Figure 25

Storm Runoff - Basin 2

Figure 26

Storm Runoff - Basin 3

TABLE 4

MONTHLY GROUNDWATER RECHARGE TO THE TRIASSIC
BRUNSWICK FORMATION
CALCULATED BY THE BASEFLOW RECESSION METHOD

Month		Groundwater Recharge Gallons/Day/Square Mile (inches) Basin 1	Basin 2	Basin 3
December	1982	441,000 (0.79)	394,000 (0.70)	406,000 (0.72)
January	1983	704,000 (1.26)	466,000 (0.83)	770,000 (1.37)
February	1983	1,103,000 (1.78)	920,000 (1.48)	1,195,000 (1.93)
March	1983	1,556,000 (2.78)	1,436,000 (2.56)	1,644,000 (2.93)
April	1983	820,000 (1.41)	1,295,000 (2.23)	2,119,000 (3.66)
May	1983	362,000 (0.65)	344,000 (0.61)	754,000 (1.34)*
June	1983	77,000 (0.13)	114,000 (0.20)	341,000 (0.59)*
July	1983	0 (0)	0 (0)	177,000 (0.32)*
August	1983	0 (0)	0 (0)	62,000 (0.11)*
September	1983	0 (0)	0 (0)	70,000 (0.12)
October	1983	0 (0)	55,000 (0.10)	101,000 (0.18)
November	1983	232,000 (0.40)	359,000 (0.62)	313,000 (0.54)
Average		441,000 (0.77)	449,000 (0.78)	663,000 (1.15)
Total		--- (9.20)	--- (9.33)	--- (13.81)

* Estimated
--- Not applicable

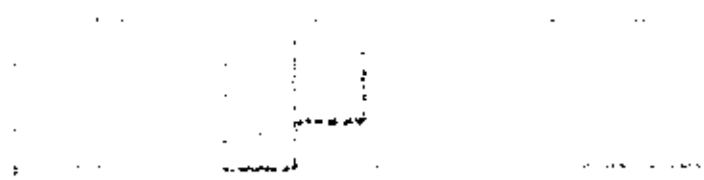


TABLE 4

MONTHLY GROUNDWATER RECHARGE TO THE TRIASSIC
BRUNSWICK FORMATION
CALCULATED BY THE BASEFLOW RECESSION METHOD

Month		Groundwater Recharge Gallons/Day/Square Mile (inches) Basin 1	Basin 2	Basin 3
December	1982	441,000 (0.79)	394,000 (0.70)	406,000 (0.72)
January	1983	704,000 (1.26)	466,000 (0.83)	770,000 (1.37)
February	1983	1,103,000 (1.78)	920,000 (1.48)	1,195,000 (1.93)
March	1983	1,556,000 (2.78)	1,436,000 (2.56)	1,644,000 (2.93)
April	1983	820,000 (1.41)	1,295,000 (2.23)	2,119,000 (3.66)
May	1983	362,000 (0.65)	344,000 (0.61)	754,000 (1.34)*
June	1983	77,000 (0.13)	114,000 (0.20)	341,000 (0.59)*
July	1983	0 (0)	0 (0)	177,000 (0.32)*
August	1983	0 (0)	0 (0)	62,000 (0.11)*
September	1983	0 (0)	0 (0)	70,000 (0.12)
October	1983	0 (0)	55,000 (0.10)	101,000 (0.18)
November	1983	232,000 (0.40)	359,000 (0.62)	313,000 (0.54)
Average		441,000 (0.77)	449,000 (0.78)	663,000 (1.15)
Total		--- (9.20)	--- (9.33)	--- (13.81)

* Estimated
--- Not applicable

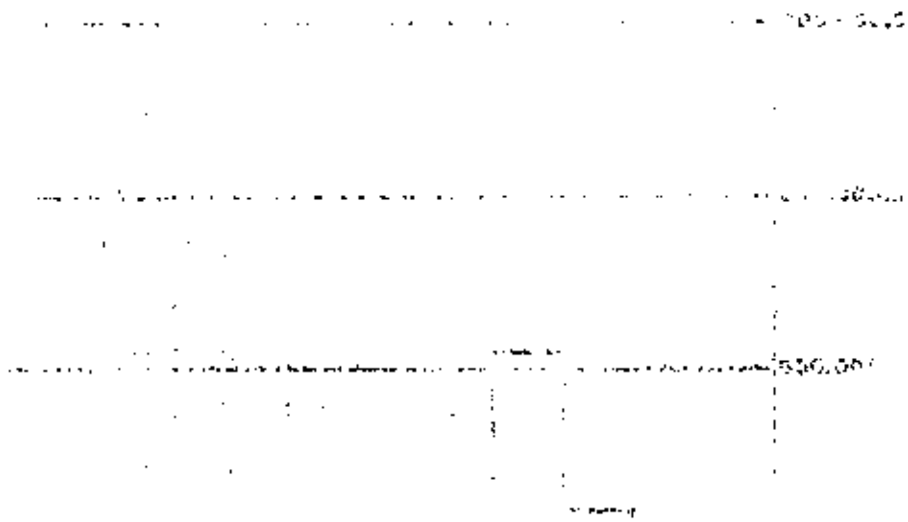


Figure 27

Monthly Groundwater Recharge
Calculated By The Baseflow Recession Method
BASIN 1

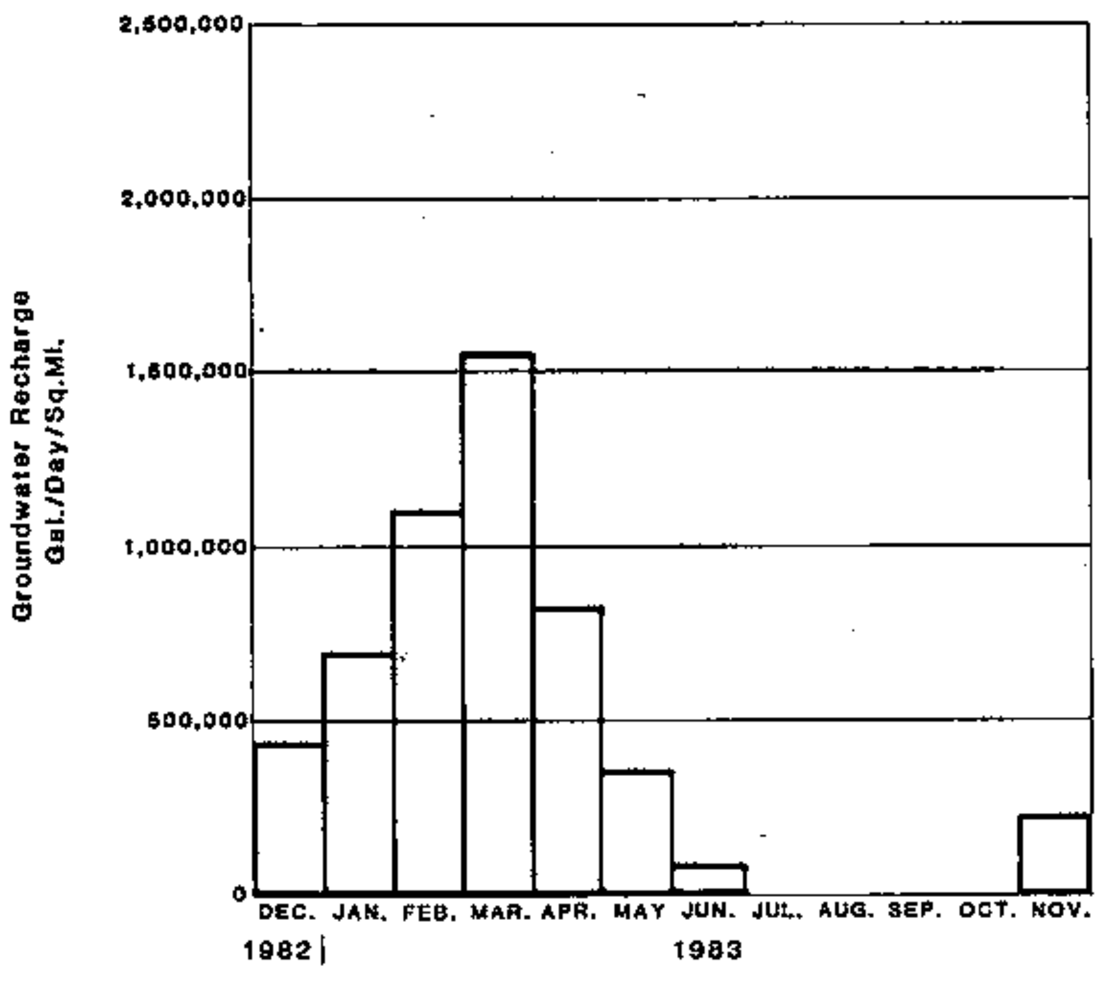
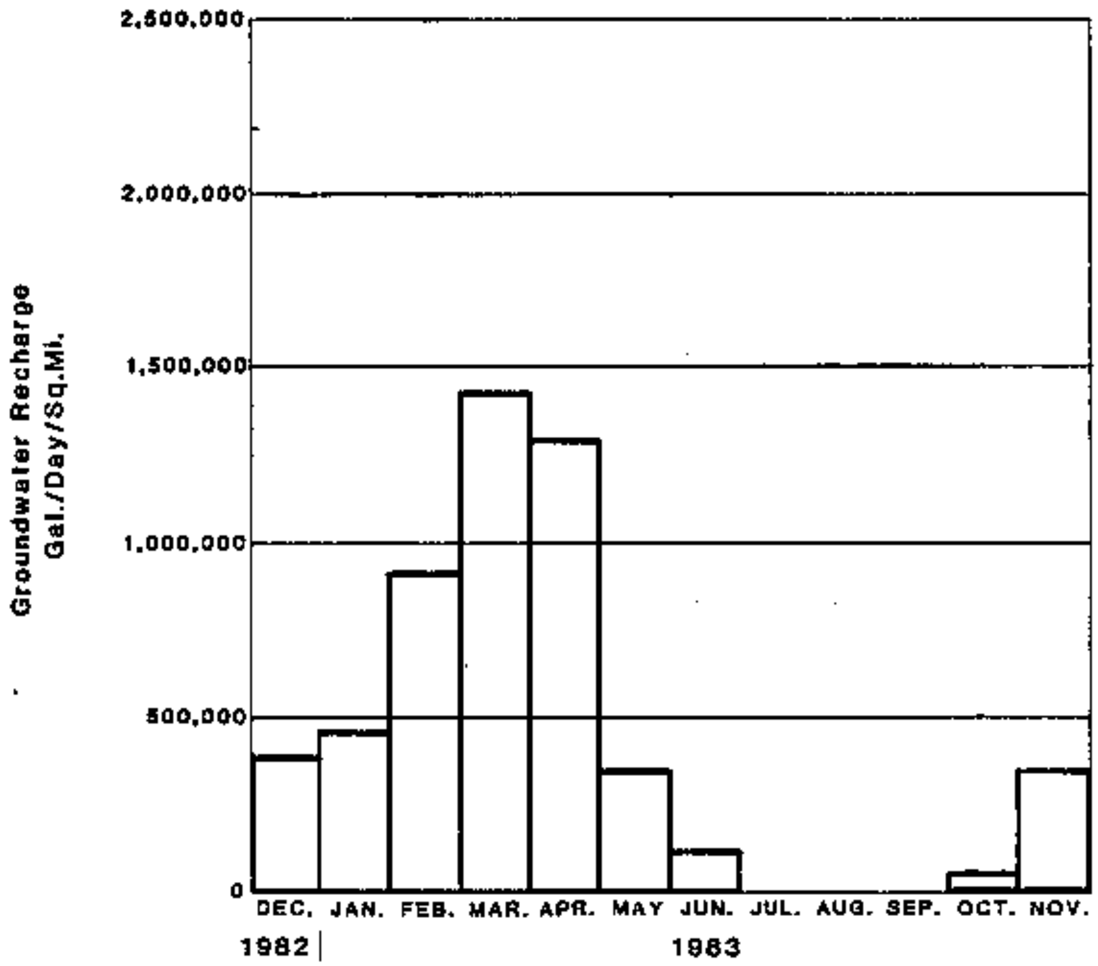


Figure 28

Monthly Groundwater Recharge
Calculated By The Baseflow Recession Method
BASIN 2



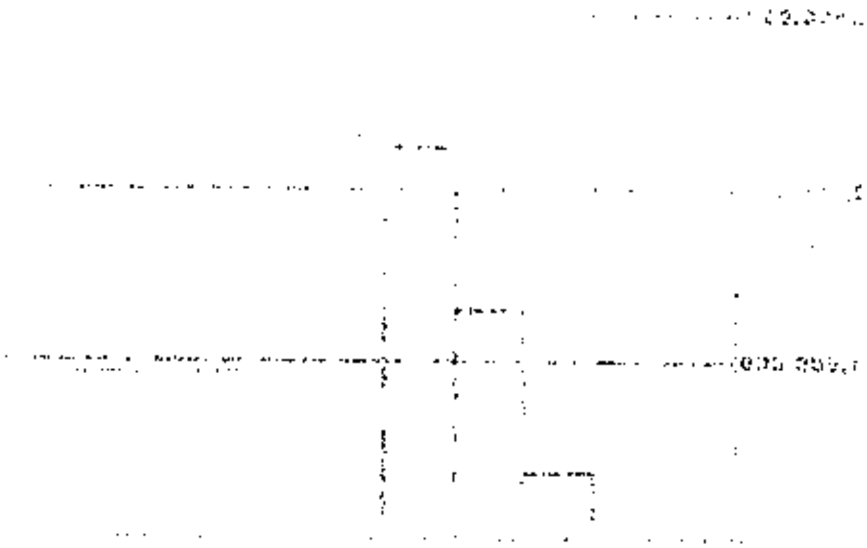
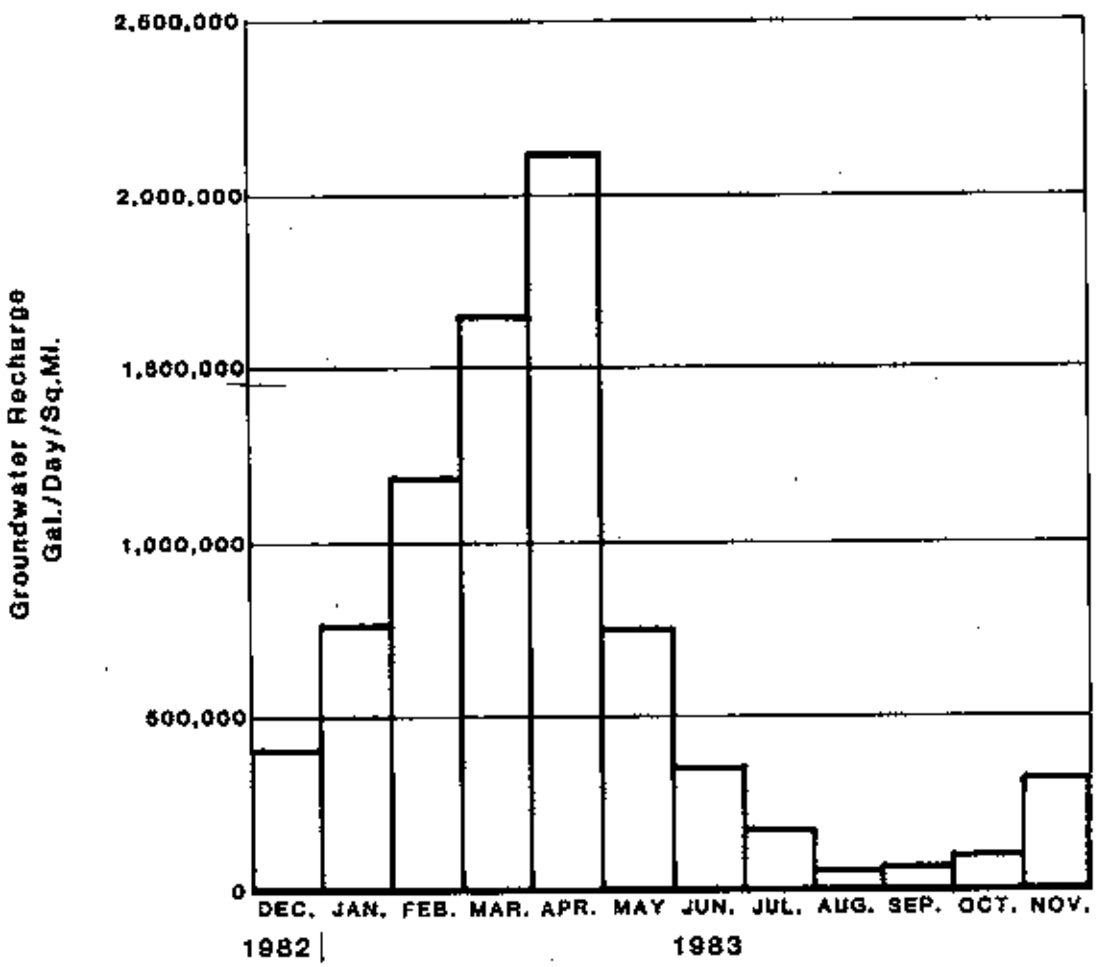


Figure 29

Monthly Groundwater Recharge
Calculated By The Baseflow Recession Method
BASIN 3



monthly recharge rates ranging from zero to 1,436,000 gallons/day/square mile and an average annual recharge rate of 449,000 gallons/day/square mile. Average monthly recharge rates for Basin 3 ranged from 52,000 to 2,119,000 gallons/day/square mile yielding an average annual recharge rate of 663,000 gallons/day/square mile.

6.2 Hydrologic Budget

Groundwater recharge was calculated using the following hydrologic budget equation:

$$R = P-ET-Q$$

where R is groundwater recharge, P is precipitation, ET is evapotranspiration and Q is surface runoff. Examples of the recharge calculations are presented in Appendix B. Precipitation data from rain gauges located in Basins 2 and 3 were used in this calculation. This data is compared with data from NOAA stations in Philadelphia and Allentown in Table 5. Due to a lack of data from Basin 3 for the months of May, June, July, August and September, precipitation data from Basin 2 was substituted for this period. Annual precipitation in the study area was fairly consistent with data from Allentown while Philadelphia recorded slightly higher levels. Precipitation at the four locations ranged from 43.03 inches at Basin 2 to 48.84 inches at Philadelphia with an average of 46.10 inches.

TABLE 5

MONTHLY PRECIPITATION
(INCHES)

Month		Basin 1 & Basin 2	Basin 3	Philadelphia*	Allentown*
December	1982	1.26	1.57	1.80	1.38
January	1983	3.06	2.96	2.81	2.84
February	1983	3.06	3.58	3.53	3.21
March	1983	5.96	5.38	6.70	5.35
April	1983	8.02	8.38	8.12	7.87
May	1983	4.64	4.64**	7.03	4.21
June	1983	2.20	2.20**	2.75	4.68
July	1983	0.95	0.95**	0.68	2.02
August	1983	1.60	1.60**	2.57	2.38
September	1983	1.97	1.97**	3.45	1.41
October	1983	4.52	6.00	3.69	4.83
November	1983	5.79	6.83	5.71	6.29
Total		43.03	46.06	48.84	46.47

*Source: National Oceanographic and Atmospheric Administration, local climatological data summaries
**Data taken from Basin 1

Surface runoff was determined through separation of the stream hydrographs into their components. Monthly surface runoff for each of the basins is presented in Table 6. The highest surface runoff occurred during the months of February, March and April in all three basins. Months with the least surface runoff were July, August, and September. Total surface runoff for the year ranged from 4.55 inches in Basin 1 to 9.60 inches in Basin 3.

Evapotranspiration was calculated using the methods of Thornthwaite (1948) and Eagleman (1967). Both of these methods yield the monthly potential evapotranspiration. Eagleman also provides a method for estimating actual evapotranspiration.

