DPST-86-658

**COLLEGE OF
EARTH AND
MINERAL
SCIENCES**

Development of a Ground-Water Velocity Model for the Radioactive Waste Management Facility Savannah River Plant, South Carolina

FINAL REPORT

EXECUTIVE SUMMARY

June, 1986

by

Richard R. Parizek, Principal Investigator and
Robert W. Root, Jr., Graduate Assistant

**The Pennsylvania
State University**

**University Park,
Pennsylvania**

1855

Development of a Ground-Water Velocity Model for the Radioactive Waste Management Facility Savannah River Plant, South Carolina

FINAL REPORT

June, 1986

Submitted to E.I. duPont and Company
Savannah River Laboratory
Aiken, South Carolina 29808

by

Richard R. Parizek, Principal Investigator and
Robert W. Root, Jr., Graduate Assistant
The Pennsylvania State University
University Park, Pennsylvania 16802

Signed Richard R. Parizek Date July 8, 1986
Robert W. Root Jr. Date July 8, 1986

TABLE OF CONTENTS

TABLE OF CONTENTS (cont'd)

TABLE OF CONTENTS (cont'd)

TABLE OF CONTENTS (cont'd)

HCl cluster wells are observed to be fairly representative of water level fluctuations in the study area. Hence, further discussion of transient phenomena usually refers to those wells.

Lag times between recharge events at the land surface and their impact on the water table is typically between one and two months, depending on the depth to the water table.

4.4 MCQUEEN BRANCH BASIN HYDROLOGIC BUDGET STUDY

4.4.1 Introduction

Numerical modeling of ground-water flow depends heavily on reliable, field-derived data to serve as model input and as calibration controls. Particularly important are ground-water recharge, which may be the major source of water for the hydrologic system, and stream baseflow, which represents the volume of water leaving the ground-water system during a period of time under the prevailing hydrogeologic conditions. The recharge may serve as the major source term and as an important boundary condition for the model. The stream baseflow represents a system parameter that should be reasonably simulated during the numerical modeling effort. Therefore, both of these terms need to be evaluated.

These two parameters are combined with several others to make up the components of the hydrologic budget of a drainage basin. The other components are precipitation, surface runoff, evapotranspiration, underflow, and soil and ground-water storage changes. A study was conducted in McQueen Branch basin to quantify the various components of the hydrologic budget.

4.4.2 Geography and Geology

The McQueen Branch basin is located east and northeast of the 200-H Separations Areas (Figure 4.6). The Branch is a tributary of Tinker Creek and is sometimes identified as "Unnamed Tributary" on maps.

The basin itself is shown in Figure 4.7. It has a topographic drainage area of 4.4 square miles. The length is about 2.3 miles and the maximum width is about 2.1 miles.

The topography is generally flat to slightly rolling near the margins of the basin and slopes gently toward the edges of the flood plain. The floodplain is usually narrow, rarely exceeding 400 ft. in width. The maximum elevation in the basin is about 345 ft. above MSL near the southeast margin; the minimum is about 145 ft. above MSL where the Branch enters Tinker Creek near its confluence with Upper Three Runs Creek.

As shown in Figure 4.7, the main stem of McQueen Branch has several small tributaries, many of which are intermittent. A small pond with an area of about two acres (Shields et al., 1980) occurs on one tributary. Several seeps occur along the valley walls where the slope merges with the floodplain. In a few cases the combined flow of a few seeps forms a short tributary. Two Carolina bays and two suspected Carolina bays were identified in the basin (Shields et al., 1980).

Most of the basin is vegetated. The uplands consist mostly of pines (ranging in age from recently planted to mature). The floodplains are primarily deciduous; some deciduous trees encroach on the valley slopes. Clearing of vegetation for the proposed S Area has significantly altered the land cover conditions in the area bounded by Road F, Road 4, and H Area.

The geology of part of the basin has been investigated in connection with the proposed saltstone disposal facility (D'Appolonia, 1981a). The hydrostratigraphy generally fits the description presented in detail in Section 3 and 4. The Tan Clay is at an elevation of about 200 to 220 ft. above MSL but appears to be discontinuous. The Green Clay is apparently relatively continuous over the basin at an elevation of 130 to 150 ft. above MSL.

McQueen Branch has incised deeply into the Barnwell Formation in the basin and has eroded into the McBean downstream from about Road F (Figure 4.7). Most of the length of the stream is in the McBean; the Congaree may outcrop in the Branch near its mouth.

4.4.3 Precipitation

Precipitation data were collected in the basin for a period of 21 months (July 1982 to April 1984). Precipitation was collected in four four-inch can-type rain gauges installed at widely-scattered locations around the basin (Figure 4.7). These gauges were emptied at a frequency of every 10 to 14 days. In addition, a weighing-type continuous recording rain gauge was operated in the basin from December 28, 1982 to April 2, 1983. Finally, daily precipitation measurements were obtained from F Area, about 2.5 miles west of the basin.

All precipitation measurements obtained from the can-type gauges are provided in Appendix F.

An analysis of variance was performed on the precipitation data to evaluate statistically the difference in measurements between gauges from the basin. The period of measurement used for the analysis of variance was from June 27, 1982 to November 7, 1983. In November 1983, one gauge was removed to make way for construction in the proposed S Area. The result of the analysis of variance suggests that rainfall does not vary significantly over the basin. This result applies to precipitation collected throughout the year; probably more variation would be seen if only rainfall during convective storm periods was considered.

Correlation coefficients were calculated to evaluate the correlation of precipitation results between rain gauges. These coefficients typically exceeded r = 0.90. Therefore, with the analysis of variance, it is reasonable to conclude that any one of the four rain gauges in McQueen Branch basin provides a representative estimate of precipitation in that basin.

Another point of interest is how much precipitation varies over the entire 10.6 square mile study area (not just the McQueen Branch basin). C. E. Murphy (1984, oral communication) of SRL compared precipitation data from several widely-distributed measuring points on the SRP site. Daily values compared very poorly, whereas annual values compared well. An acceptable correlation was found for monthly data, although some scatter was still observed.

Rainfall data obtained from F Area, about 2.5 miles west of McQueen Branch basin, was compared to data collected in the basin. The Thiessen polygon method of areal rainfall determination was applied to the basin gauges. The following weights were calculated for each gauge:

Gauge	Weight
1	0.3223
2	0.1805
3	0.3197
4	0.1775

The precipitation for each interval was multiplied by the appropriate weight and then summed. The result was a weighted average for precipitation over the basin (see Figure 4.8 and Appendix F). This average was then compared to the equivalent value from F Area. A correlation coefficient of r = 0.87 was calculated, suggesting reasonably good correlation for data collected at intervals of 10 to 14 days. Therefore, it is probably reasonable to apply F Area data to the basin on this sort of time scale. Individual, unweighted gauges were correlated with F Area data, also; coefficients on the order of r = 0.85 were calculated.

Daily precipitation values obtained from the basin during December 1982 to April 1983, were compared to corresponding values from F Area. A correlation coefficient of r = 0.22 was calculated. This is a rather poor result, considering the data were obtained during a time of few, if any, convective storms. The poor correlation is probably due to details of data collection, such as different times of day that the data were obtained. It is unlikely that the real correlation on a daily basis is so low.

Precipitation for the original period of the hydrologic budget study (November 1, 1982 to May 19, 1984) totaled 81.69 inches. For the subperiod March 1, 1983 to March 31, 1984, precipitation totaled 52.48 inches. Weekly weighted precipitation values are given in Appendix F.

4.4.4 Ground-Water Hydrology

Well water levels were measured in the McQueen Branch basin in order to compare water table fluctuations with variations in the other parameters of the hydrologic budget. Water levels were measured on some routine basis in thirty-four wells distributed throughout the basin. Frequency of routine measurement varied for different wells from continuous to only quarterly (see Table 4.12). The locations of all wells are shown in Figure 4.9. Note that all but one well (BH2A) are located west of the Branch.

The main interest in the water level measurement program was to define the water table configuration and its seasonal changes. Only 22 of the routinely measured wells were truly water table wells. This fact is indicated in Table 4.12, which also includes pertinent information on each well. All water level measurements are included in Appendix G.

In general, quarterly water level measurements (all made up by R. W. Root, Jr.), varied in a similar fashion for almost all wells in the basin. Most water levels rose and fell simultaneously. There are notable exceptions: Wells SDS-14 and SDS-14A frequently vary in water level in an inverse fashion with the others (this observation is discussed further below). Over the nearly two year period of quarterly measurements, the water table in the basin varied mostly through a range of about five ft. The quarterly measurements were not used further in the budget analysis.

Monthly measurements of ten wells in the basin were made by SRL personnel. The actual measurements are tabulated in Appendix G and an example is plotted in Figure 4.10. The monthly data cover a longer period than the quarterly data but show generally the same tendencies: all wells (except SDS-14A) vary in the same direction and the amplitude of water level changes is mostly within seven ft.

Continuous water level recorders were maintained on Wells SDS 8, SDS 16A, and SDS 17 from June 1982 through June 1984. Charts were changed monthly, although some gaps in data exist. The weekly average water levels in these wells for the period November 1982 through April 1984 are plotted in Figure 4.11 (a-b) and are listed in Appendix G. The monthly and continuous water level measurements were used in the budget analysis.

Again, the three wells responded in a very similar fashion. Water levels in the wells gradually rose four to five ft. from November 1982 to peak in late July or early August 1983. This rise was followed by a gradual decline of two to three ft. until late February or early March 1984. As of April, 1984, water levels in the wells were rising again.

As discussed above, well water level measurements obtained at different intervals are available from McQueen Branch basin. Comparing the results from the different intervals, it was found that quarterly measurements missed some reversals in direction of water level change;

namely, the start of water level rises in February and March, 1984. On the other hand, continuous records did not provide much more definition of this reversal. Therefore, for routine data collection, monthly measurements are probably sufficient.

With most well water levels varying in a similar fashion, there is a possibility that some wells are more nearly "representative" of the basin-wide mean water-table fluctuations. Continuous water level recorders were installed on three wells (SDS 8, SDS 16A, and SDS 17) at the beginning of the study because it was believed that one or more of these wells was reasonably representative. SDS 8 and SDS 17 are upland wells, in similar topography as most of the basin. SDS 16A is on a slope nearer to McQueen Branch and thus, could be more representative of the more sloped portions of the basin.

A linear regression analysis was run comparing 20 monthly measurements from each of the wells monitored by SRL. The method applied to water level data was discussed by Healy (1964).

The correlation coefficient matrix is shown in Table 4.13. For most cases, the correlation coefficients exceed r = 0.85, suggesting a good correlation between water level fluctuations.

Some simple statistics on these correlation coefficients follow:

Well	Mean "r"	Standard Deviation of "r"
SDS 1	0.938	0.068
SDS 5	0.847	0.092
SDS 6	0.927	0.070
SDS 7D	0.932	0.070
SDS 8	0.919	0.063
SDS 12C	0.932	0.075
SDS 16A	0.798	0.047
SDS 17	0.933	0.045
SDS 19	0.836	0.063

Based on these results (which do not include Well SDS 14A), more wells are highly correlated with Wells SDS 1, SDS 17, SDS 7D, SDS 12C, and SDS 6. The poorest average correlation is associated with SDS 16A, nearer to the Branch. Correlation with SDS 8 is fairly high. The smallest standard deviations of "r" are associated with SDS 17, SDS 16A, SDS 8, and SDS 19. Differences between the wells are not great, from a correlation standpoint. Although SDS 1 appears to be the most representative, overall SDS 17 may be a better choice. Also, SDS 8 is probably adequate. Therefore SDS 8 and SDS 17 are reasonably representative of the wells measured. If continuous water level records were to be obtained in the future from the basin, SDS 17 is probably the best choice.

SDS 14A exhibits a negative correlation with all other wells measured. The possibility that SDS 14A is representing a perched zone may explain this behavior. During wet periods water levels rise in this well while the true or regional water table has not yet been impacted by the recharge event. Later, the regional water table begins to increase in response to the recharge event and to a contribution from the perched zone, observed as a decline in SDS 14A water level. Presumably SDS 14A responds in the same direction as other wells during periods of overlap, but these periods have not been observed during the monthly measurements.

A perfect correlation of all water level fluctuations would not be expected. Variation in recharge capacity, vertical hydraulic conductivity, depth to water, topographic position, and the like should cause deviations from perfect correlation. SDS 16A may illustrate some of these effects, being closer to the Branch and in a more sloping topographic environment. Probably most significant is its proximity to the Branch. SDS 16A has the lowest standard deviation in monthly measurements of all wells surveyed. Therefore, as a correlator with other wells, all of which are upland, SDS 16A is not suitable.

The fact that no monthly measurements of water levels are available from the basin east of the Branch to some degree weakens making broad generalizations on water table fluctuations. Given the similarity in geology, topography, and vegetative cover, however, one could expect similar responses in the eastern portion of the basin. The only well available in that portion of the basin is BH 2A and only quarterly measurements have been obtained. In general, BH 2A shows the basin trend of a gradual rise in water level into Summer 1983, followed by a decline into later winter and a recovery during Spring 1984. Therefore, the assumption is probably justifiable that water table fluctuations are similar on both sides of the Branch.

Fluctuations of the water table mostly within a range of five ft. are not especially large. The average water table elevation in the uplands of the basin is on the order of 225 ft. above MSL. The average elevation of McQueen Branch along the reach receiving baseflow from these uplands is about 175 ft. above MSL. The head difference, then, between uplands recharge area and Branch discharge area is about 50 ft.

The factor controlling the variation of specific discharge of ground water in the basin is the variation of hydraulic head, as the hydraulic conductivity and flow path length remain constant. The specific discharge, and hence the baseflow, are controlled by head in the uplands (neglecting ground-water evapotranspiration for the moment). Head in the uplands varying through a range of five ft. constitutes only about a 10% variation in specific discharge. It is questionable whether the baseflow in McQueen Branch has been measured sufficiently accurately to see such a small fluctuation. This important point is discussed further below under "Surface Hydrology".

4.4.5 Surface Hydrology

4.4.5.1 General

Surface storage of water in the basin is limited. A few identified or suspected Carolina bays occur in the area. These bays do not hold water, although ground water may occur within a few feet of the surface beneath some bays during and shortly after periods of heavy rain. A large Carolina bay southwest of Road F frequently held water and supported some aquatic flora and fauna. However, this bay was removed by construction in the proposed S-Area site.

A two-acre pond occurs on one tributary of McQueen Branch (Figure 4.7). The small size of this pond probably limits its overall influence on the basin. Some storm-runoff retention may occur in the pond, but the drainage area above the dam is less than ten percent of the total basin area. A siltation pond near the proposed S Area site may attenuate storm runoff in this part of the basin. Again, its area is very small, so its influence is probably negligible.

McQueen Branch has several tributaries, as shown in Figure 4.7. The upper reaches of several of these tributaries are intermittent.

The extreme upper reach of the mainstem of the stream receives some discharge from H Area. This discharge is mainly storm water runoff from roofs and paved areas. A small amount of cooling water is also discharged from an H Area facility; however, the volume has been measured at only 528 gallons per day — about 0.0008 cfs. During periods of no precipitation, efforts have been made to measure these discharges by current meter. Flow has normally been too low for accurate measurement, but total H Area non-storm discharges are estimated at less than 0.1 cfs. Therefore, other than during storms, H Area does not appear to contribute significantly to McQueen Branch flow.

Based on information provided by Mike Lewis, SRP (oral communication, 1983), the total area of H Area that may contribute storm water runoff to the basin was estimated. Assuming that all surfaces are impervious, storm water runoff is contributed by an area of about 4.5×10^6 square feet. Presumably, not all surfaces are impervious; a rough estimate is 50 percent. The assumed impervious area would represent an increase of about three percent to the McQueen Branch basin area when precipitation, runoff and evapotranspiration are considered.

Current meter measurements of stream discharge were made in McQueen Branch periodically between July, 1982 and April, 1984. Due to difficulties with access to the stream, routine measurements have only been made from the point indicated on Figure 4.7 by the designation "Weir". This designation refers to the weir installation constructed in March 1983. The weir operated, along with a continuous water level recorder until April, 1984, at which time the installation was destroyed by a large falling tree.

The weir was installed on March 5, 1983, with the assistance of C. E. Murphy, D. W. Hayes, and C. D. Outz, all of SRL. The installation consisted of a rectangular weir with end contractions and a crest length of 9.6 ft. The long crest length was required because storm flows in the stream were expected to exceed 75 cfs. A rating curve was developed for the weir using the appropriate weir equation and current meter measurements. McQueen Branch basin area above the weir to 3.47 square miles.

4.4.5.2 McQueen Branch Baseflow

Figure 4.12 is a hydrograph for weekly baseflow at the weir installation on McQueen Branch. No surface runoff is included. The weekly values are provided in Appendix H. Intermittent measurements are available prior to March 5, 1983; continuous measurements are available thereafter.

Baseflow for the period November 1, 1982 to May 19, 1984 totaled 17.57 inches. For the subperiod March 1, 1983 to March 31, 1984, baseflow totaled 11.87 inches.

Two sets of data are shown. Those points designated "high flow" correspond to the higher stage occurring every day before ground-water evapotranspiration is significant; this higher stage generally occurs around 8:00 or 9:00 a.m. during the summer. The "low flow" points occur about 6:00 or 7:00 p.m. during the summer. The effect subsides during the fall, disappears in the winter, and gradually returns during the spring.

The value of estimating the baseflow is that it represents discharge from the ground-water system due to long-term precipitation effects that produce variations in recharge to the water table. Thus, one might expect periods of higher precipitation to produce more ground-water recharge and thus, higher stands of the water table. These higher water tables should be accompanied by higher baseflows. At least as a first approximation for a given set of ground-water levels, the observed baseflow should represent the quantity of recharge required to maintain the water levels at their given values assuming no ground-water evapotranspiration or underflow.

Hydrologic budgets have been determined for many basins and are reported in the literature. Schicht and Walton (1961) report on hydrologic budgets for three small watersheds in Illinois. They provided rating curves of mean ground-water stage versus ground-water runoff in each basin. As expected, the higher the mean ground-water stage the higher the baseflow component of total streamflow. An added feature of such rating curves is that seasonal separation of the curves provides an estimate of ground-water evapotranspiration which intercepts some ground water before it can contribute to baseflow or be discharged across a gauging station.

The baseflow hydrograph should be compared to the hydrograph of Well SDS-17 in Figure 4.11(a-b). It is apparent that the well hydrograph and the baseflow hydrograph are varying approximately inversely with respect to one another; in fact, the correlation coefficient between SDS-17 and the low flow plot is $r = -0.51$. A theory to explain this relationship is discussed below.

Prior to the discussion of this inversion, the actual stage vs. discharge values are presented. The data were organized into a table in which all baseflow values associated with a particular ground-water stage, and the month and date of the measurement, are listed. (Because of the limited usefulness of these data, only the SDS 17 water level elevations are used, rather than a mean ground-water stage.) The data are plotted in Figure 4.13.

The inverse nature of the relationship is apparent: higher baseflow is associated with lower water table elevation. Baseflow values for June through October are the lowest, with those from November through February being intermediate, and those from March through May being the highest. This figure will be discussed further below.

It appears that the lowest baseflow occurs in the summer, as expected, with higher baseflows occurring in March and April. High evapotranspiration (both from the ground water and from the stream itself) during the summer could be causing low baseflow despite the higher ground-water stage measured during the summer. As evapotranspiration declines through the winter the baseflow recovers. Therefore, the actual baseflow with little or no evapotranspiration operating, to correspond to the high water table stage observed in SDS 17 during Summer 1983, would be an extrapolation of the early 1983 data forward and the early 1984 data backward to a baseflow value on the order of six cfs or more. Compared to the baseflow observed during Summer 1983 of about two cfs, then, over four cfs of water were being removed by evapotranspiration during the height of summer.

A value of four cfs would represent the volume of water presumably being removed by vegetation in the floodplain of the Branch, as the water table is too deep elsewhere for root penetration. How much of the floodplain is experiencing ground-water evapotranspiration is uncertain but an area of 100 acres was estimated based on the distribution of the floodplain on topographic maps and from aerial photographs. Four cfs then would be an evapotranspiration rate of about 0.04 inches per hour (4.0 cfs x 3600 secs/hr x 12 in/ft ÷ (100 acres x 43560 ft^2/acre)). This rate, of course, is not maintained for 24 hours per day. If it is maintained for only six hours then the evapotranspiration rate is 0.24 inches per day during the height of the summer. Hubbard (1984) suggested reasonable values to be 0.15 to 0.25 inches per day. A Penman-Monteith evapotranspiration analysis made as part of this study (and discussed below) indicated a value of about 0.24 inches per day. Therefore, the rate needed to maintain the observed low baseflow during the summer is realistic when the area of the floodplain is considered.

