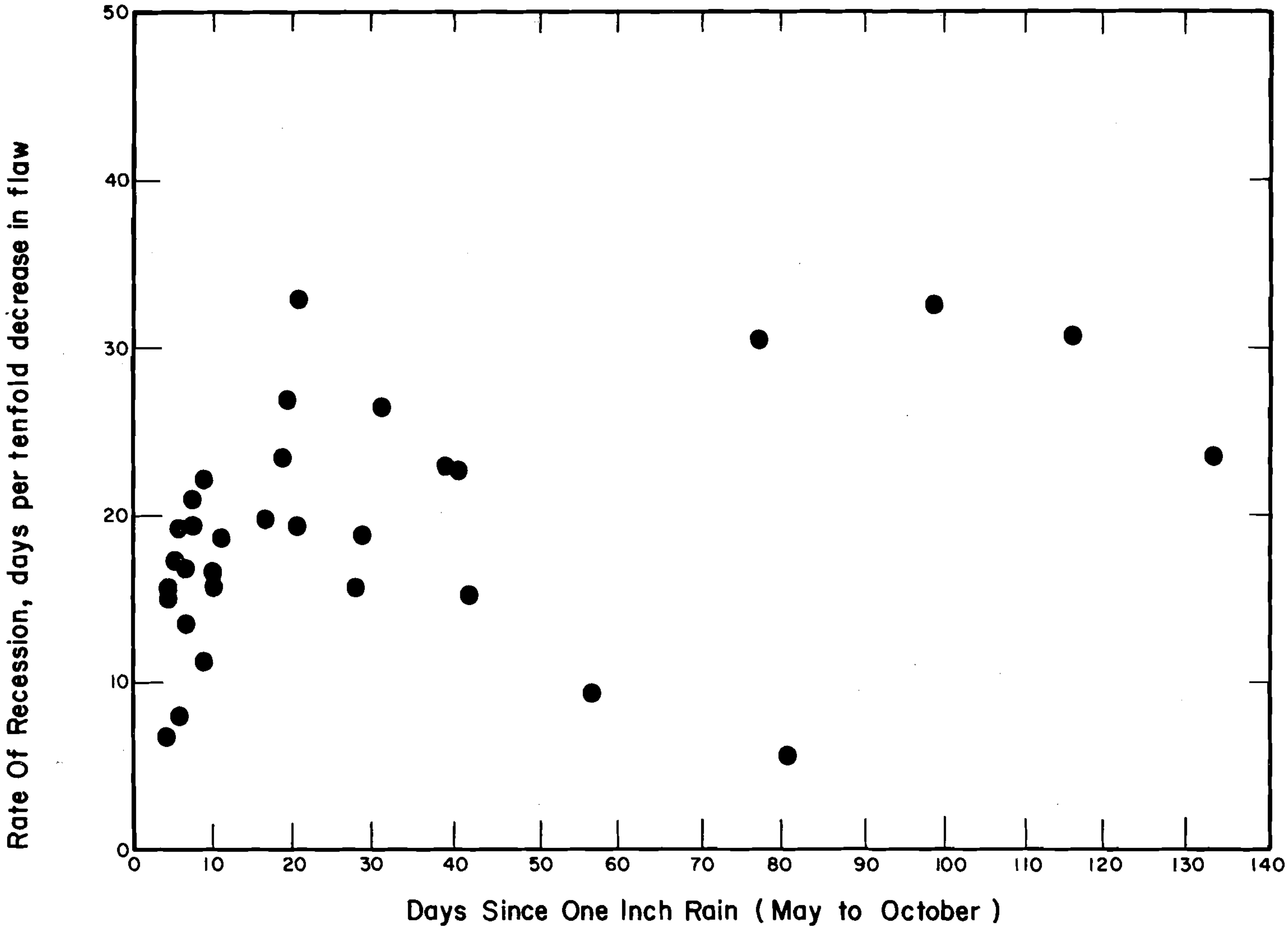

Figure 3. Rate of Recession vs. Number of days Since Occurrence of a Storm up 1" or more for Money Creek Above Lake Bloomington

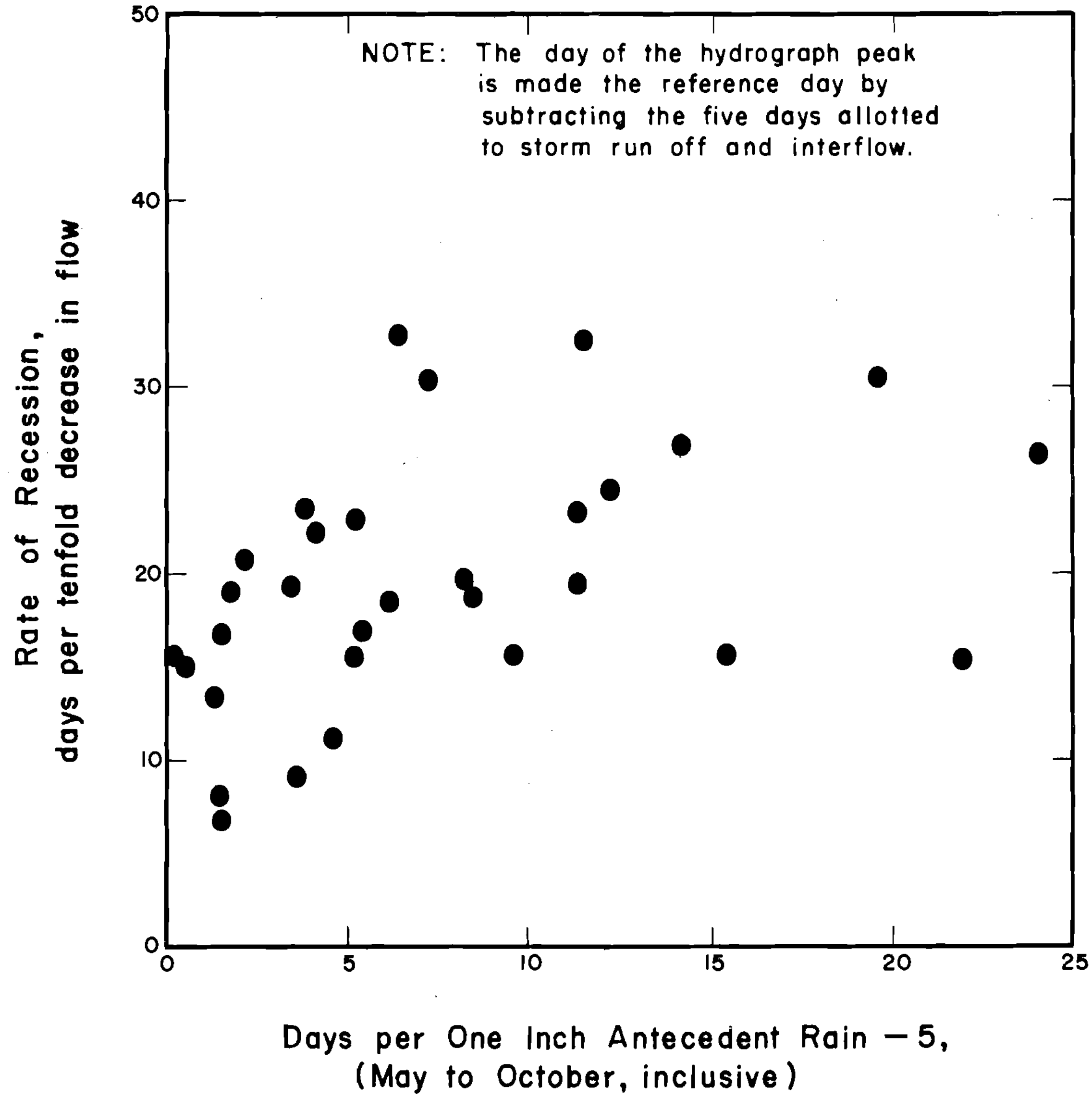

Figure 4. Rate of Recession vs. Number of Days Since a Total of 1" of Rain had Fallen for Money Creek Above Lake Bloomington.