A summary of the climatic data used in the calculations is presented in Table 7 and the resultant evapotranspiration data are presented in Table 8. Monthly potential evapotranspiration calculated using the Thornthwaite (1948) method was considerably less than that calculated using the Eagleman (1967) method. The total potential evapotranspiration for the year was determined to be 25.31 inches using the Thornthwaite (1948) method and 41.47 inches using the Eagleman (1967) method. Actual evapotranspiration was estimated to be 29.86 inches for the year based upon Eagleman (1967).

The actual evapotranspiration calculated by the Eagleman method was

TABLE 6

MONTHLY SURFACE RUNOFF
(INCHES)

Month		Basin 1	Basin 2	Basin 3
December	1982	0.10	0.04	0.06
January	1983	0.24	0.43	0.47
February	1983	1.16	0.64	1.74
March	1983	1.63	1.04	1.46
April	1983	1.17	1.34	2.28
May	1983	0	0.50	0.73*
June	1983	0	0.26	0.36*
July	1983	0	0	0.16*
August	1983	0	0.14	0.10*
September	1983	0	0.14	0.29
October	1983	0	0.24	0.53
November	1983	0.25	0.74	1.42
Total		4.55	5.51	9.60

* Estimated

TABLE 7

MEAN MONTHLY TEMPERATURE AND RELATIVE HUMIDITY

Month		Mean Monthly* Temperature (°C)	Mean Monthly Percent** Relative Humidity
December	1982	4.3	75
January	1983	-0.02	69
February	1983	0.2	65
March	1983	6.3	63
April	1983	10.4	66
May	1983	16.4	67
June	1983	21.7	66
July	1983	24.6	62
August	1983	24.3	66
September	1983	19.9	64
October	1983	13.1	71
November	1983	6.5	74

*Source: Upper Perkiomen Valley Park, Green Lane, Pennsylvania
**Source: National Oceanographic and Atmospheric Administration average of Philadelphia and Allentown relative humidity data

TABLE 8

MONTHLY EVAPOTRANSPIRATION IN THE STUDY AREA
(INCHES)

Month		Potential		Actual
		Thornthwaite (1948)	Eagleman (1967)	Eagleman (1967)
December	1982	0.44	1.15	0.83
January	1983	0	0.73	0.53
February	1983	0.01	0.92	0.66
March	1983	0.73	1.65	1.19
April	1983	1.47	2.50	1.80
May	1983	2.73	4.09	2.94
June	1983	4.05	6.00	4.32
July	1983	4.80	7.56	5.44
August	1983	4.71	6.92	4.98
September	1983	3.58	5.55	4.00
October	1983	2.02	3.01	2.17
November	1983	0.77	1.39	1.00
Total		25.31	41.47	29.86

used in the groundwater recharge calculations. Annual potential evapotranspiration as calculated by the Thornthwaite method is much lower than would be expected for the study area. Based upon the results from both methods and Eagleman's comparison of the two methods, which is discussed in Section 4.4, it is apparent that the Eagleman method is more accurate.

Monthly groundwater recharge rates calculated for each of the basins using the hydrologic budget are presented in Table 9 and illustrated in Figures 30, 31, and 32. The highest recharge rates occurred during the month of April in all three basins as illustrated in Figures 20, 21 and 22. Groundwater recharge for April ranged from 2,493,000 gallons/day/square mile in Basin 3 to 2,942,000 gallons/day/square mile in Basin 1. During the months of June, July, August and September each of the basins had water deficits. Average annual recharge was calculated to be 424,000 gallons/day/square mile, 321,000 gallons/day/square mile and 380,000 gallons/day/square mile for Basins 1, 2, and 3 respectively.

Monthly precipitation, evapotranspiration, storm runoff and recharge, in inches are plotted for the three basins in Figures 33, 34, and 35. These graphs facilitate a comparison of the proportions of these four parameters throughout the year. It is evident that the majority of the annual precipitation is lost to evapotranspiration. In fact, approximately 67 percent of the annual precipitation

TABLE 9

MONTHLY GROUNDWATER RECHARGE TO THE
TRIASSIC BRUNSWICK FORMATION
CALCULATED BY THE HYDROLOGIC BUDGET METHOD

Month		Groundwater Recharge Gallons/Day/Square Mile (inches)		
		Basin 1	Basin 2	Basin 3
December	1982	178,000 (0.33)	212,000 (0.39)	385,000 (0.68)
January	1983	1,268,000 (2.29)	1,159,000 (2.10)	1,103,000 (1.96)
February	1983	766,000 (1.24)	1,088,000 (1.76)	732,000 (1.18)
March	1983	1,792,000 (3.14)	2,120,000 (3.73)	1,534,000 (2.73)
April	1983	2,942,000 (5.05)	2,845,000 (4.88)	2,493,000 (4.30)
May	1983	926,000 (1.70)	644,000 (1.20)	542,000 (0.97)*
June	1983	-1,228,000 (-2.12)	-1,380,000 (-2.38)	-1,438,000 (-2.48)*
July	1983	-2,517,000 (-4.49)	-2,517,000 (-4.49)	-2,608,000 (-4.65)*
August	1983	-1,895,000 (-3.38)	-1,975,000 (-3.52)	-1,954,000 (-3.48)*
September	1983	-1,140,000 (-2.03)	-1,222,000 (-2.17)	-1,339,000 (-2.32)
October	1983	1,359,000 (2.35)	1,225,000 (2.11)	1,850,000 (3.30)
November	1983	2,638,000 (4.54)	2,355,000 (4.05)	2,557,000 (4.41)
Average		424,000 (0.73)	380,000 (0.66)	321,000 (0.55)
Total		--- (8.62)	--- (7.66)	--- (6.60)

Note: Negative sign indicates groundwater loss for the month
--- Not applicable
* Estimated

Figure 30

Monthly Groundwater Recharge Calculated by the Hydrologic Budget Method Basin 1

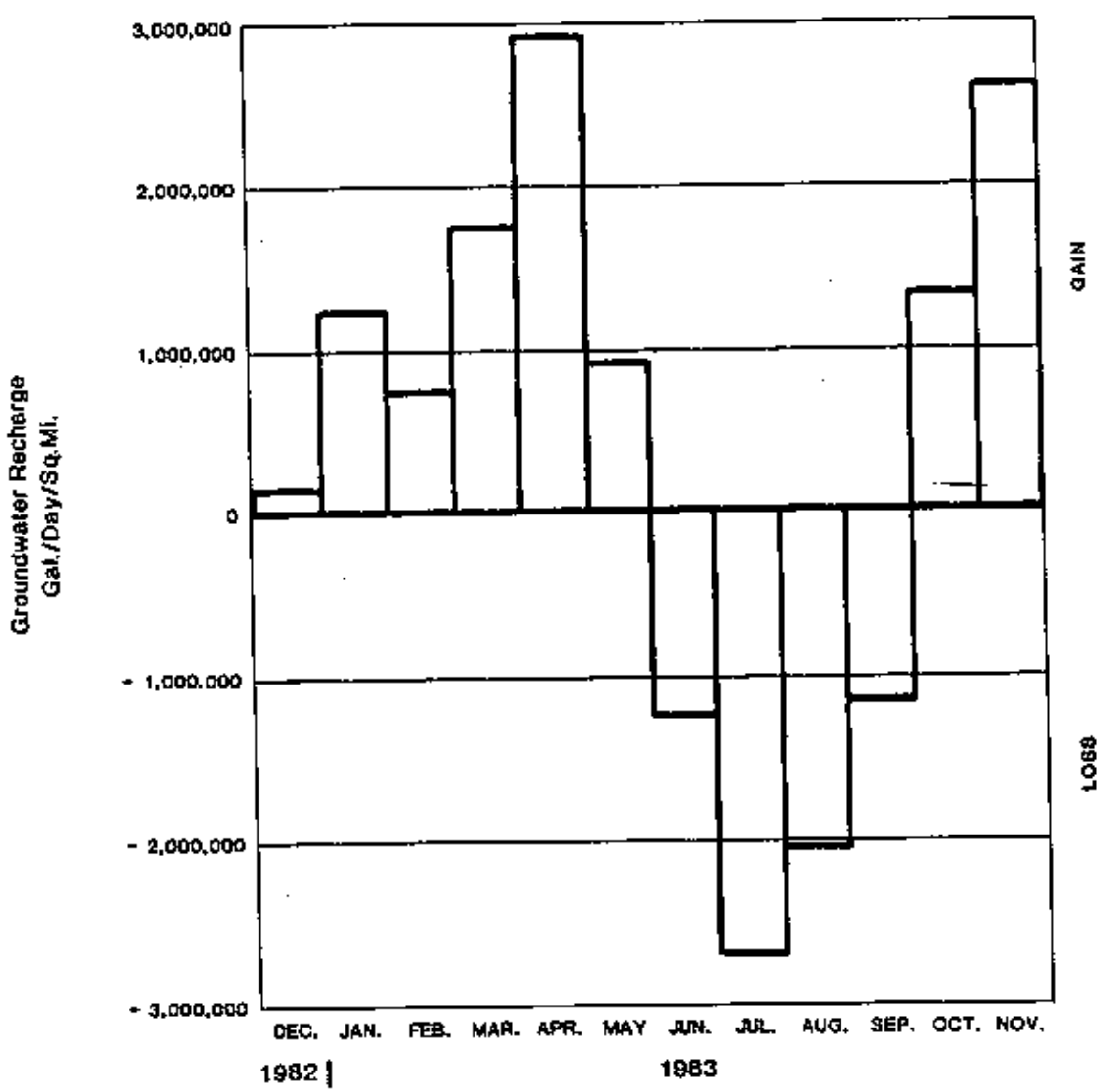


Figure 31

Monthly Groundwater Recharge Calculated by the Hydrologic Budget Method Basin 2

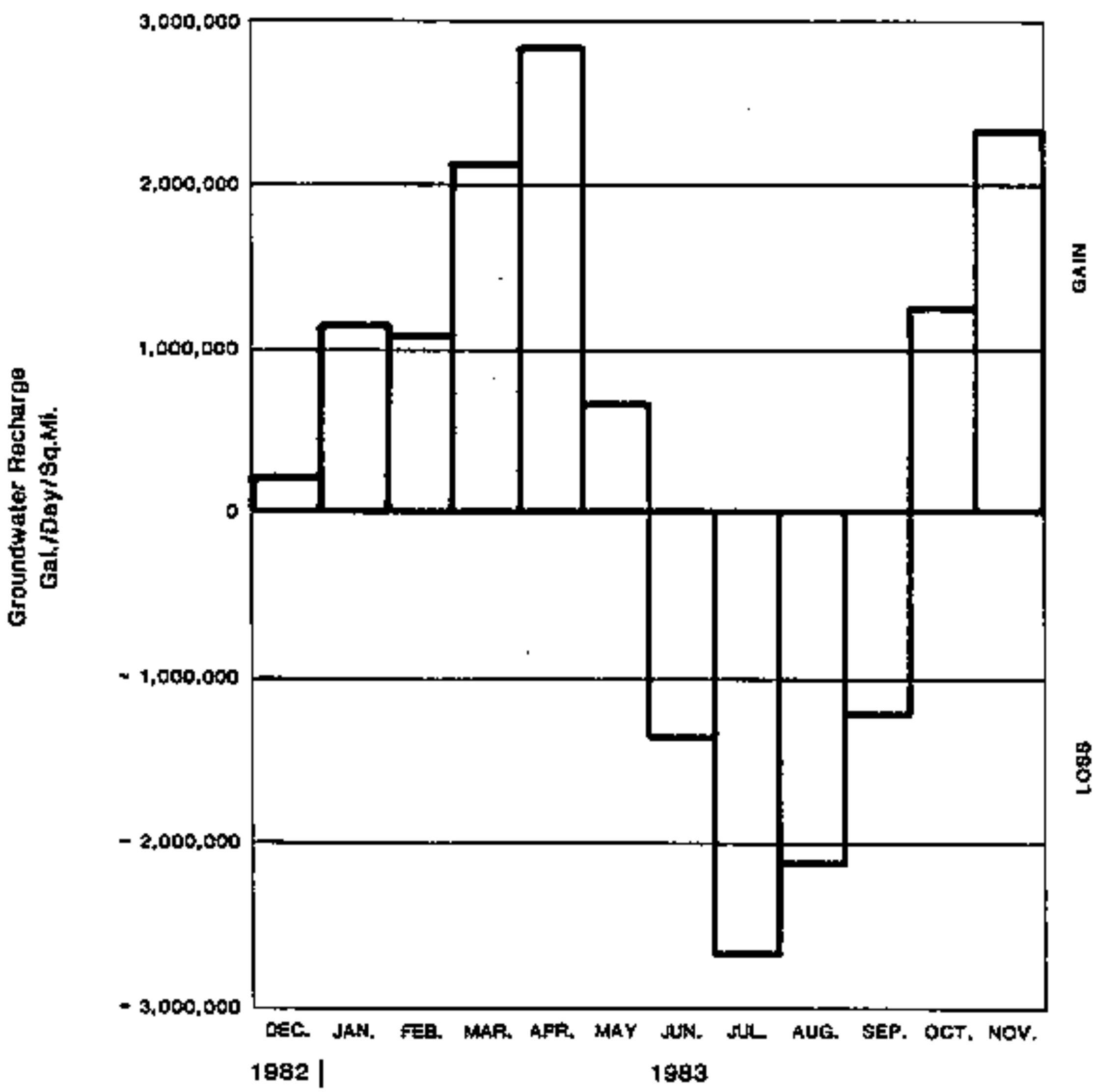


Figure 32

Monthly Groundwater Recharge
Calculated by the Hydrologic Budget Method
BASIN 3

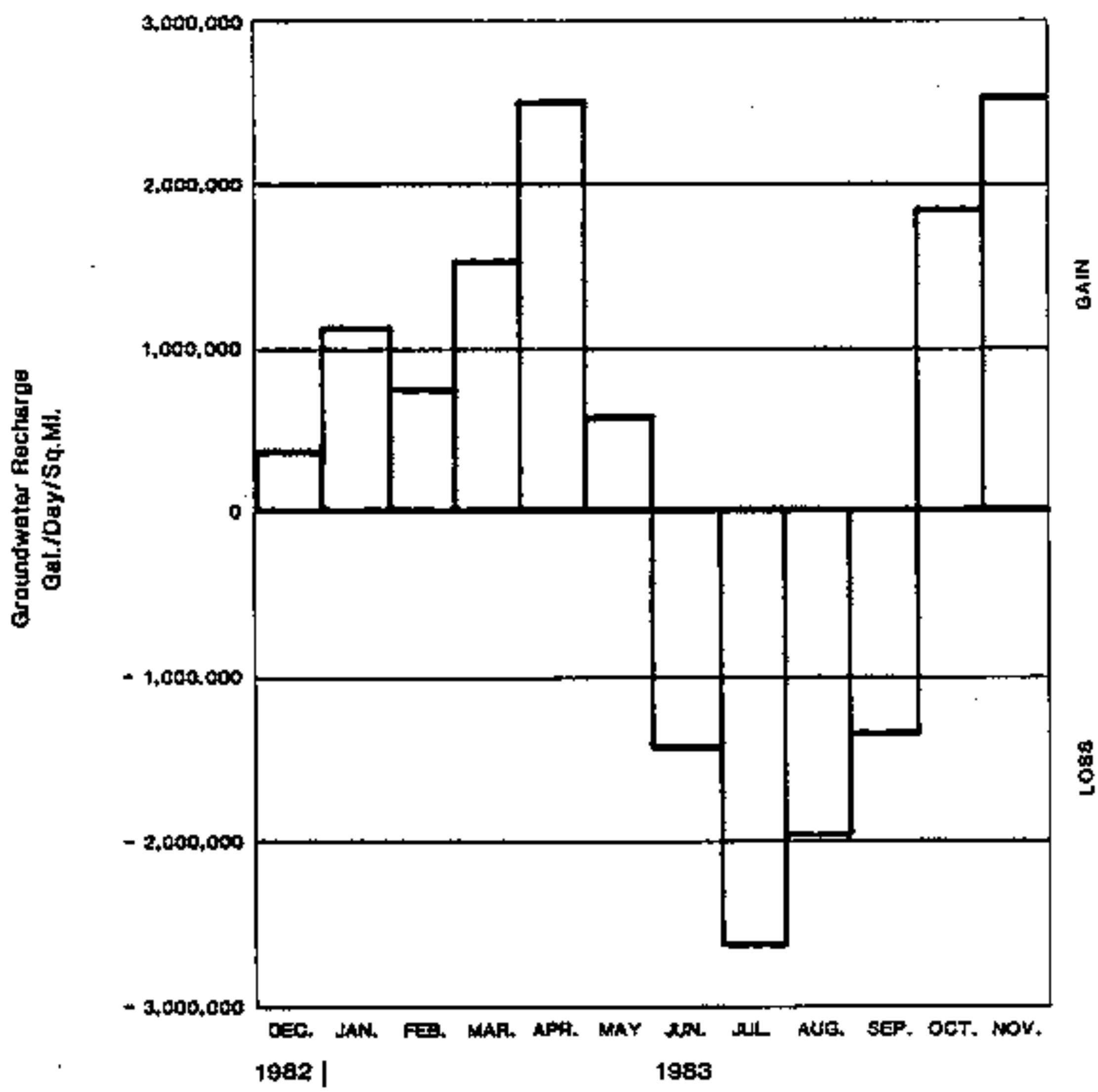


Figure 33

Relationship Between Precipitation, Evapotranspiration, Surface Runoff, and Groundwater Recharge - Basin 1

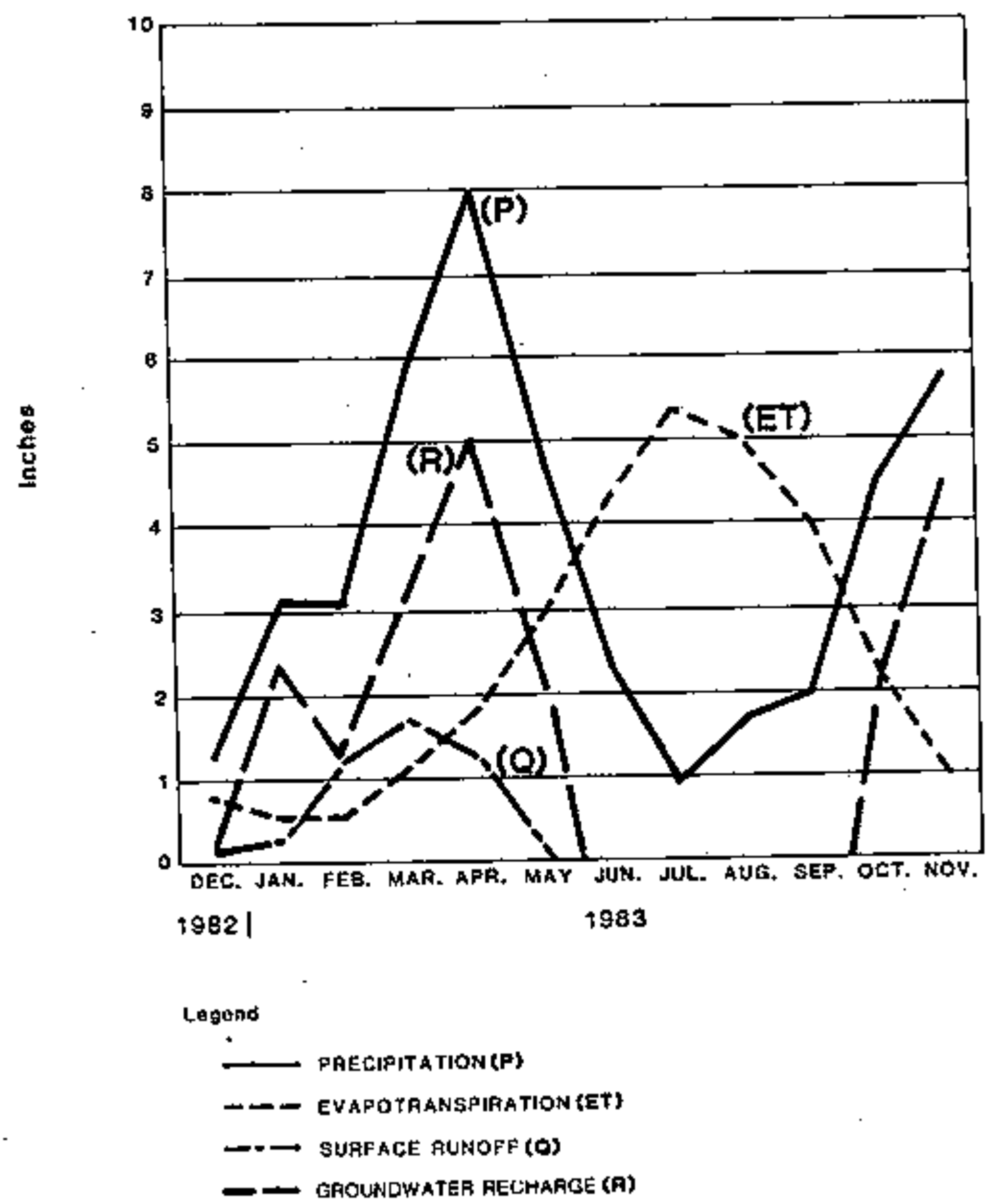


Figure 34

Relationship Between Precipitation, Evapotranspiration, Surface Runoff, and Groundwater Recharge - Basin 2