Therefore, the explanation of the inversion of the ground-water stage-baseflow relationship involves a seasonal time lag coupled with a strong ground-water evapotranspiration effect. The time lag component involves a delay in the water table response to spring recharge events of two to three months. Thus, the water table is seen to rise in all wells in the basin during the spring but does not peak until early to mid-summer. Concurrently with the water table rise, ground-water evapotranspiration from the densely-vegetated, primarily deciduous floodplain intercepts and removes much of the ground water moving toward and down the Branch. A low summer baseflow associated with a high water table stand results.

The following scenario then would explain the baseflow vs. water level relationship in Figure 4.13. During the summer the time lag associated with spring recharge events has caused the ground-water stage to rise and peak. However, high rates of ground-water evapotranspiration cause baseflow to be very low. (Extending this idea, if the ground-water stage during the summer was lower than that observed, the baseflow would have been even less.) Through the late summer and fall the water table slowly declines, presumably causing less baseflow. However, the ground-water evapotranspiration probably declines more rapidly, so that there is a net increase in baseflow. In the spring, water levels start to rise again due to recharge but so does ground-water evapotranspiration. Thus, even as water levels increase, baseflow declines. The arrows indicate the general direction of the trend.

4.4.5.3 Surface Runoff into McQueen Branch

Continuous water level records from the weir pool on McQueen Branch indicated that a number of storm events put significant volumes of water into the Branch. The hydrograph expression of these storm events is a sudden rapid rise to a sharp peak, followed by a sharp decay of most of the water level rise, and terminated by a slower decay of the remaining rise. The sharp water level rise generally takes one to three hours to peak; the sharp decline takes only slightly longer. Usually, the impact of even large storms is gone within two to three days.

A continuous recording precipitation gauge was operating in the McQueen Branch basin between late December 1982 and early April 1983. The weir was operating during the latter third of this period. Rainfall intensities varied between 0.05 to 0.35 inches per hour and averaged about 0.10 inches per hour. Even the smallest measurable rain recorded in the gauge (on the order of 0.05 inches) caused a stage change at the weir. The time lag between the beginning of rainfall events and their manifestation at the weir was commonly less than two hours.

The weir pool records obtained from the continuous recorder were reviewed to estimate storm runoff. Forty-eight separate storm events were identified. Due to a lack of completely continuous record, it is known that a few storm events were missed. Also, at least three events were of such large magnitude that their expression on the chart cannot be defined.

The resolution of the storm hydrographs is necessarily coarse, due to the time scale on the charts (32 days). Therefore, it is difficult to obtain short interval estimates of stage. However, an effort was still made to obtain approximate values. Each storm event was numbered and the time at which it began was noted. Values of stage were then obtained at several points of time as stage vs. time in hours from the beginning of the event. Only values of stage where a significant change in hydrograph slope occurred were taken. These time-stage data were entered into the computer and run through a program to calculate discharge using the appropriate weir equation. The computer program produced a time-discharge plot that was then planimetered to determine the total volume of water discharged over the weir during the storm event.

In a few cases, the stream discharge exceeded the 30 cfs believed to be the limit of the accuracy of the weir. Because no below-weir stage measurements were made, no correction can be applied to those data exceeding the limit. Therefore, some error is imposed in the resulting calculations.

Runoff discharges were totaled by week to correspond to the available baseflow and precipitation measurements. An assumption was then made that the runoff came evenly off of the entire basin and a runoff in inches per week was calculated. Also, the percentage of total precipitation that went to surface runoff was calculated. Figure 4.14 shows a plot of runoff vs. time and Figure 4.15 shows percentage of precipitation that is runoff vs. time.

Runoff from the surface between November 1, 1982 and May 19, 1984 averaged about 6.5 percent of precipitation (about 5.3 inches). Figure 4.14 suggests a crude seasonality to runoff variation with time, with the lowest during the summer and higher values during winter and spring. The results are inconsistent, though, due to the variability of ambient soil moisture conditions and rainfall intensity.

The possibility exists that some significant portion of the observed runoff came from H Area. No measurements were made under the appropriate conditions. However, some approximate calculations can be made.

Assuming that the total impervious area in H Area contributing to the observed runoff is 2.3×10^6 square ft., this area would contribute a volume of 1.6×10^7 cubic ft. of rainfall during the study period, given that total precipitation was 81.69 inches. Total runoff volume determined from the hydrographs was 4.3×10^7 cubic ft. It was then assumed that all runoff from the impervious area entered McQueen Branch. Thus, 37% of the observed runoff would have been contributed by H Area and only 2.7×10^7 cubic ft. actually ran off of the basin. This latter volume translates to 3.35 inches or only about four percent of total precipitation.

It can be estimated, then, that H Area has had some impact on the overall budget of the study area in terms of volumes of water (i.e., it contributes about 37% of storm runoff). Rapid movement of water as runoff into the Branch from H Area may also contribute to the rapid response of the stream to storm flow.

Total runoff for the period November 1, 1982 to May 19, 1984 equalled 5.29 inches or about 6.5% of precipitation; accounting for H Area runoff a more realistic number for surface runoff might be 3.35 inches (4.1%). For the subperiod March 1, 1983 to March 31, 1984 (i.e., 13 months), the corresponding values for runoff are 3.60 inches (6.9% of precipitation) and 2.27 inches (4.3% of precipitation). For a year of average precipitation (about 47.78 inches) the runoff values are 3.24 inches including H Area and 2.05 inches excluding H Area.

Hubbard (1984) subjectively estimated a surface runoff value of two inches for an average year of 47 inches of rainfall. These results support that estimate. As with most components, of course, surface runoff is quite variable, being a function of surface cover, topographic slope, and ambient soil moisture conditions.

4.4.6 Evapotranspiration

The significant influence of evapotranspiration on baseflow in McQueen Branch has been discussed in connection with the ground-water stage—baseflow inversion. C. E. Murphy, SRL (1984, oral communication) suggested that evapotranspiration accounts for 62-66% of precipitation, based on field measurements. Hubbard (1984) estimated from field measurements and the Thornthwaite method that evapotranspiration removes about 64% of precipitation falling on the low-level waste burial grounds. Thus, it is an important factor to consider in the hydrologic budget.

Evapotranspiration was estimated using the Penman-Monteith evaporation method (Monteith, 1965). The method requires information on characteristics of the local weather and vegetation. These characteristics include incoming solar radiation, vapor density of the air, and the resistance of the air and vegetation to heat and water transport. The result of applying the method is a value for the rate of transport of water from the surface by evaporation and by transpiration. In this case the value is the potential evapotranspiration rate, which assumes that sufficient water is available to be moved into the air at that rate.

Daily evapotranspiration rates for each vegetation type were calculated and converted to weekly values. All weekly values are provided in Appendix I.

A vegetative cover map was made of the basin. Development of the map depended on topographic maps, high-level aerial photographs, and low-level aerial photographs taken during an overflight of the basin in December, 1983.

The map was then planimetered to determine the relative percent of the different vegetative types. The resulting values were:

evergreen forest	67%
deciduous forest	18%
grass and unvegetated	15%

It is noteworthy that deciduous trees are almost entirely restricted to stream floodplains and slopes to the uplands. This is presumably due to the concentration of pine plantations in the more easily farmed uplands.

A weighted average evapotranspiration was calculated. The weekly results are listed in Appendix I and are plotted in Figure 4.16. These values are assumed to better represent the true potential evapotranspiration than that of any specific vegetation type.

The shallow water table associated with the McQueen Branch floodplain (and for other study area floodplains, for that matter) presumably allows actual evapotranspiration to approximately equal potential evapotranspiration in these areas. However, most of the study area is upland recharge area with water table levels well below the root zone. Therefore, actual evapotranspiration for most of the study area cannot be calculated exactly. The assumption can be made that actual evapotranspiration equals potential evapotranspiration when sufficient precipitation has occurred. However, when little or no precipitation has occurred, actual evapotranspiration may include reduction of soil moisture along with removing available precipitation. Thus, soil-moisture budget techniques must be applied.

Routinely measuring soil-moisture conditions in the basin was beyond the scope of this study. Some measurements were made at the beginning and ending of the budget period — these will be discussed later.

Potential evapotranspiration for the period November 1, 1982 to May 19, 1984 was calculated to total 52.81 inches. For the subperiod March 1, 1983 to March 31, 1984 potential evapotranspiration was calculated to total 43.03 inches.

4.4.7 Soil Moisture Measurements

Water entering the ground at the surface must pass through the unsaturated zone before reaching the water table. This zone has a storage capacity, and this capacity must be filled before recharge occurs at the water table. Therefore, one component of the hydrologic budget is the amount of water entering the ground that goes into soil moisture storage.

An attempt was made to estimate the amount of water entering storage by making soil moisture measurements in the basin at two different times: November 3, 1982, and May 15, 1984. The measurements were made at the four locations shown in Figure 4.7 using a neutron probe lowered into aluminum access tubes. For both dates, the moisture content of the soil in percent was determined. The moisture content represents the percentage of a volume of soil that contains water; if the volume of soil is fully saturated, then the moisture content represents the total porosity. The plot of moisture content versus depth for each date of each site is shown in Figure 4.17(a-d). (Site SM2 was removed by construction work prior to May, 1984, measurement).

It appears from Figure 4.17(a-d) that the moisture contents at three sites are very high. For example, for depths greater than about 80 inches, the moisture contents routinely exceed 50%, and at a depth of 60 inches at site SM1 in May, 1984, the moisture content approached 80%. These very high values raise doubts about the validity of using the soil moisture measurements for estimating this component of the hydrologic budget. Therefore, soil moisture change was assumed to be negligible for all further analysis.

4.4.8 Underflow

The potential exists for water to be lost beneath the stream gauge by underflow. Such water is lost from the budget because there is no way to adequately measure it unless a detailed drilling and testing program is carried out in the vicinity of the stream gauging station. The amount of underflow is estimated using Darcy's Law.

The following values were used for the parameters of Darcy's Law:

Thickness of material beneath gauge (down to Green Clay) = 45 ft.
Hydraulic conductivity = 3 fpd
Width of flow zone = 800 ft.
Hydraulic gradient = 10/800

Therefore Q = kiA = (3 fpd) x (10/800) x (45 feet x 800 feet)

= 1350 cfd
= 0.016 cfs

This represents an essentially negligible volume when compared to baseflow in McQueen Branch. Therefore, underflow through the McBean Formation past the gauge is not considered further.

Leakage of water through the Green Clay underlying the basin into the Congaree Formation is possibly a greater sink for the hydrologic budget. Some calculations were made to estimate its significance.

The total area of the basin upstream from the weir is 3.47 square miles or 9.7×10^7 square feet. Assuming that the thickness of the Green Clay averages seven feet then the head gradient across the Clay is on the order of $40/7 = 5.7$ ft./ft.

No accurate measure of the vertical hydraulic conductivity of the Green Clay is available. The arithmetic mean of vertical hydraulic conductivities of 19 clay samples similar to the Green Clay given by Morris and Johnson (1967, p. 21) is 2.7×10^{-4} fpd.

Again, using Darcy's Law a specific discharge of 1.5×10^5 cfd was calculated. This represents 6.7 inches of water per year. For the period November 1, 1982 to May 19, 1984, the total leakage would have been 10.4 inches while for the subperiod March 1, 1983 to March 31, 1984, the total would have been 7.3 inches.

Such a calculation has numerous uncertainties associated with it. The Green Clay is relatively continuous over the study area but probably has some discontinuities that would allow greater leakage. Certainly the thickness and head difference across it vary in space. Finally, the vertical conductivity of the Green Clay is only assumed from the literature. Therefore, it is difficult to evaluate how reliable such leakage rates are. This component of underflow will be discussed further later.

4.4.9 Ground-Water Storage

A change in water table elevation represents a change in the amount of ground-water storage. The volume of water associated with the storage change is determined by multiplying the change in water table elevation by the specific yield. The water level is easily determined by observation wells. The specific yield is more difficult to evaluate.

An attempt was made to define a gravity yield using the period of water table rise between late December 1982 and late June 1983. Figure 4.18 is a plot of average water table elevation change showing this rise of 3.96 ft.

The equation to be used is:

$$Y_g = \frac{P - RO - ET - U}{dH} \qquad (4.4)$$

where P = precipitation
RO = surface runoff and baseflow
ET = evapotranspiration
U = underflow (assumed negligible)
dH = change in water table elevation

A lag of two months between recharge event at the surface and water table response was assumed. The following values of the parameters were obtained for the period late October 1982 to late April 1983.

P = 27.68 inches
RO = 1.63 inches (surface runoff) and 6.47 inches (baseflow)
ET = 8.83 inches

Substituting these values into Equation 4.4 gives:

$$Y_g = \frac{27.68 \text{ in.} - 8.10 \text{ in.} - 8.83 \text{ in.}}{3.96 \text{ ft.} \times 12 \text{ in./ft.}}$$

$$Y_g = 0.23$$

A gravity yield of 23% is high relative to the 11% determined by Rasmussen and Andreasen (1959) for a Coastal Plain setting in Maryland; 23% may more closely represent the actual specific yield. (Note that the gravity yield is the volume percent of water associated with a rise or fall of the water table over a certain period of time, while the specific yield is the volume percent for infinite time. Therefore, the gravity yield converges on the specific yield with increasing time.)

The period from June 25, 1983 to March 26, 1984, saw a continuous decline of the water table in the basin, as shown in Figure 4.18. Total average decline was 2.57 ft. Although precipitation occurred during this period, the high evapotranspiration through September 1983 probably limited recharge. Therefore, it may be assumed that the water-table change observed was due entirely to drainage.

The volume of water being removed from the ground-water system during this time of water table decline was determined. This included baseflow over the weir and ground-water evapotranspiration. The components to the drainage were determined on an incremental and a cumulative basis and several values of gravity yield were calculated; these are shown in Table 4.14.

Water table elevations are available at several time points during the drainage period so an incremental calculation was made for each. The total inches of baseflow and of evapotranspiration were determined. From these the total volume of water removed was calculated, using the area of the basin and the area of the active flood plain, respectively. Underflow was assumed to be negligible. A cumulative calculation was made for each increment in order to integrate the components over an increasingly longer period of time.

It is obvious that there is no consistency to the results; in fact, one value of gravity yield was over 100%. This inconsistency may arise due to the need to use such small head changes; if these changes are in error by only a few tenths of a foot the resulting gravity yield varies greatly.

It is reasonable that the specific yield should be generally approximated by the effective porosity, as both represent conditions of open, transmissive porous material. A number of effective porosity measurements have been made on material from the overall study area and these are briefly reviewed.

D'Appolonia (1981b, 1982) determined effective gravity porosity and effective porosity at five psi pressure for 24 undisturbed samples, 22 of which were from McQueen Branch basin. No indication is given in the reports on how long drainage occurred under either gravity or pressurized conditions. Values for effective gravity porosity ranged from 0.1% to 11.3% and averaged around 2.6%. These are very low values for these types of materials, suggesting relatively high clay or silt contents and/or short drainage times. The effective porosity at five psi pressure was somewhat higher, ranging from 1.9% to 28.1% and averaging about 12%. Materials covered the full range from medium sand to clayey and silty fine sand.

Effective porosity measurements have been made on eight undisturbed samples from the central and western portions of the study area. The values ranged from 14% to 39% and averaged about 24%. These data were derived from the total porosity and a soil moisture retention curve developed for each sample. Therefore, they are probably more representative of real field conditions.

A brief review of available literature was made to better define specific yield values from similar materials elsewhere. Rasmussen and Andreasen (1959) used a value of 11% for gravity yield but this was applied to weekly water table changes, not four weeks or more as observed in this study area. A value of 25% was estimated for the medium sands of their Coastal Plain site. Johnson (1967) compiled a sizeable file of specific yields for various material that showed a very wide range in values. For silty and clayey sands, he reported values ranging from 4% to 30%; the average was around 15-20%.

It is concluded, then, that specific yield is characterized by great variability. Based on the budget study results, effective porosity measurements, and literature review, a value of 22% is defined for the purpose of this study. This value will be used in ground-water storage calculations under the assumption that drainage or resaturation is relatively rapid. Considering the small changes in storage observed during the study, the overall budget will not be particularly sensitive to this parameter.

4.4.10 Hydrologic Budget

At this point, all components of the hydrologic budget have been considered. These include precipitation, stream baseflow, surface runoff, soil moisture change, ground-water storage change, evapotranspiration, and underflow. Theoretically, the components should balance.

The original budget period was defined as early November, 1982 through mid-May, 1984. The soil moisture measurements discussed in Subsection 4.4.7 were made at these times so that its change could be defined; the conclusion was that no change would be assumed. Weekly values for most parameters were determined so that subperiods could be specified. Table 4.15 lists weekly values in inches for the components precipitation, calculated potential evapotranspiration, stream baseflow, and surface runoff. A weekly or monthly balanced budget was not possible because soil moisture measurements were not made at such frequent intervals.

Table 4.16 summarizes the total values of the components for the period November 1, 1982 to May 19, 1984. Underflow was initially considered negligible. Ground-water storage change was calculated by multiplying the average water table elevation change during the period (1.90 ft.) by the specific yield (22%).

The hydrologic budget shown in Table 4.16 is nearly balanced, suggesting that most components of the budget have been accounted for. About 1.3% is not accounted for. This percentage translates to about one inch of unaccounted precipitation and may represent underflow from the system, particularly across the Green Clay.

In order to reduce some of the uncertainties associated with certain parameters, a subperiod was defined for an additional budget calculation. This subperiod runs from March 1, 1983 (when the weir was installed), through March 31, 1984 (when the weir was removed). This provides better control on baseflow and storm runoff estimates. In addition, it makes more feasible the assumption that soil moisture has not changed, since the soils were probably at field capacity at both the beginning and end of the period.

Table 4.17 lists the values for the various budget components for this period. Total average water table elevation change was 1.32 ft. Total precipitation was significantly less than for the longer period given in Table 4.16 (i.e., 52.48 versus 81.69 inches); the winter precipitation of late 1982 and early 1983 and the heavy spring precipitation of April, 1984, are not included. On the other hand, the periods November 1, 1982, to March 1, 1983, and from March 31, 1984 to May 19, 1984, are not characterized by high evapotranspiration. As a result, the evapotranspiration listed in Table 4.17 is not greatly different from that shown in Table 4.16 (i.e., 43.03 versus 52.81 inches).

Therefore, as shown in Table 4.17, evapotranspiration computed by the Penman-Monteith method represents 82% of precipitation for the period. Such a high value is unlikely.

Assuming that soil moisture storage change and underflow are negligible, evapotranspiration was solved for, using the measured values of the remaining components; a value of 63.9% was calculated. This value is well within the range described by other workers.

Total surface runoff was calculated at about seven percent of total precipitation. There is some uncertainty as to how much of this is from H Area. However, some estimates made accounting for this possibility reduced actual basin runoff to about four percent of precipitation.

Because of the apparent influence of ground-water evapotranspiration from the McQueen Branch floodplain on the flow in the Branch, the baseflow value does not represent true recharge to the water table. The total baseflow plus ground-water storage gives at least an approximation: in this case, recharge would be about 30% of total precipitation. The calculation of recharge will be considered in the next section.

The fact that the budget balances reasonably well suggests that underflow may not be a significant component of the budget. Of particular interest would be leakage downward through the Green Clay. Although there is presumably some error in all of the measured components, total leakage downward is probably no more than a few percent of total precipitation, as shown in Table 4.16.

An extensive field and laboratory effort would be required to fully evaluate the magnitude of leakage through the Green Clay. This would involve piezometer construction above, below, and within the Clay and performance of pumping and laboratory tests for hydraulic conductivity measurments. A fully screened well would be required below the clay for pumping purposes in order to impose sufficient drawdown to evaluate the leakage; pumping tests performed in short-screen piezometers in the past have proven inadequate.

Alternatively, it is anticipated that the numerical model will provide an estimate of this leakage. A properly calibrated model will indicate where all water entering the system leaves the system. Ground-water recharge that cannot be accounted for as exiting by those sinks for which measurements are available (namely, stream baseflow) is presumably leakage through clay layers or underflow beneath Upper Three Runs Creek or Four Mile Creek.