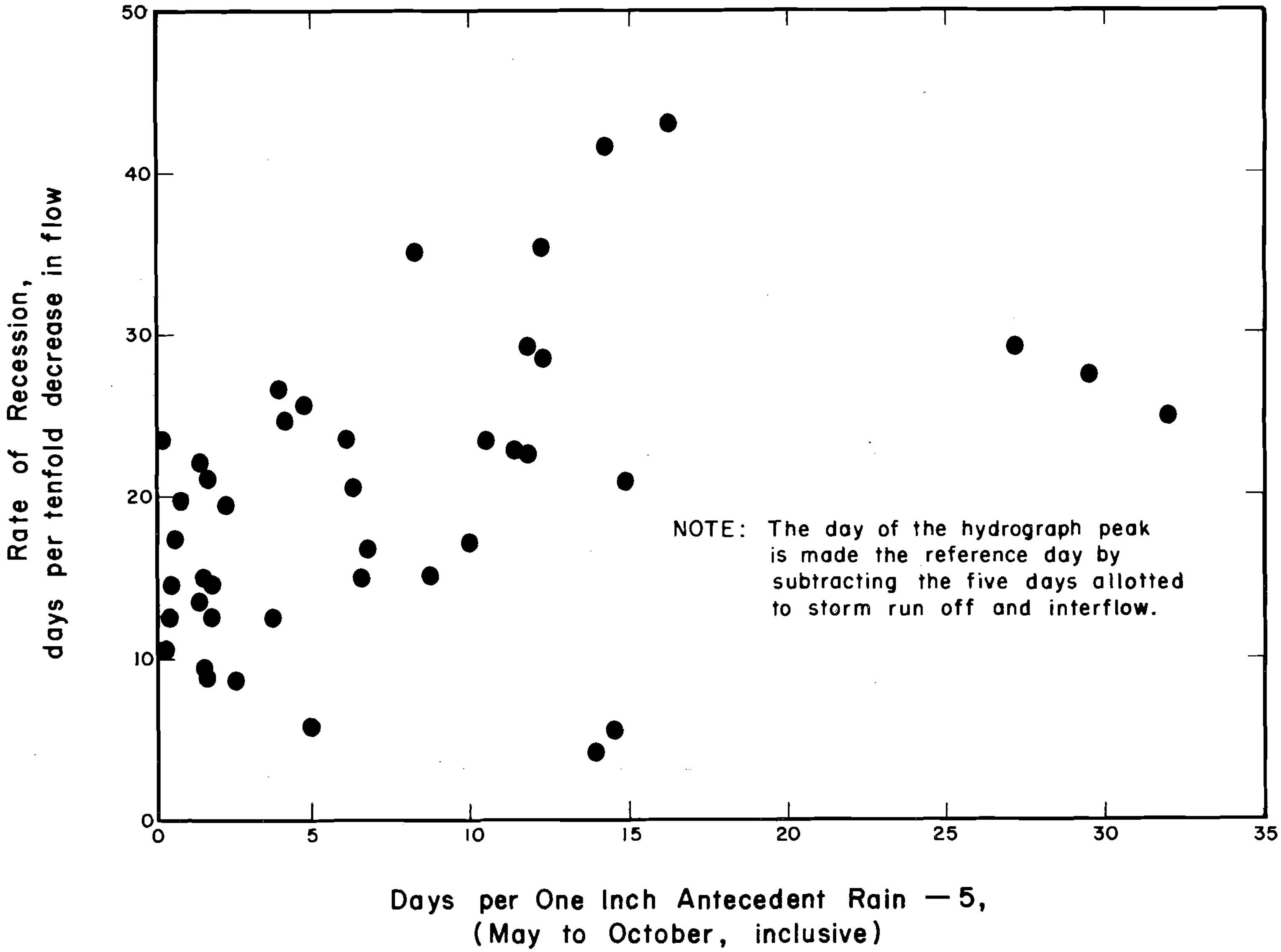

Figure 5. Rate of Recession vs. Number of Days Since a Total of 1'' of Rain Had Fallen for Panther Creek near El Paso.

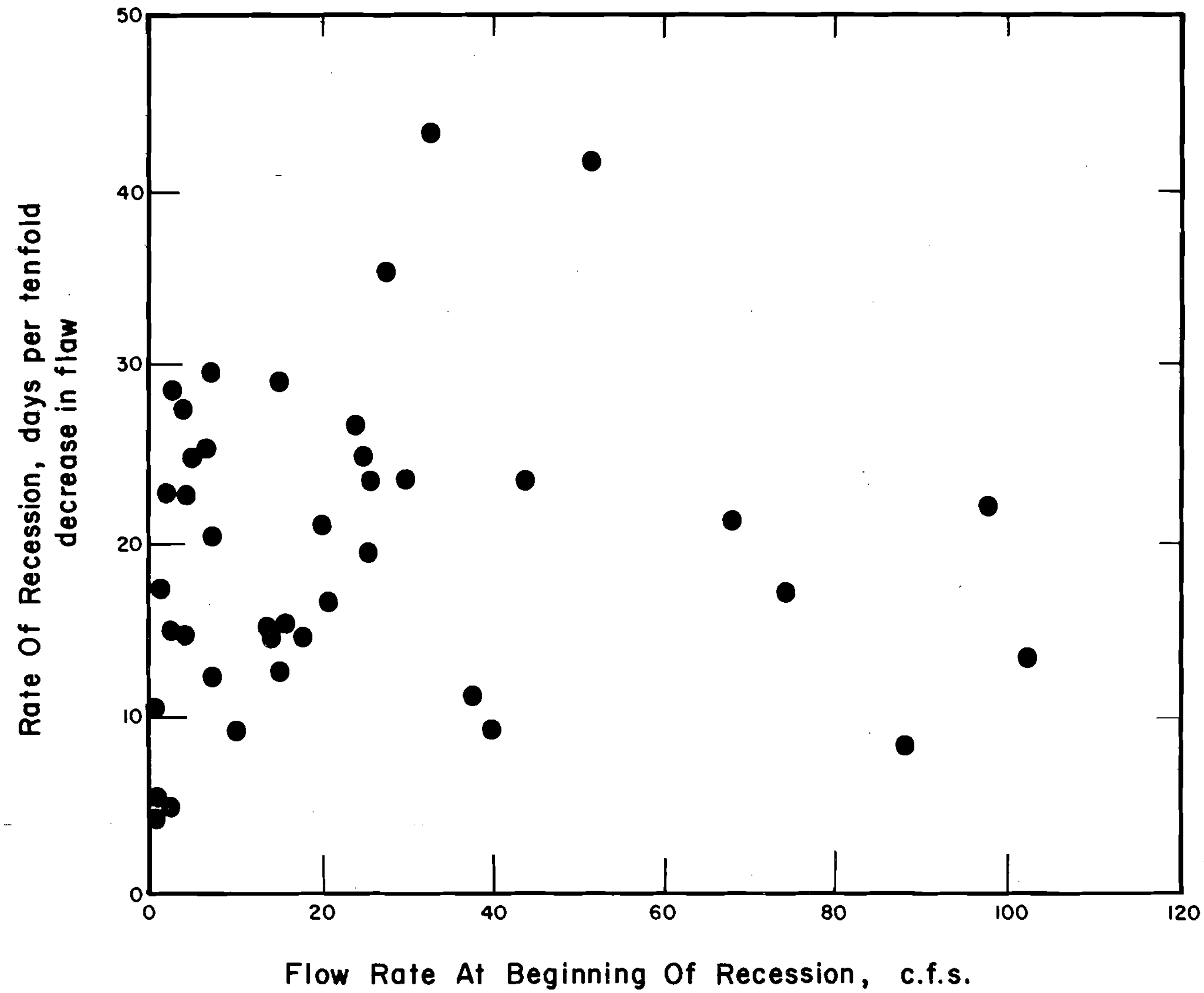

Figure 6. Rate of Recession vs. Flow Rate of the Beginning of the Recession for Panther Creek near El Paso