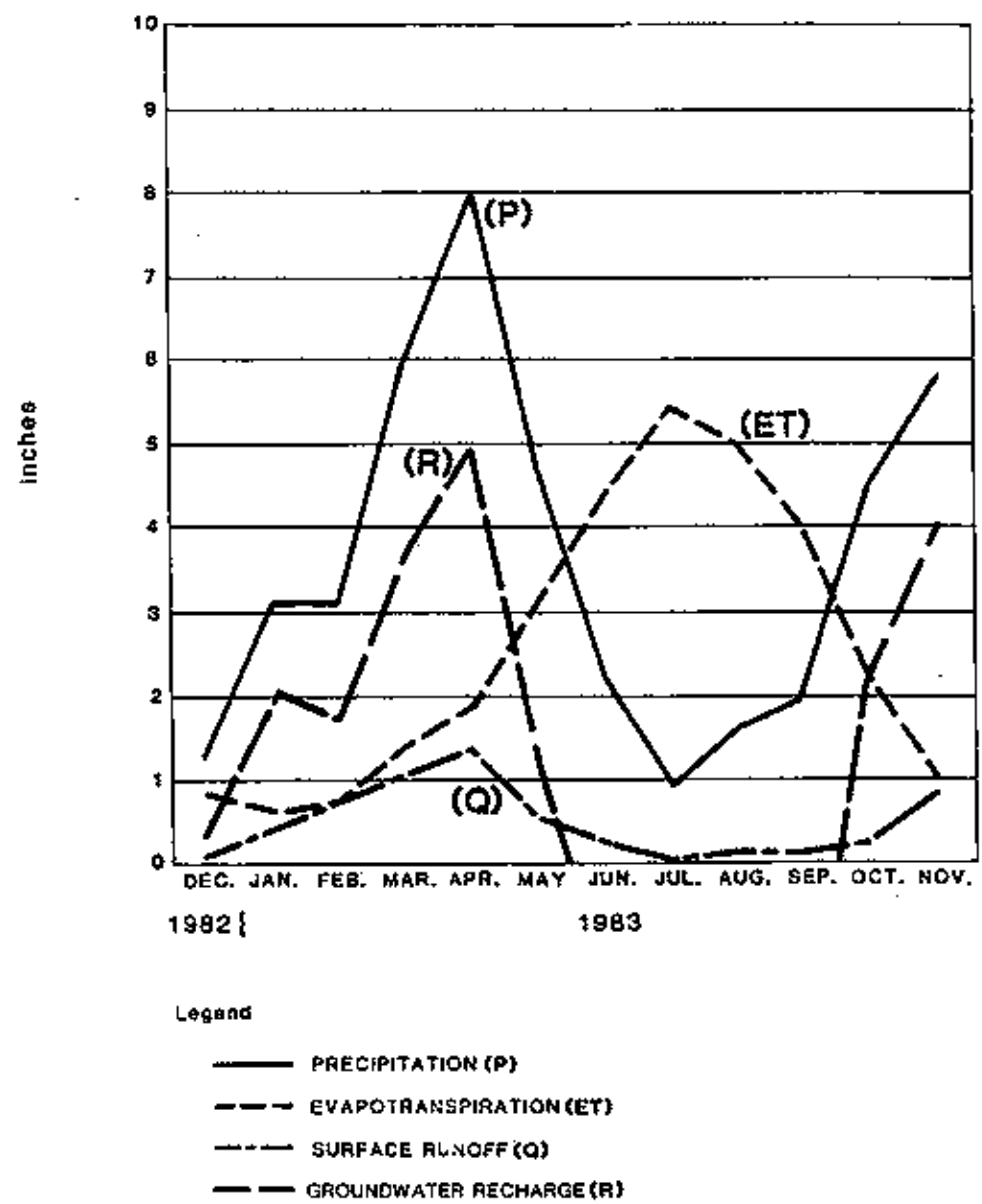
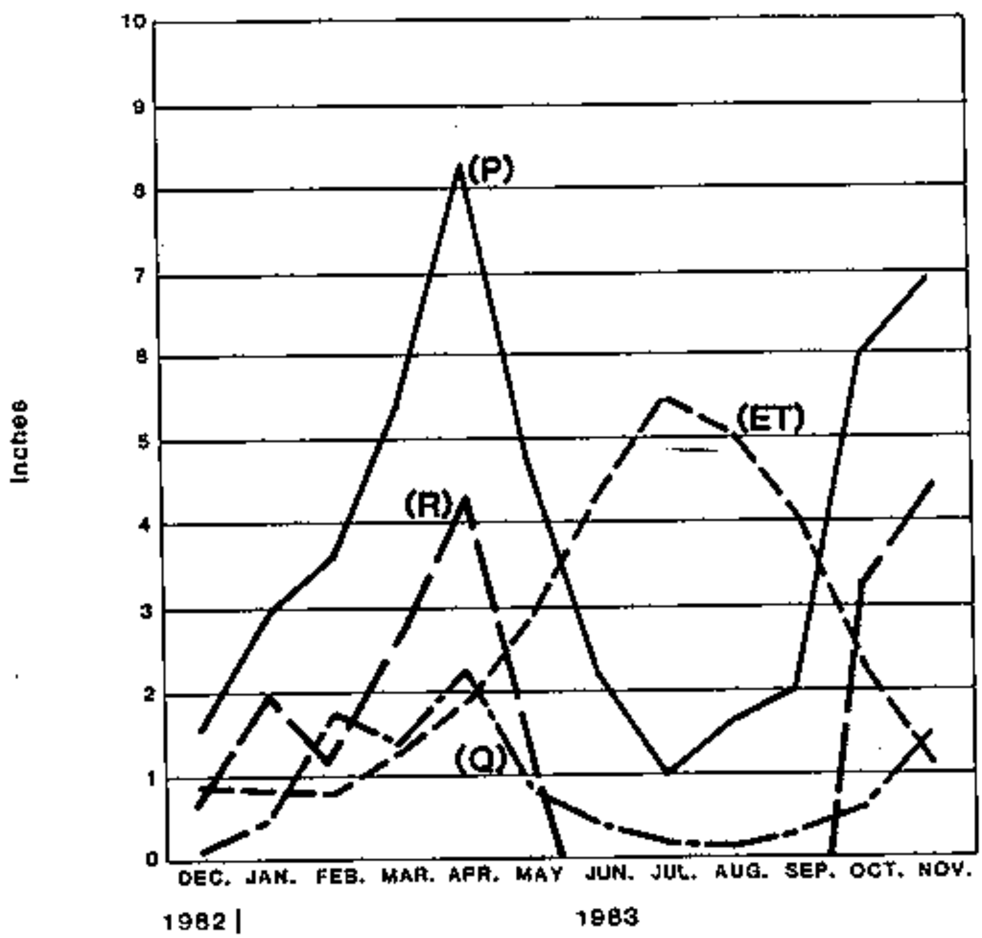


Figure 35

Relationship Between Precipitation Evapotranspiration, Surface Runoff, and Groundwater Recharge - Basin 3



Legend

- PRECIPITATION (P)
- EVAPOTRANSPIRATION (ET)
- SURFACE RUNOFF (Q)
- GROUNDWATER RECHARGE (R)

is evaporated or transpired. The total percentage of precipitation which was lost as storm runoff ranged from 11 percent in Basin 1 to 21 percent in Basin 2. Groundwater recharge accounted for 20 percent, 28 percent and 14 percent of the annual precipitation in Basins 1, 2 and 3, respectively.

6.3 Summary of Results

A summary of the calculated average annual groundwater recharge rates is presented in Table 10. The average of the groundwater recharge rates for the three basins studied, calculated by the base-flow recession method and the average of the groundwater recharge rates calculated by the hydrologic budget method are 518,000 gallons/day/square mile and 375,000 gallons/day/square mile respectively. The average of all calculated groundwater recharge rates is 447,000 gallons/day/ square mile.

TABLE 10

SUMMARY OF CALCULATED
AVERAGE ANNUAL GROUNDWATER RECHARGE RATES

(GALLONS/DAY/SQUARE MILE)

	Baseflow Method	Hydrologic Budget	Average
Basin 1	441,000	424,000	433,000
Basin 2	449,000	380,000	415,000
Basin 3	663,000	321,000	492,000
Average	518,000	375,000	447,000

7.0 CONCLUSIONS AND DISCUSSIONS

The objectives of this study were to compare the baseflow recession and hydrologic budget methods of calculating groundwater recharge, to assess the accuracy of previously published recharge rates for the Brunswick Formation and determine if there is significant areal variation in recharge rates. These objectives were accom- plished; however, the destruction of a weir and the resultant gap in the streamflow data from Basin 3, made it necessary to estimate base-flow and storm runoff for four months. As a result of this, the accuracy of the calculated recharge rates for Basin 3 was diminished, making an assessment of the areal variation in groundwater recharge less accurate.

7.1 Comparison of Methods

There are advantages and disadvantages associated with the use of both the baseflow recession and hydrologic budget methods. The baseflow recession method requires only streamflow data whereas the hydrologic budget also requires various forms of climatological data. Evapotranspiration is probably the most difficult parameter to determine for a hydrologic budget. Due to the fact that lysimeters are usually expensive to install and operate, empirical formulas are primarily used for calculating evapotranspiration. The accuracy of these formulas is generally proportional to their complexity. Some of the more complex methods require very detailed meteorological data such as wind speeds at two heights above the ground and other information which is not readily available and is expensive to collect. The Eagleman (1967) method is one of the more accurate of the methods not requiring voluminous inputs, in the opinion of the writer.

Another disadvantage of the hydrologic budget is that storm runoff, which is difficult to measure, must be quantitified. However, the storm runoff which must be approximated when not measurable is less important than evapotranspiration. This is illustrated by the fact that with an annual rainfall of 44.5 inches, 30.0 inches of water are lost to evaporation and transpiration, and approximately 6.5 inches are lost as storm runoff.

Use of a hydrologic budget allows calculation of more realistic monthly groundwater recharge rates, particularly for the summer months. During periods of zero stream flow, the basin is represented as having no groundwater recharge when using the baseflow recession method. In actuality, there can be a severe groundwater deficit during these periods as shown in the monthly hydrologic budget data. Months with low flows may be determined to have low groundwater recharge rates by the baseflow recession method when in reality, they have water losses. The baseflow recession method is best suited for determining groundwater recharge over longer periods of time, such as a year or more, whereas a hydrologic budget is applicable for most time intervals.

Annual recharge rates calculated by the baseflow recession method were consistently greater than those calculated using the hydrologic budget. Differences in the recharge rates determined by the two methods are probably representative of inaccuracies in the evapotranspiration calculations. All of the other parameters which were measured directly in the field should be more accurate than the evapotranspiration which was calculated through an empirical formula.

The groundwater recharge rate for Basin 3 was greater than Basins 1 and 2 as determined by the baseflow method. Based upon the hydrologic budget, however, the opposite was true. Considering the reliability of the data and the lithology of Basin 3 the recharge rates calculated by the baseflow method are probably the most accurate.

7.2 Comparison of Calculated and Previously Published Recharge Rates

The hydrologic budget yielded annual groundwater recharge rates which are fairly consistent with the published range of 300,000 to 400,000 gallons/day/square mile. Annual recharge rates calculated by the baseflow recession method were slightly higher than the published range of recharge rates.

Groundwater recharge rates calculated in this study and by Moody and Associates (1975) are based upon data from a period of one year. Variations in annual precipitation and other meteorologic conditions result in variations in annual groundwater recharge rates. Moody and Associates (1975) state that they selected the 1970 hydrologic year "because it was considered representative of a year of normal precipitation and recharge conditions." The average annual precipitation for the study area based upon NOAA Local Climatological Data Summaries for Allentown and Philadelphia, Pennsylvania is 42.47 inches. This average is derived from data for the period from 1944 to 1981. NOAA data also indicates that annual precipitation for the 1970 hydrologic year, totalled 38.06 inches. Annual precipitation measured during this study was 43.03 inches in Basin 1 and 46.06 inches in Basin 3. Thus, conditions were slightly wetter than average during this study, which may explain why groundwater re- charge rates calculated by the baseflow method exceeded the range established by Moody and Associates (1975).

7.3 Areal Variation in Groundwater Recharge

Groundwater recharge rates calculatd for Basin 1 and Basin 2 using the baseflow recession and hydrologic budget methods were very similar. The groundwater recharge rates calculated for Basin 3 were significantly different from Basin 1 and Basin 2. Results of the baseflow recession method indicate that recharge was approximately 50 percent greater in Basin 3 than the other two basins. Based upon the hydrologic budget, recharge in Basin 3 was 15 to 25 percent lower than Basin 1 and Basin 2. The results of the baseflow recession method appear to be more consistent with geologic conditions in Basin 3. The presence of the fanglomerate and the aureole associated with the diobase intrusives would be expected to increase recahrge in Basin 3.

7.4 General Conclusions

Monthly groundwater recharge rates illustrate the fact that groundwater recharge is influenced by both climatic and geologic factors. For example, recharge was greatest during April when the average for the three basins was 2,760,000 gallons/day/square mile. If this recharge rate can occur in April, then geologically it is feasible throughout the year. The reason for less recharge during the remaining months is the climate. Increased evapotranspiration and decreased precipitation are the primary factors. Maximum potential recharge would occur if an unlimited volume of precipitation were available and other climatic factors were excluded. The maximum potential recharge rate would be dependent solely upon the hydraulic conductivity of the aquifer and the overlying soils.

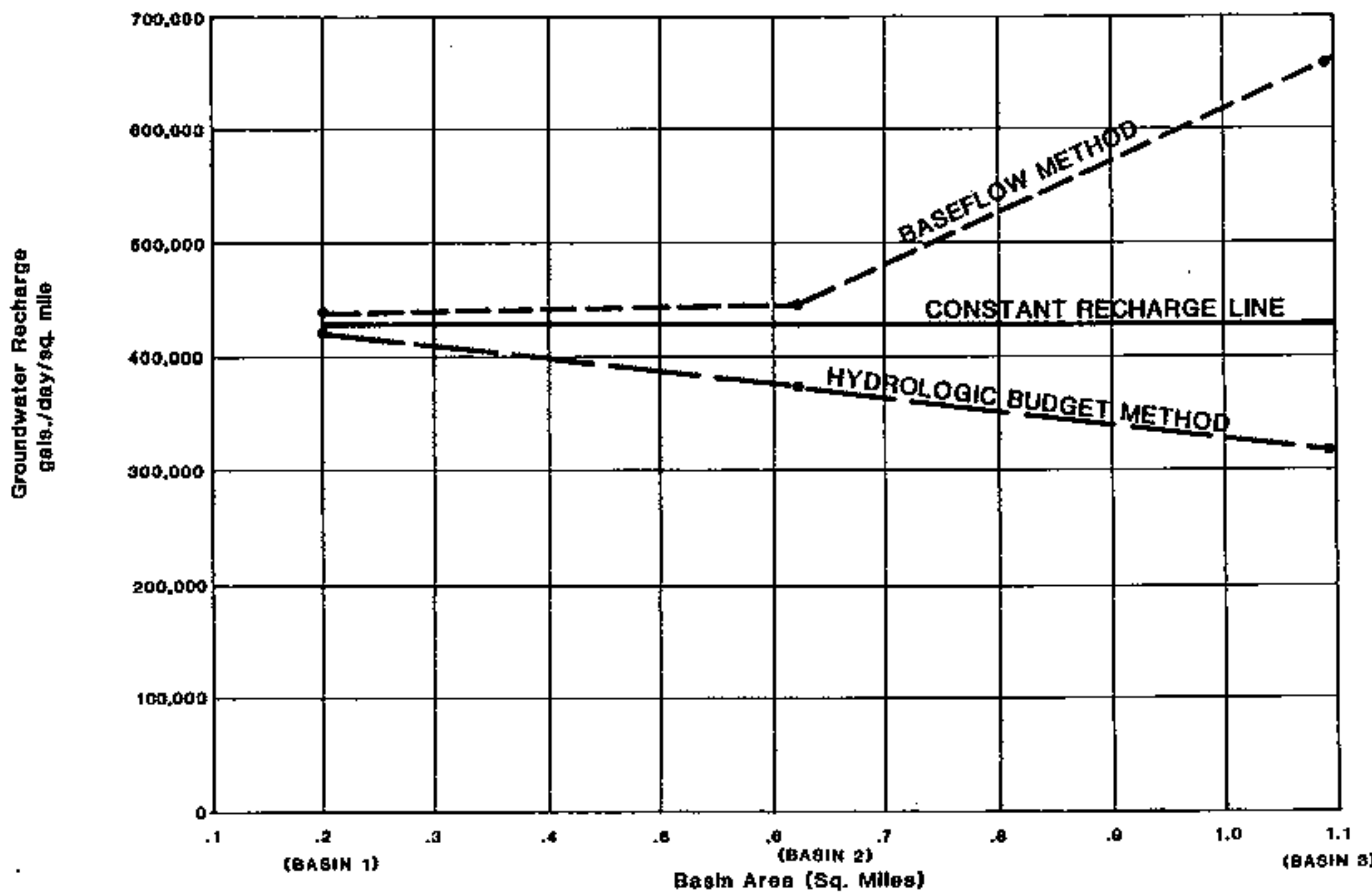
The results of the hydrologic budget indicate a large water deficit for the three basins during the months of June, July, August, and September. This deficit is due to evapotranspiration of soil moisture and evapotranspiration directly from the water table in areas where it is shallow. Groundwater evapotranspiration can represent a significant portion of the hydrologic budget. Olmstead and Hely (1962) reported that during the two years which they investigated, groundwater evapotranspiration in the Brandywine Creek watershed (west of study area) was equivalent to 11 percent of the average annual precipitation. Annual precipitation was six inches above normal during their investigation. A study conducted by R. E. Wright and Associates, Inc. (1983) indicated that groundwater evapotranspiration in the study area was equal to approximately 5 percent of the annual precipitation. During the period of the study by R. E. Wright and Associates, Inc. (1983) annual precipitation was about three inches below normal.

As seen in Figure 36 when the average groundwater recharge rates calculated in this study are plotted against basin area, the values obtained using the hydrologic budget method exhibit a linear trend. This trend indicates a constant decrease in the groundwater recharge rate with increasing basin area. Results from the baseflow method do not exhibit such a trend and conversely show an increase in the recharge rate with increasing basin area.