4.5 GROUND-WATER RECHARGE

4.5.1 Introduction

The primary reason for developing the hydrologic budget of McQueen Branch basin was to generate estimates of recharge to the water table. This parameter is a major source term for the numerical model and the system response is sensitive to its variations. Thus, a representative value was sought.

Recharge to the water table is a function of many factors. These factors include the duration and intensity of precipitation, land use characteristics, vegetation types and densities, topographic slope, evapotranspiration, and soil characteristics. These factors may interact in a complex fashion. Seasonal fluctuations in precipitation and evapotranspiration further complicate the picture.

The first approach used to quantify recharge is to develop a ground-water budget which integrates time and physical characteristics of the system. The resulting value for recharge may be viewed as an average, unless conditions during the budget period were greatly different from normal (e.g., unusually high or low precipitation). This approach is discussed below.

4.5.2 Ground-Water Budget

A ground water budget can be developed using the values of the various parameters developed so far in the overall basin hydrologic budget. The relevant equation is:

$$GR = BF + ET + U + dGW \qquad (4.5)$$

where GR = ground-water recharge
BF = baseflow
ET = evapotranspiration (ground water)
U = underflow (assumed negligible)
dGW = change in ground-water storage

GR is the total volume of water reaching the water table and causing a change in its distribution.

The parameters of the equation must be converted to volumes because ground-water evapotranspiration in this case is not operating over the entire basin. The potential evapotranspiration value is used because of the shallowness of the water table in the floodplain. The period March 1, 1983 through March 31, 1984 is used because the budget parameters are better defined.

From Table 4.17, a value for baseflow of 11.87 inches was obtained. The area of the basin upstream from the weir is 9.7×10^7 square ft. The total volume of baseflow during the period, then, was 9.6×10^7 cubic ft.

Actual evapotranspiration from the floodplain was estimated as 33.53 inches (Table 4.17) and the floodplain area was estimated at 100 acres. Thus, 1.2×10^7 cubic ft. of evapotranspiration came from the floodplain (and essentially zero from everywhere else because of the depth of the water table).

Total average water table elevation change during the period was 1.32 ft. When multiplied by the specific yield (0.22) and by the area of the basin, it was calculated that 2.8×10^7 cubic ft. of water went into ground-water storage.

The underflow beneath the weir was calculated earlier to be negligible. Leakage downward through the Green Clay is difficult to quantify by independent means. The fact that no water was unaccounted for in the budget defined in Table 4.17 suggests that the leakage may not be great. Therefore, for the present study, it was assumed to be negligible.

The components of baseflow, ground-water evapotranspiration, and change in ground-water storage sum to 1.36×10^8 cubic ft. of water entering the ground-water system during the budget period. Dividing this number by the area of the basin gives an average recharge value of 16.82 inches. The total precipitation was determined to be 51.40 inches, assuming a two-month lag before recharge reaches the water table. Thus, this recharge value represents 32.7% of total precipitation. For an average year of 47.78 inches of precipitation, average recharge may be 15.62 inches.

Hubbard (1984, p. 6) suggested that "in an average year about one-third of the rainfall recharges ground water". This conclusion was based on rough estimates of the components of the hydrologic budget. The result of this budget study supports that. Cahill (1982) also used a value of 15 inches per year for average recharge based on a hydrologic budget study.

Therefore, it is believed that 15 inches per year represents an average recharge value for the average rainfall year. This value would maintain water levels in the system at their mean levels. The value tells one nothing about seasonal variability -- this will be addressed later.

4.5.3 Instantaneous Discharge Measurements

A series of stream discharge measurements were made in McQueen Branch in February, 1983, to investigate variation in this parameter along the stream length. The location and value of each measurment are shown in Figure 4.19. Using a topographic map, the area of the drainage basin above each discharge measurement was planimetered for its area. The assumption was then made that for the time of year evapotranspiration was probably minimal and that for an instant of time change in ground-water storage could be neglected. Therefore, the observed discharge represented the instantaneous recharge over the portion of the basin upstream from the measurement point. Such a recharge, of course, would only be applicable to the current water table distribution. It is recognized that underflow probably increases at each upstream measuring point but there is too much uncertainty associated with calculating this parameter to justify doing so.

The observed discharge at each location is listed in Table 4.18, less 0.2 cfs observed to be entering the stream from H Area. Also provided are the area of the sub-basin and the calculated instantaneous recharge value.

Stations 11, 10, 9, 8, 5, 4, 1, and 13 are progressively more upstream along the mainstem of the stream. They have generally a trend toward increased recharge rate higher in the basin; this is probably a function of the lower discharge rates upstream and the increased inaccuracy in measuring them.

In general, then, the instantaneous recharge rate does not vary a great deal over the basin and averages about 16 inches per year. This is not greatly different from the 15 inches per year calculated by the ground-water budget integrated over 13 months. Note that the latter recharge estimate was based on discharge at the weir (Station 9) where the instantaneous recharge rates was calculated to be 16.1 inches/year. Again, this value is about one-third of average precipitation.

4.5.4 Recharge in June 1982

A major objective of the effort to evaluate ground-water recharge was to define the recharge conditions associated with the water table distribution in the overall study area in late June and early July, 1982. At that time, water levels were measured in 275 wells and water table and potentiometric maps were made. These head maps are input into the numerical model of the study area.

What is required is an estimate of what recharge rate is needed to maintain those observed head distributions at those steady-state levels. It was assumed that an estimation of the total amount of water leaving the study area would provide a good value of recharge.

Several streams bound the study area. Upper Three Runs creek on the north receives considerable leakage from the Congaree Formation; therefore, its baseflow does not relate directly to recharge in the study area. Four Mile Creek on the south receives much of its baseflow from the study area. However, part of this baseflow comes from seepage basins that receive plant discharges. Also, Four Mile Creek itself receives plant liquid discharges. Therefore, its baseflow is difficult to define. McQueen Branch is the only bounding stream receiving its baseflow solely from natural sources.

At the time of the collection of the well water levels the baseflow in McQueen Branch was about 2.10 cfs. At this time of year (June) the calculated potential evapotranspiration was about 1.6 inches per week. These two factors combined constitute the volume of water being removed from the system at the time of the observed water table distribution (neglecting underflow). These values translate to a recharge rate of 12 inches per year distributed uniformly over the basin. This lower value is consistent with the lower stand of the water table at this time (see

Figure 4.18). Therefore, based on the available information a recharge rate of 12 inches per year would maintain the water table at its observed elevation in late June -early July, 1982.

It is recognized that the true distribution of the water table is a result of a complex interaction of hydrogeological processes. Presumably, the lag time between surface recharge events and the associated water table response varies with depth to the ground water. The water table at a depth of 30 ft. is responding to a different recharge event than the water table at a depth of 100 ft. Also, the water table at any point is influenced by conditions up- and down-gradient, in addition to what influences it from above and below. For these reasons, it is difficult to define exactly what recharge value would be necessary to maintain the water table point at a particular elevation. The value of 12 inches per year is an integration of all of these effects.

4.5.5 Recharge Through the Tan Clay

Hubbard (1984) suggested a calculation that would indicate how much of the water recharged to the water table was discharged to streams above the Tan Clay and how much passed through into the McBean Formation. For the low-level waste burial ground, the split was determined to be one-third above the Tan Clay and two-thirds below. A similar calculation was attempted for McQueen Branch basin.

The instantaneous discharge values obtained in February, 1983, were used (Figure 4.19 and Table 4.18). Some error may be involved here because only one measurement was available; an average of several measurements would have been preferable. It was estimated that the Tan Clay outcrop occurs at about the location of Station 4, with a stream discharge of 2.2 cfs. Total drainage basin area above Station 11 is 4.12 square miles. The resulting areal discharge rate at Station 4 is, therefore, 0.53 cfs per square mile. This translates to a ground-water discharge above the Tan Clay of 7.2 inches per year. At Station 11 the total discharge rate is equivalent to 15.2 inches per year. Therefore, 47% of recharge is discharged above the Tan Clay and 53% leaks through the Tan Clay to be discharged from the McBean Formation.

From these results it is seen that the Tan Clay appears to have more impact on vertical flow in this area than in the vicinity of the burial grounds. Considering the discontinuous nature of the Tan Clay, it is not unreasonable that it might differ. It is also consistent with head difference data shown in Table 4.7. Head differences across the Tan Clay were obtained from several clusters of wells located in the overall study area. In Well Clusters BGC1, BGC2, BGC3, and M37 (all located near the burial grounds) the head differences ranged from three to five ft. Values from several BH borings (in S Area) ranged from one to six ft.; some of these values were measured within the Branch basin. However, head differences from HC well clusters (located in the upper portion of the basin) ranged from 4 to 23 ft. and averaged 13 ft. This suggests, then, that the Tan Clay in portions of the Branch basin significantly reduces leakage downward from the Barnwell into the McBean. This contributes to a higher baseflow above the Tan Clay in this area (47% of recharge) compared to the low-level waste burial grounds (33%). Again, the Tan Clay is seen to be a feature of quite variable hydrologic significance.

4.5.6 Seasonal Fluctuations in Recharge

As mentioned earlier, several temporal factors have an impact on recharge to the ground-water system. Most significant of these are precipitation and evapotranspiration. They have a direct bearing on the soil moisture content, which controls how much water is rejected by the land surface as runoff, how much is dedicated to satisfying soil moisture requirements, and how much is allowed to pass through the shallow soil and become ground-water recharge.

Figure 4.4 shows how precipitation has varied through time. There is no strong seasonality to these data, although the fall months normally have less rainfall than others. Therefore, the seasonality of water levels in wells must be due to the seasonality of parameters other than precipitation.

Two parameters with seasonal fluctuations are evapotranspiration and surface runoff. The seasonality of evapotranspiration in the McQueen Branch basin was demonstrated in Figure 4.16. The weaker seasonality of runoff was shown in Figure 4.14.

Temporal variation of recharge is difficult to define because of the uncertainty associated with quantifying the controlling parameters. Methods are available to estimate potential evapotranspiration based on such parameters as vegetation type and atmospheric heat load; these methods usually give different results because of different assumptions. Runoff may be estimated using stream flow data. The simplest assumption, then, is that recharge to the water table is equal to the total precipitation less runoff and evapotranspiration.

The missing component is how much infiltrating water is used to satisfy the soil moisture deficit. In order to evaluate this parameter, frequent measurements are required of soil moisture content. Such data were not available from the study area. Therefore, the simpler assumption was used to estimate recharge.

The hydrologic budget study in McQueen Branch basin suggested the following values for seasonal runoff:

Season	Percent of precipitation
Winter and spring	8
Summer	2
Fall	5

These values were used to reduce precipitation for this parameter.

Evapotranspiration was estimated using several approaches. The hydrologic budget study used the Penman-Monteith method (Monteith, 1965). Hubbard (1984) provided estimates of monthly or seasonal evapotranspiration rates obtained from several sources: the Thornthwaite method (1948), pan evaporation measurements, and water balance studies on research lysimeters. The rates obtained by each method are shown in Table 4.19. The Thornthwaite analysis and the pan measurements were based on averages over the period 1963 to 1982 and 1974 to 1978, respectively. Water balance studies were done over the period 1980 to 1982.

Values vary considerably between methods when considered on a monthly or seasonal basis. As expected, the rates are higher in summer and lower in winter. Deviations in estimates are presumably due to the different assumptions inherent in the approaches.

Total annual evapotranspiration does not vary much between the methods. The annual totals represent from 62% to 76% of total precipitation. Therefore, recharge estimates (before runoff) using these results suggest 24% to 38% of precipitation (on the order of 12 to 18 inches) enters the ground as recharge. These average annual values, however, are of little use in the present discussion.

Another approach used in estimating recharge on a monthly or seasonal basis was to employ a National Weather Service (NWS) hydrologic model. Such a model is used in flood forecasting. Precipitation was routed to various components of the hydrologic cycle, including evapotranspiration, surface runoff, and ground-water recharge. Evapotranspiration was calculated based on estimated potential evapotranspiration for the appropriate time of year. Soil moisture conditions were approximated by considering the amounts of precipitation and evapotranspiration. Precipitation in excess of that needed to satisfy soil moisture deficiency was routed to surface runoff and to ground-water recharge. Practical experience with the model led National Weather Service personnel to suggest that the recharge values calculated by the model were a reasonable approximation of the true value. The model was obtained by SRL from the National Weather Service in 1977.

The NWS hydrologic model was used to estimate recharge based on several assumptions. Potential evapotranspiration was specified on a daily basis at a value believed to be reasonable. Five percent of the study area was assumed to be impervious (e.g., buildings and parking lots). Forest, of which 90% was evergreen, was assumed to cover 50% of the study area. The model was run to cover the period 1977 through 1983 and the monthly recharge rates were calculated.

The results of all ground-water recharge calculations are given in Table 4.20. The recharge values obtained from the Penman-Monteith and Thornthwaite methods and from the pan evaporation and lysimeter measurements were averaged to obtain a mean for these four approaches. Results from the NWS model are also provided.

On the average the lysimeter measurements give the highest recharge values (mean equals 1.96 inches per month) and the NWS model gives the lowest (mean equals 0.78 inches per month). However, the relative values vary seasonally. The Thornthwaite method usually gives the highest values of recharge for winter and spring but are more nearly average during summer and fall. The four methods are highly correlated in their results, suggesting that they may only differ in the magnitude of their values.

Figure 4.20 shows a comparison between the average calculated ground-water recharge and the hydrograph of Well HC1E. There is a very close correspondence between recharge events and fluctuations of water levels in this well. Periods of little or no recharge are accompanied by declines in the water level for various periods of time. Therefore, the qualitative relationship between computed recharge and water-level fluctuations is documented. The difficulty resides in quantifying that relationship.

The ground-water recharge values calculated using the NWS model are generally the lowest of the values obtained using all the methods. One would like to assume that the NWS results are the more realistic, since this method accounts (although crudely) for the soil moisture deficiency. However, annual totals of recharge obtained from this method are always low (on the order of 10% to 20% of annual precipitation) when compared to the 30% to 35% estimated using the hydrologic budget. Thus, these values may not be completely representative.

REFERENCES

Bouwer, Herman, 1969, Planning and interpreting soil permeability measurements: Jour. Irr. and Drain. div., Am. Soc. Civ. Eng., pp. 391-402.

Cahill, J. M., 1982, Hydrology of the low-level radioactive solid-waste burial site and vicinity near Barnwell, South Carolina: U.S. Geol. Surv. Open File Rept. 82-863, 101 p.

Christensen, E. J. and D. E. Gordon, 1983, Technical Summary of Groundwater Quality Protection Program at Savannah River Plant: Sav. Riv. Lab. Rept. DPST-83-829, v. 1.

Cooper, H. H., Jr., J. D. Bredehoeft, and I. S. Papadopoulos, 1967, Response of a finite-diameter well to an instantaneous charge of water: Wat. Res. Res., v. 3, pp. 263-269.

D'Appolonia Consulting Engineers, Inc., 1981a, Report: Boring and instrument installation — DWPF Salt Disposal Site, Savannah River Plant, South Carolina, Project No. 80-582.

D'Appolonia Consulting Engineers, Inc., 1981b, Report: DWPF — Stage 1 investigation aquifer performance tests, 200-S Area, Savannah River Plant, South Carolina, Project No. 76-372.

Freeze, R. A. and J. A. Cherry, 1979, Groundwater: Prentice-Hall, Inc., Englewood, NJ, 604 p.

Healy, H. G., 1964, Two-variable linear correlation analyses of water-level fluctuations in artesian wells in Florida: U.S. Geol. Surv. Prof. Paper 501-D, pp. D199-D202.

Hubbard, J. E., 1984, Water budget for SRP burial ground area: Sav. Riv. Plant Rept. DPST-83-742, 23 p.

Hvorslev, M. J., 1951, Time lag and soil permeability in groundwater observations: U.S. Army Corps of Engin., Waterways Exper. Station Bull. 36, Vicksburg, Miss.

Johnson, A. I., 1967, Specific yield — Compilation of specific yields for various materials: U.S. Geol. Surv. Wat. Sup. Paper 1662-D, pp. D1-D80.

Langley, T. M. and W. L. Marter, 1973, The Savannah River Plant Site: U.S. AEC Rept. DP-1323, 175 p.

Marine, I. W. and K. R. Routt, 1975, A ground-water model of the Tuscaloosa aquifer at the Savannah River Plant: in U.S. ERDA Rept. DP-1374, pp. 14-1 to 14-10.

Monteith, J. L., 1965, Evaporation and environment: Symp. Soc. Exp. Biol., v. 19, pp. 205-234.

Morris, D. A. and Johnson, A. I., 1967, Summary of hydrologic and physical properties of rock and soil materials, as analyzed by the Hydrologic Laboratory of the U.S. Geological Survey, 1948-60: U.S. Geol. Surv. Water-Supply Paper 1839-D, 42 p.

Rasmussen, W. C. and G. E. Andreasen, 1959, Hydrologic budget of the Beaverdam Creek Basin, Maryland: U.S. Geol. Surv. Wat. Sup. Paper 1472, 106 p.

Root, R. W., Jr., 1977, Results of pumping tests in shallow sediments in the Separations Areas: in U.S. DOE Rept. DP-1455, pp. 55-57.

Root, R. W., Jr., 1979, Subsurface hydrology of Coastal Plain sediments in the SRP Separations Areas: in U.S. DOE Rept. DP-1526, pp. 207-212.

Root, R. W., Jr., 1983, Numerical modeling of ground-water flow at the Savannah River Plant: U.S. DOE Rept. DP-1638, 29 p.

Root, R. W., Jr. and I. W. Marine, 1977, A conceptual geohydrological model of the Separations Areas: in U.S. DOE Rept. DP-1455, pp. 63-68.

Root, R. W., Jr. and I. W. Marine, 1978, Water-level fluctuations in Coastal Plain sediments: in U.S. DOE Rept. DP-1489, pp. 65-68.

Schicht, R. J. and W. C. Walton, 1961, Hydrologic budgets for three small watersheds in Illinois: Ill. St. Wat. Surv. Rept. of Invest. 40, 40 p.

Shields, J. D., N. D. Woody, A. S. Dicks, G. J. Hollod, J. Schalles, and G. J. Leversee, 1980, Locations and areas of ponds and Carolina bays at the Savannah River Plant: U.S. DOE Rept. DP-1525, 19 p.

Siple, G. E., 1967, Geology and ground-water of the Savannah River Plant and vicinity, South Carolina: U.S. Geol. Surv. Wat. Sup. Paper 1941, 113 p.

Thornthwaite, C. W., 1948, An approach toward a rational classification of climate: Geog. Rev., v. 38, no. 55.