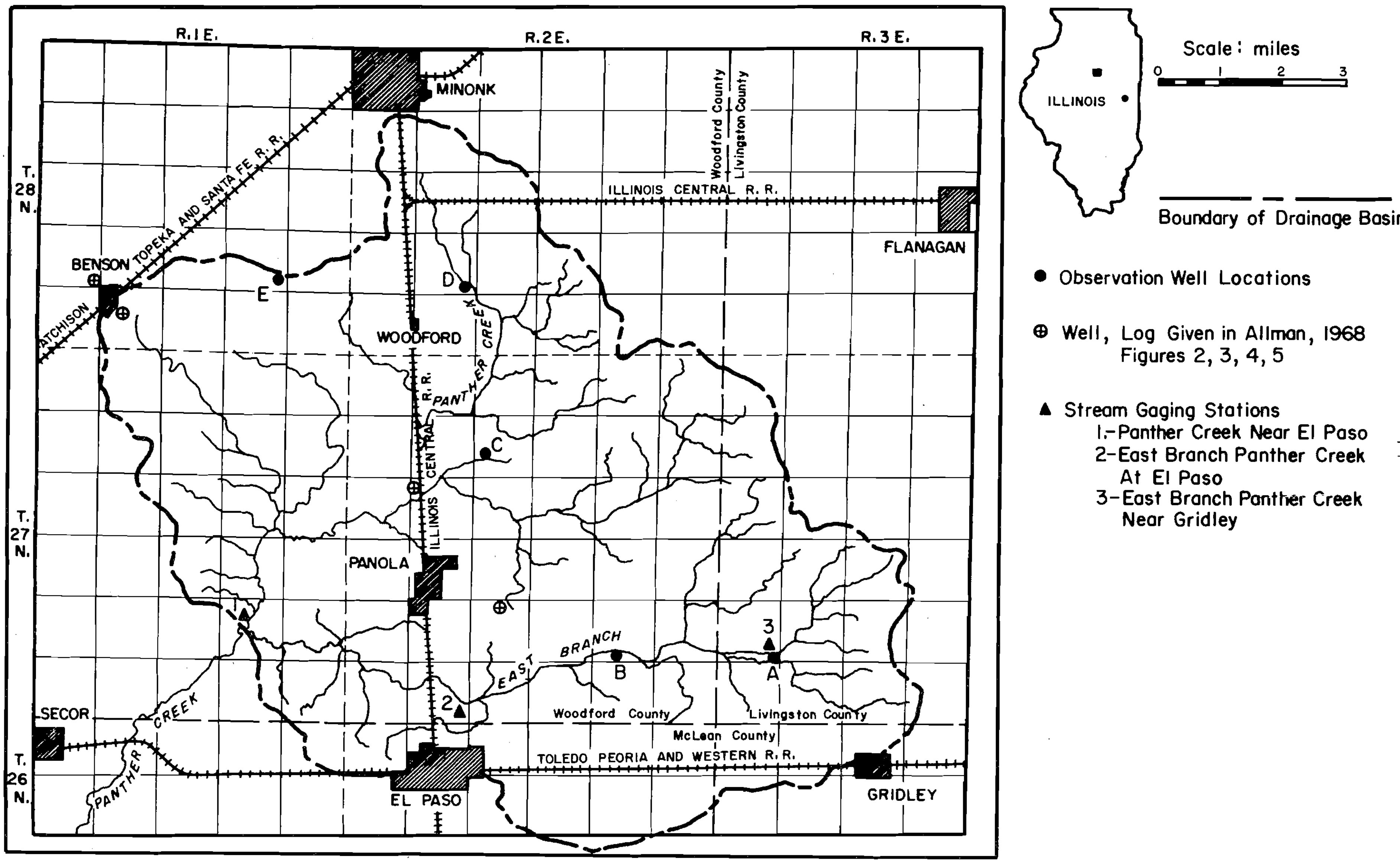

Figure 7. Hydrologic Map of Panther Creek Drainage Basins. (after Allman, 1967, and Schicht and Walton, 1961).

storage in river connected aquifers is not the main source of water for base-flow in this basin, because the storage capacity of these aquifers is not nearly great enough to account for the volume of base-flow. Allman also shows that leakage from deep aquifers is negligible so that base-flow must derive from water that has entered the groundwater reservoir as infiltration from precipitation and moved subsequently in a normal gravity flow system (Toth, 1962-1963.) Allman did not follow the rigorous method of identifying base-flow recession described above, but attempted to be objective in selecting recessions free of the influence of direct runoff - and/or interflow.

Stepwise multiple regression analysis was used to determine the relationships between base-flow and the factors that influence it for the Panther Creek Basin. The rate of recession was weighted according to the duration of the recession, so that the longer, more reliable recessions received proper consideration. Table 2 lists the eight variables with the highest linear correlation coefficients between the variable and the weighted base-flow recession value.

Stepwise multiple regression analysis resulted in the following equation, which has a correlation coefficient of 0.9167356 (all figures are presented to seven significant figures, as printed out by the computer).

$$S = 34.77590 - 0.02728838\,A + 0.9693883\,B - 0.001840270\,C + 9.960399D + 0.3969670\,E - 0.5951381G - 0.28414664\,H + 1.484719\,J \tag{1}$$

where S = recession rate (days per tenfold decrease in flow)

A = initial discharge rate in cfs (cubic feet per second) at the start of the recession,

B = number of days since the peak discharge of the last major storm,

C = peak daily discharge of the last major storm,

D = total precipitation (inches) during the recession,

E = average minimum daily temperature (degrees Fahrenheit) over the duration of the recession,

G = average daily temperature (degrees Fahrenheit) for the period from one to five days preceding the start of the recession,

H = average daily evaporation (inches) during the recession,

J = total runoff (inches) during the month preceding the month in which the recession started.

Table 2.

Eight Variables with the Highest Correlation Coefficients with Base-Flow Recession Slope for Panther Creek near El Paso

Variable	Correlation Coefficient
Number of days since the last major storm	+0.6358959
Average minimum daily temperature (degrees Fahrenheit) for the one to five day period preceding the beginning of the base-flow recession	-0.4641566
Average daily temperature (degrees Fahrenheit) for the one to five day period preceding the beginning of the base-flow recession	-0.4418390
Average maximum daily temperature (degrees Fahrenheit) for the one to five day period preceding the beginning of the base-flow recession	-0.4228529
Discharge (cfs) at the beginning of the base-flow recession	-0.4180146
Average daily evaporation (inches) for the one to five day period preceding the beginning of the base-flow recession	-0.2882772
Average daily evaporation (inches for the duration of the base-flow recession	-0.2478789
Total runoff (inches) for M_1	+0.2162449

The first variable added in this equation (B) indicates that the greater the number of days since the last major storm, the smaller the slope of the recession curve. This would tend to indicate that the base-flow recession curve is not a straight line, but rather forms a curve which is concave-up on a semilogarithmic plot. This could be the result of factors such as a constant-flow source discharging into the stream, an increasing gravity yield with time of drainage, a decreasing permeability with an increasing depth to the water, and the discharge of large quantities of subsurface flow or perched water. Most likely cause for this high correlation is that the base-flow recession slopes of short duration actually include some interflow.

The second and third variables added in the stepwise multiple regression analysis were the average daily temperature for the one to five day period preceding the beginning of the base-flow recession (G), and the average minimum temperature during the base-flow recession (E), respectively. The average daily temperature was 62.°F. The average minimum daily temperature was 57.2°F. It should be noted that opposite signs are present for these two variables. Standard deviations for E and F were 26.7°F and 31.2°F, respectively. When $G \geq 0.663E$, then the effect of these two variables is to steepen the slope of the base-flow recession curve. Assuming E to be 52.2°F, then for these two variables to reduce the slope of the base-flow recession curve, G would need to have values greater than or equal to 34.7°F. The difference between the minimum daily temperature and the average daily temperature over a ten-day period is seldom this great. Thus, the author believes that these two variables, when considered as a pair, significantly affect the base-flow recession slope.

The fourth variable added was the discharge of the last major storm (C). The greater the discharge of the last major storm, the steeper the base-flow recession slope assuming all the other variables to be constant. This would be expected since variable (B) indicated that the greater the number of days since the last major storm, the less steep the base-flow recession curve. Both these variables indicate that the base-flow recession slope is concave-up on a semilogarithmic plot of discharge against time. Bank storage would also produce a similar correlation.

The fifth variable entered was the average daily evaporation during the base-flow recession curve (H). The greater the average daily evaporation during the base-flow recession curve, the steeper the slope. Losses due to evaporation from the stream surface would reduce the total discharge and the rate at which the discharge occurs. The correlation coefficient between the average daily temperature during the base-flow recession curve and the average minimum daily temperature during this period is 0.6647919 which indicates a fair correlation between the temperature and pan evaporation.

The sixth variable added was the discharge at the beginning of the base-flow recession curve (A). Higher discharges are associated with steeper base-flow recession slopes. This agrees with variables B and C as discussed above.

The seventh variable added (J) was the runoff in inches from the basin during the month preceding the month in which the recession started. The greater the total runoff, the less steep the base-flow recession slope. The greater the total runoff, in general, the greater the recharge to the water table and the lower the soil moisture deficiency. If high total runoff generally coincides with low soil moisture deficiency, this could indicate that there is a lower loss of groundwater due to evapotranspiration when there is a low soil moisture deficiency. This in turn would decrease the slope of the base-flow recession curve. It may be argued that, the greater the runoff, the lower the monthly temperature resulting in a lower rate of evapotranspiration.

The eighth variable added was the total precipitation that occurred at Gridley over the duration of the base-flow recession curve (D). The greater the precipitation, the less steep is the base-flow recession curve. The precipitation falling would be expected to decrease the slope for numerous reasons. Generally the evapotranspiration losses of groundwater would decrease during periods of rainfall because of a lower temperature, lower intensity of solar radiation, and high relative humidity. Soil moisture deficiency would also be decreased which could result in a lower loss of groundwater due to evapotranspiration. Direct precipitation falling on the stream would also increase the total amount of runoff. Numerous small showers over the period of the base-flow recession curve could add small amounts of water to the stream that would produce peak flows small enough that they were not discernible using mean daily discharge.