The United States Geological Survey records daily water levels in two wells in Montgomery County, Pennsylvania. These wells which are designated as MG-225 and MG-884 are located in Norristown and West Point, respectively. Well Mg-225 which is drilled in the Stockton Formation is 300 feet deep and Well MG-884 which is drilled in the

Figure 36

Relationship Between Groundwater Recharge and Basin Area

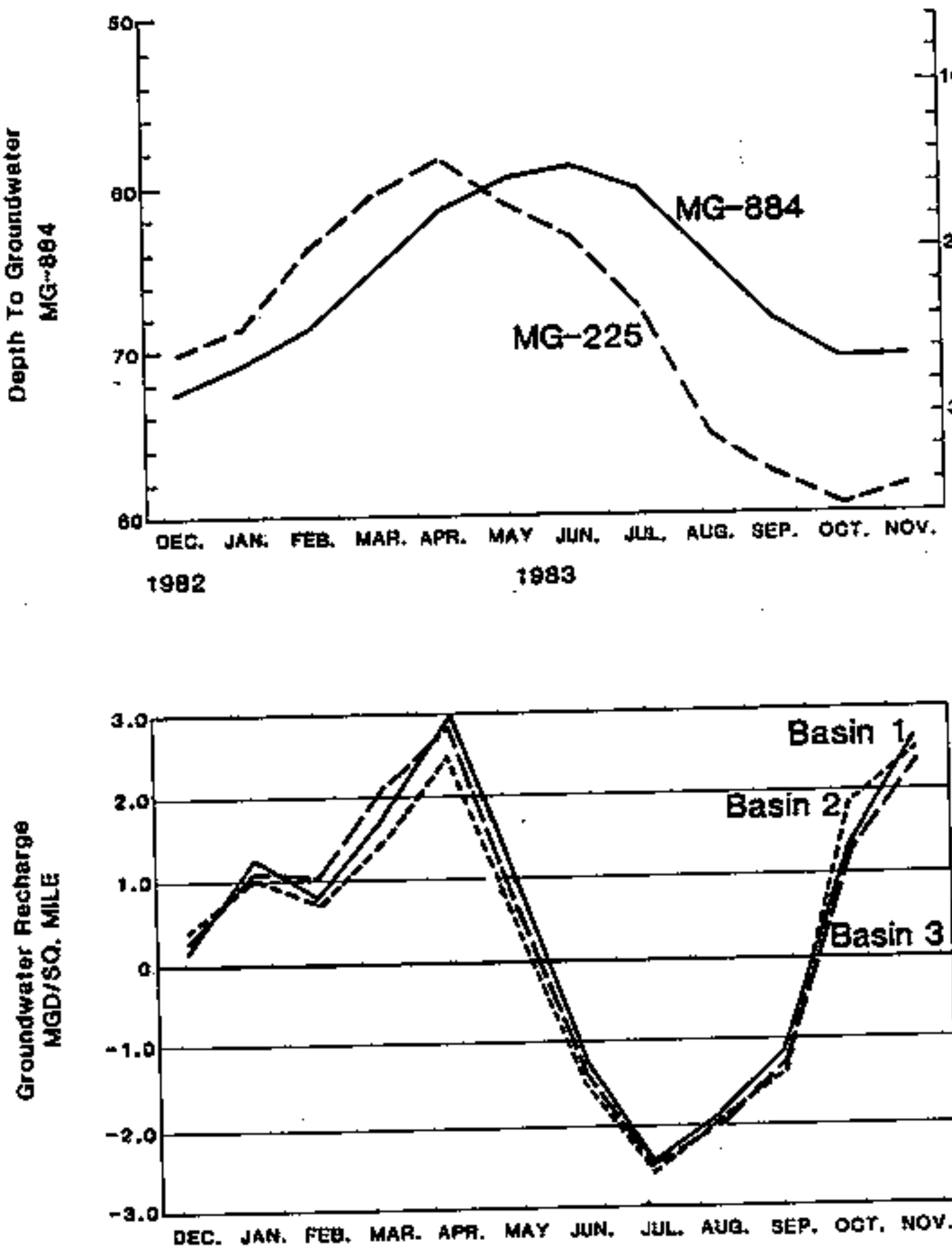


Brunswick Formation is 600 feet deep. Average monthly depth to water in these wells has been plotted on Figure 37, where it is compared with the monthly groundwater recharge rates calculated for the three basins using the hydrologic budget. Monthly groundwater recharge calculated by the baseflow method was not plotted since it is not as representative of actual conditions. Although Well MG-225 is not in the Brunswick Formation and neither of them are within the study basins, they do permit an evaluation of general groundwater fluctuations during the year.

Groundwater levels in Well MG-225 very closely reflected the changes in monthly groundwater recharge rates. Variations in the monthly groundwater recharge rates were also reflected in Well MG-884, however there was a lag time of over two months. The lag in the groundwater levels in MG-884 is probably due to the depth of the well. Due to the fact that weathering of the Brunswick Formation decreases rapidly below depths of approximately 200 feet, it is slightly more permeable at depth, resulting in slightly confined conditions (Longwill and Wood 1965).

Figure 37

Relationship Between Groundwater Levels and Groundwater Recharge



SOURCE OF GROUNDWATER LEVEL DATA: UNITED STATES GEOLOGICAL SURVEY.

8.0 SUMMARY OF CONCLUSIONS

Based upon the results of this study, the following conclusions have been made:

1. Both the baseflow and hydrologic budget methods yield reasonable annual groundwater recharge rates.

2. The hydrologic budget yields more accurate monthly groundwater recharge rates.

3. The baseflow method is easier to use and requires much less data.

4. The previously published range of groundwater recharge rates for the Brunswick Formation, 300,000 to 400,000 gallons/day/square mile may be slightly conservative.

5. The rate of groundwater recharge to the Brunswick Formation varies in different areas primarily due to geologic heterogeneity.

6. Climatic factors affect groundwater recharge as much as, if not more than, geologic factors within the Brunswick Formation.

7. Observed groundwater levels correspond fairly closely with seasonal variations in the groundwater recharge rate.

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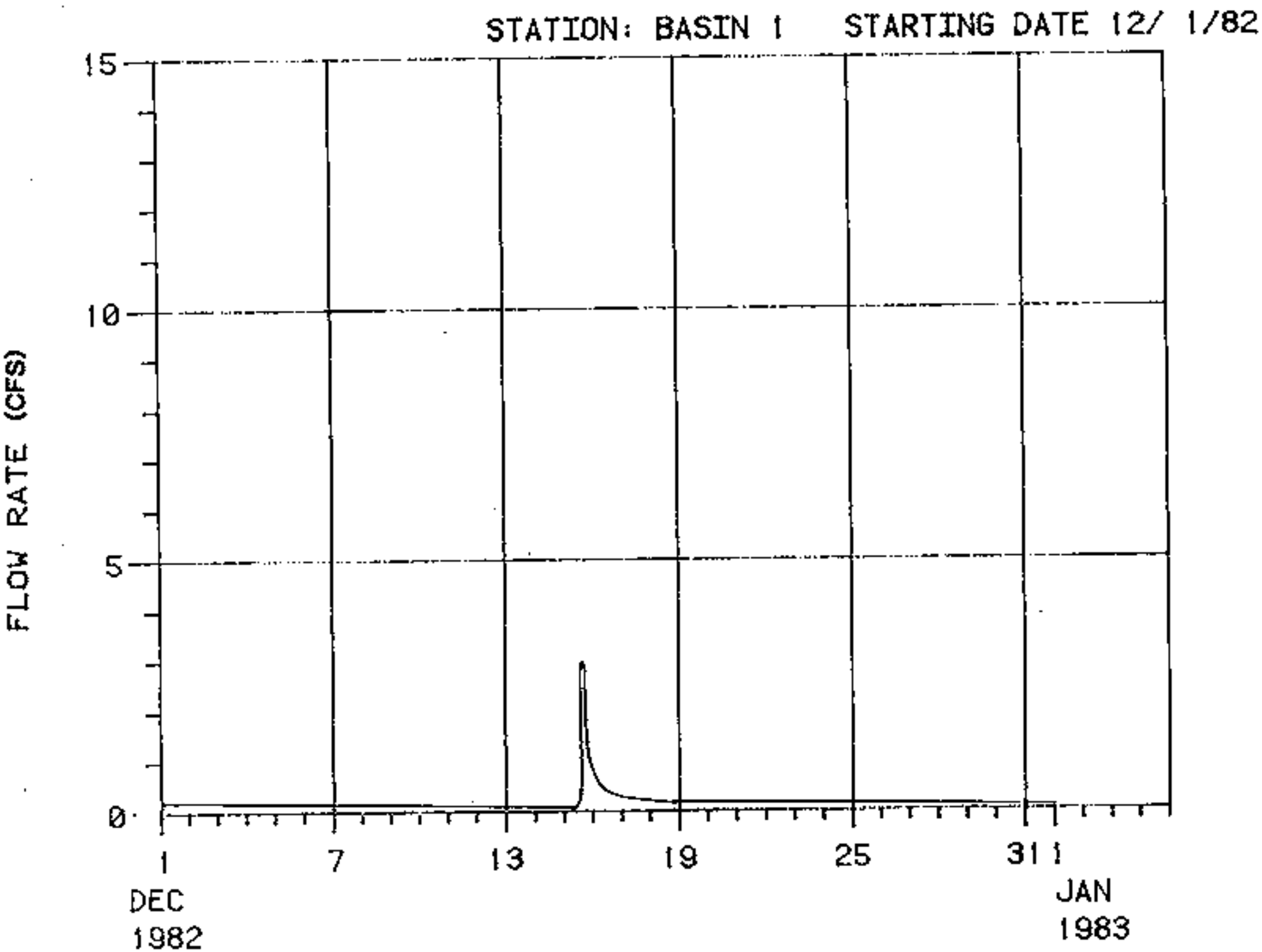
APPENDIX A