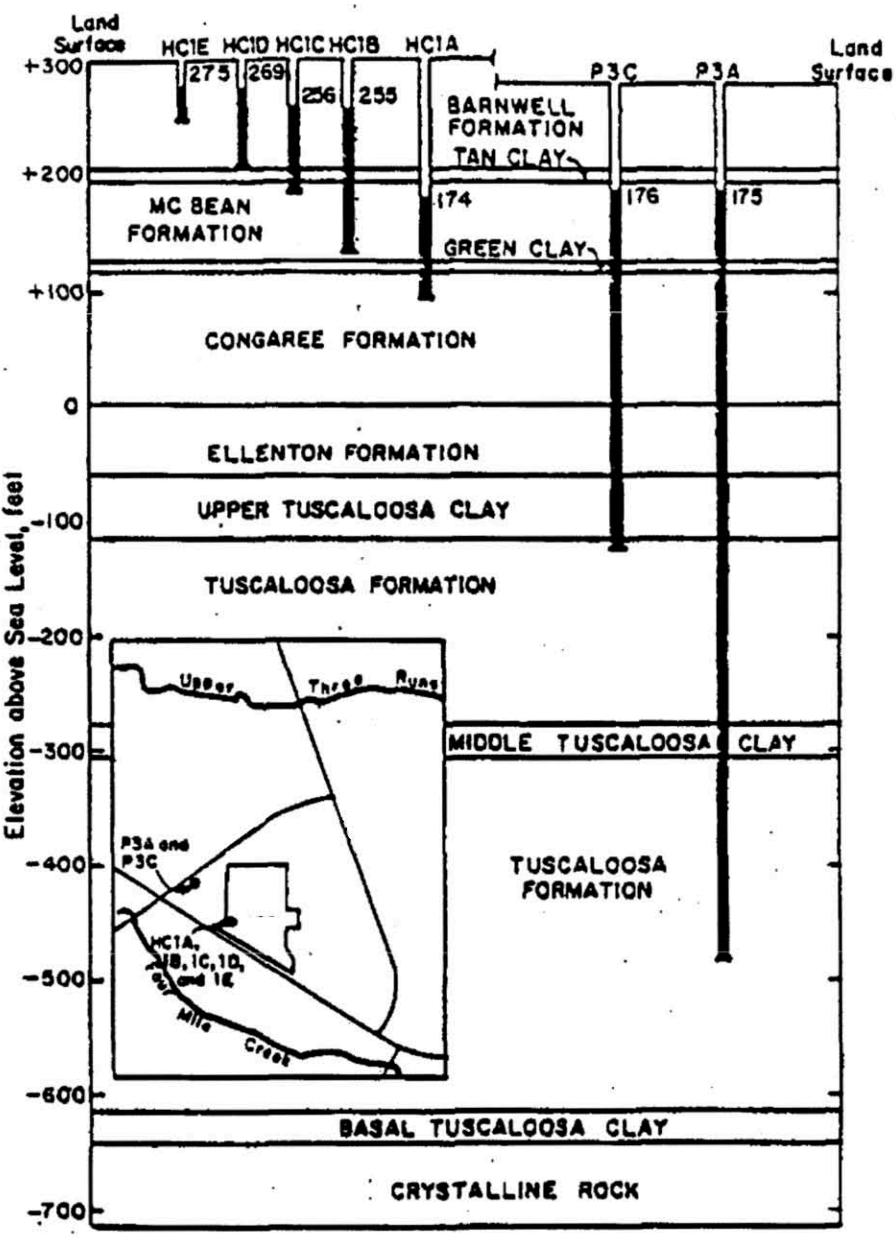


FIGURE 4.1 VERTICAL HEAD RELATIONSHIPS IN FORMATIONS UNDERLYING THE STUDY AREA. INSERT SHOWS THE LOCATIONS OF WELLS. HEAD MEASUREMENTS ARE FOR LATE JUNE, 1982.

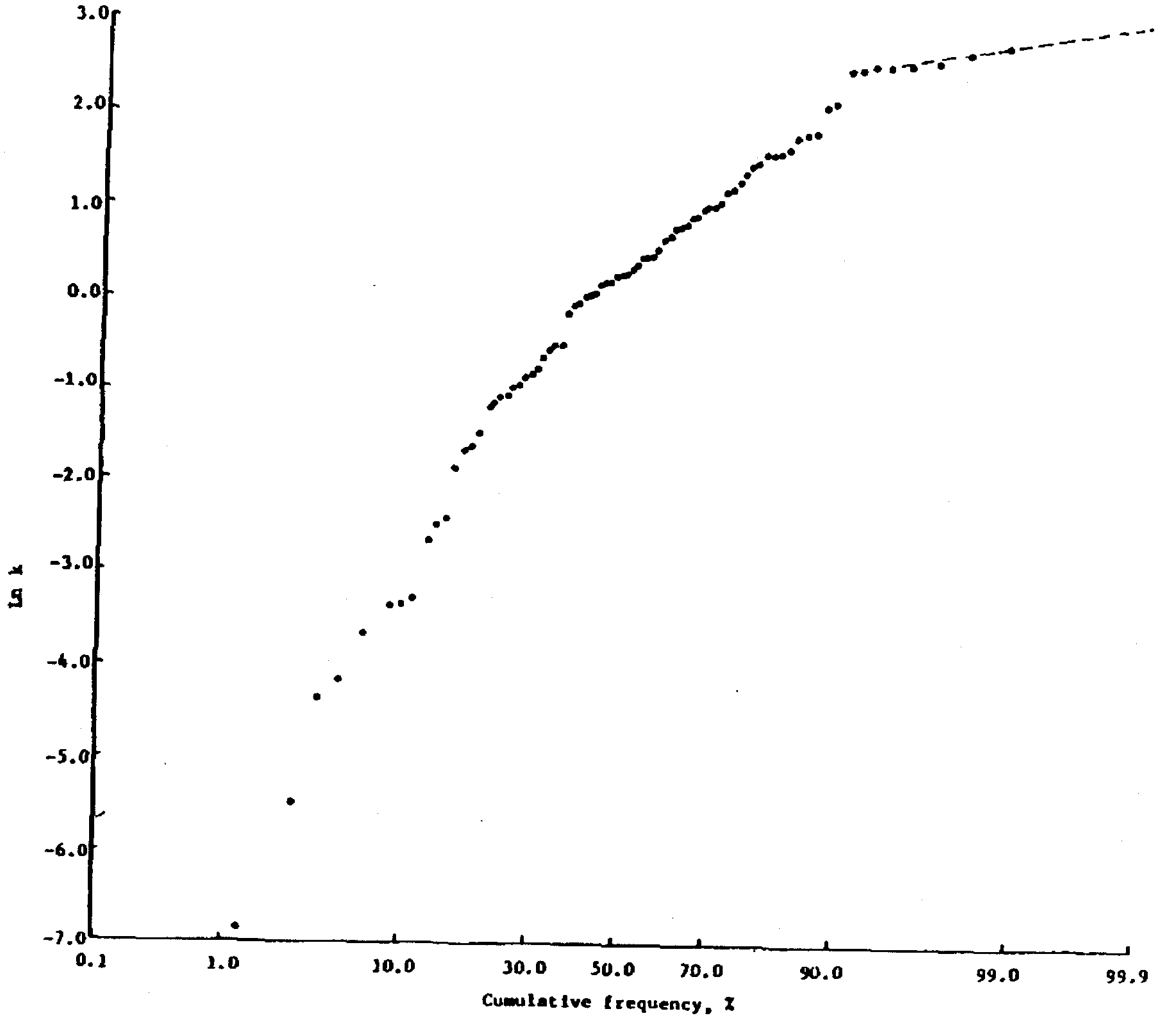


FIGURE 4.2. EXCEEDENCE PLOT OF HYDRAULIC CONDUCTIVITIES OBTAINED FROM SLUG TESTS.

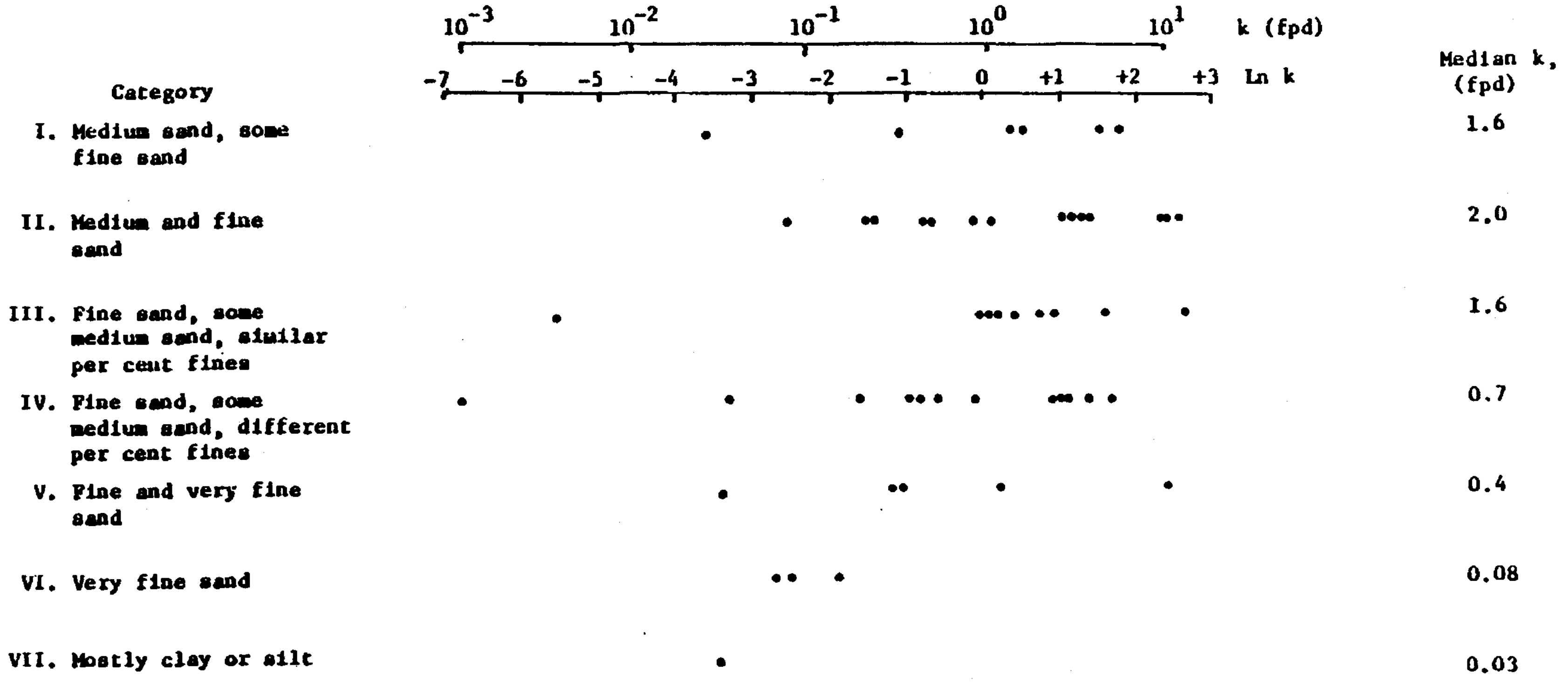


FIGURE 4.3. FIELD-MEASURED HYDRAULIC CONDUCTIVITIES FROM SRP, CATEGORIZED BY GRAIN-SIZE DISTRIBUTION.

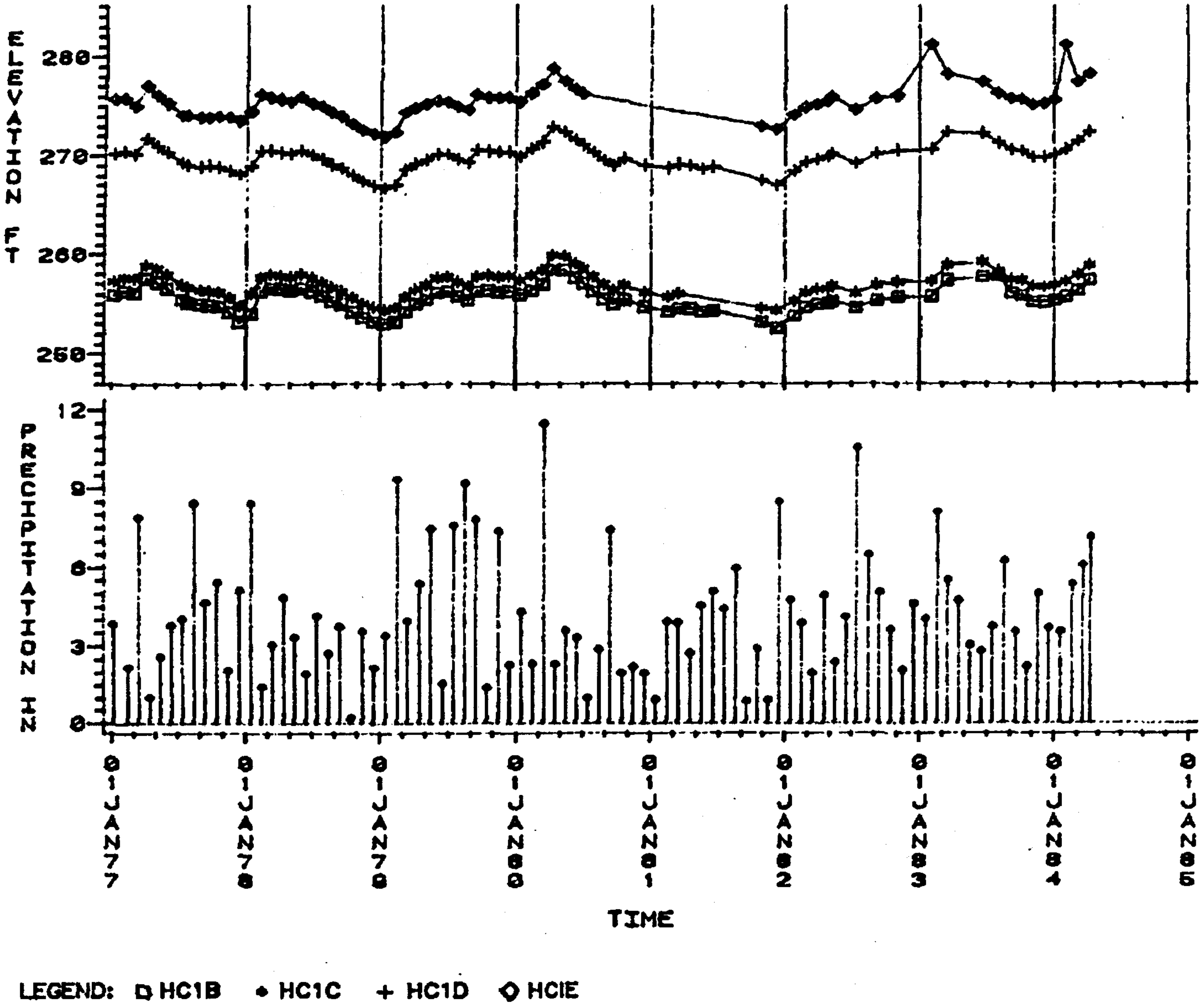


FIGURE 4.4. HYDROGRAPHS OF HC1B, HC1C, HC1D, AND HC1E VS TIME DISTRIBUTION OF PRECIPITATION.

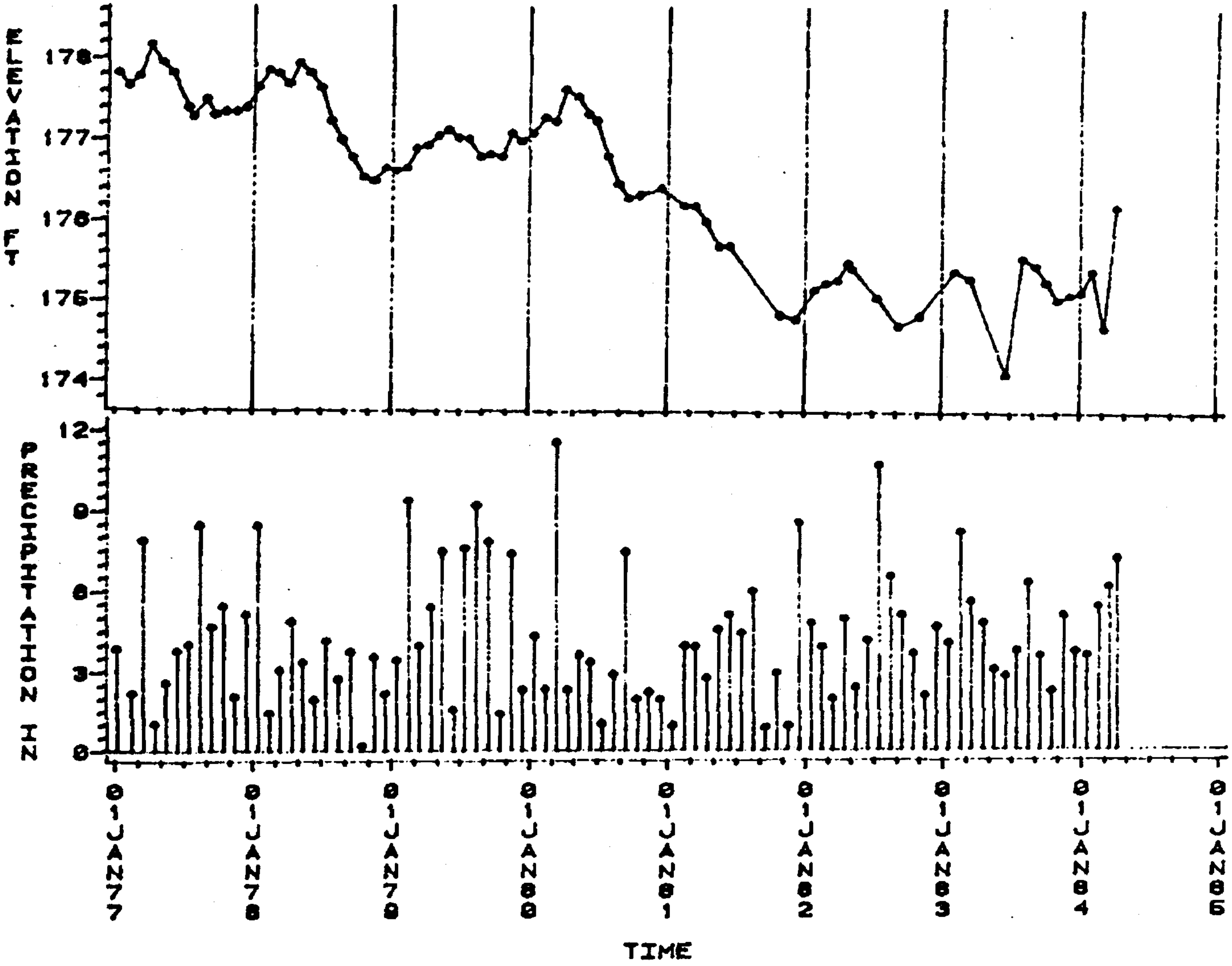


FIGURE 4.5. HYDROGRAPH OF HC1A AND TIME DISTRIBUTION OF PRECIPITATION.

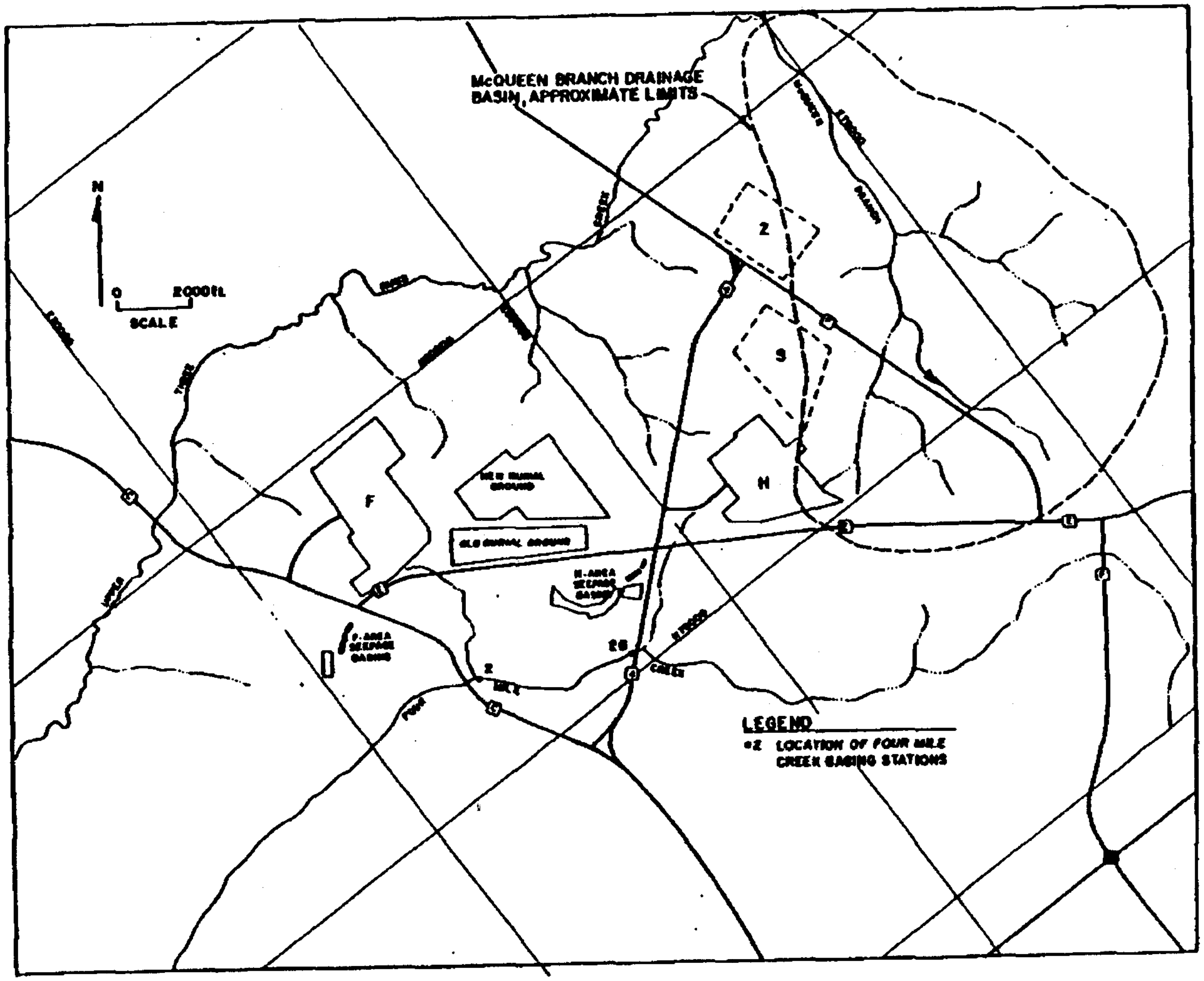


FIGURE 4.6. MAP OF THE STUDY AREA SHOWING THE LOCATION OF MCQUEEN BRANCH DRAINAGE BASIN.