These variables partially explain the variation in the slopes of base-flow recession curves for the Panther Creek basin. Numerous variables were omitted either because they were not available or the author did not believe they were significant. In some cases they were considered indirectly. The data over a wide range of meteorological and hydrological conditions have been grouped, which could cause the equation derived above for the factors affecting base-flow recession slopes to be invalid at times of the year which had a poor representation in the sample used in this study.

Relationship Between Base-Flow and Water Levels in Wells

Base-flow of a stream is known to be related to groundwater potential gradients which in turn are reflected by water levels in wells. In spite of a high time lag for the wells used in this study, they are still useful as piezometers, under certain conditions. Table 3 shows the relationship between various wells and the recession rate, as calculated by stepwise multiple regression analysis.

Table 3.

Correlation Coefficients Between Log_e of Depth to Water Level and Average Rate of Groundwater Discharge During Recession.

WELL	CORRELATION COEFFICIENT
A	-0.8875797
B	-0.6896098
C	-0.3070205
D	-0.7417258
E	-0.4793773

Figures 8 and 9 show the relationship between base-flow in Panther Creek and depth to water in wells A and E, respectively. Several authors have used such graphs for evaluating the groundwater component of flow during storm runoff as well as for dry-weather flow (Schicht and Walton, 1961). There is no evidence that the relationship is valid except during intervals of base-flow recession. Table 4 lists the nine variables which have the highest correlation coefficients with the base-flow of Panther Creek.

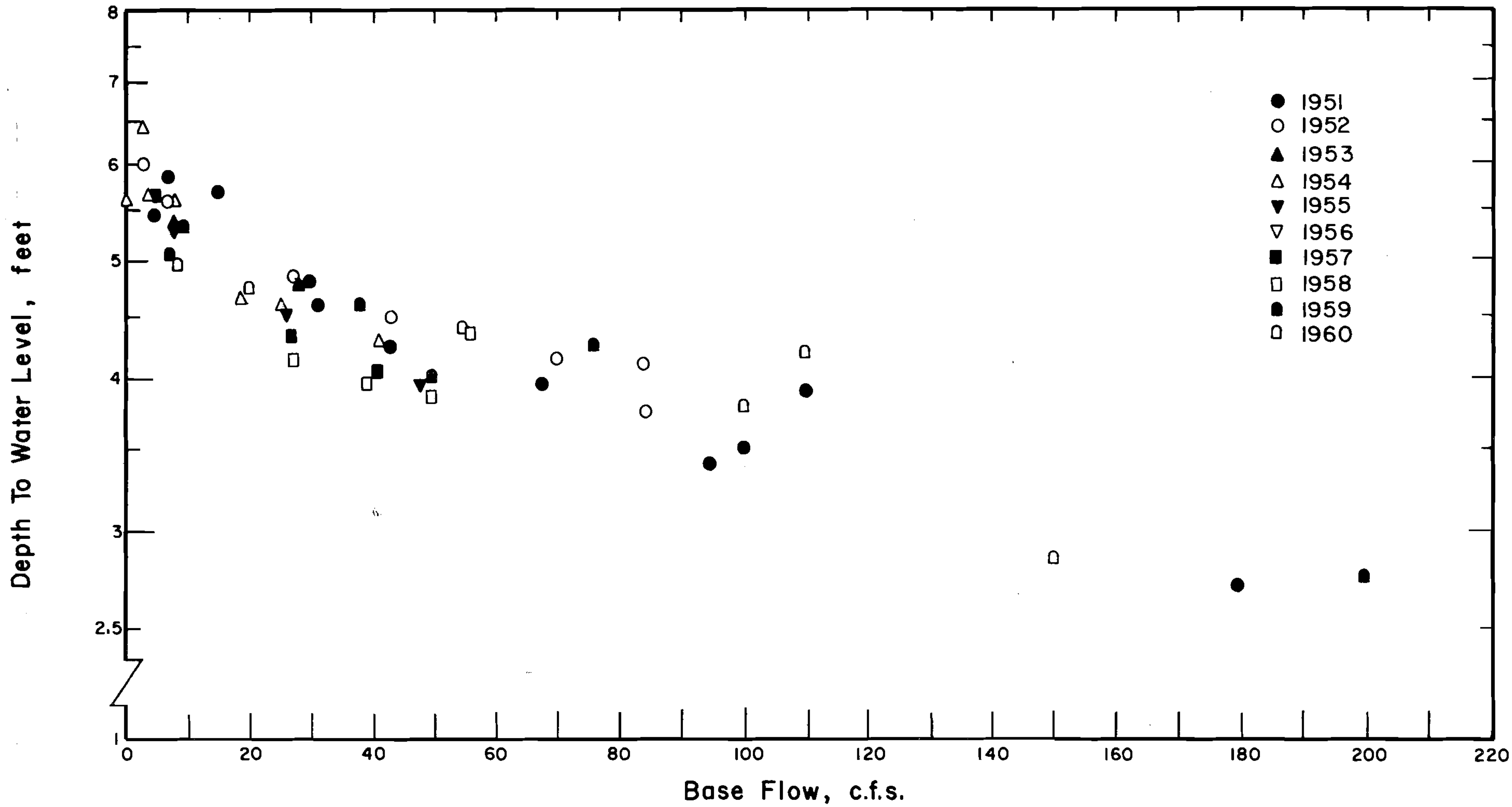

Figure 8, Depth to Water Level in Well A vs. Base-flow of Panther Creek near El Paso (from Allman, 1968).

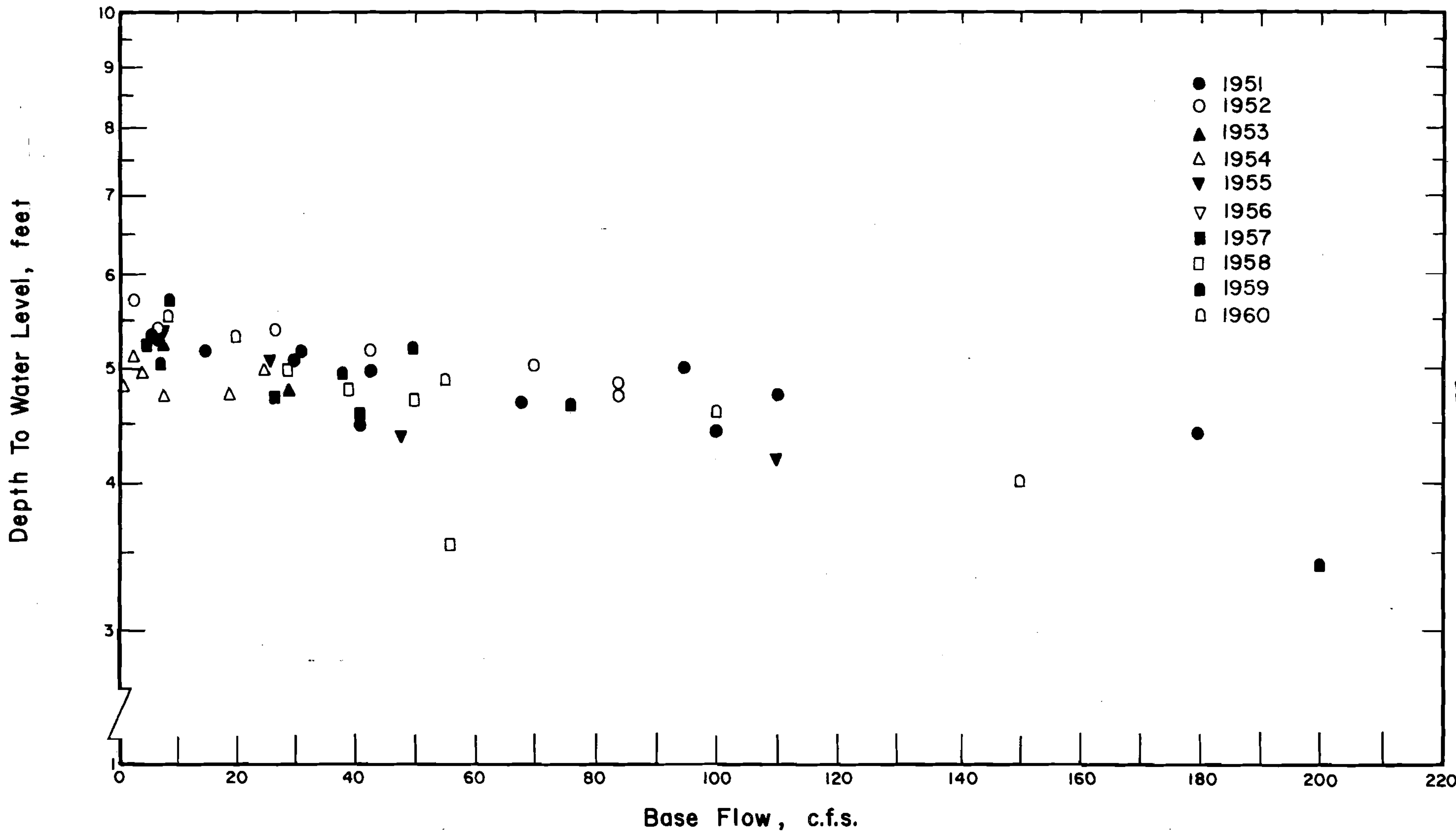

Figure 9. Depth to Water Level in Well E vs. Base-flow of Panther Creek near El Paso (from Allman, 1968),

Table 4.