STREAM HYDROGRAPHS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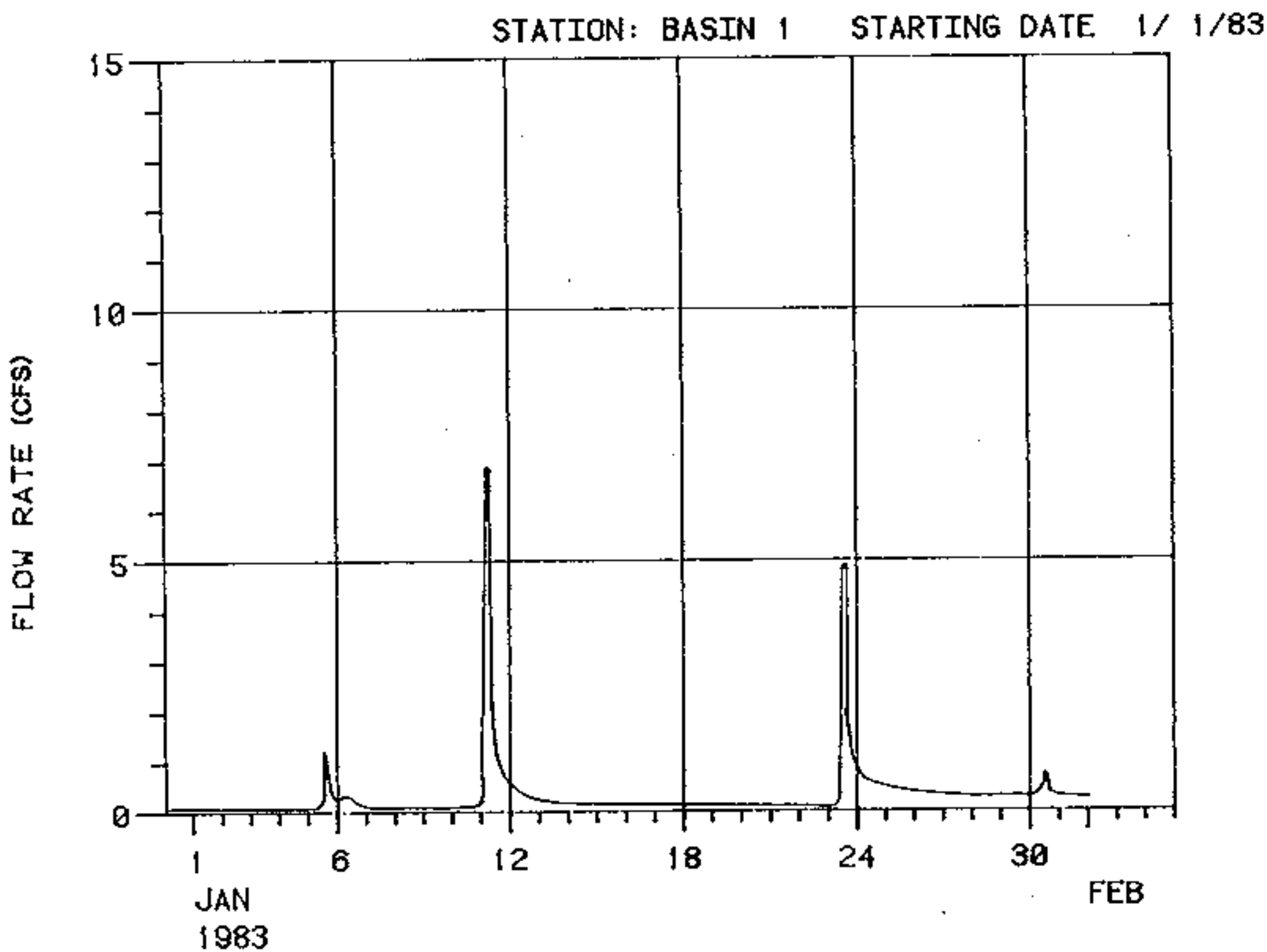
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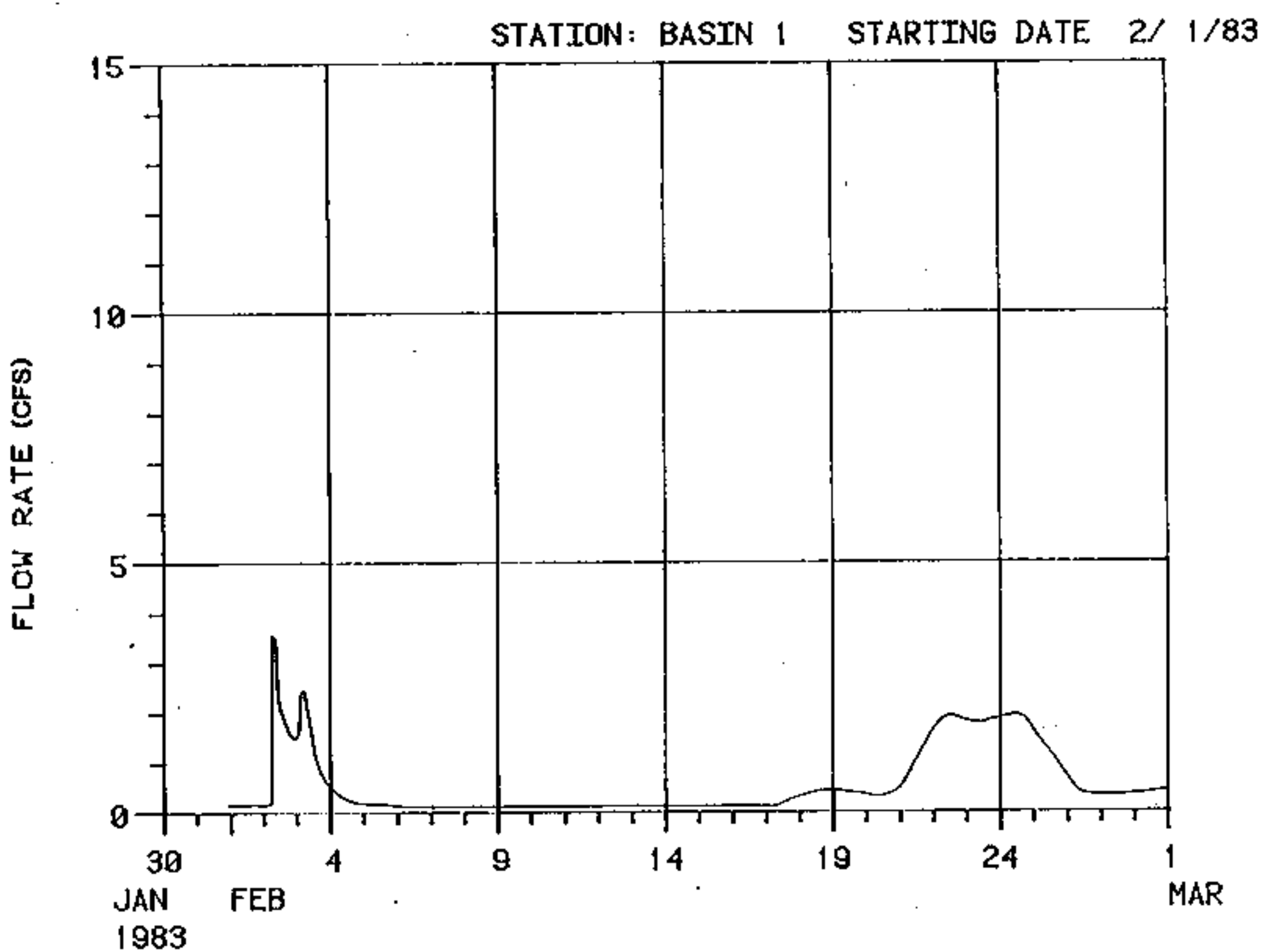
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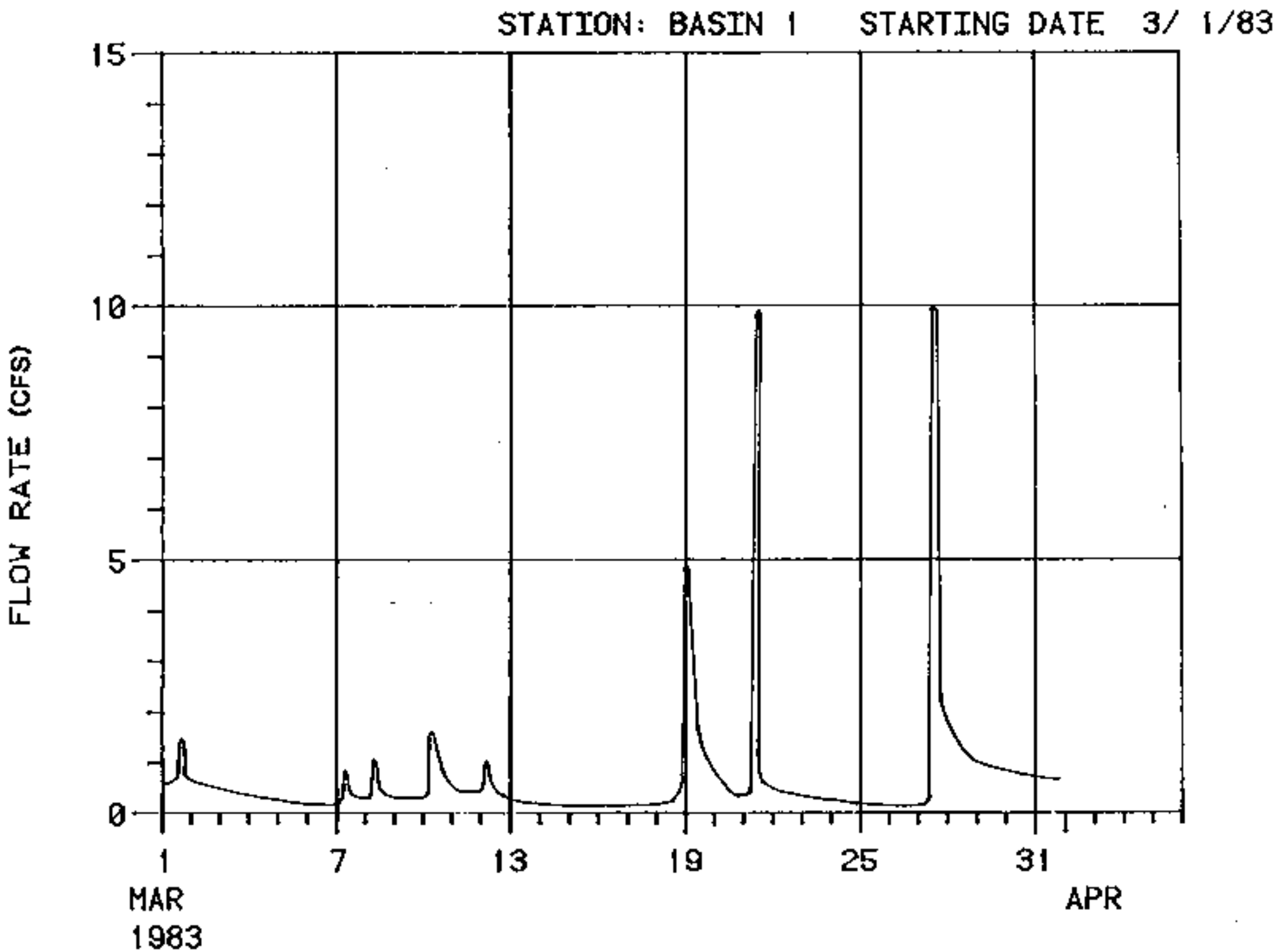
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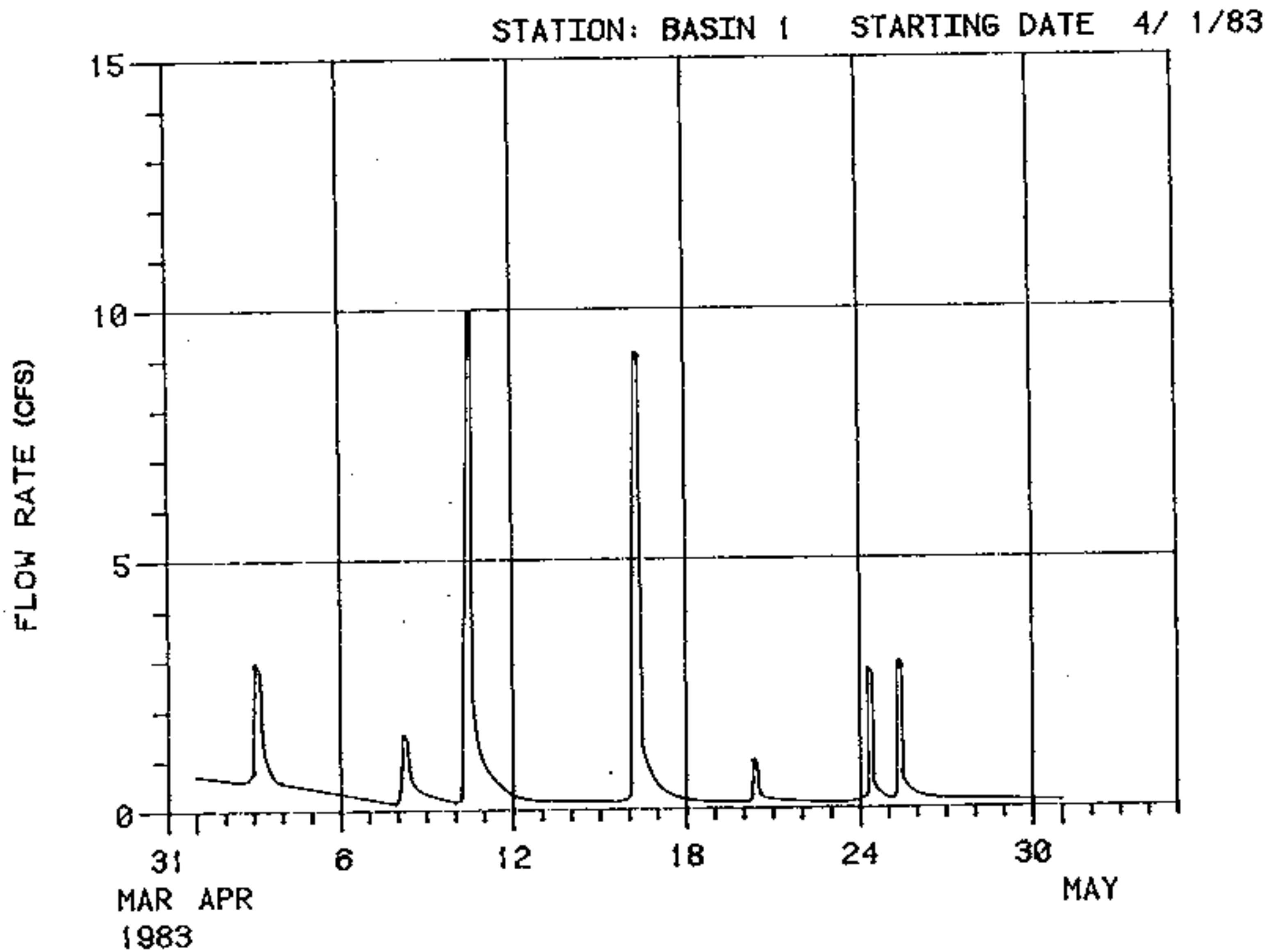
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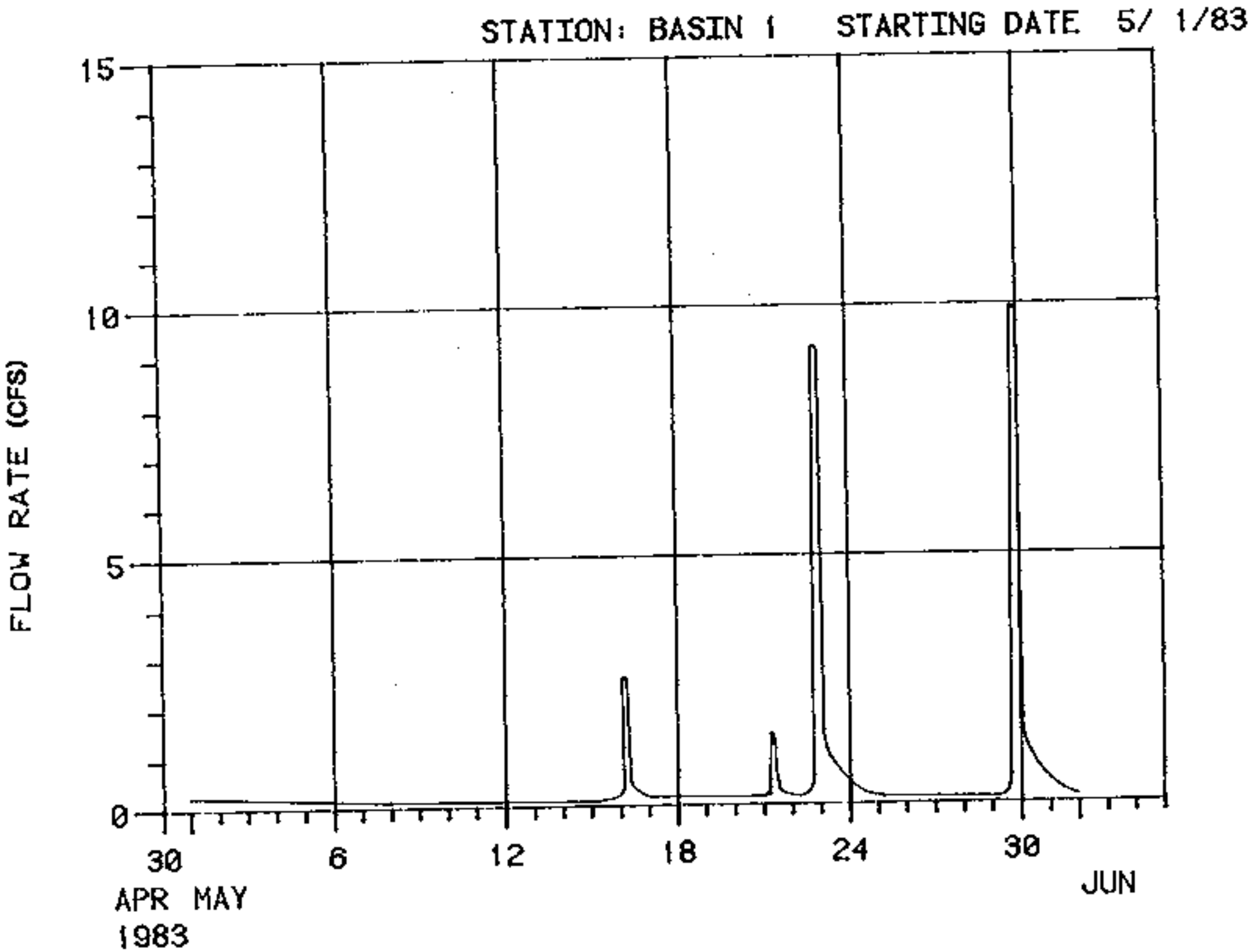
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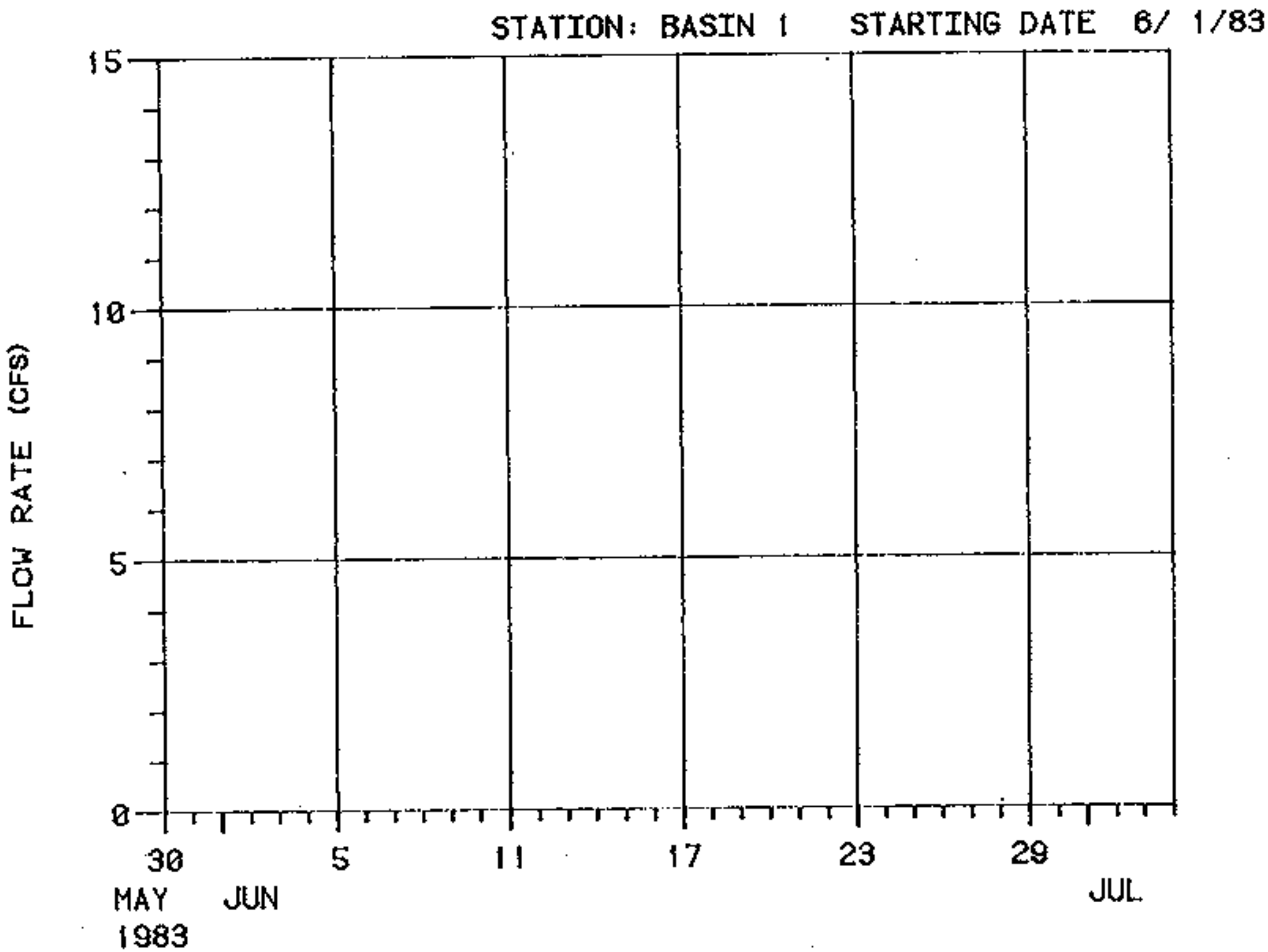
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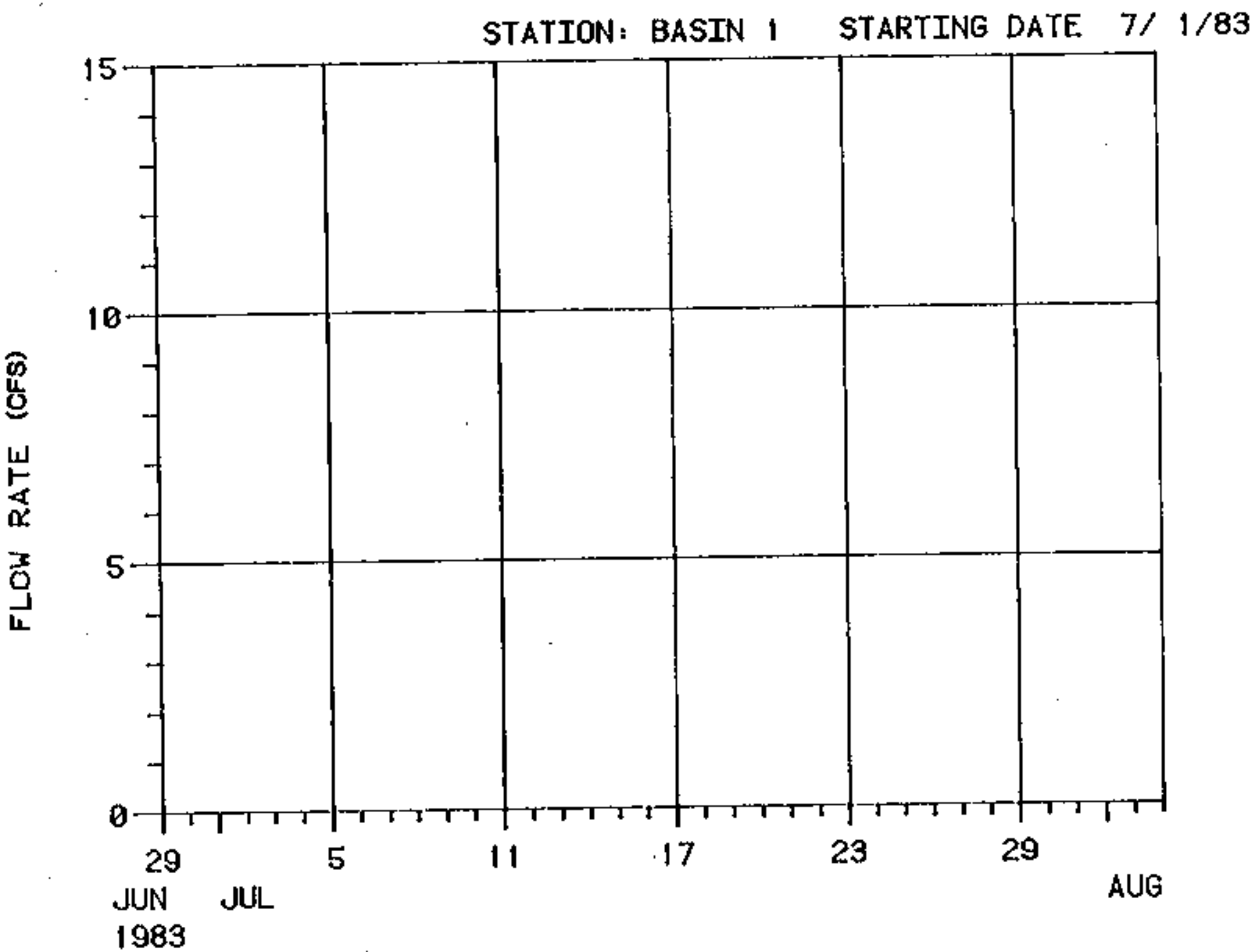