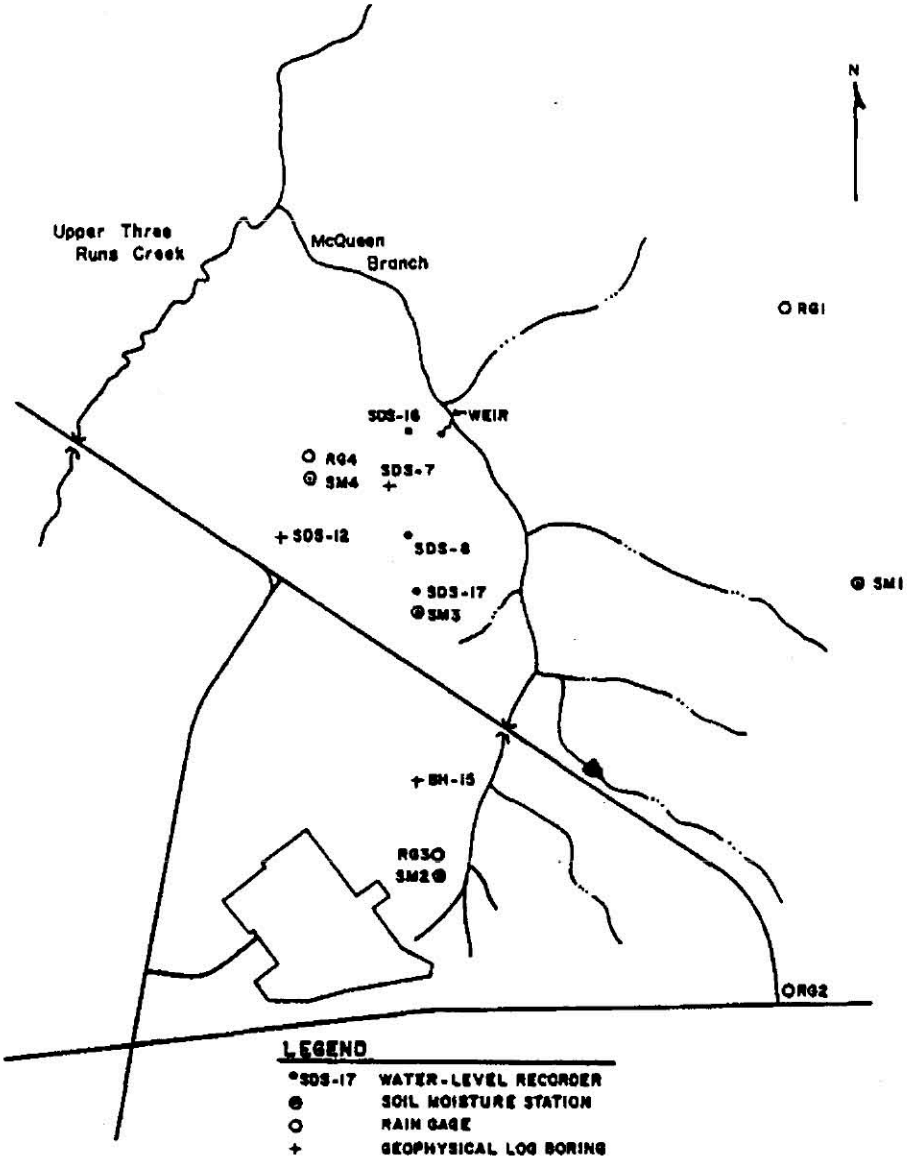


FIGURE 4.7. LOCATIONS OF MONITORING FACILITIES FOR THE MCQUEEN BRANCH BASIN HYDROLOGIC BUDGET STUDY.

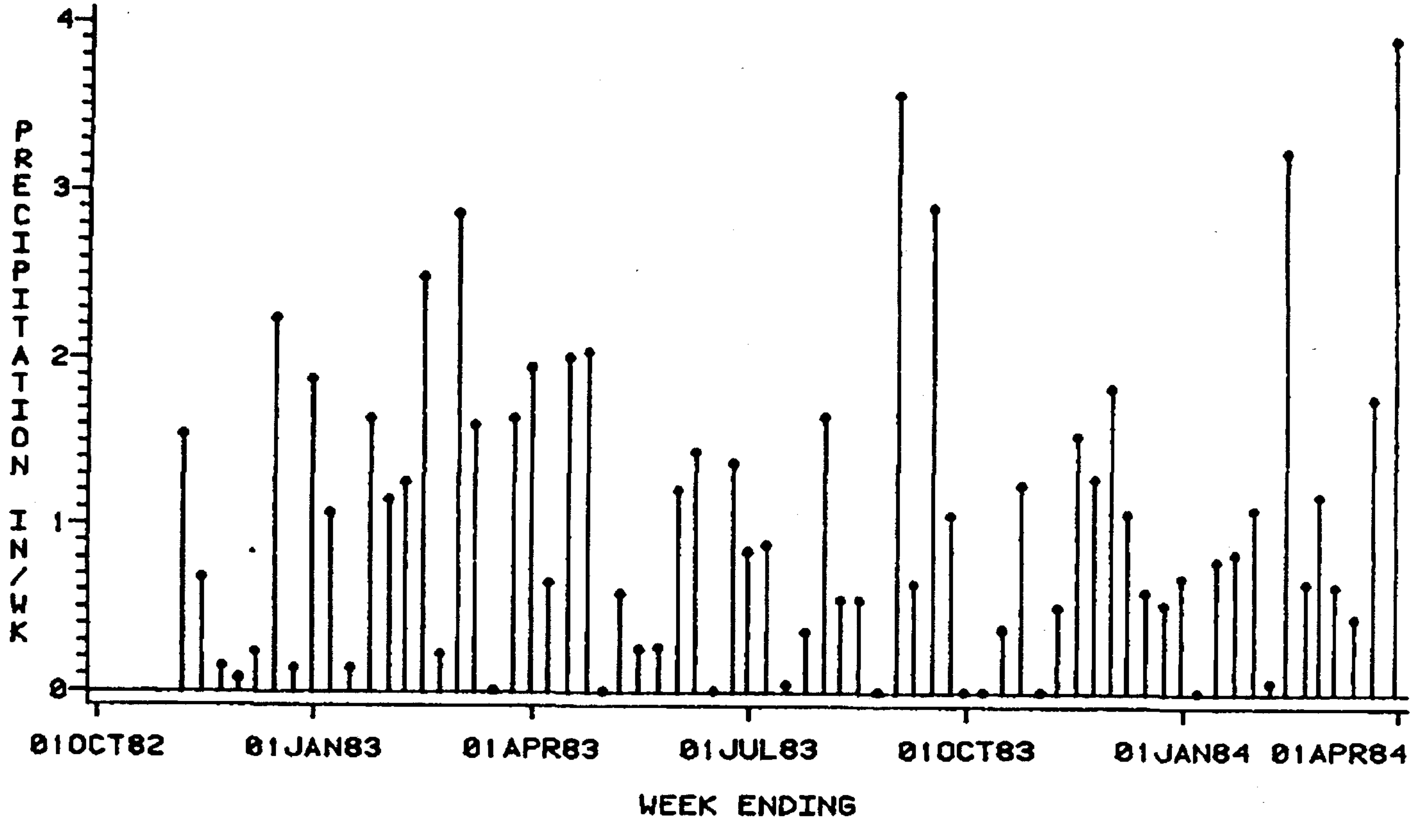


FIGURE 4.8. WEEKLY AVERAGE WEIGHTED PRECIPITATION. WEEKLY PRECIPITATION WEIGHTED FROM FOUR RAIN GAGES UNTIL NOVEMBER ,1983, WEIGHTED FROM THREE GAGES THEREAFTER.

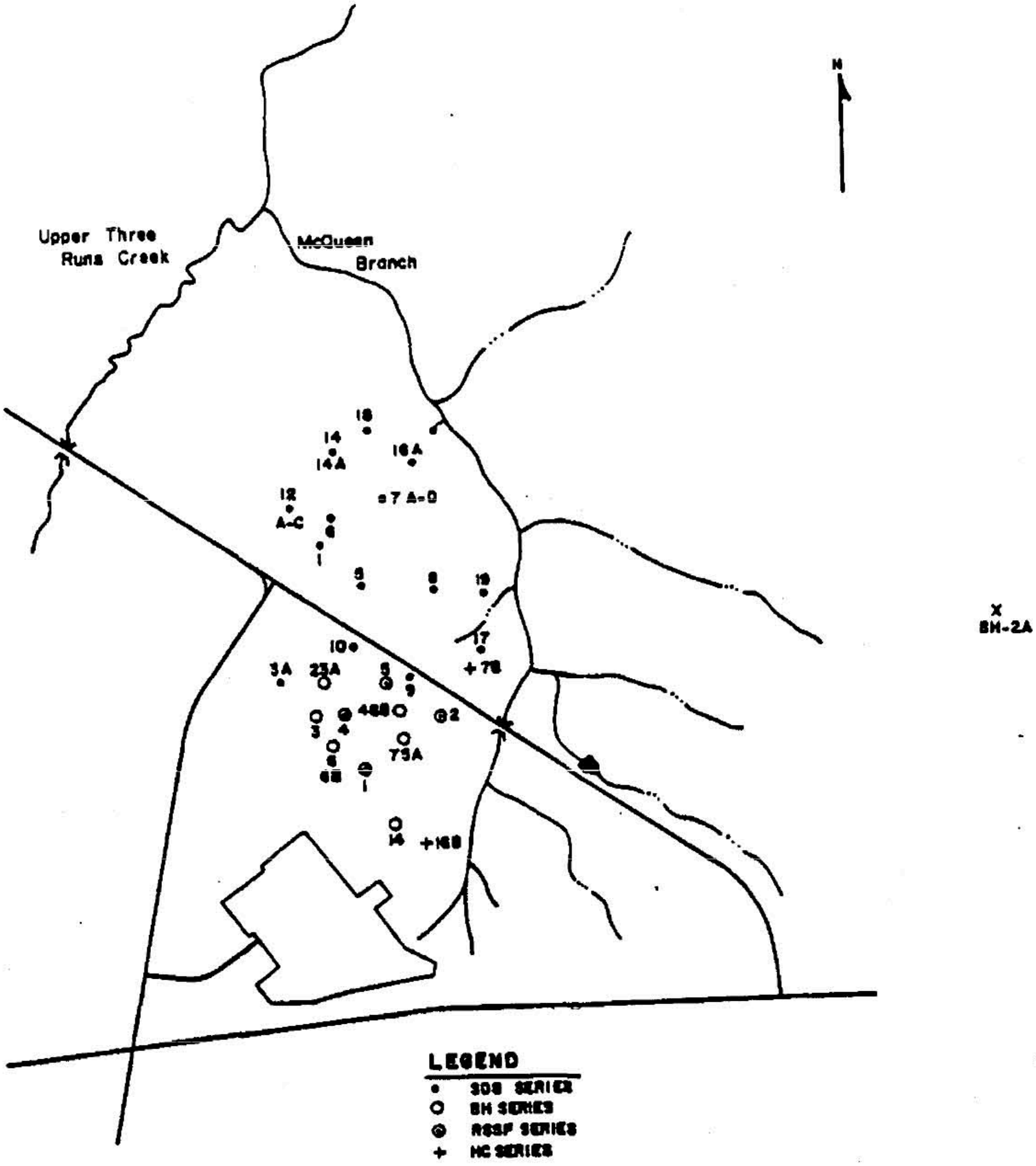


FIGURE 4.9. LOCATIONS OF WELLS IN MCQUEEN BRANCH BASIN ROUTINELY MEASURED FOR WATER LEVELS DURING THE HYDROLOGIC BUDGET STUDY.

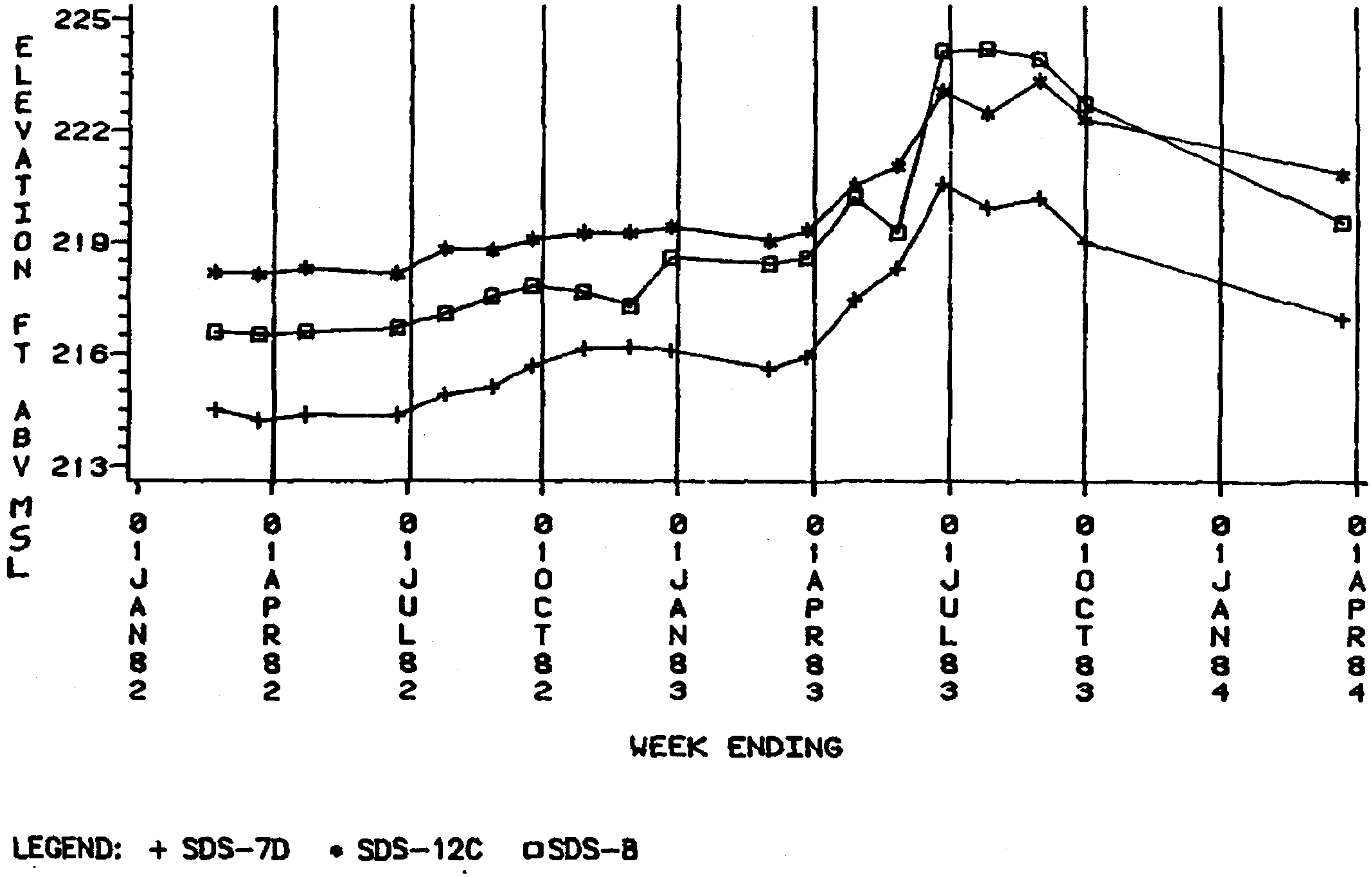


FIGURE 4.10. HYDROGRAPHS OF SDS-7D, SDS-12C AND SDS-8.

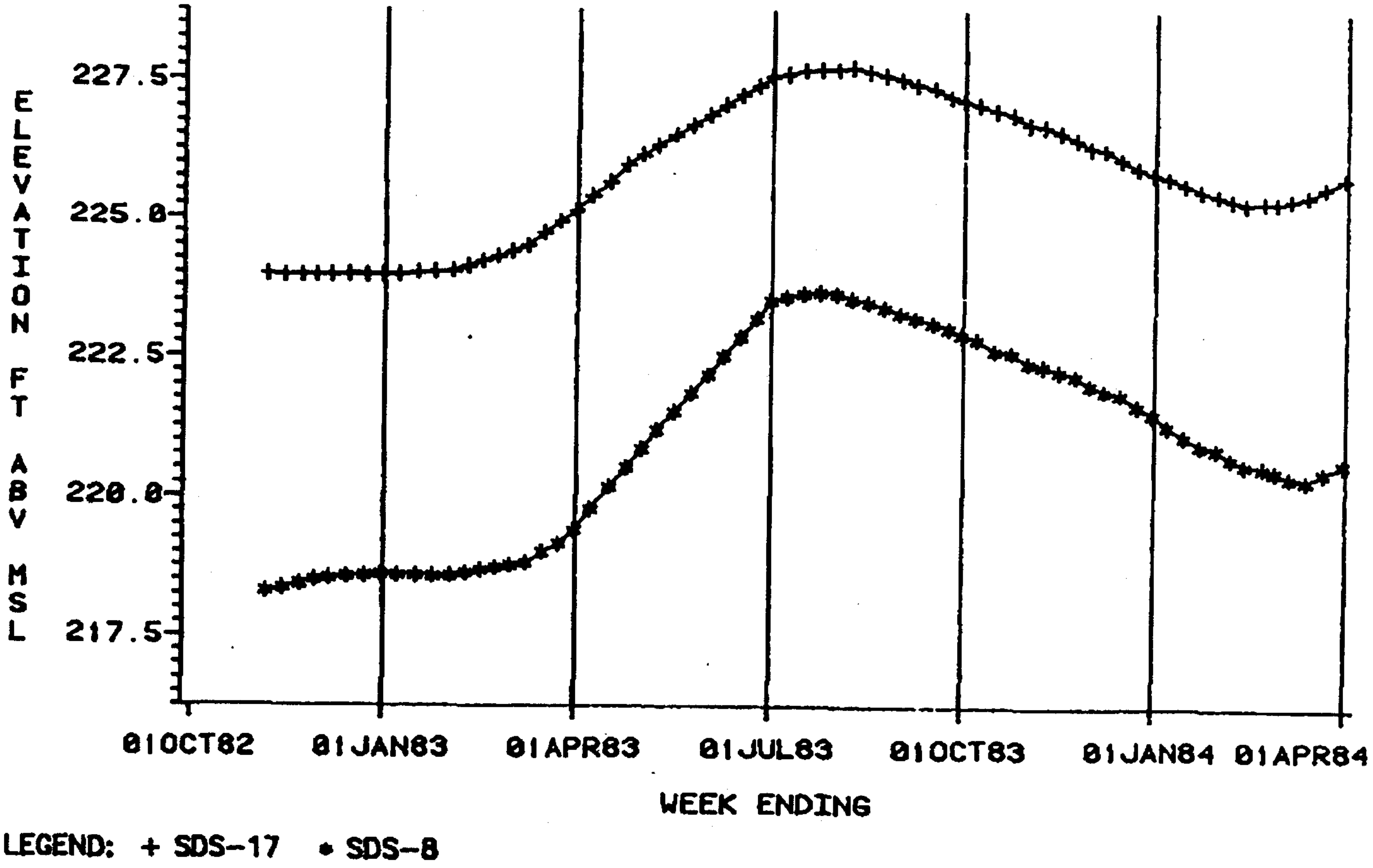


FIGURE 4.11A. HYDROGRAPHS OF SDS-17 AND SDS-8.