Nine Variables with the Highest Correlation Coefficients with the Rate of Base-Flow in Panther Creek near El Paso.

Variable	Correlation Coefficient
$\log_e$ of depth (feet) to water level in well A	-0.8782670
$\log_e$ of depth (feet) to water level in well E	-0.6823314
Average maximum daily temperature (degrees Fahrenheit) from six to ten days prior to beginning of base-flow	-0.4403618
Average maximum daily temperature (degrees Fahrenheit) from 11 to 15 days prior to beginning of base-flow	-0.4388881
Average daily temperature (degrees Fahrenheit) from six to ten days prior to beginning of base-flow	-0.4374790
Average daily temperature (degrees Fahrenheit) from 11 to 15 days prior to beginning of base-flow	-0.4365793
Total monthly evaporation (inches) for M_2	-0.4331650
Average minimum daily temperature (degrees Fahrenheit) from six to ten days prior to beginning of base flow	-0.4319515
Average minimum daily temperature (degrees Fahrenheit) from 11 to 15 days prior to beginning of base-flow	-0.4133116

Stepwise multiple regression analysis resulted in the following equation, which has a correlation coefficient of 0.9109751:

$$Q = 513.8282 - 211.9034\ A - 101.3219\ B + 0.004900893\ C \qquad (2)$$

where Q = rate of groundwater discharge (cfs)

A = $\log_e$ of depth to water level in well A (feet)

B = $\log_e$ of depth to water level in well E (feet)

C = maximum daily mean discharge of the last major storm (cfs).

In spite of all the variables influencing the base-flow recession of an individual stream it is still possible to show a relationship between mean base-flow recession and the catchment area. Figure 10 shows this relationship for Panther Creek near El Paso and the two sub basins (East Branch Panther Creek at El Paso and East Branch Panther Creek near Gridley). Figure 11 shows the same relationship for the other basins in the investigation.

Isotopic Evidence of Source of Base-Flow

A total of eight water samples, three from the Panther Creek catchment and five from the Kaskaskia Creek catchment just west of Champaign, were collected and sent to Isotopes, Inc., of Westwood, New Jersey for tritium analysis. The results are shown in Table 5.

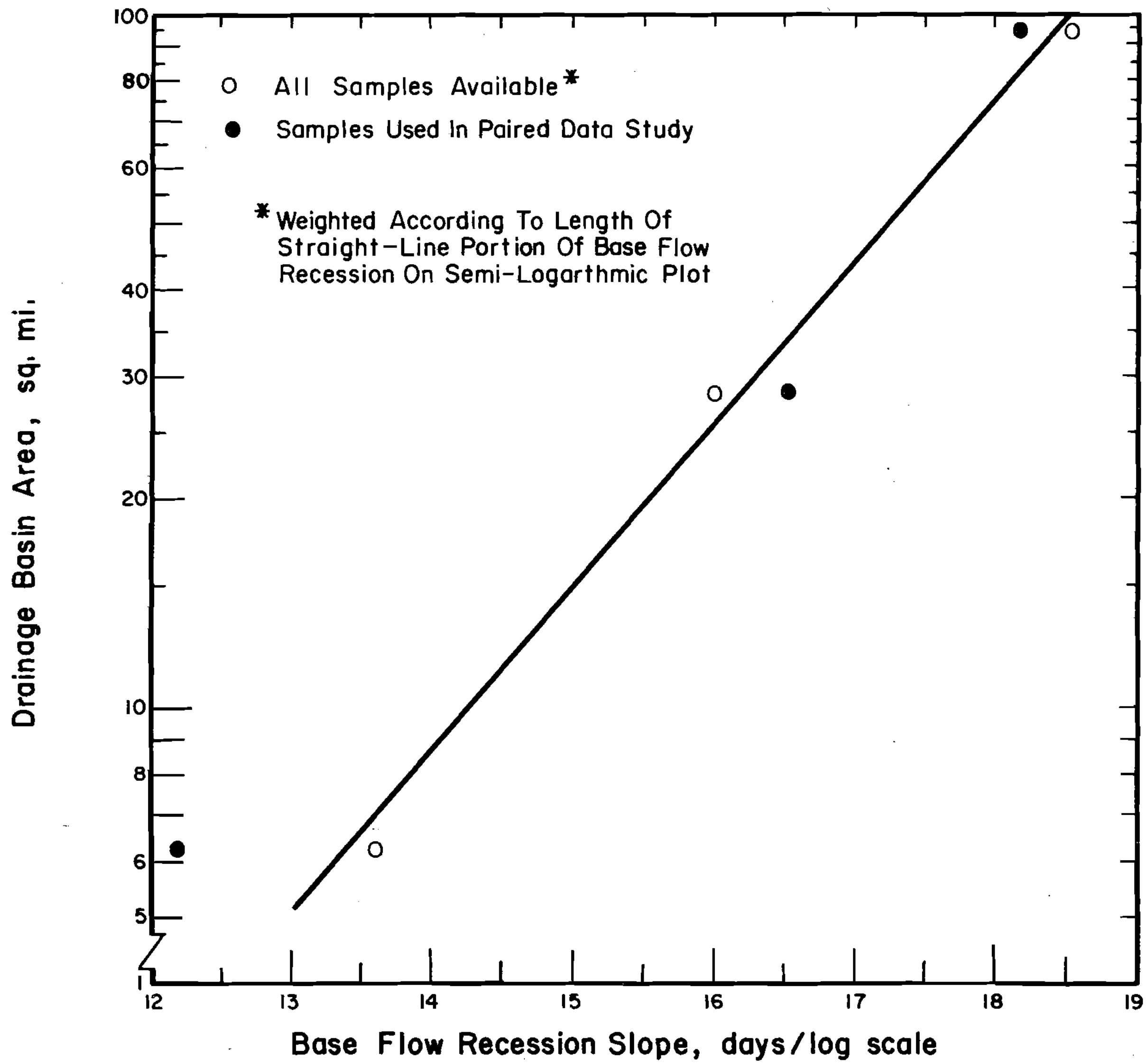

Figure 10. Drainage Basin Area vs. Average Base-Flow Recession Slope (from Allman, 1968).

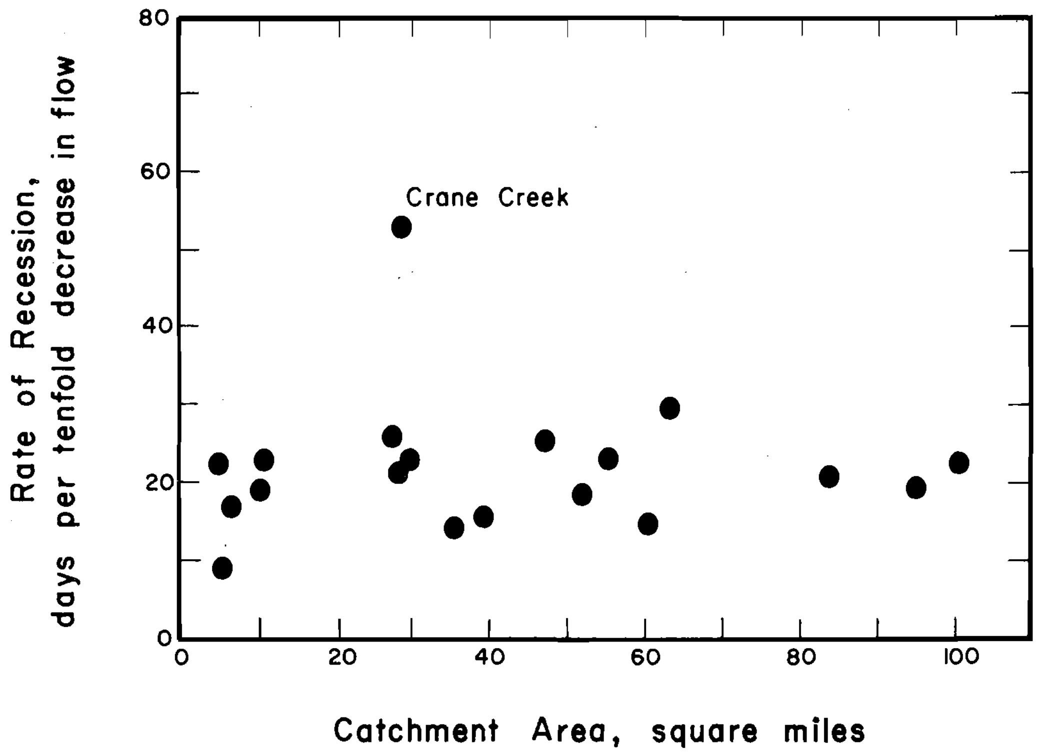

Figure 11. Relation Between Rate of Recession vs. Catchment area.