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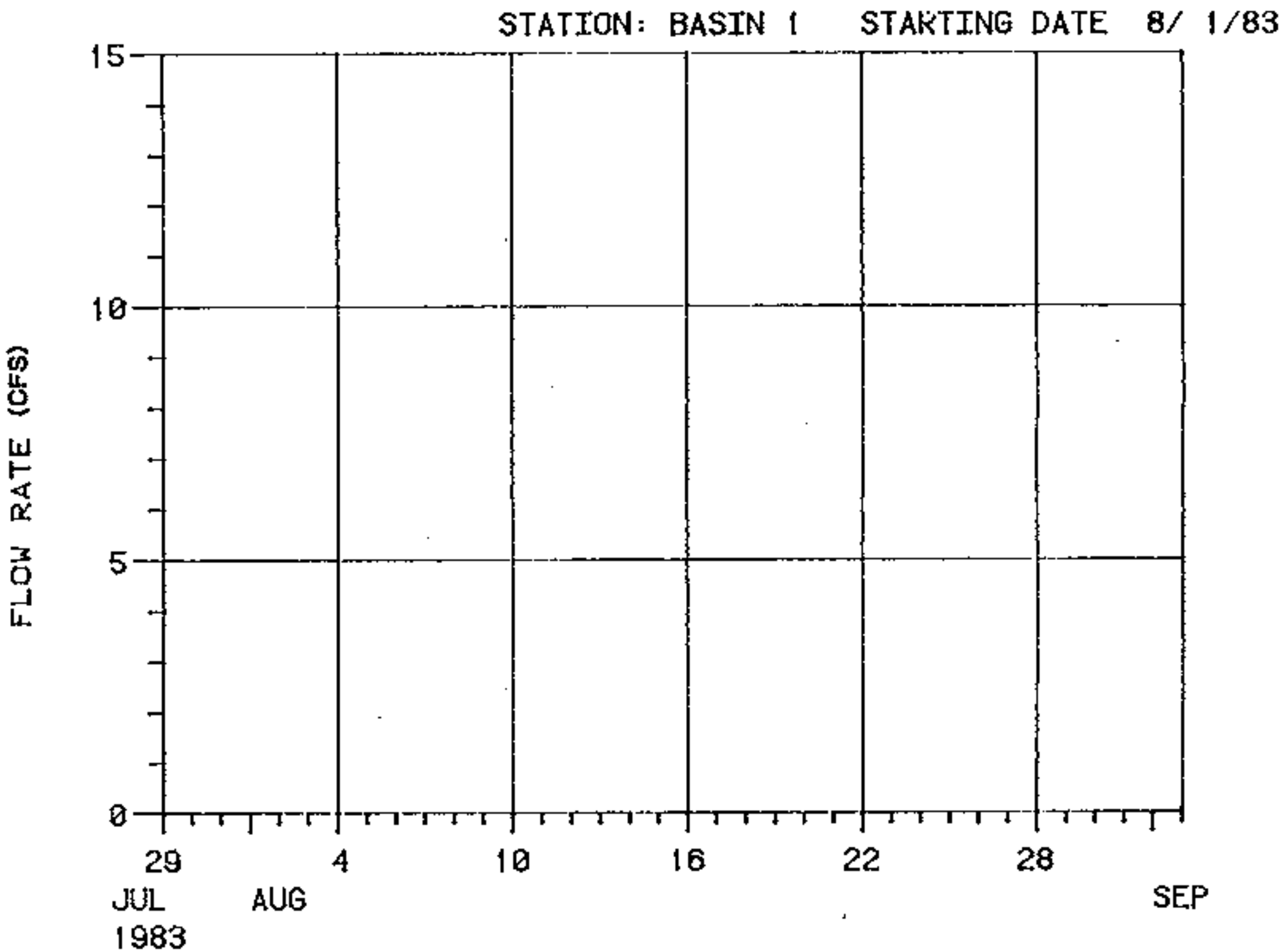
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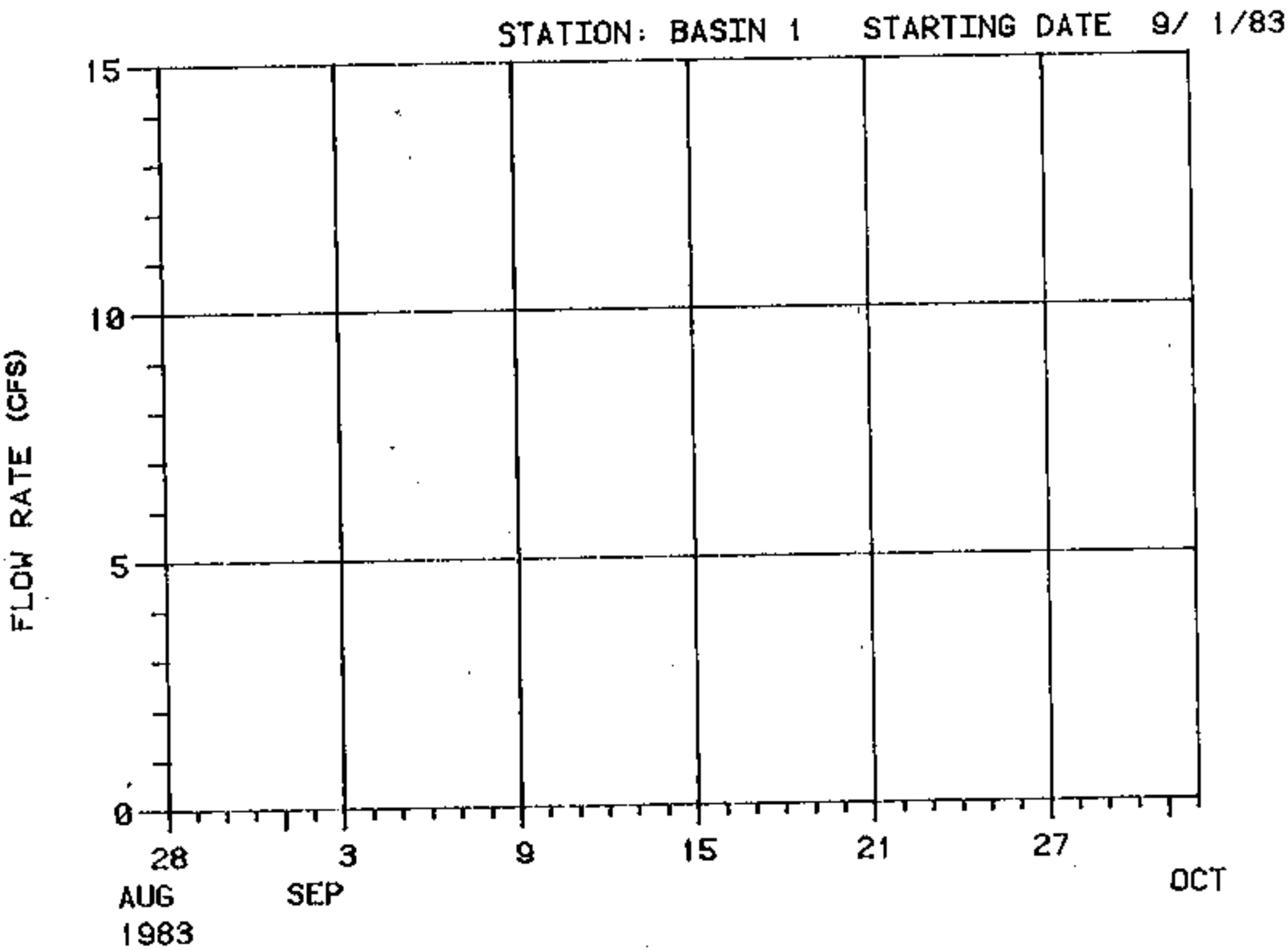
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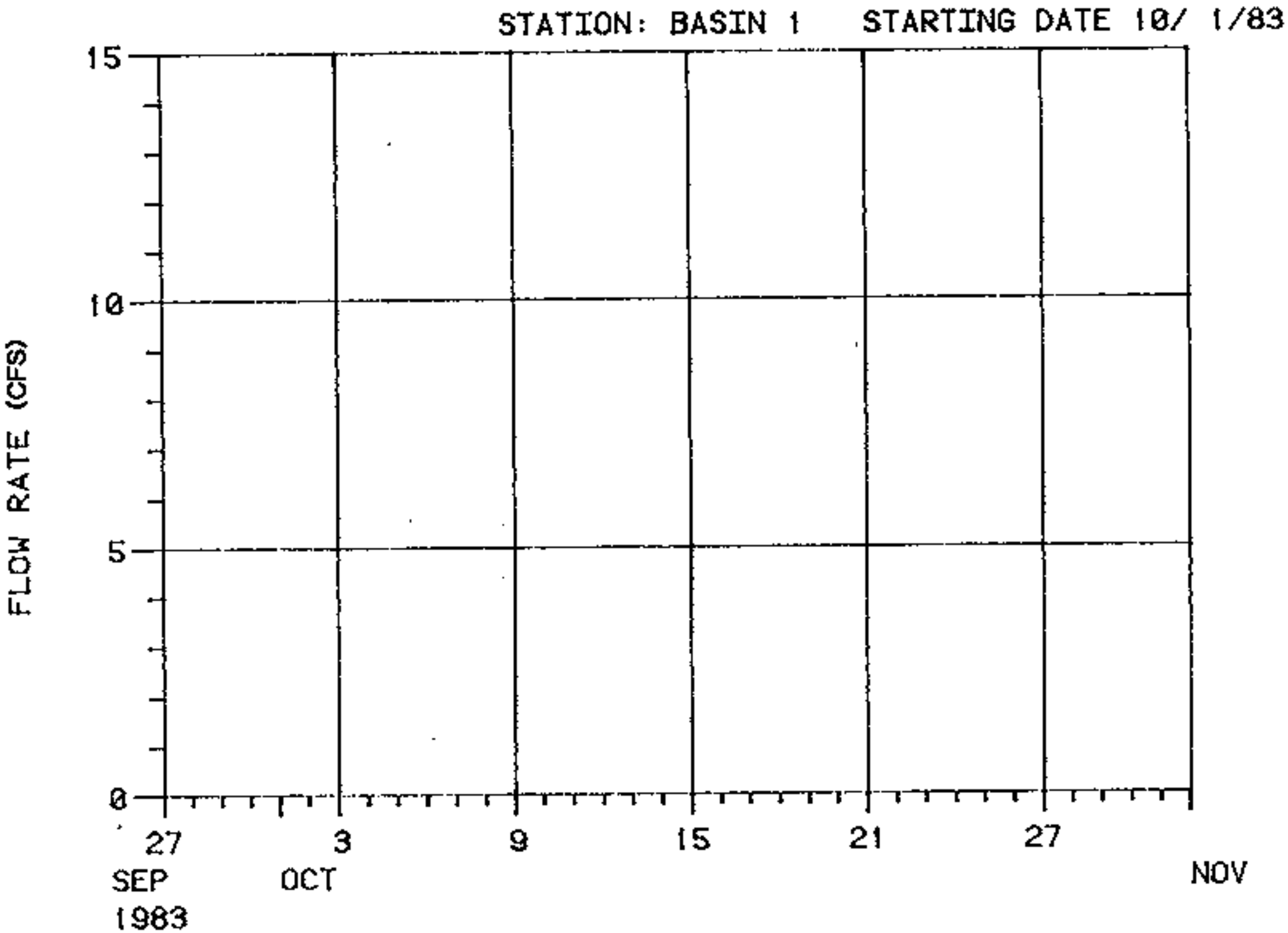
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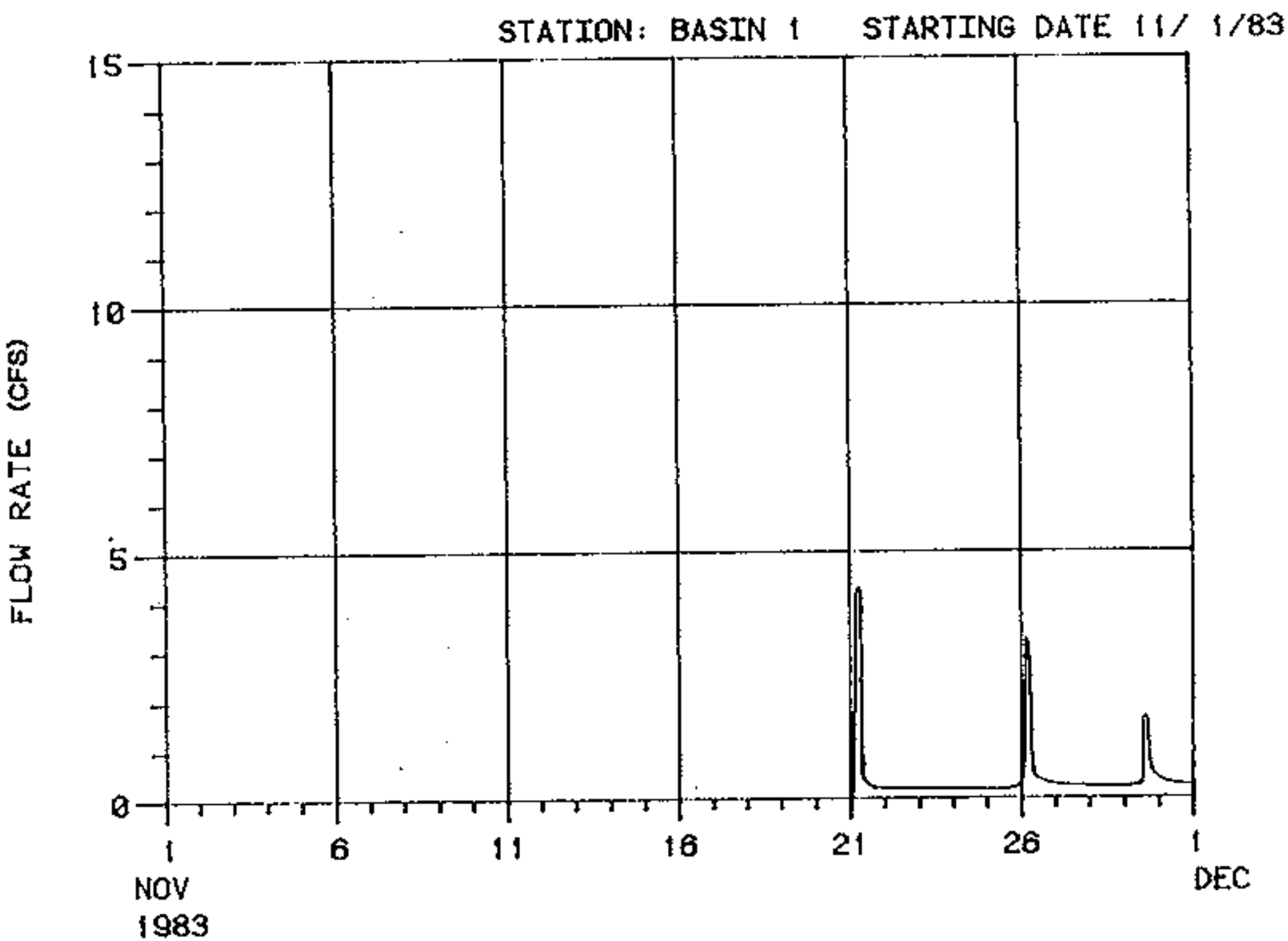
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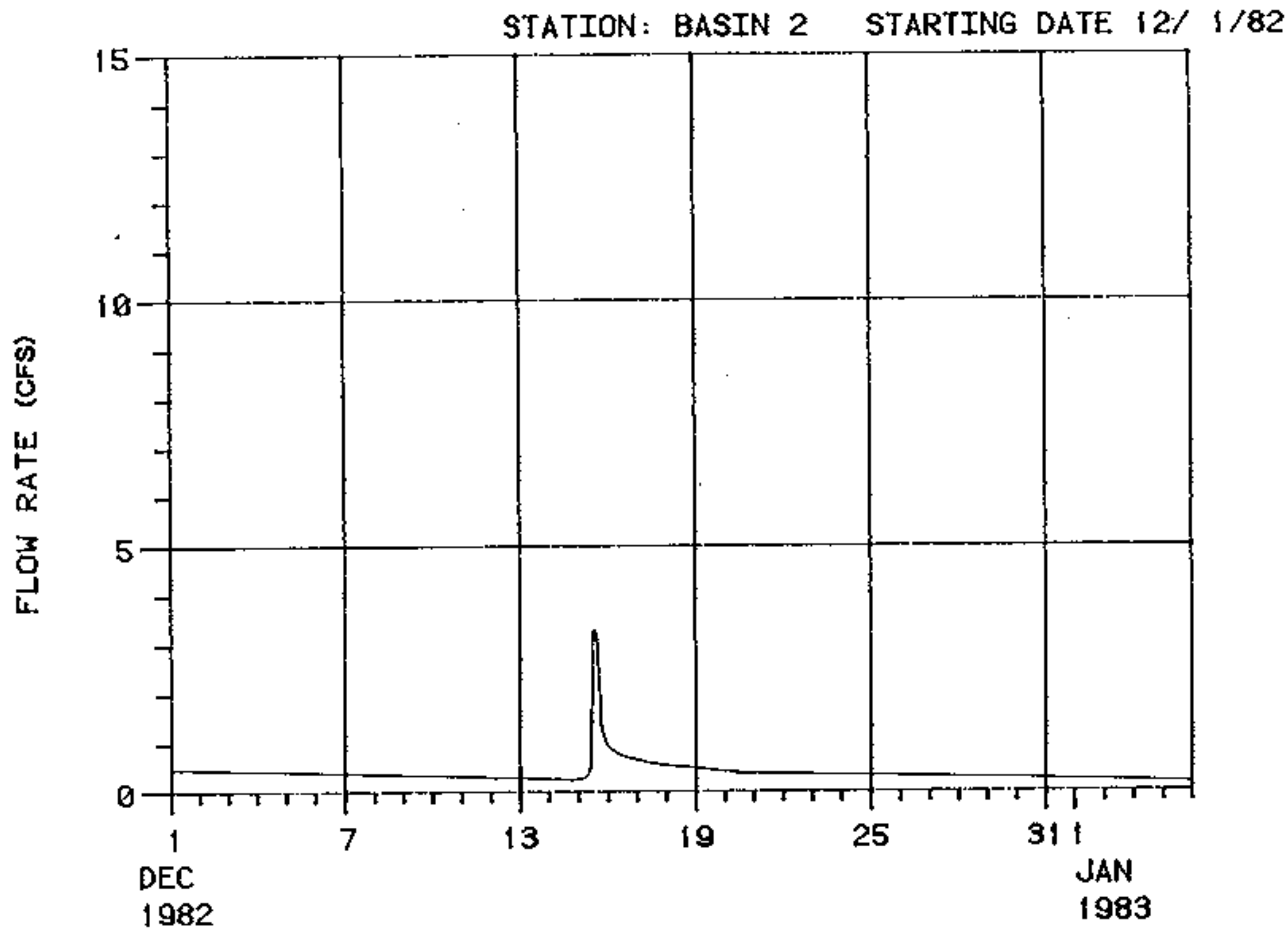
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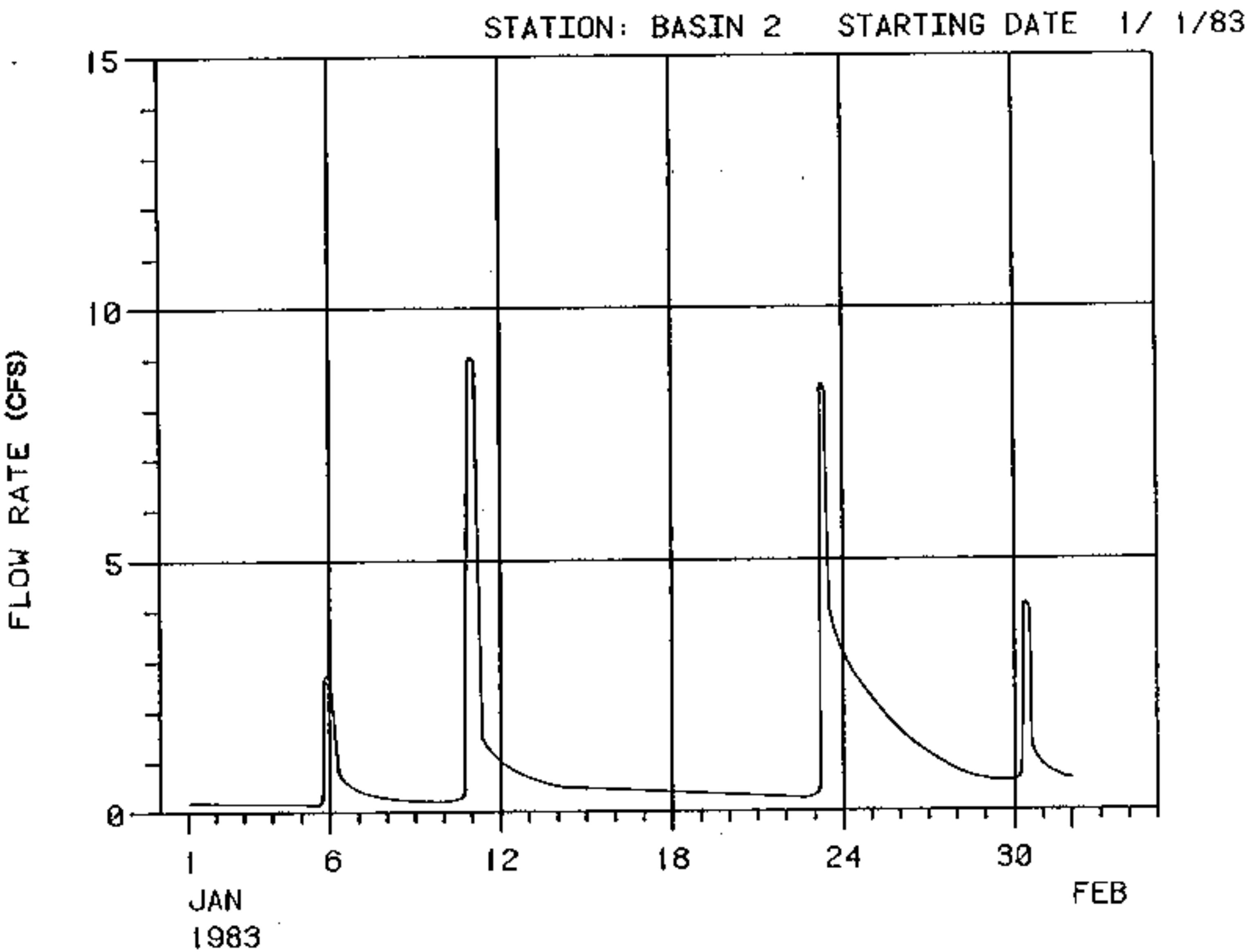
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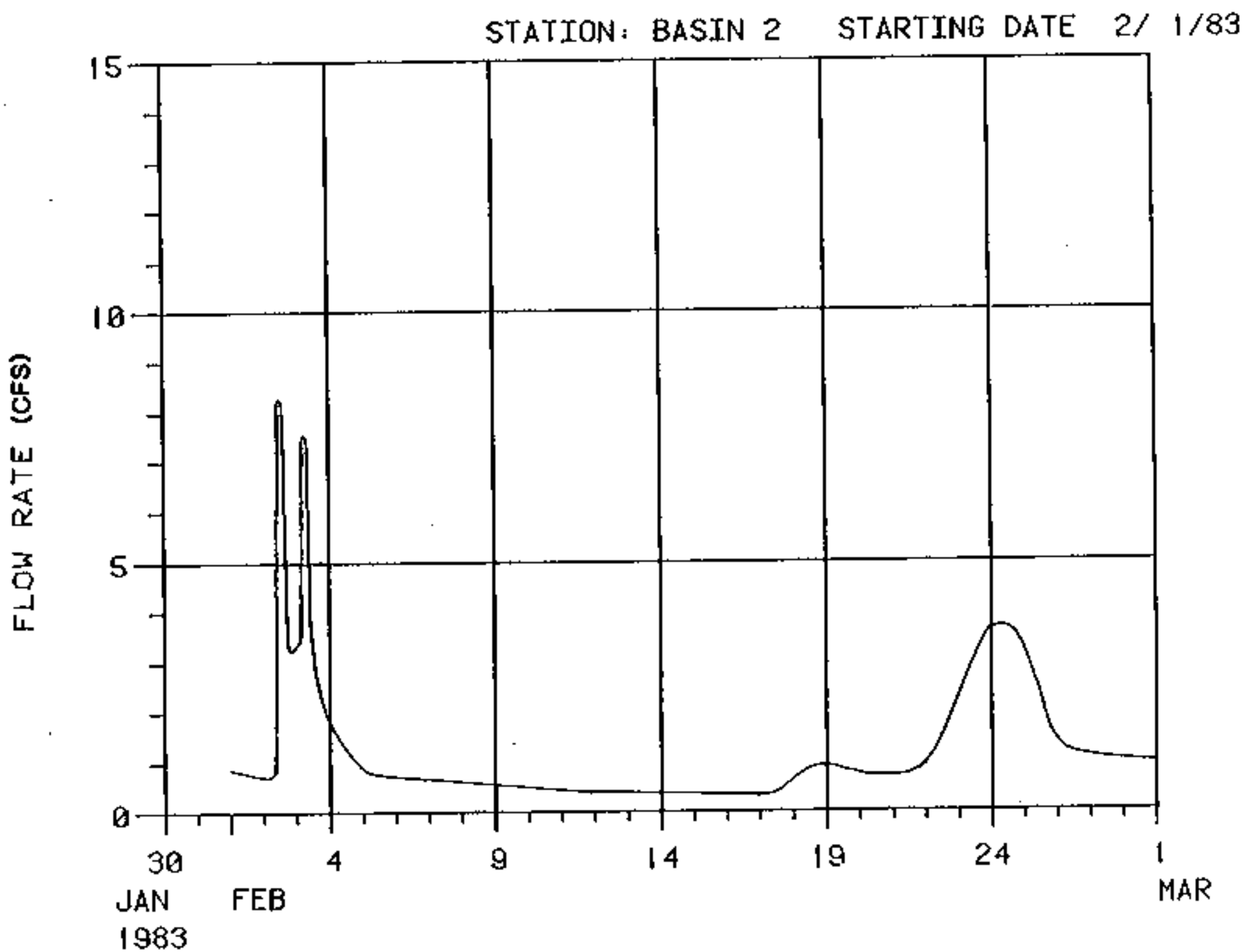