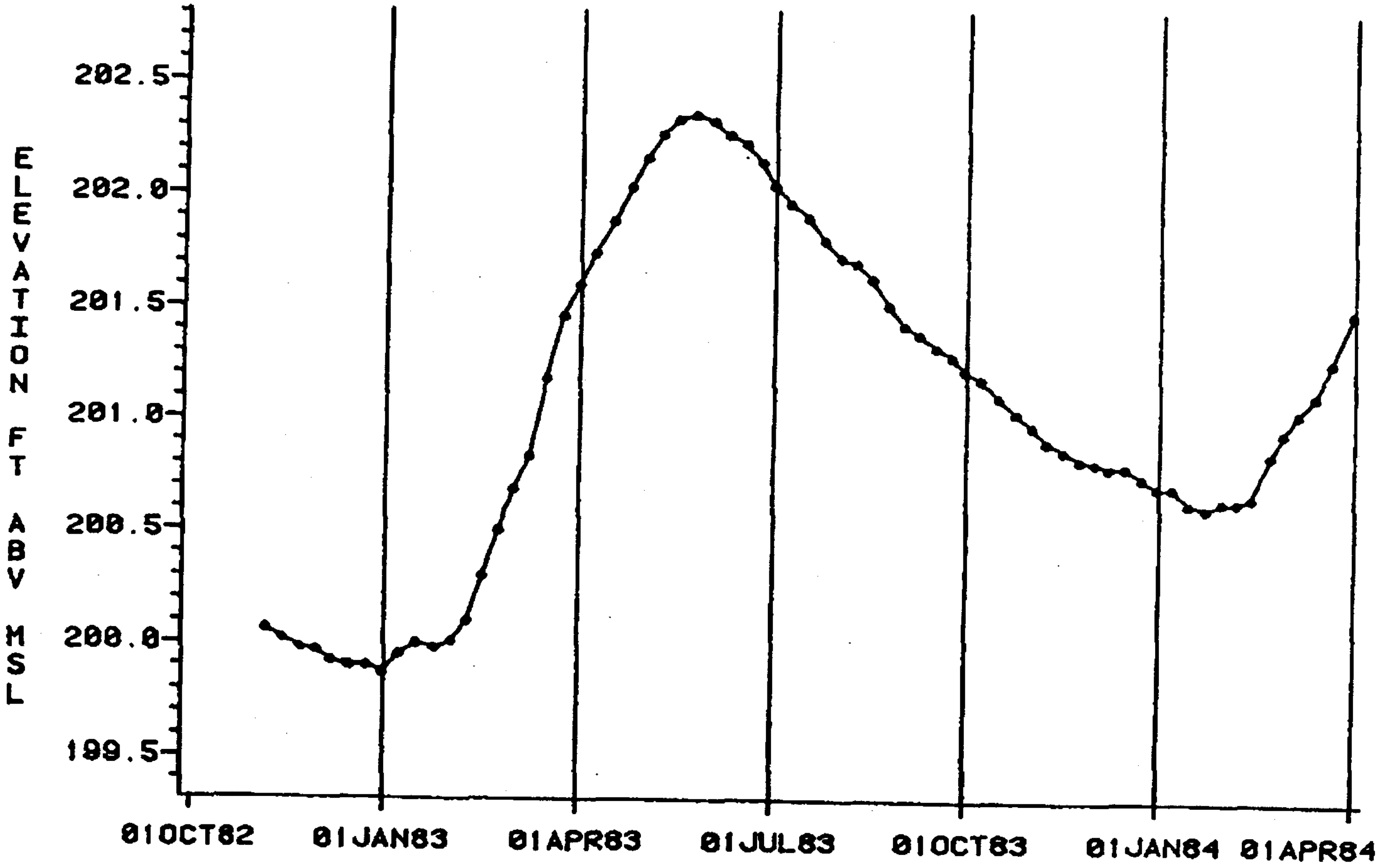
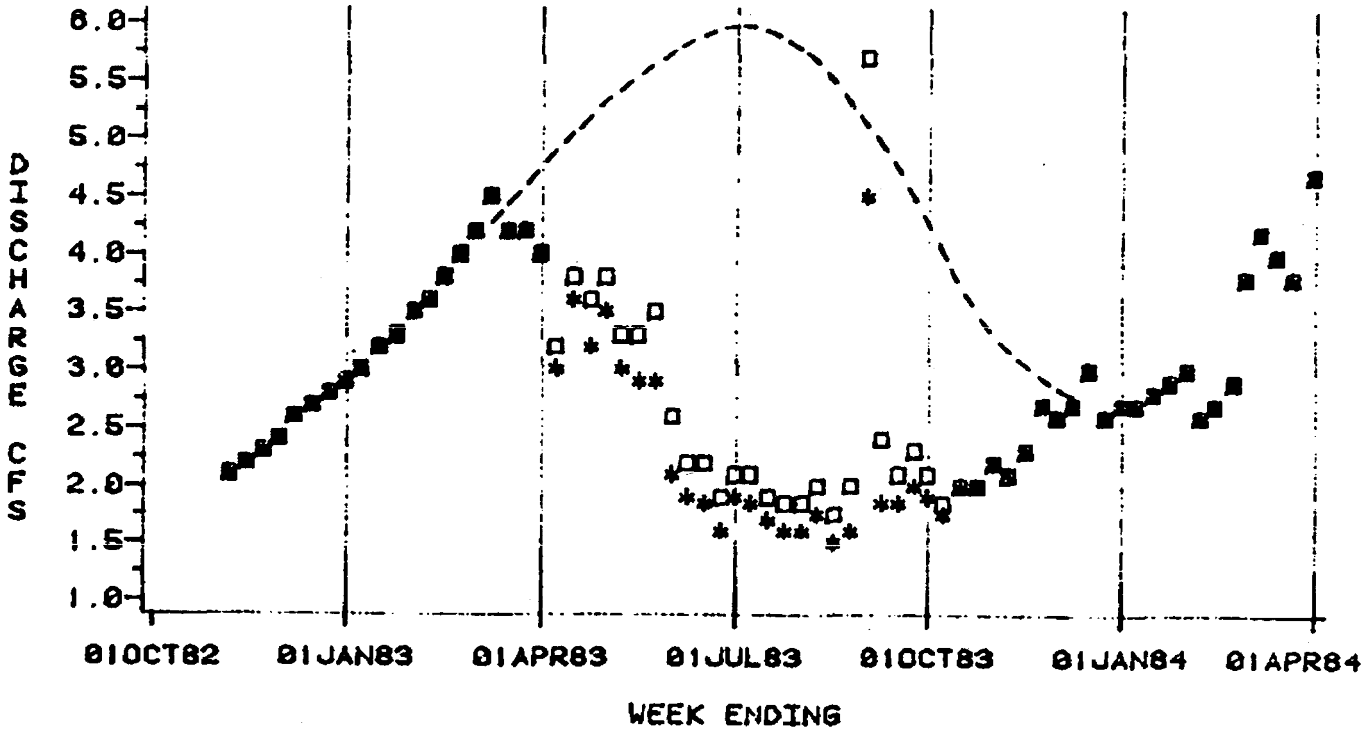


FIGURE 4.11B. HYDROGRAPH OF SDS-10A.



LEGEND: ▫ HIFLO * LOFLO ---- ESTIMATED BASEFLOW CORRECTED FOR GROUND-WATER ET

FIGURE 4.12. BASEFLOW HYDROGRAPH, MCQUEEN BRANCH.

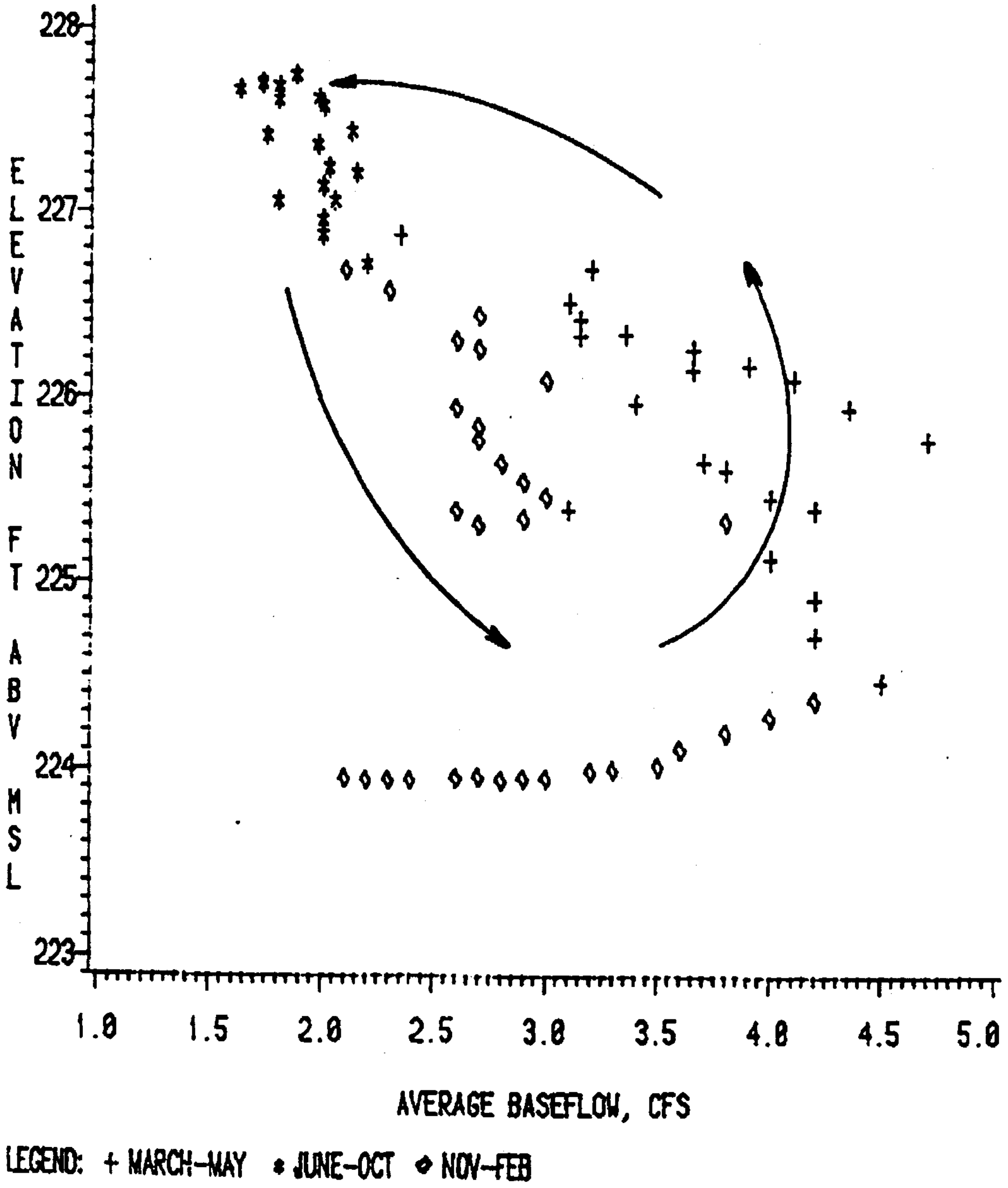


FIGURE 4.13. MCQUEEN BRANCH BASEFLOW VS. SDS-17 WATER LEVEL ELEVATION.

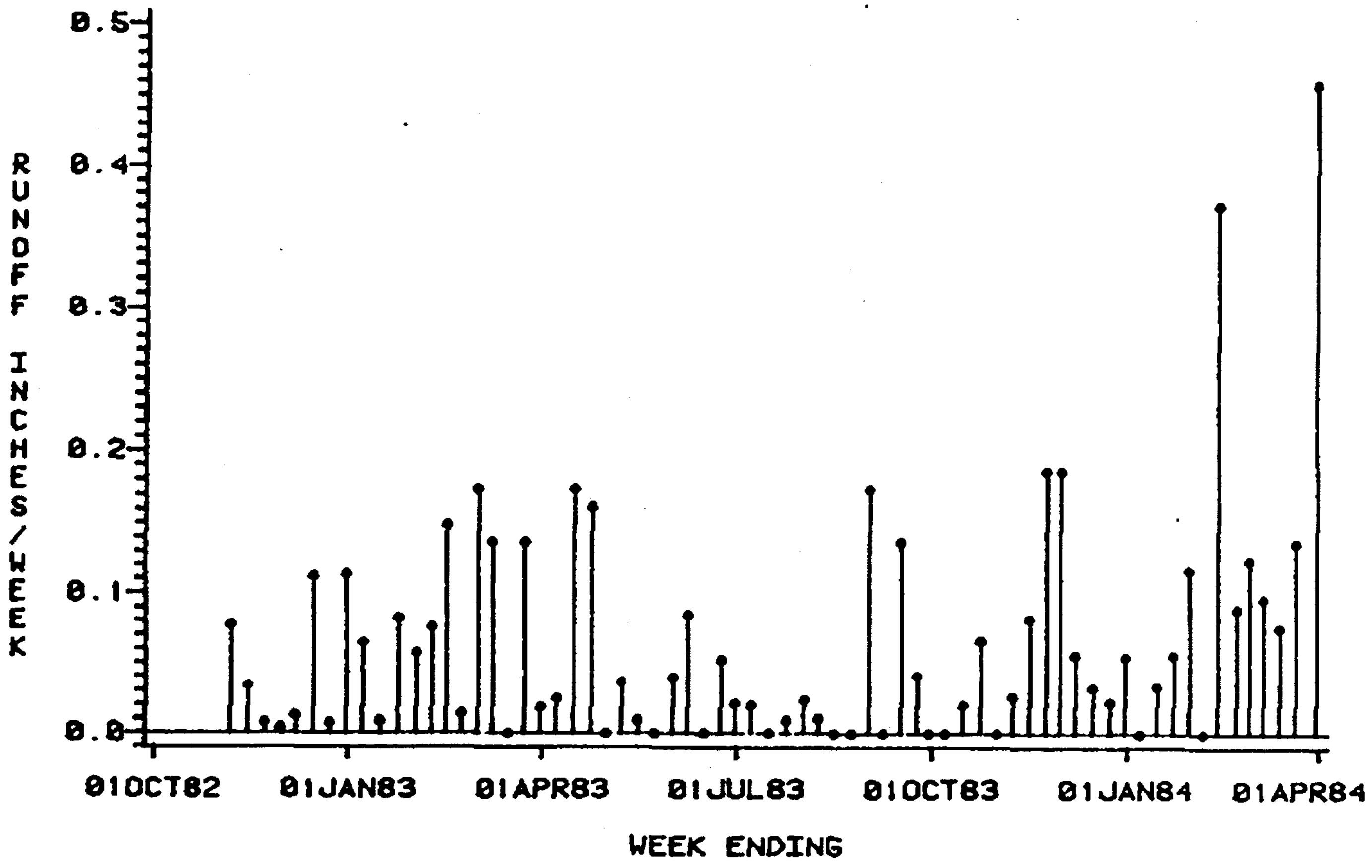


FIGURE 4.14. MCQUEEN BRANCH SURFACE RUNOFF.

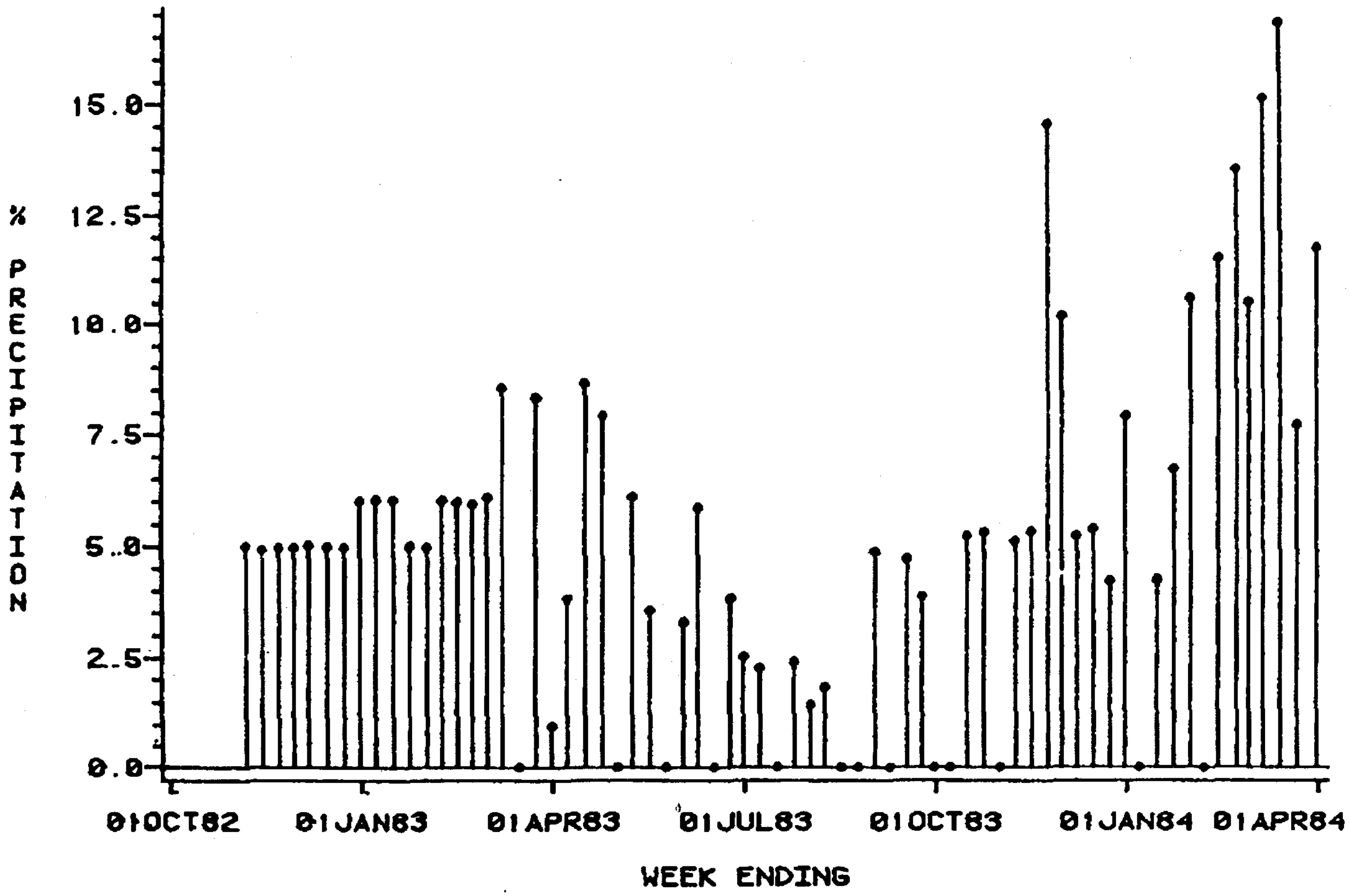


FIGURE 4.15. PERCENTAGE OF PRECIPITATION THAT IS SURFACE RUNOFF.