Table 5.

Tritium Analyses

Project Sample No.	Isotopes Inc. Sample No.	TU Assay (As reported)	Location of Sample Collection Point All T are North All R are East
PC-1	TC2221E	2.0±.3	NW Sec. 32T27R3, 1/4 mile south of gaging station on East Branch Panther Creek near Gridley on farm of John Murray - drilled well 280' deep
PC-2	TC2222E	378±13	SE Sec. 30T27R3, just north of gaging station on East Branch Panther Creek near Gridley, on farm of John Murray - dug well 30' deep
PC-3	TC2223E	227±7	Near center of Sec. 23T27R1E, shallow hole in sand in creek channel.
K-1	TC2216E	305±11	South center Sec. 30T20R8 - Kaskaskia ditch
K-2	TC2217E	259±13	South center Sec. 30T20R8 - 18" hole in gravel, Kaskaskia ditch.
K-3	TC2218E	0.4±0.3	SW sec. 8T19R8, well 141' deep.
K-4	TC2219E	350±17	NW Sec. 8T19R8, dug well total depth 45'
K-5	TC2220E	8.2±.5	SE Sec. 31T20R8, drilled well 240' deep.

The tritium content of samples PC-1, K-3 and K-5 indicates relatively "old" water. This is not surprising as all three are from deep drilled water wells. The value for K-5 suggests the influence of "post-bomb" tritium. The absence of "dead" water in these samples suggests an active flow system. The two samples taken from shallow pits in the creek beds of Panther Creek and Kaskaskia ditch both have less tritium than the shallow wells or streams, indicating, as expected, that this water has entered the ground some time previously, and therefore is not from bank storage. Although the likelihood of contamination from the surface water is great, the pattern of the analytic result is realistic and indicates reliability.

4. CONCLUSIONS

Base-flow recession curves as determined from straight-line segments on the recession limb on a semilogarithmic plot of stream discharge versus time for Panther Creek near El Paso do not have a constant slope throughout the year. The area is extensively tiled with large portions of the stream channel consisting of ditches. A considerable portion of the base-flow discharged appears to originate from tile drains with a portion of the low flow originating from tiles draining the El Paso and Benson areas. Channel storage and bank storage are considered to be negligible.

The variables considered in the investigation were as follows: air temperatures; pan evaporation; stream runoff, both during the preceding the base-flow recession curve or constant flow; and precipitation, occurring during the base-flow recession curve. The hydrologic variables considered were as follows: the flow rates at the beginning, end, and time-mid-point of the recession curve; the days since the last major and minor storms; the peak mean daily discharge of the preceding major and minor storms; the length or duration of the base-flow recession curve; and the water levels in six observation wells.

Well A was one of the wells used in the study of factors affecting base-flow discharge rates because of the high correlation between the natural logarithm of the depth to the water level and the average discharge occurring during the base-flow recession curve, and because of a fairly complete record of water levels.

Well E was used since records of water levels were available and the data was as complete as that for well A. The plot for well E shows a fair correlation between the depth to the water level and the base flow.

Wells B, C, D, and F were not considered because of the sparse data which would decrease the sample size considerably.

Table 4 lists nine variables having the highest correlation coefficients with the rate of base-flow in Panther Creek near El Paso. Stepwise multiple regression resulted in the following equation which has a multiple correlation coefficient of 0.9109751:

$$Q = 513.8282 - 211.9034A - 101.3219B + 0.004900893C$$

where Q is the rate (cfs) of ground water discharge,

A is the $\log_e$ of the depth (feet) to the water level in well A,

B is the $\log_e$ of the depth (feet) to the water level in well E,

C is the maximum daily mean discharge (cfs) of the last major storm.

For normal base-flow recession slopes weighted according to duration, the following variables were found to be significantly correlated at the 90 percent confidence level: the number of days since the last major storm; the average daily temperature for the one to five-day period preceding the beginning of the base-flow recession curve; the peak mean daily discharge of the last major storm; the average minimum daily temperature over the duration of base-flow recession; the average daily evaporation during the base-flow recession curve; the discharge rate at the beginning of the base-flow recession curve; the total runoff for the month preceding the month during which the base-flow recession occurred (M_0); and the total precipitation during the base-flow recession curve. Various other factors on which no quantitative measures were made, but which may be very important on determining the base-flow recession curve are as follows: changes in the viscosity of the water discharged from the tiles; direct losses from the water table due to evapotranspiration; and the presence of possible phreatophytes along the stream.

The relationship between depth to water levels in various wells and the groundwater runoff was shown to be highly correlated in only a few wells.

The evidence from tritium analyses, base-flow records and water levels, all seem to confirm the belief of a normal gravity flow system in these basins. If this is the case, then it is not possible that the recharge by leakage to underlying aquifers, as calculated by Walton (1960) is correct, because, over a large part of the catchment, the shallow groundwater is moving towards the stream, and therefore cannot be moving downward to the aquifers. The significance of this fact on the ultimate hydrologic regimen should be examined because of its significance in the future.

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APPENDIX

BASE-FLOW RECESSION DATA

Bay Creek at Pittsfield, Illinois 5-5125

t_1[1]	t_2[2]	Recession Rate[3]
25-8-61	29-8-61	9.99
19-9-61	22-9-61	16.7
8-11-61	12-11-61	41.6
26-3-62	29-3-62	20.8
22-4-62	27-4-62	55.6
15-6-62	23-6-62	19.9
21-7-63	27-7-63	15.5
18-9-63	25-9-63	15.99
11-4-64	17-4-64	16.4

[1]Date at start of Recession

[2]Date at end of Recession

[3]Days required for a tenfold decrease in flow rate, when the baseflow recession is drawn as a straight line.

West Bureau Creek at Wyonet, Illinois 5-5570

t_1	t_2	Recession Rate
2-4-61	8-4-61	39.4
13-6-61	18-6-61	20.9
10-7-61	12-7-61	11.2
16-8-61	1-9-61	35.8
19-9-61	21-9-61	18.1
5-10-61	10-10-61	43.9
8-11-61	13-11-61	37.6
28-11-61	9-12-61	52.7
17-5-62	25-5-62	26.9
2-6-62	4-6-62	22.3
17-6-62	21-6-62	32.9
11-8-62	23-8-62	19.1
5-4-63	15-4-63	114.6
5-5-63	9-5-63	13.4
23-7-63	27-7-63	9.1
7-9-63	10-9-63	11.2
12-4-64	15-4-64	14.5
19-5-64	23-5-64	20.4
7-6-64	11-6-64	16.6
25-6-64	2-7-64	10.1

Poplar Creek at Elgin, Illinois 5-5505

t_1	t_2	Recession Rate
16-12-59	20-12-59	23.1
4-4-60	8-4-60	13.9
2-6-60	4-6-60	19.7
18-7-60	25-7-60	20.2
30-7-60	3-8-60	12.2
1-4-61	4-4-61	22.2
3-5-61	5-5-61	14.8
16-6-61	18-6-61	6.8
9-7-61	12-7-61	18.4
19-9-61	21-9-61	11.1
5-10-61	10-10-61	18.2
8-11-61	11-11-61	22.8
27-11-61	8-12-61	40.99
26-3-62	28-3-62	11.99
18-4-62	20-4-62	21.2
17-5-62	20-5-62	15.8
15-6-62	21-6-62	12.9
3-8-62	5-8-62	16.4
14-8-62	19-8-62	21.4
28-5-64	31-5-64	16.3
8-6-64	11-6-64	9.01
28-6-64	1-7-64	4.2
3-8-64	9-8-64	8.1

Crow Creek near Henry, Illinois 5-5585

t_1	t_2	Recession Rate
12-6-61	19-6-61	25.9
9-7-61	12-7-61	16.6
5-10-61	10-10-61	22.9
8-11-61	12-11-61	31.2
27-11-61	3-12-61	35.7
6-2-62	8-2-62	16.99
26-3-62	28-3-62	21.2
16-5-62	25-5-62	38.1
14-6-62	20-6-62	25.2
26-6-62	29-6-62	25.3
2-8-62	4-8-62	23.7
14-8-62	23-8-62	21.9
30-8-62	2-9-62	32.6
5-5-63	9-5-63	20.6
25-7-63	30-7-63	22.8
21-5-64	25-5-64	28.3
26-6-64	30-6-64	7.99