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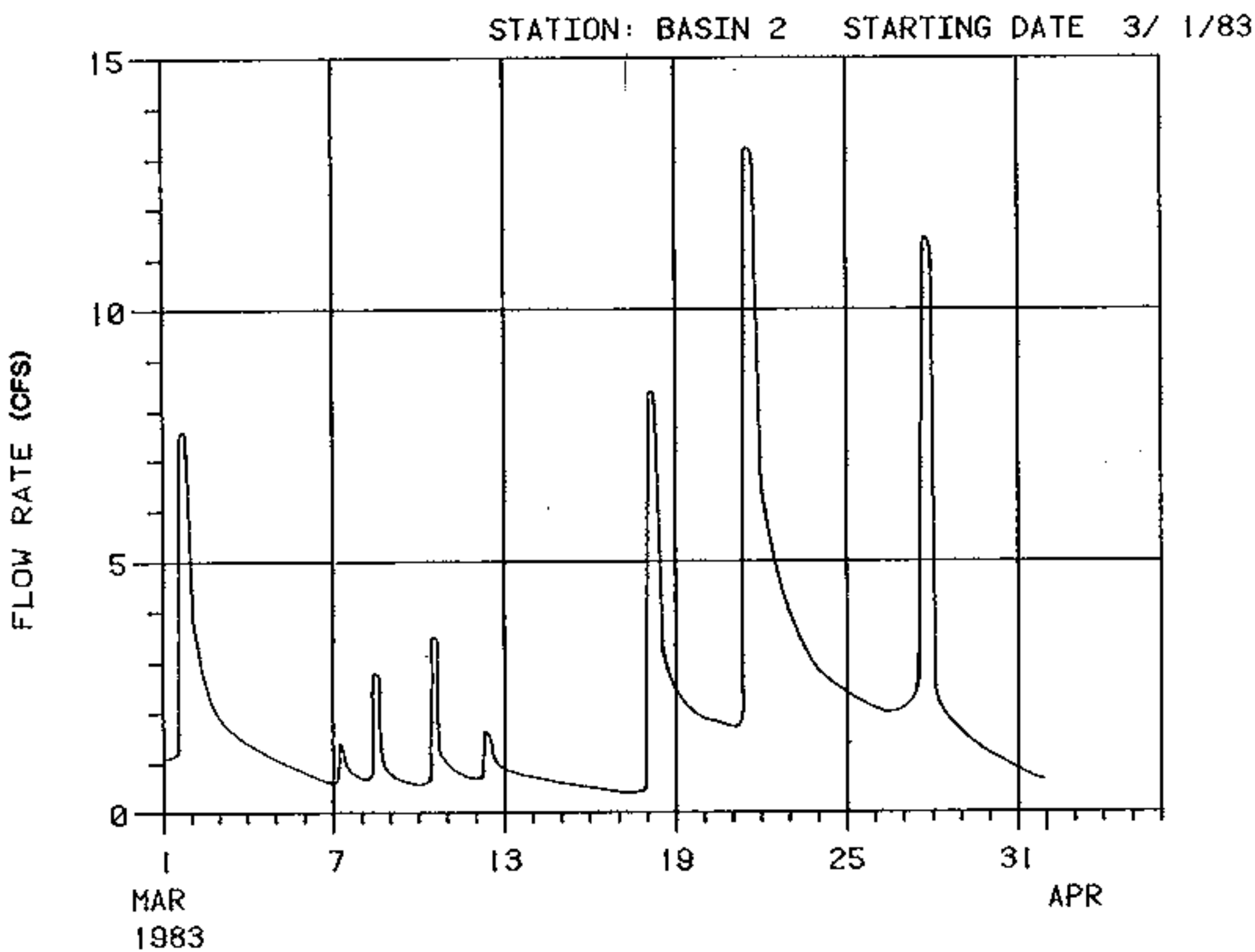
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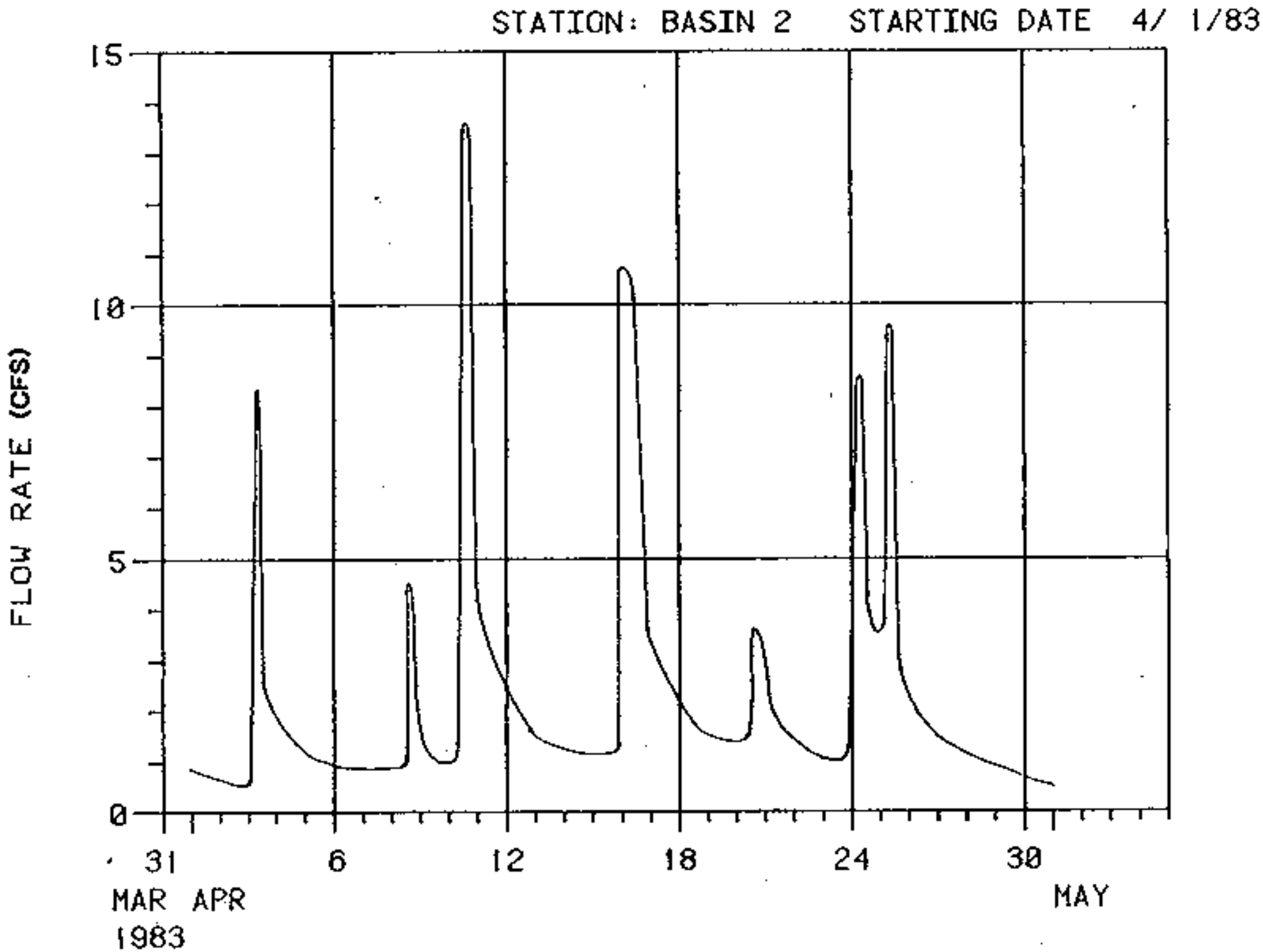
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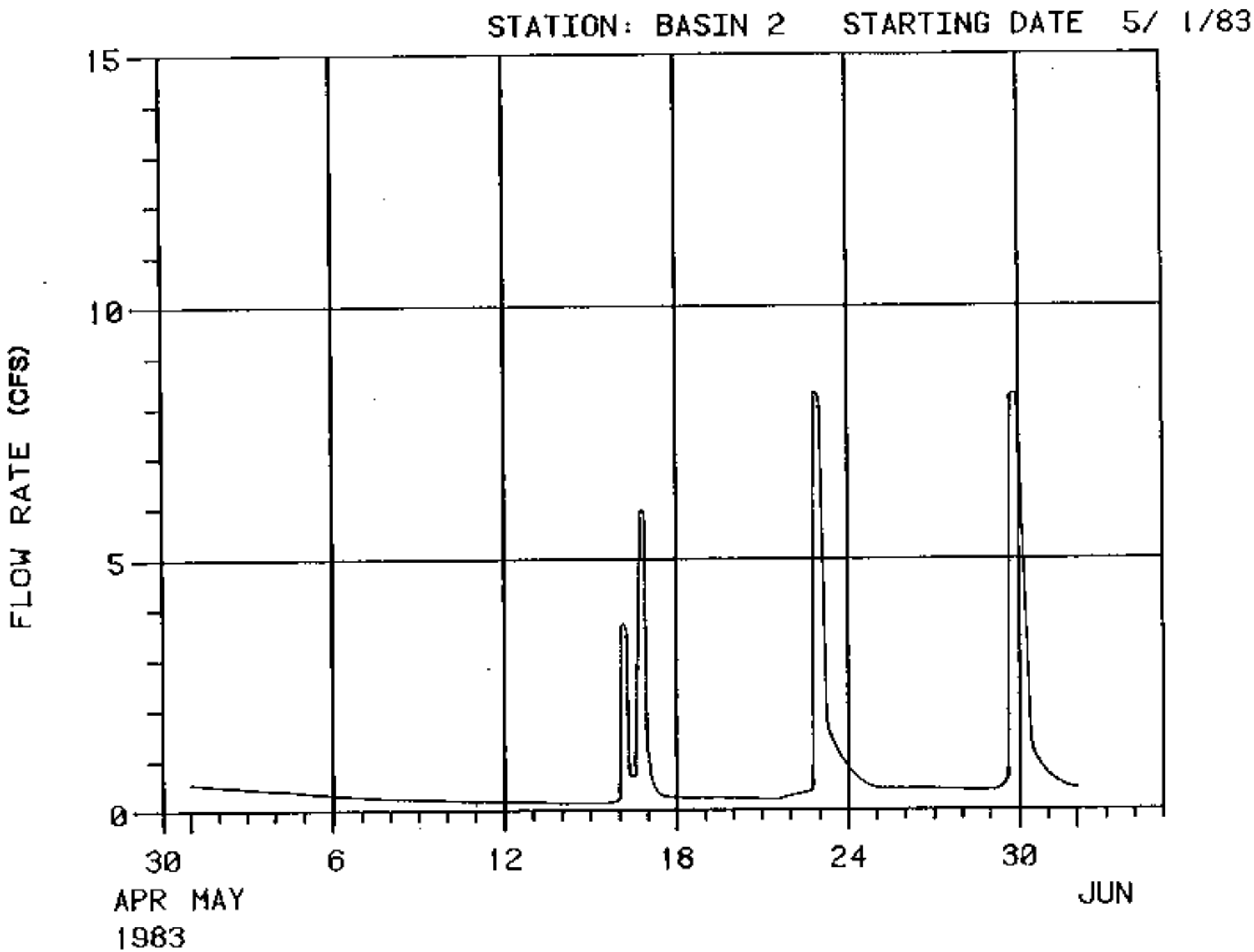
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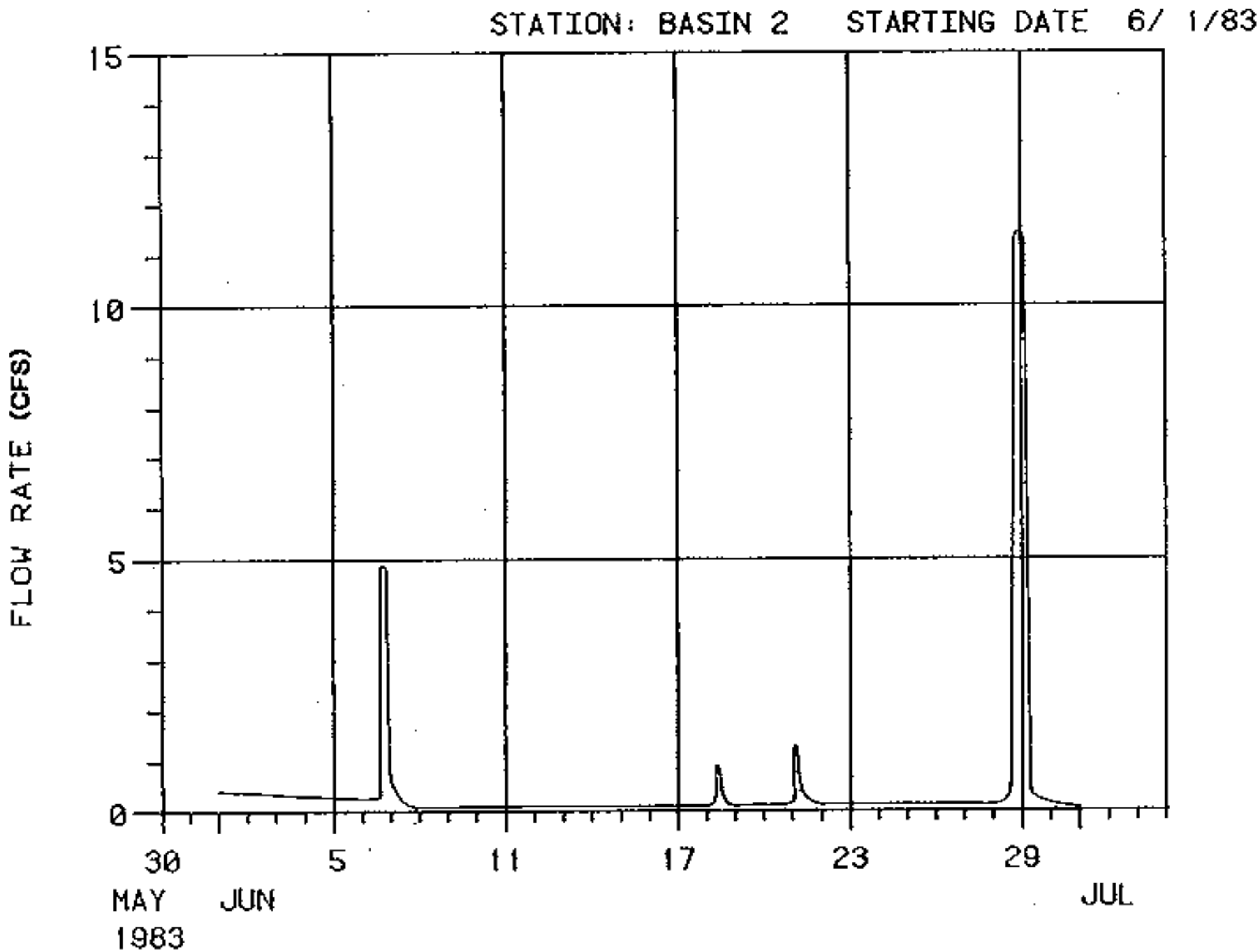
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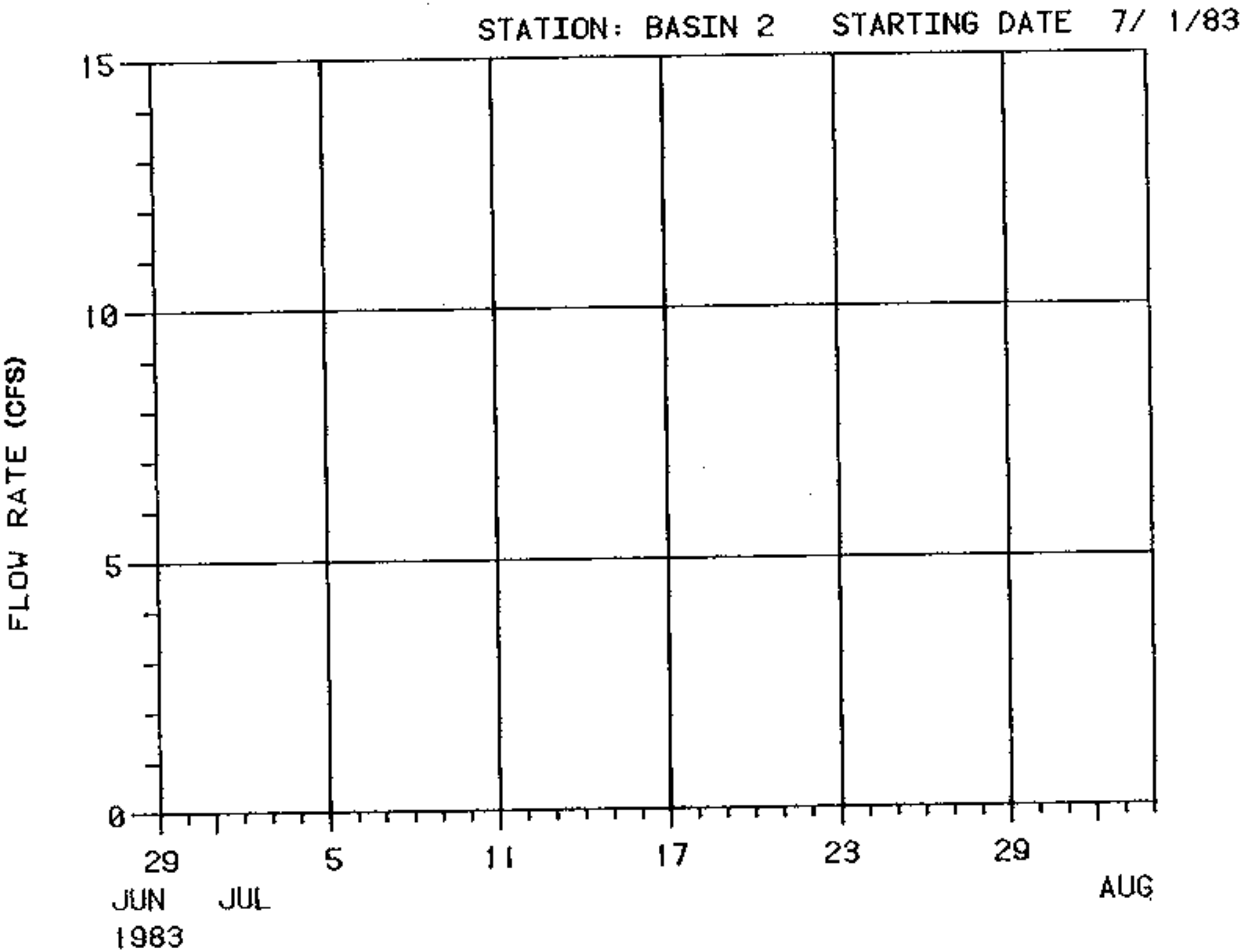
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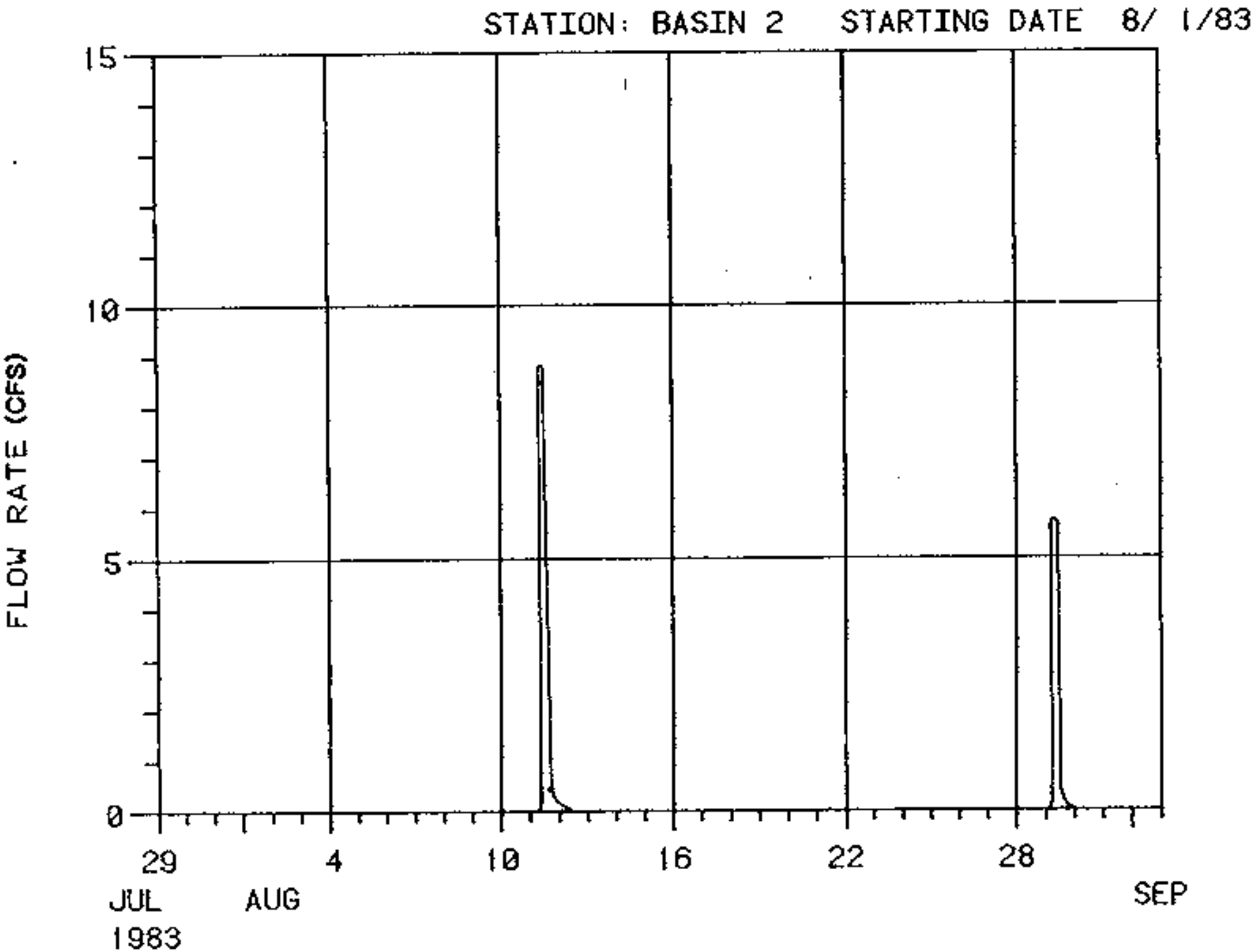
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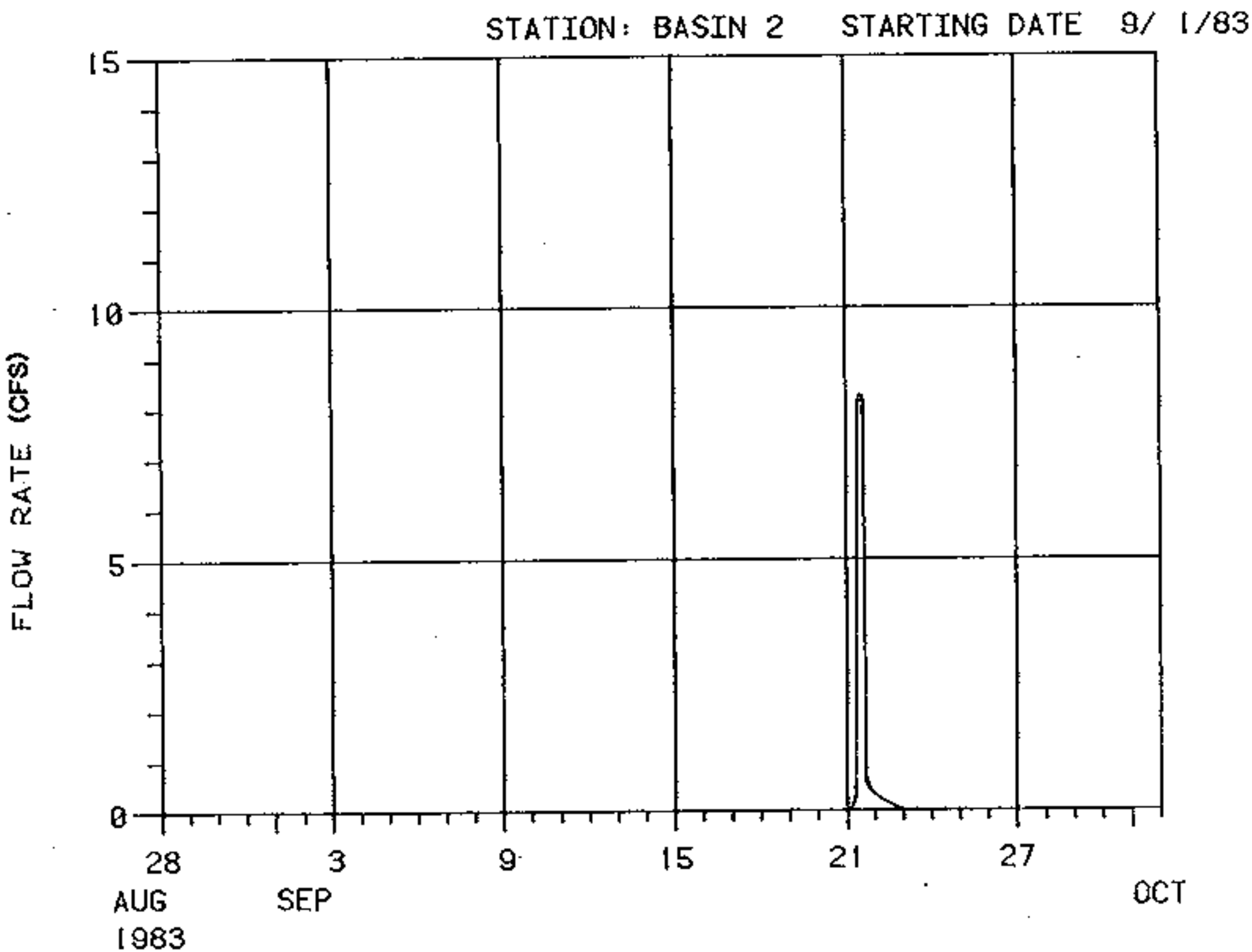