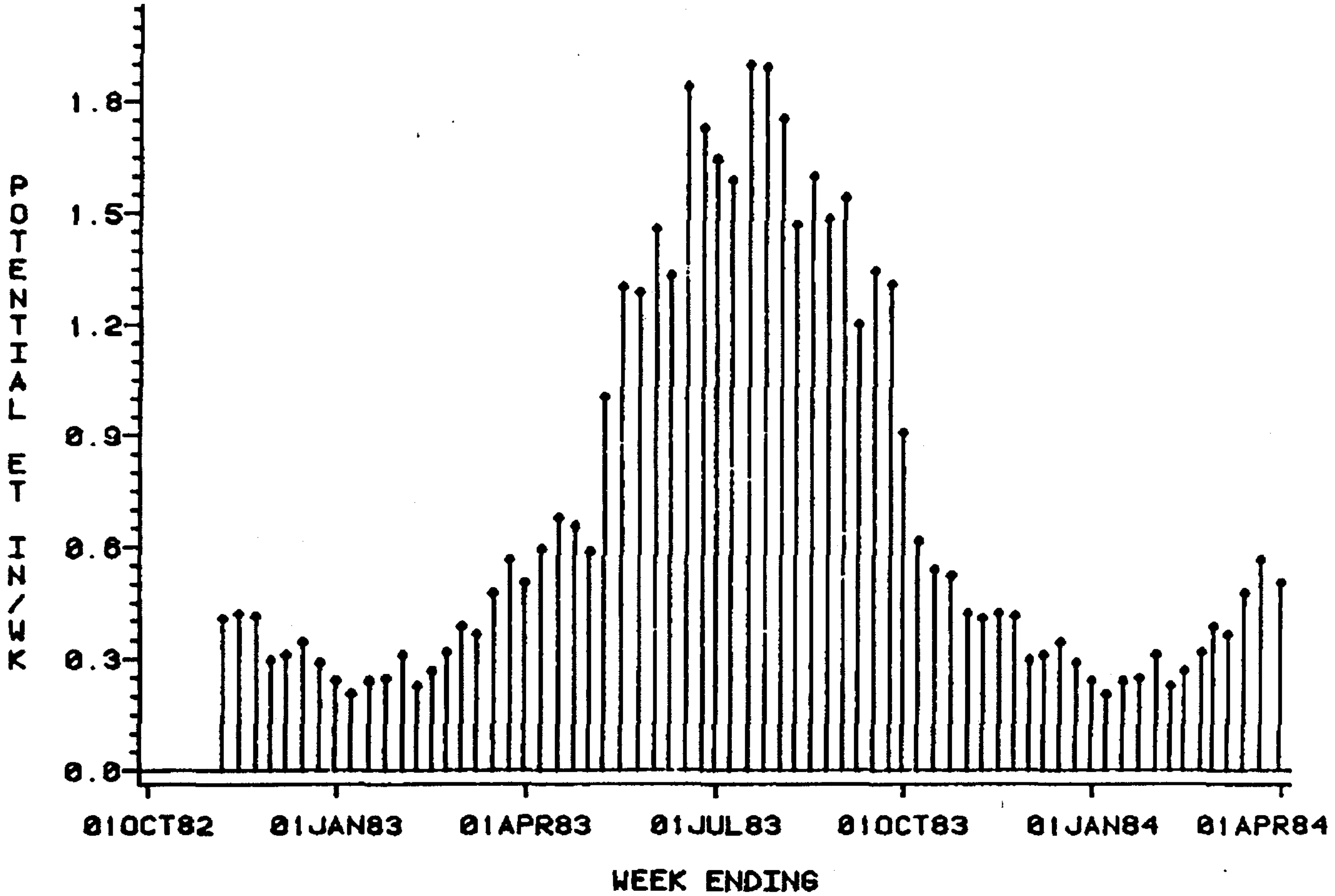


FIGURE 4.16. WEEKLY AVERAGE POTENTIAL EVAPOTRANSPIRATION VS. TIME.

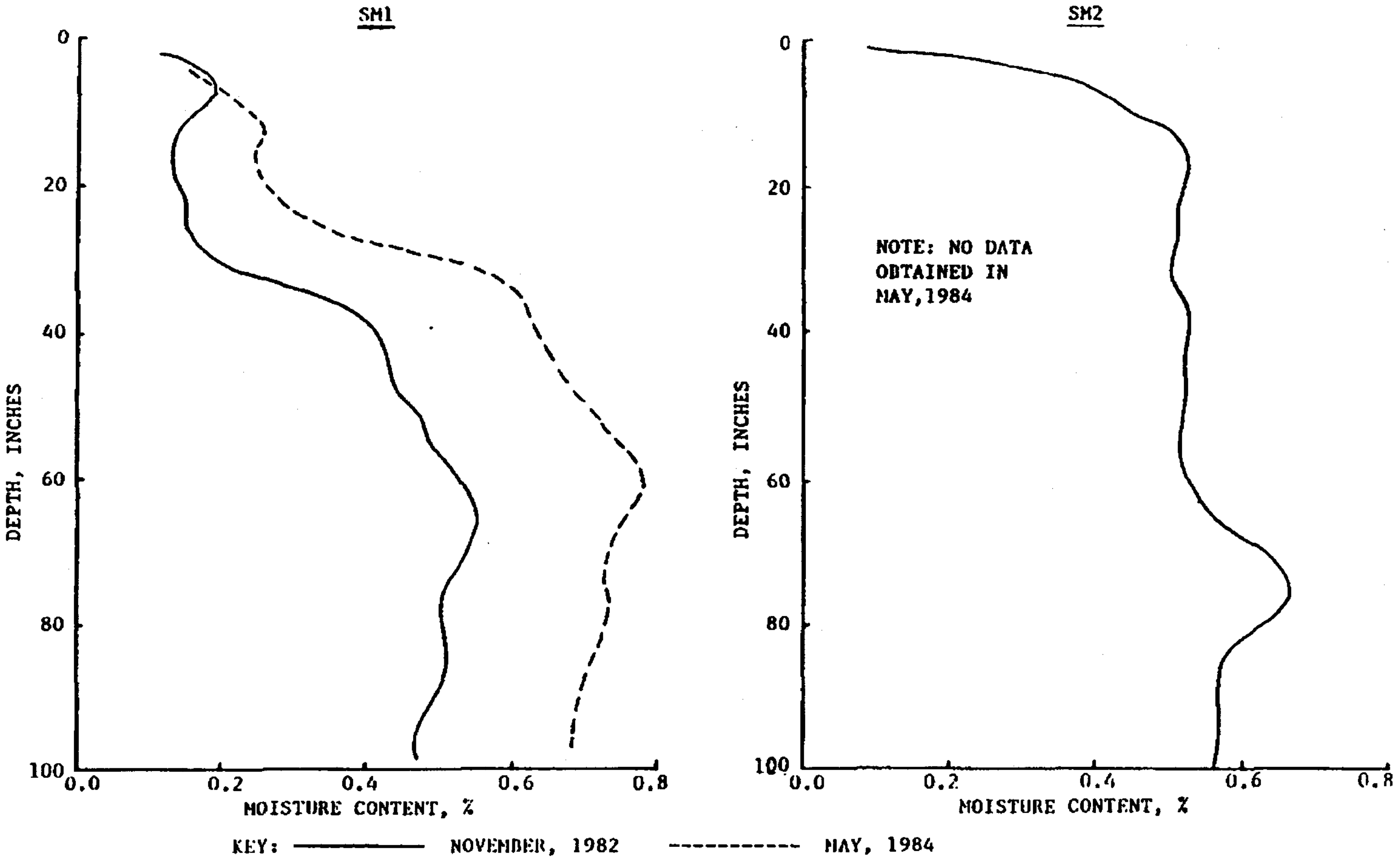


FIGURE 4.17A,B. SOIL MOISTURE CONTENT VS. DEPTH, SITES SM1 AND SM2.

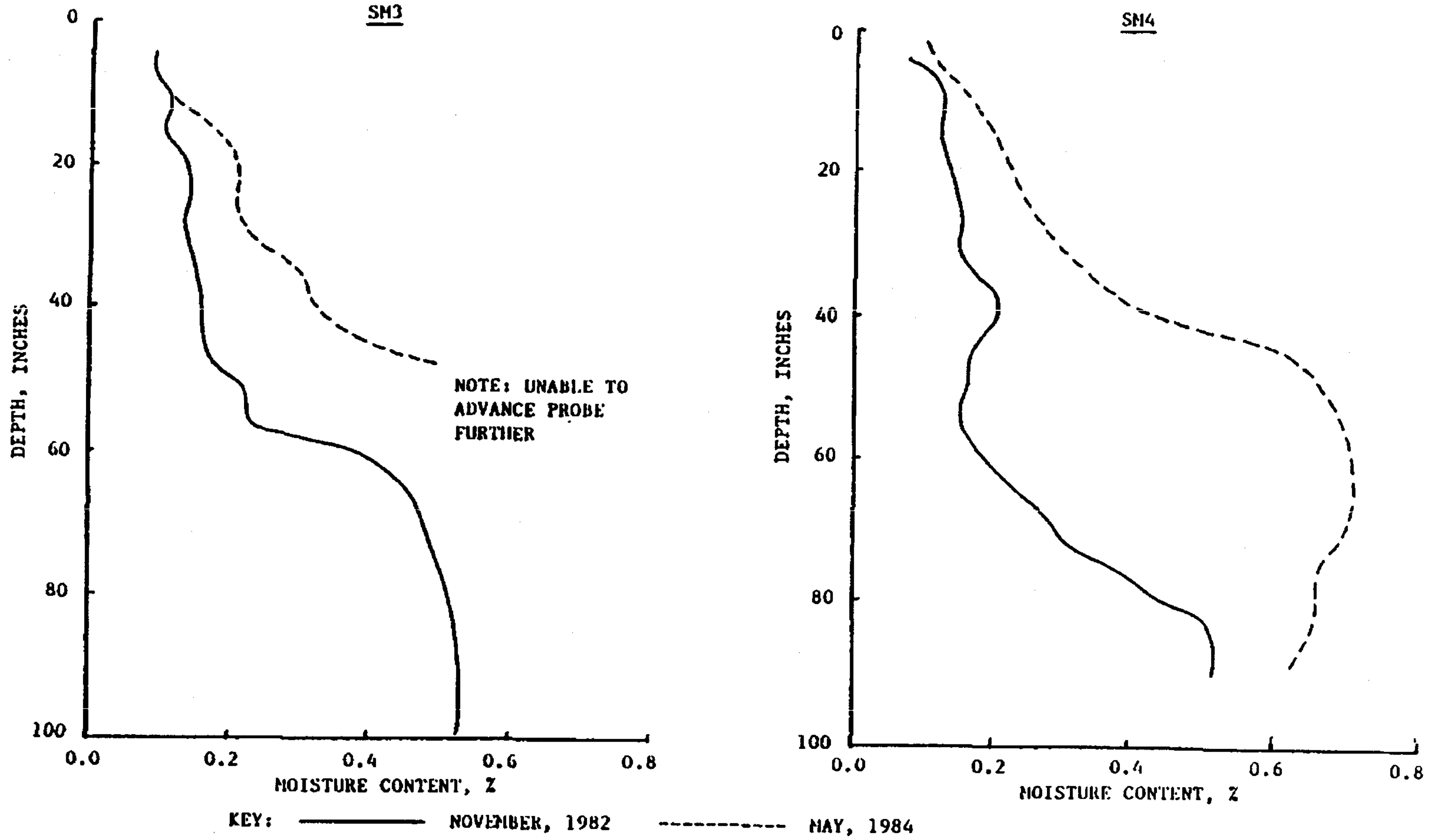


FIGURE 4.17C,D. SOIL MOISTURE VS. DEPTH, SITES SM3 AND SM4.

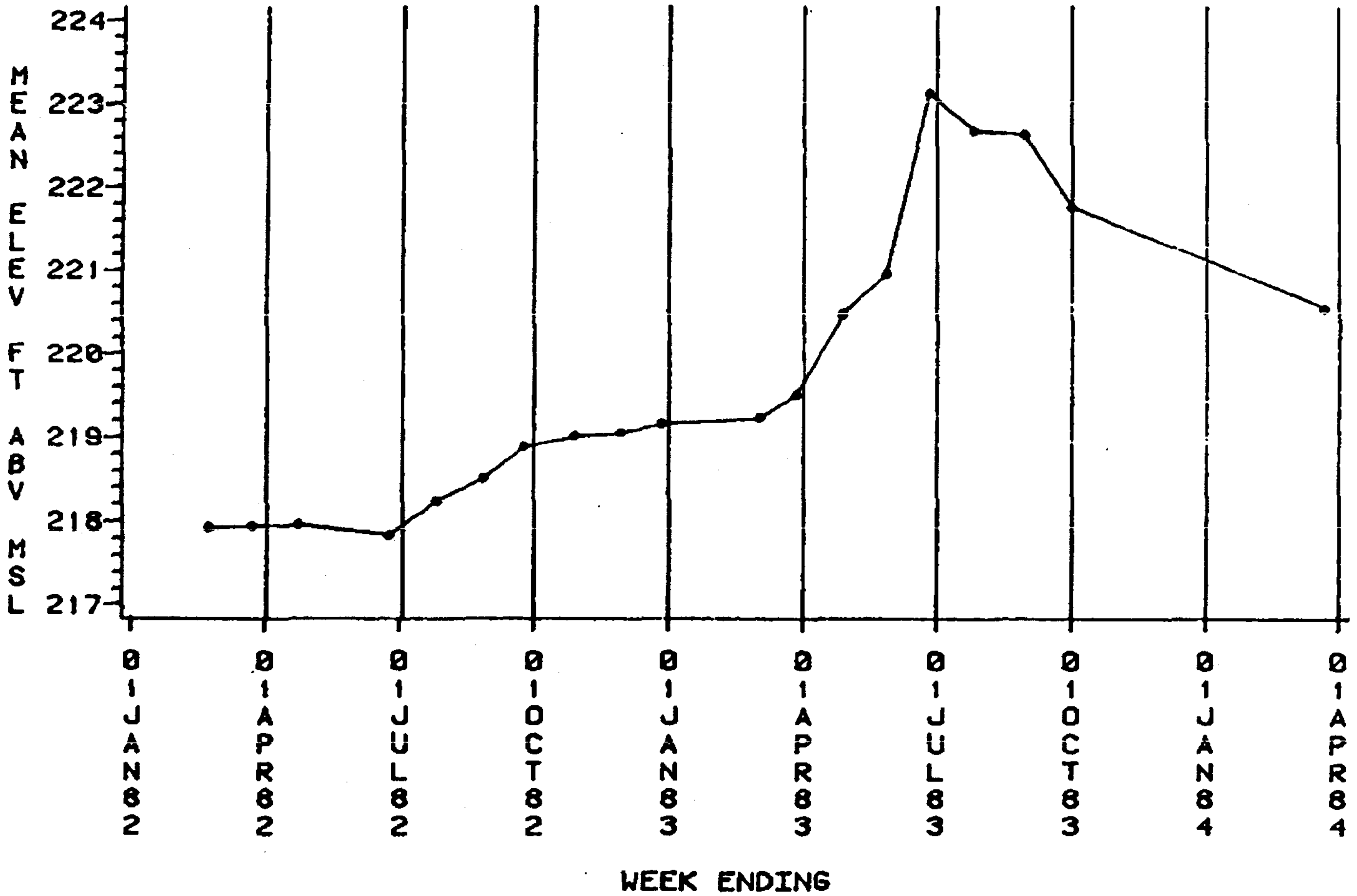


FIGURE 4.18. HYDROGRAPH OF MEAN WATER TABLE ELEVATION, MCQUEEN BRANCH BASIN.

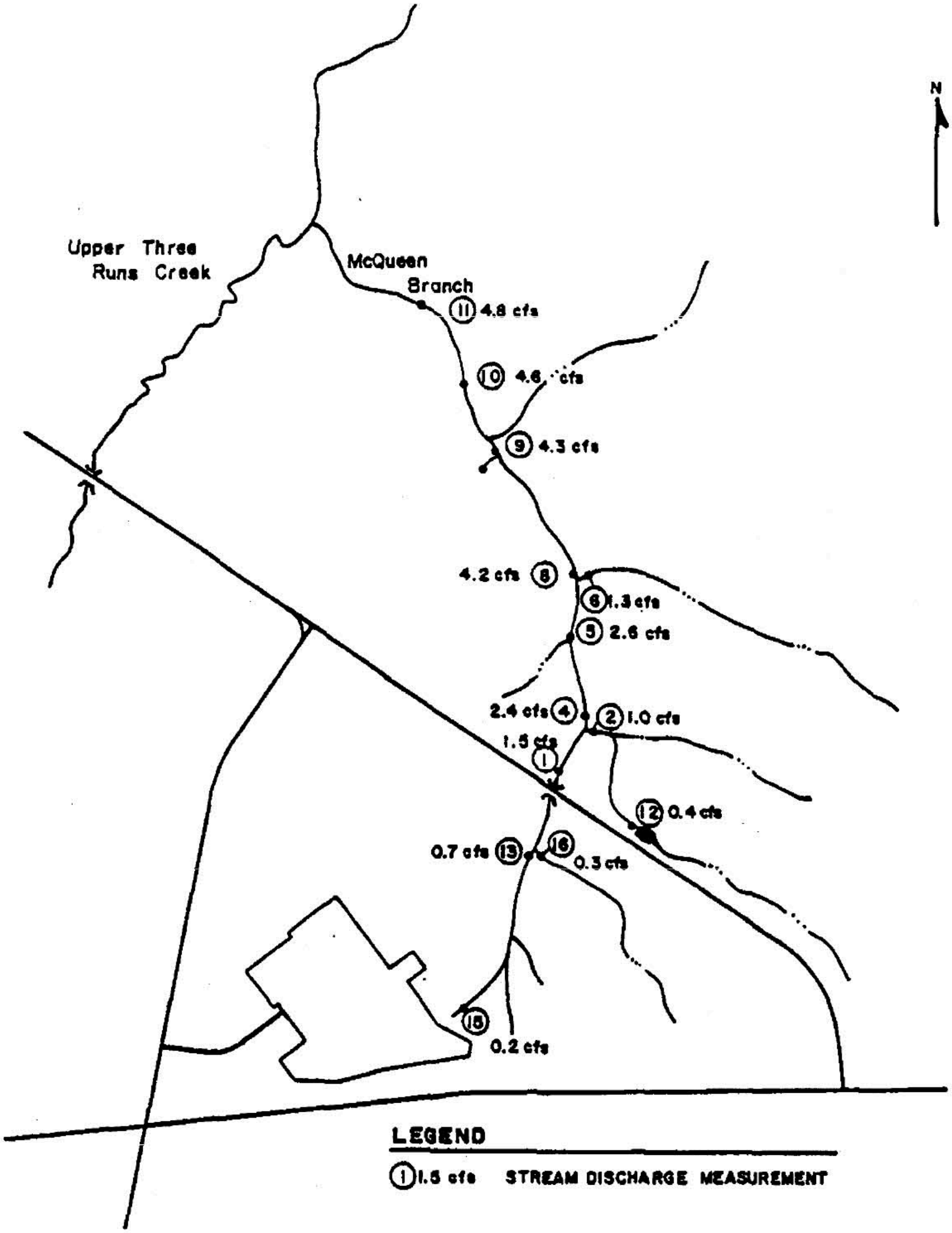


FIGURE 4.19. MCQUEEN BRANCH DRAINAGE BASIN AND INSTANTANEOUS STREAM DISCHARGE MEASUREMENTS MADE ON FEBRUARY 27, 1983.

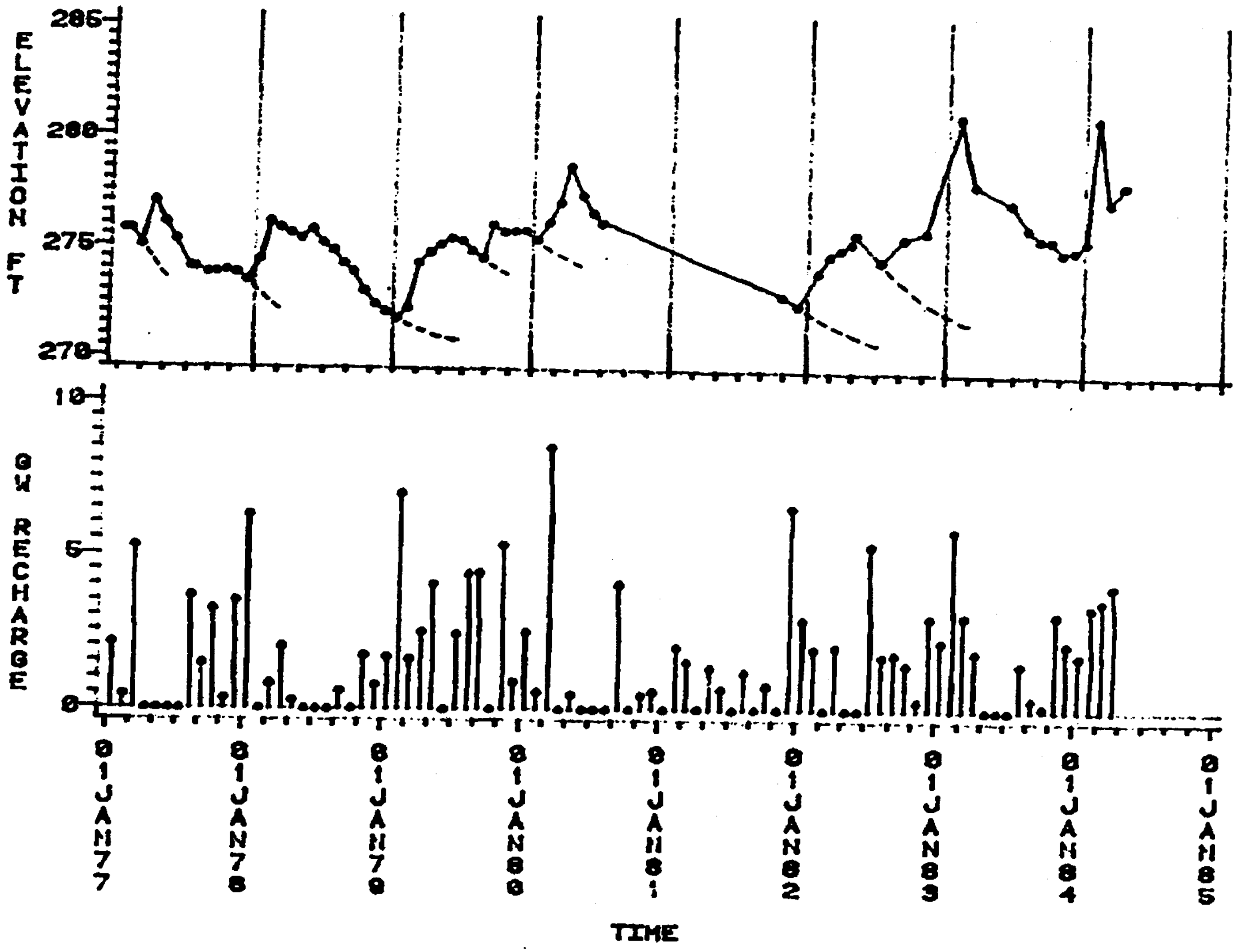


FIGURE 4.20. HYDROGRAPH OF HC1E AND THE TIME DISTRIBUTION OF AVERAGE COMPUTED GROUND-WATER RECHARGE.