East Bureau Creek near Bureau, Illinois 5-5575

t_1	t_2	Recession Rate
5-11-60	7-11-60	24.7
22-11-60	27-11-60	68.3
26-3-61	8-4-61	46.5
13-6-61	18-6-61	12.1
5-10-61	10-10-61	19.4
8-11-61	12-11-61	31.1
27-11-61	7-12-61	38.2
26-3-62	28-3-62	18.6
10-4-62	12-4-62	38.2
22-4-62	27-4-62	65.8
17-5-62	25-5-62	46.99
17-6-62	22-6-62	30.5
28-6-62	1-7-62	35.01
7-7-62	10-7-62	19.3
14-8-62	23-8-62	24.6
5-4-63	14-4-63	25.2
5-5-63	9-5-63	14.8
25-7-63	30-7-63	8.1
5-2-64	11-2-64	20.9
21-2-64	25-2-64	4.8
11-4-64	15-4-64	10.7
18-5-64	2-6-64	19.4
26-6-64	5-7-64	16.99

East Branch Panther Creek at El Paso, Illinois 5-5665

t_1	t_2	Recession Rate
15-4-50	18-4-50	29
14-5-50	20-5-50	30
8-7-50	15-7-50	19
25-7-50	7-8-50	11.5
20-8-50	27-8-50	25
14-10-50	25-10-50	43.5
23-3-51	26-3-51	26.5
16-5-51	20-5-51	24.5
1-6-51	6-6-51	22.5
4-7-51	7-7-51	22.5
1-8-51	5-8-51	13.6
3-9-51	9-9-51	10
12-10-51	17-10-51	38
30-11-51	5-12-51	40.2
27-3-52	30-3-52	27.6
19-4-52	21-4-52	16.3
28-4-52	5-5-52	35.0
31-7-52	2-8-52	26.0
25-2-53	1-3-53	19.0
27-3-53	29-3-53	22.3
19-6-53	24-6-53	10
11-7-53	16-7-53	23.7
27-7-53	2-8-53	17.1
17-8-53	28-8-53	11.8
8-2-54	13-2-54	12.1
13-5-54	26-5-54	27.8
27-6-54	29-6-54	25.0
12-7-54	18-7-54	9.8
1-9-54	6-9-54	8.5
20-10-54	24-10-54	24.5
3-12-54	7-12-54	16
10-3-55	13-3-55	18.4
31-3-55	3-4-55	18.7
30-4-55	3-5-55	29.5
18-5-55	21-5-55	19.9
17-6-55	29-6-55	31.6
5-7-55	13-7-55	12.0
28-7-55	4-8-55	8.0
10-5-56	14-5-56	28.6
6-6-56	14-6-56	17.2
17-2-57	22-2-57	9.5
3-3-57	10-3-57	18.5
3-5-57	9-5-57	14.3
19-6-57	21-6-57	10.7
8-7-57	11-7-57	22.0

East Branch Panther Creek at El Paso, Illinois 5-5665 (cont)

t_1	t_2	Recession Rate
27-7-57	2-8-57	13.0
20-11-57	1-12-57	10.3
12-4-58	17-4-58	22.8
10-9-58	14-9-58	13.4
22-3-59	24-3-59	16.5
14-4-59	17-4-59	46.5
3-5-59	9-5-59	13.1
6-6-59	9-6-59	14.6
10-7-59	16-7-59	24.5
5-1-60	11-1-60	27.0
16-2-60	20-2-60	16.1
26-3-61	8-4-61	27.5
19-9-61	21-9-61	9.9
8-11-61	11-11-61	23.2
26-3-62	28-3-62	19.6
17-5-62	24-5-62	23.0
15-6-62	30-6-62	23.0
6-4-63	15-4-63	16.4
5-5-63	9-5-63	24.8
25-7-63	27-7-63	6.8
18-5-64	1-6-64	71.9
26-6-64	2-7-64	11.7

Fond du Lac Creek near East Peoria 5-5615

t_1	t_2	Recession Rate
19-5-61	24-5-61	10.2
8-11-61	12-11-61	22.3
27-11-61	3-12-61	15.4
26-3-62	28-3-62	11.7
16-5-62	25-5-62	11.3
5-5-63	9-5-63	6.1
11-4-64	17-4-64	6.7

Gimlet Creek near Sparland 5-5590

t_1	t_2	Recession Rate
12-6-61	19-6-61	8.9
8-11-61	12-11-61	27.9
6-2-62	8-2-62	2.7 (?)
14-2-62	16-2-62	3.4 (?)
26-3-62	28-3-62	29.9
27-4-62	29-4-62	74.8
16-5-62	25-5-62	41.0
15-6-62	20-6-62	32.00
1-8-62	4-8-62	9.4
1-4-63	14-4-63	17.4
5-5-63	9-5-63	21.1

Farm Creek at East Peoria, Illinois 5-5620

t_1	t_2	Recession Rate
8-11-62	12-11-62	16.5
13-4-62	26-4-62	32.7
16-5-62	23-5-62	12.6
15-6-62	1-7-62	18.6
5-5-63	9-5-63	14.7
5-10-63	15-10-63	13.2

Ackerman Creek at Farmdale, Illinois 5-5605

t_1	t_2	Recession Rate
19-5-61	24-5-61	26.7
8-11-61	12-11-61	27.8
28-11-61	3-12-61	36.3
26-3-62	28-3-62	13.8
17-5-62	25-5-62	18.8

Farm Creek at Farmdale, Illinois 5-5605

t_1	t_2	Recession Rate
10-4-61	15-4-61	29.5
19-5-61	27-5-61	40.1
19-9-61	21-9-61	18.9
8-11-61	12-11-61	42.7
27-11-61	3-12-61	37.1
26-3-62	28-3-62	28.9
13-4-62	27-4-62	46.7
16-5-62	24-5-62	24.9
15-6-62	30-6-62	28.5
6-4-63	15-4-63	17.4
5-5-63	9-5-63	11.8
11-4-64	15-4-64	10.4
18-5-64	23-5-64	29.3

Money Creek near Towanda, Illinois 5-5644

t_1	t_2	Recession Rate
27-3-61	8-4-61	26.1
16-8-61	1-9-61	21.9
9-9-61	11-9-61	25.9
19-9-61	22-9-61	8.1
9-11-61	12-11-61	13.6
28-11-61	3-12-61	18.3
26-3-62	29-3-62	16.4
22-4-62	27-4-62	61.7
17-5-62	24-5-62	48.6
15-6-62	30-6-62	26.5
27-7-62	4-8-62	26.3
14-8-62	18-8-62	32.1
15-9-62	24-9-62	8.0
6-4-63	15-4-63	22.3
18-5-64	2-6-64	48.8
26-6-64	2-7-64	21.4
30-7-64	5-8-64	8.2

Money Creek above Lake Bloomington 5-5695

t_1	t_2	Recession Rate
13-10-50	25-10-50	100 (Dashed Recession Line)
8-3-51	11-3-51	16.9
23-3-51	26-3-51	14.6
18-4-51	24-4-51	16.9
16-5-51	20-5-51	19.3
1-6-51	6-6-51	32.8
4-7-51	7-7-51	17.2
28-7-51	30-7-51	23.5
3-8-51	5-8-51	15.9
27-11-51	6-12-51	57.3
27-3-52	29-3-52	24.0
19-4-52	22-4-52	27.9
28-4-52	1-5-52	15.0
27-6-52	1-7-52	13.5
28-7-52	3-8-52	15.8
26-8-52	31-8-52	16.3
6-9-52	16-9-52	19.2
27-9-52	12-10-52	15.1
9-12-52	13-12-52	22.6
28-12-52	1-1-53	142 (?)
25-2-53	1-3-53	14.6
23-3-53	29-3-53	24.2
29-5-53	5-6-53	30.1
19-6-53	24-6-53	18.4
11-7-53	15-7-53	15.6
27-7-53	5-7-53	15.6
17-8-53	2-9-53	11.1
21-5-54	25-5-54	26.3
12-7-54	19-7-54	5.6
1-9-54	16-10-54	8.0
20-10-54	24-10-54	22.0
31-3-55	4-4-55	30.1
30-4-55	3-5-55	34.6
19-5-55	21-5-55	23.6
30-6-55	4-7-55	26.9
28-7-55	30-7-55	6.6
28-11-55	30-11-55	11.5
12-4-56	15-4-56	23.0
7-5-56	14-5-56	19.4
4-6-56	7-6-56	20.9
30-6-56	2-7-56	18.5