THE HYDROGRAPH ALSO SHOWS THE EXTRAPOLATION OF WATER-LEVEL RECESSIONS.(----).

Table 4.14. Calculations of gravity yield for the period June 1983 to March 1984.

Date	Average head, ft.	Time of drainage, days	Baseflow, ft.^{3}		Evapotranspiration, ft.^{3}		Volume of aquifer drained, ft.^{3}		Gravity yield, %	
			Incremental	Cumulative	Incremental	Cumulative	Incremental	Cumulative	Inc.	Cum.
6-25-83	223.11	0	4.84×10^6 (0.60)[1]	4.84×10^6 (0.60)	2.55×10^6 (7.03)	2.55×10^6 (7.03)	4.26×10^7 (0.44)[2]	4.26×10^7 (0.44)	17	17
7-25-83	222.67	30	4.68×10^6 (0.58)	9.51×10^6 (1.18)	2.29×10^6 (6.30)	4.84×10^6 (13.33)	4.84×10^6 (0.05)	4.74×10^7 (0.49)	144	30
8-29-83	222.62	65	8.87×10^6 (1.10)	1.84×10^7 (2.28)	2.29×10^6 (6.31)	7.13×10^6 (19.64)	8.42×10^7 (0.87)	1.32×10^8 1.36)	13	19
10-1-83	221.75	98	4.22×10^7 (5.23)	6.05×10^7 (7.51)	3.08×10^6 (8.48)	1.02×10^7 (28.12)	1.17×10^8 (1.21)	2.49×10^8 (2.57)	39	28
3-26-84	220.54	275								

[1] Baseflow or evapotranspiration in inches during the period.

[2] Head change during the period in ft.

Table 4.15. Baseflow, precipitation, potential evapotranspiration, and surface runoff values for the hydrologic budget. All values are in inches per week.

Week Ending	Baseflow	Rainfall	Potential ET	Runoff
07NOV82	0.157549	1.54	0.40874	0.076909
15NOV82	0.188630	0.68	0.42247	0.033493
23NOV82	0.197204	0.15	0.41544	0.007443
30NOV82	0.180055	0.08	0.29785	0.003969
07DEC82	0.195061	0.24	0.31158	0.012032
15DEC82	0.231500	2.24	0.34625	0.111642
23DEC82	0.240074	0.14	0.29097	0.006947
31DEC82	0.248648	1.88	0.24272	0.112882
07JAN83	0.225070	1.07	0.20787	0.064504
15JAN83	0.274370	0.14	0.24239	0.008435
23JAN83	0.282945	1.64	0.24927	0.081871
31JAN83	0.300093	1.15	0.31158	0.057061
07FEB83	0.270084	1.26	0.22848	0.075668
14FEB83	0.285088	2.49	0.27003	0.148856
21FEB83	0.300093	0.23	0.31861	0.013645
28FEB83	0.315097	2.86	0.38780	0.173665
07MAR83	0.337604	1.60	0.36719	0.136451
15MAR83	0.360111	0.01	0.47793	0.000000
23MAR83	0.360111	1.64	0.56788	0.136451
31MAR83	0.342963	1.95	0.50572	0.018607
07APR83	0.232572	0.65	0.59585	0.024809
15APR83	0.317241	2.01	0.67895	0.173665
23APR83	0.291519	2.04	0.65816	0.161260
30APR83	0.273835	0.01	0.58915	0.000000
07MAY83	0.236323	0.59	1.00710	0.035973
15MAY83	0.265797	0.26	1.30420	0.009179
23MAY83	0.274370	0.27	1.29120	0.000000
31MAY83	0.201491	1.21	1.45970	0.039695
07JUN83	0.153798	1.44	1.33420	0.084352
15JUN83	0.173625	0.01	1.84040	0.000000
23JUN83	0.150046	1.37	1.72810	0.052099
30JUN83	0.150046	0.84	1.64530	0.021088
07JUL83	0.148171	0.88	1.58990	0.019847
15JUL83	0.154334	0.05	1.90060	0.000000
23JUL83	0.147903	0.36	1.89370	0.008683
31JUL83	0.147903	1.65	1.75330	0.023569
07AUG83	0.140668	0.55	1.46980	0.010048
15AUG83	0.139329	0.55	1.59960	0.000000
23AUG83	0.154334	0.01	1.48490	0.000000
31AUG83	0.437278	3.57	1.54150	0.173665
07SEP83	0.159424	0.65	1.20080	0.000000
15SEP83	0.169338	2.90	1.34600	0.136451
23SEP83	0.184342	1.06	1.31090	0.040935
30SEP83	0.150046	0.01	0.90850	0.000000

Table 4.15 (continued)

Week Ending	Baseflow	Rainfall	Potential ET	Runoff
07OCT83	0.135042	0.01	0.61780	0.000000
15OCT83	0.171482	0.38	0.54024	0.019847
23OCT83	0.171482	1.24	0.52345	0.065745
31OCT83	0.188630	0.01	0.42265	0.000000
07NOV83	0.157549	0.51	0.40874	0.026050
15NOV83	0.197204	1.54	0.42247	0.081871
23NOV83	0.231500	1.28	0.41544	0.186069
30NOV83	0.195061	1.83	0.29785	0.186069
07DEC83	0.202562	1.07	0.31158	0.055821
15DEC83	0.257222	0.60	0.34625	0.032252
23DEC83	0.222926	0.53	0.29097	0.022328
31DEC83	0.231500	0.69	0.24272	0.054580
07JAN84	0.202562	0.01	0.20787	0.000000
15JAN84	0.240074	0.79	0.24239	0.033493
23JAN84	0.248648	0.83	0.24927	0.055821
31JAN84	0.257222	1.10	0.31158	0.116604
07FEB84	0.195061	0.07	0.22848	0.000000
14JAN84	0.202562	3.24	0.27003	0.372139
23FEB84	0.279729	0.66	0.31861	0.089313
29FEB84	0.244361	1.18	0.38780	0.124046
07MAR84	0.315097	0.64	0.36719	0.096756
15MAR84	0.342963	0.45	0.47793	0.075668
23MAR84	0.325815	1.77	0.56788	0.136451
31MAR84	0.402982	3.91	0.50572	0.458971
07APR84	0.326351	1.77	0.59585	0.124046
15APR84	0.351538	1.00	0.67895	0.059542
23APR84	0.334390	3.32	0.65816	0.198474
30APR84	0.273835	3.32	0.58915	0.198474
07MAY84	0.251328	2.00	1.00710	0.120325
15MAY84	0.270083	0.01	1.30420	0.000000

Table 4.16. Components of the hydrologic budget for the period November 1, 1982 to May 19, 1984.

Component	Value (inches)	Percentage of precipitation
Total precipitation	81.69	—
Total baseflow	17.57	21.5
Total runoff (H Area and basin)	5.29	6.5
Ground-water storage	5.02	+6.1
Total evapotranspiration (Penman-Monteith)	52.81	64.6
Soil moisture storage	0.00	0.0
		98.7%
Possible underflow	1.06	1.3%

Table 4.17. Components of the hydrologic budget for the period March 1, 1983 through March 31, 1984.

Component	Value (inches)	Percentage of precipitation
Total precipitation	52.48	—
Total baseflow	11.87	22.6
Total runoff (H Area and basin)	3.60	6.9
Ground-water storage	3.48	6.6
Soil moisture storage	0.0	0.0
		36.1%
Total evapotranspiration (Penman-Monteith)	43.03	82.0%
Actual evapotranspiration (from budget)	33.53	63.9%

Table 4.18. Recharge rates for McQueen Branch Basin segments — February 27, 1983.

Upstream from station	Q, cfs.	Area mis.^{2}	Recharge, in./yr.	
11	4.6	4.12	15.2	
10	4.4	3.79	15.8	
9	4.1	3.47	16.1	Weir installation
8	4.0	3.20	17.0	
5	2.4	1.85	17.6	
4	2.2	1.71	17.4	
1	1.3	0.895	19.7	
13	0.5	0.370	18.3	
6	1.3	1.23	14.3	
2	1.0	0.723	18.8	
12	0.4	0.411	13.2	
16	0.3	0.278	14.7	

Table 4.19. Seasonal or monthly evapotranspiration rates obtained from various methods. Rates are in inches per month. (All but the Penman-Monteith values are from Hubbard, 1984; Penman-Monteith values were obtained from the McQueen Branch hydrologic budget study.)

Source Month	Penman-Monteith	Thornthwaite	Evaporation Pans	Research Lysimeters	Average
Jan	1.2	0.55	1.98	2.13	1.5
Feb	1.2	0.55	2.48	2.13	1.6
Mar	2.0	1.18	2.75	2.13	2.0
Apr	2.0	2.64	3.32	1.90	2.5
May	2.0	4.41	2.90	1.90	2.8
Jun	5.6	5.91	3.66	1.90	4.3
Jul	5.6	6.73	4.24	3.37	5.0
Aug	5.6	5.94	3.47	3.37	4.6
Sep	2.0	4.41	2.15	3.37	3.0
Oct	2.0	2.36	2.14	1.37	2.0
Nov	2.0	1.02	2.21	1.37	1.7
Dec	1.2	0.43	1.97	1.37	1.3
Annual total, inches	32.4	36.13	33.27	26.3	
Period of record	1983-1984	1963-1982	1974-1978	1980-1982	

TABLE 4.20. GROUND-WATER RECHARGE (IN INCHES PER MONTH) CALCULATED BY VARIOUS METHODS.

PPT = PRECIPITATION
GWRCPM = RECHARGE CALCULATED BY THE PENMAN-MONTEITH METHOD
GWRCT = RECHARGE CALCULATED BY THE THORNTHWAITE METHOD
GWRCP = RECHARGE CALCULATED USING PAN EVAPORATION METHODS
GWRCL = RECHARGE CALCULATED BASED ON LYSIMETER STUDIES
GWRCA = AVERAGE RECHARGE CALCULATED USING THE ABOVE METHODS
GWRCF = RECHARGE CALCULATED USING THE NATIONAL WEATHER SERVICE HYDROLOGIC MODEL
NA = NOT AVAILABLE

MONTH	YEAR	PPT	GWRCPM	GWRCT	GWRCP	GWRCL	GWRCA	GWRCF
1	1976	4.22	2.68	3.33	1.90	1.75	2.41	2.12
2	1976	1.50	0.18	0.83	0.0	0.0	0.0	0.31
3	1976	3.95	1.63	2.45	0.88	1.50	1.61	1.43
4	1976	2.22	0.04	0.0	0.0	0.14	0.0	0.0
5	1976	10.86	7.99	5.56	7.09	8.09	7.19	2.78
6	1976	6.40	0.67	0.36	2.61	4.37	2.00	0.52
7	1976	3.28	0.0	0.0	0.0	0.0	0.0	0.06
8	1976	2.41	0.0	0.0	0.0	0.0	0.0	0.0
9	1976	5.40	3.13	0.72	2.98	1.76	2.15	0.0
10	1976	5.54	3.26	2.90	3.12	3.89	3.29	0.29
11	1976	3.89	1.70	2.68	1.49	2.33	2.05	0.98
12	1976	4.82	3.23	4.00	2.46	3.06	3.19	2.59
1	1977	3.86	2.35	3.00	1.57	1.42	2.08	1.83
2	1977	2.20	0.82	1.47	0.0	0.0	0.43	0.57
3	1977	7.90	5.27	6.09	4.52	5.14	5.25	3.75
4	1977	1.02	0.0	0.0	0.0	0.0	0.0	0.0
5	1977	2.61	0.40	0.0	0.0	0.50	0.0	0.0
6	1977	3.79	0.0	0.0	0.05	1.31	0.0	0.0
7	1977	4.02	0.0	0.0	0.0	0.57	0.0	0.0
8	1977	8.43	2.66	2.32	4.79	4.89	3.66	0.21
9	1977	4.66	2.43	0.02	2.28	1.06	1.45	0.13
10	1977	5.44	3.17	2.81	3.03	3.80	3.20	0.93
11	1977	2.07	0.0	0.95	0.0	0.60	0.32	0.0
12	1977	5.14	3.53	4.30	2.76	3.36	3.49	2.55
1	1978	8.44	6.56	7.21	5.78	5.63	6.29	4.71
2	1978	1.45	0.13	0.78	0.0	0.0	0.0	0.14
3	1978	3.07	0.82	1.64	0.07	0.69	0.80	0.81
4	1978	4.85	2.46	1.82	1.14	2.56	1.99	0.70
5	1978	3.33	1.06	0.0	0.16	1.16	0.26	1.14
6	1978	1.94	0.0	0.0	0.0	0.00	0.0	0.0
7	1978	4.13	0.0	0.0	0.0	0.68	0.0	0.0
8	1978	2.72	0.0	0.0	0.0	0.0	0.0	0.0
9	1978	3.74	1.55	0.0	1.40	0.18	0.57	0.0
10	1978	0.20	0.0	0.0	0.0	0.0	0.0	0.0
11	1978	3.54	1.36	2.34	1.15	1.99	1.71	0.0
12	1978	2.17	0.80	1.57	0.03	0.63	0.76	0.0

TABLE 4.20. (CONTINUED)

MONTH	YEAR	EPT	GWRCPM	GWRCT	GWRCP	GWRCL	GWRCA	GWRCF
1	1979	3.41	1.94	2.59	1.16	1.01	1.67	0.19
2	1979	9.31	7.37	8.02	6.09	6.44	6.98	3.28
3	1979	3.95	1.63	2.45	0.88	1.50	1.61	1.52
4	1979	5.37	2.94	2.30	1.62	3.04	2.47	1.32
5	1979	7.44	4.84	2.43	3.94	4.94	4.04	1.59
6	1979	1.55	0.0	0.0	0.0	0.0	0.0	0.0
7	1979	7.55	1.80	0.67	3.16	4.03	2.41	0.01
8	1979	9.14	3.36	3.02	5.49	5.59	4.36	1.53
9	1979	7.77	5.36	2.97	5.23	4.01	4.40	2.49
10	1979	1.38	0.0	0.0	0.0	0.0	0.0	0.29
11	1979	7.34	4.97	5.95	4.76	5.60	5.32	2.82
12	1979	2.29	0.91	1.68	0.14	0.74	0.87	0.30
1	1980	4.29	2.75	3.40	1.97	1.82	2.48	2.20
2	1980	2.33	0.94	1.59	0.0	0.01	0.55	0.94
3	1980	11.44	8.52	9.34	7.77	8.39	8.50	5.79
4	1980	2.31	0.13	0.0	0.0	0.23	0.0	0.48
5	1980	3.57	1.28	0.0	0.38	1.38	0.48	0.0
6	1980	3.30	0.0	0.0	0.0	1.33	0.0	0.0
7	1980	0.95	0.0	0.0	0.0	0.0	0.0	0.0
8	1980	2.86	0.0	0.0	0.0	0.0	0.0	0.0
9	1980	7.38	5.01	2.60	4.86	3.64	4.03	0.05
10	1980	1.95	0.0	0.0	0.0	0.48	0.0	0.0
11	1980	2.21	0.10	1.08	0.0	0.73	0.45	0.0
12	1980	1.96	0.60	1.37	0.0	0.43	0.56	0.0
1	1981	0.93	0.0	0.31	0.0	0.0	0.0	0.05
2	1981	3.91	2.40	3.05	1.12	1.47	2.01	0.87
3	1981	3.87	1.56	2.38	0.81	1.43	1.54	0.52
4	1981	2.71	0.49	0.0	0.0	0.59	0.02	0.54
5	1981	4.51	2.15	0.0	1.25	2.25	1.35	0.05
6	1981	5.05	0.0	0.0	1.29	3.05	0.66	1.86
7	1981	4.39	0.0	0.0	0.06	0.93	0.0	0.0
8	1981	5.92	0.20	0.0	2.33	2.43	1.20	0.0
9	1981	0.85	0.0	0.0	0.0	0.0	0.0	0.0
10	1981	2.88	0.74	0.38	0.60	1.37	0.77	0.0
11	1981	0.91	0.0	0.0	0.0	0.0	0.0	0.0
12	1981	8.45	6.57	7.34	5.80	6.40	6.53	0.83
1	1982	4.73	3.15	3.80	2.37	2.22	2.88	2.08
2	1982	3.86	2.35	3.00	1.07	1.42	1.96	1.84
3	1982	1.95	0.0	0.61	0.0	0.0	0.0	0.40
4	1982	4.90	2.51	1.87	1.19	2.61	2.04	0.87
5	1982	2.37	0.18	0.0	0.0	0.28	0.0	0.0
6	1982	4.07	0.0	0.0	0.33	2.09	0.0	0.0
7	1982	10.53	4.72	3.59	6.08	6.95	5.33	1.11
8	1982	6.45	0.72	0.38	2.85	2.95	1.72	2.27
9	1982	5.02	2.77	0.36	2.62	1.40	1.79	0.05
10	1982	3.61	1.43	1.07	1.29	2.06	1.46	0.89
11	1982	2.06	0.0	0.94	0.0	0.59	0.31	0.0
12	1982	4.58	3.01	3.78	2.24	2.84	2.97	1.59

TABLE 4.20. (CONTINUED)

MONTH	YEAR	PPT	GWRCPM	GWRCT	GWRCP	GWRCL	GWRCA	GWRCF
1	1983	4.00	2.48	3.13	1.70	1.55	2.21	1.90
2	1983	8.06	6.22	6.87	4.94	5.29	5.83	4.46
3	1983	5.49	3.05	3.87	2.30	2.92	3.03	2.22
4	1983	4.71	2.33	1.69	1.01	2.43	1.86	1.63
5	1983	3.00	0.76	0.0	0.0	0.86	0.0	NA
6	1983	2.77	0.0	0.0	0.0	0.81	0.0	NA
7	1983	3.71	0.0	0.0	0.0	0.27	0.0	NA
8	1983	6.21	0.49	0.15	2.62	2.72	1.49	NA
9	1983	3.52	1.34	0.0	1.19	0.0	0.36	NA
10	1983	2.21	0.10	0.0	0.0	0.73	0.13	NA
11	1983	4.98	2.73	3.71	2.52	3.36	3.08	NA
12	1983	3.66	2.17	2.94	1.40	2.00	2.13	NA
1	1984	3.53	2.05	2.70	1.27	1.12	1.78	NA
2	1984	5.34	3.71	4.36	2.43	2.78	3.32	NA
3	1984	6.05	3.57	4.39	2.82	3.44	3.55	NA
4	1984	7.11	4.54	3.90	3.22	4.64	4.07	NA