Money Creek Above Lake Bloomington, continued

24-7-56	31-7-56	9.3	
23-8-56	25-8-56	3.8	(?)
3-3-57	10-3-57	31.3	
3-5-57	9-5-57	16.9	
21-6-57	25-6-57	22.4	
9-7-57	15-7-57	15.0	
29-10-57	1-11-57	23.3	
26-11-57	2-12-57	26	
6-1-58	19-1-58	43.4	
12-4-58	19-4-58	56.2	
10-5-58	15-5-58	32.4	
27-5-58	30-5-58	30.4	
30-6-58	2-7-58	20.0	
10-9-58	15-9-58	24.6	

Hickory Creek above Lake Bloomington 5-5650

t_1	t_2	Recession Rate
8-1-50	13-1-51	14.4
28-1-51	30-1-51	2.6
8-3-51	10-3-51	11.4
23-3-51	26-3-51	24.3
18-4-51	24-4-51	17.1
16-5-51	20-5-51	21.6
1-6-51	6-6-51	32.8
28-7-51	30-7-51	10.2
3-9-51	5-9-51	32.2
18-9-51	21-9-51	4.0
28-11-51	6-12-51	50.8
27-3-52	28-3-52	26.9
19-4-52	21-4-52	14.9
28-4-52	31-5-52	22.6
27-6-52	2-7-52	18.8
28-7-52	2-8-52	6.6
26-8-52	31-8-52	6.4
5-9-52	7-9-50	5.0
25-2-53	1-3-53	15
23-3-53	29-3-53	29.2
29-5-53	5-6-53	31.1
19-6-53	23-6-53	19.8
27-7-53	3-8-53	12.3
21-8-53	30-8-53	4.7
13-5-54	15-5-54	40.6
21-5-54	24-5-54	40.6
12-7-54	18-7-54	12.1
20-10-54	24-10-54	21.0
31-3-55	4-4-55	26.9
30-4-55	3-5-55	26.7
18-5-55	21-5-55	16.4
30-6-55	4-7-55	23.3
7-5-56	14-5-56	18.6
24-7-54	28-7-56	3.0
3-3-57	10-3-57	37.8
3-5-57	9-5-57	19.0
21-6-57	25-6-57	20.6
28-7-57	3-8-57	12.4
29-10-57	1-11-57	12.6
6-1-58	19-1-58	38.0
29-3-58	1-4-58	35.8
12-4-58	19-4-58	34.1
9-5-58	14-5-58	34.6
27-5-58	30-5-58	28.1
10-9-58	14-9-58	19.3

East Branch Panther Creek near Gridley 5-5660

t_1	t_2	Recession Rate
14-5-50	20-5-50	25.3
8-7-50	15-7-50	2.3 (?)
25-7-50	7-8-50	8.3
23-3-51	26-3-51	19.8
16-5-51	20-5-51	29.9
1-6-51	5-6-51	19.6
12-10-51	18-10-51	16.1
3-11-51	5-11-51	6.1
30-11-51	4-12-51	34.6
27-3-52	30-3-52	34.1
19-4-52	21-4-52	21.7
28-4-52	5-5-52	22.4
31-7-52	2-8-52	6.8
26-8-52	31-8-52	16.4
28-12-52	1-1-53	6.4
25-2-53	1-3-53	16.8
19-6-53	29-6-53	16.9
11-7-53	16-7-53	6.0
27-7-53	2-8-53	6.3
7-5-54	22-5-54	23.4
30-4-55	3-5-55	46.4
17-6-55	29-6-55	11.4
10-5-56	14-5-56	13.4
6-6-56	14-6-56	13.1
19-6-56	21-6-56	10.2
12-4-57	19-4-57	25.4
30-6-57	2-7-57	15.0
22-3-59	24-3-59	18.1
3-5-59	9-5-59	22.0
5-1-60	11-1-60	17.4
23-1-60	26-1-60	17.1
16-2-60	20-2-60	14.4

Panther Creek near El Paso 5-5670

t_1	t_2	Recession Rate
15-4-50	18-4-50	48.4
14-5-50	20-5-50	41.9
8-7-50	15-7-50	20.9
25-7-50	7-8-50	14.4
20-8-50	29-8-50	29.8
8-1-51	14-1-51	13.9
8-3-51	10-3-51	13.4
23-3-51	26-3-51	17.3
16-5-51	20-5-51	22.0
1-6-51	6-6-51	23.6
4-7-51	7-7-51	13.5
28-7-51	5-8-51	23.5
3-9-51	9-9-51	19.8
12-10-51	18-10-51	23.6
30-11-51	6-12-51	49.7
27-3-53	30-3-52	30.6
19-4-52	21-4-52	34.1
28-4-52	5-4-52	33.0
30-7-52	2-8-52	22.6
26-8-52	29-8-52	14.9
6-9-62	13-9-52	22.9
9-12-52	13-12-52	35.1
28-12-52	1-1-53	35.4
25-2-53	1-3-53	16.9
27-3-53	29-3-53	24.8
29-5-53	4-6-53	26.6
19-6-53	24-6-53	9.3
11-7-53	15-7-53	11.4
27-7-53	2-8-53	15.1
17-8-53	3-9-53	17.3
13-5-54	22-5-54	43.3
12-7-54	19-7-54	5.0
1-9-54	19-9-54	9.2
20-10-54	24-10-54	24.8
31-3-55	3-4-55	25.9
30-4-55	3-5-55	22.1
18-5-55	21-5-55	17.3
17-6-55	29-6-55	21.2
28-7-55	5-8-55	14.4
4-9-55	10-9-55	10.1
10-5-56	14-5-56	20.3
5-6-56	14-6-56	12.5

Panther Creek near El Pase - continued

17-2-57	23-2-57	13.2
3-5-57	9-5-57	19.4
24-6-57	26-6-57	8.5
8-7-57	11-7-57	16.3
28-7-57	2-8-57	14.9
28-10-57	1-11-57	21.9
24-11-57	2-12-57	24.9
11-3-58	23-3-58	36.2
12-4-58	19-4-58	27.3
9-5-58	14-5-58	29.1
27-5-58	31-5-58	27.6
10-9-58	14-9-58	28.5
20-3-59	24-3-59	19.7
14-4-59	17-4-59	44.8
15-6-59	21-6-59	35.5
10-7-59	16-7-59	25.4
11-8-59	14-8-59	5.4
21-8-59	23-8-59	4.0
16-10-59	22-10-59	12.3
9-11-59	11-11-59	80.6
30-11-59	10-12-59	37.8
18-7-60	23-7-60	24.8

Indian Creek near Wyoming 5-5688

t_1	t_2	Recession Rate
9-7-61	12-7-61	24.9
19-9-61	21-9-61	14.4
6-10-61	10-10-61	15.1
8-11-61	12-11-61	32.6
27-11-61	3-12-61	36.8
26-3-62	29-3-62	24.0
20-4-62	27-4-62	57.1
15-6-62	1-7-62	28.6
10-8-62	23-8-62	68.4
21-3-63	24-3-63	22.9
6-4-63	15-4-63	35.8
5-5-63	11-5-63	18.2
13-6-63	18-6-63	28.1
25-7-63	30-7-63	32.8
12-4-64	17-4-64	31.4
25-6-64	2-7-64	22.7
19-7-64	24-7-64	27.1
16-8-64	20-8-64	43.3

Crane Creek near Easton 5-5825

t_1	t_2	Recession Rate
21-11-60	26-11-60	68.8
27-2-61	3-3-61	106
25-8-61	2-9-61	102.7
19-9-61	23-9-61	24.2
8-11-61	12-11-61	50.7
14-2-62	16-2-62	33.0
26-3-62	28-3-62	20.1
13-4-62	16-4-62	36.1
23-4-62	27-9-62	35.7
23-4-62	27-4-62	52.0
16-6-62	29-6-62	45.6
6-4-63	15-4-63	30.9
24-7-63	27-7-63	53.0
12-5-64	23-5-64	96.0
26-6-64	2-7-64	25.0
17-7-64	24-7-64	30.1

North Fork Mauvaise Terre Creek near Jacksonville 5-5860

t_1	t_2	Recession Rate
28-2-61	3-3-61	23.1
25-5-61	28-5-61	19.9
17-8-61	19-8-61	19.9
25-8-61	2-9-61	31.1
19-9-61	23-9-61	15.7
2-12-61	4-12-61	90
26-3-62	28-3-62	16.8
16-5-62	24-5-62	35.6
15-6-62	18-6-62	18.6
6-4-63	10-4-63	17.6
25-7-63	27-7-63	14.7
2-6-64	4-6-64	43.5
26-7-64	30-7-64	5.2