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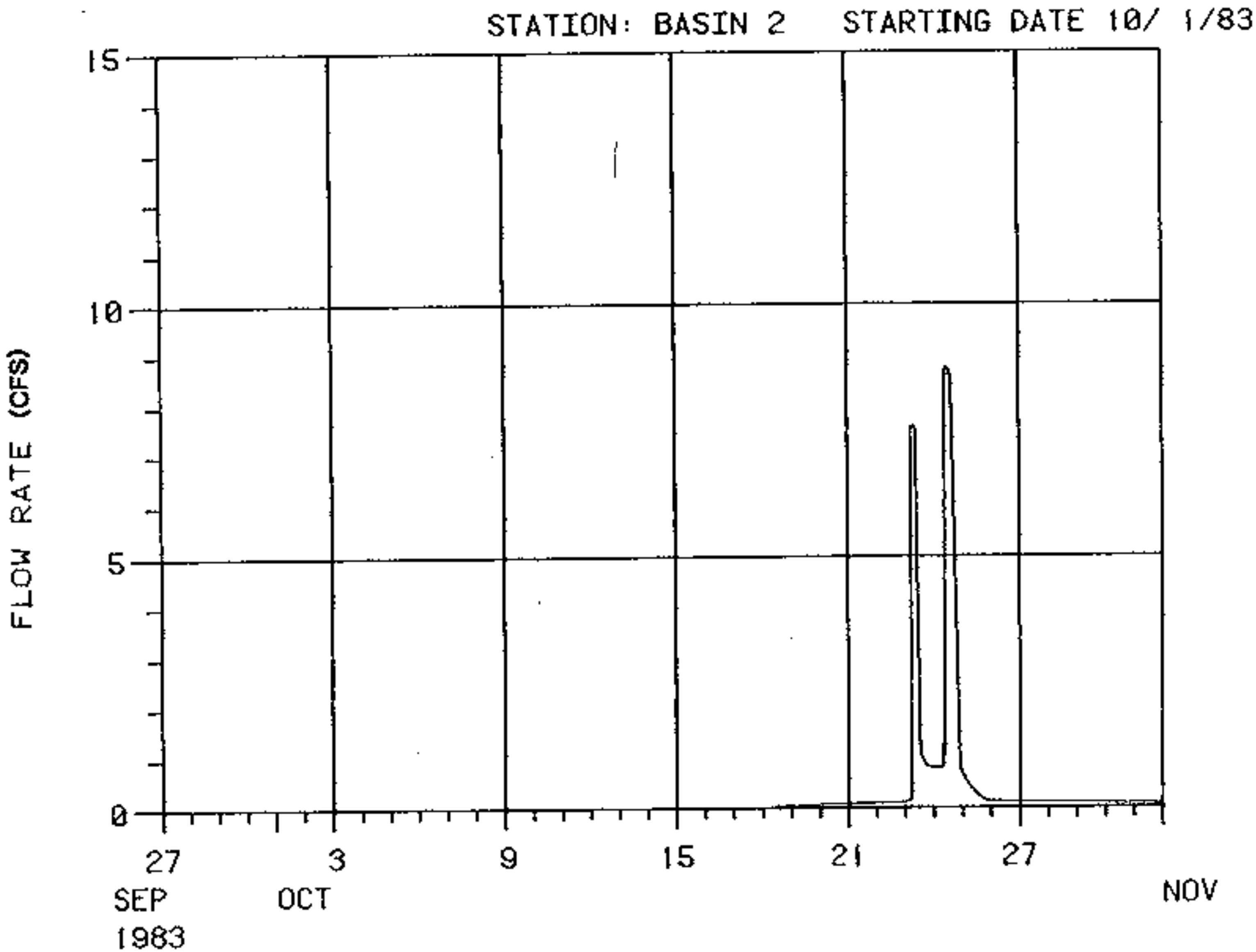
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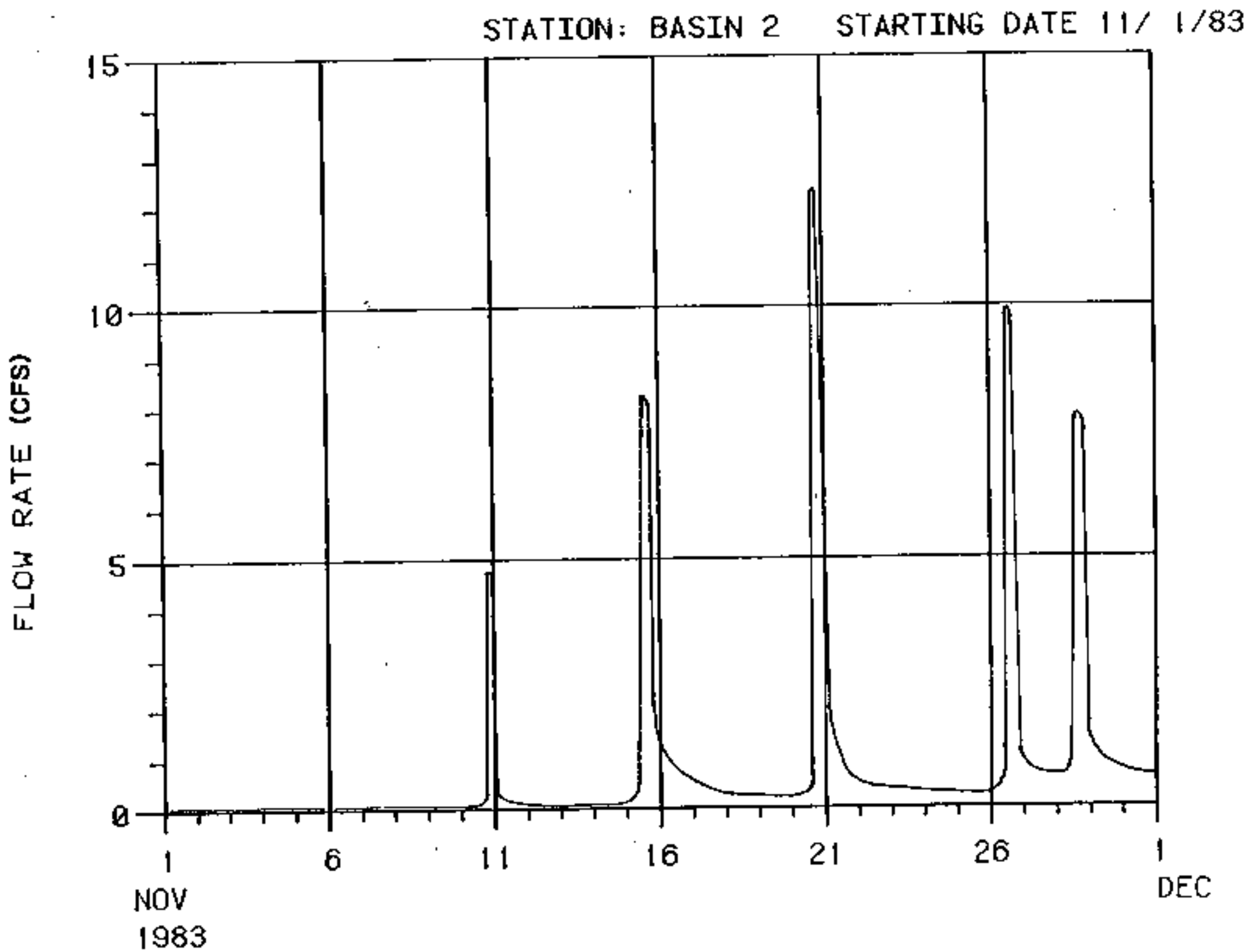
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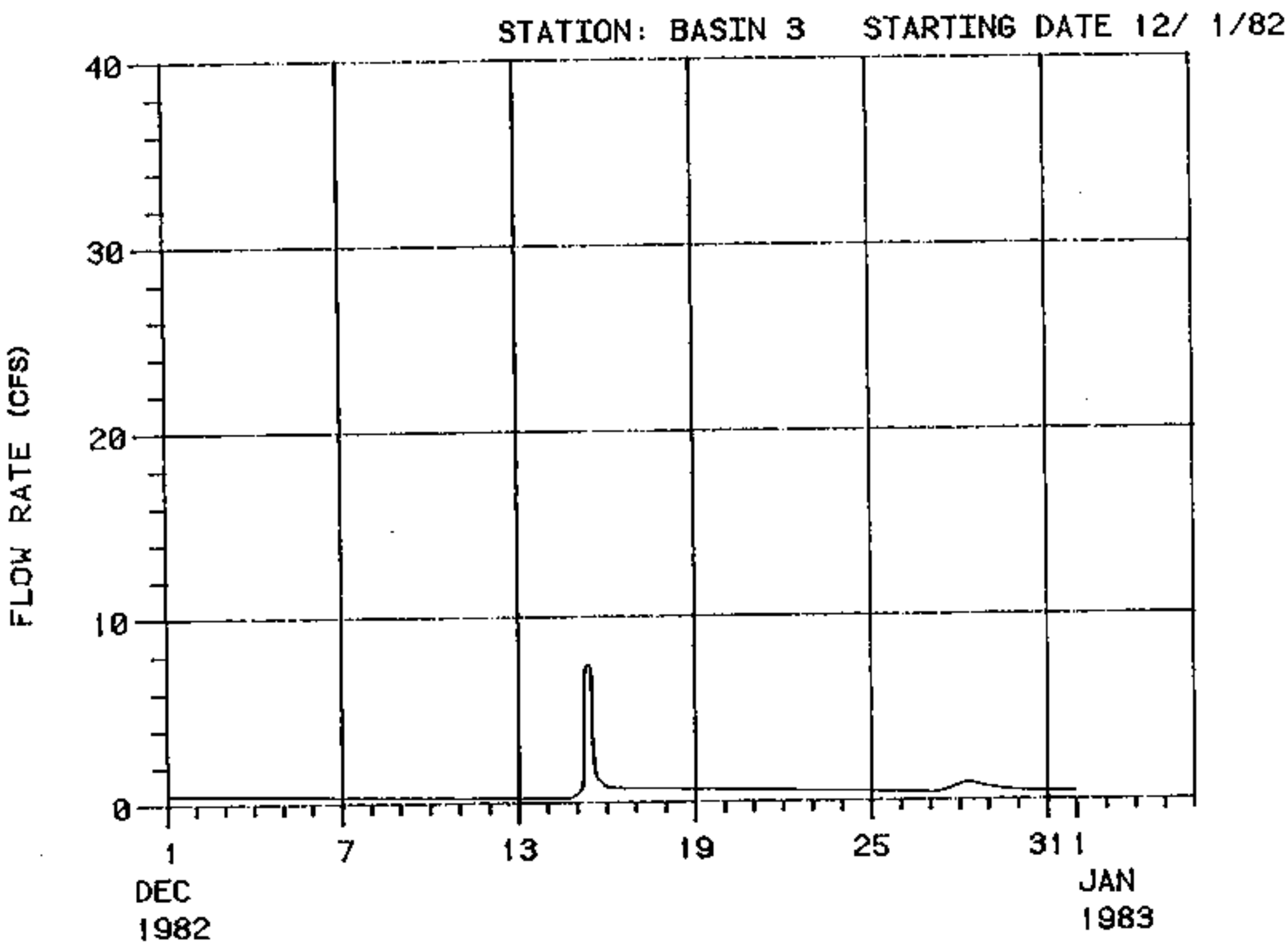

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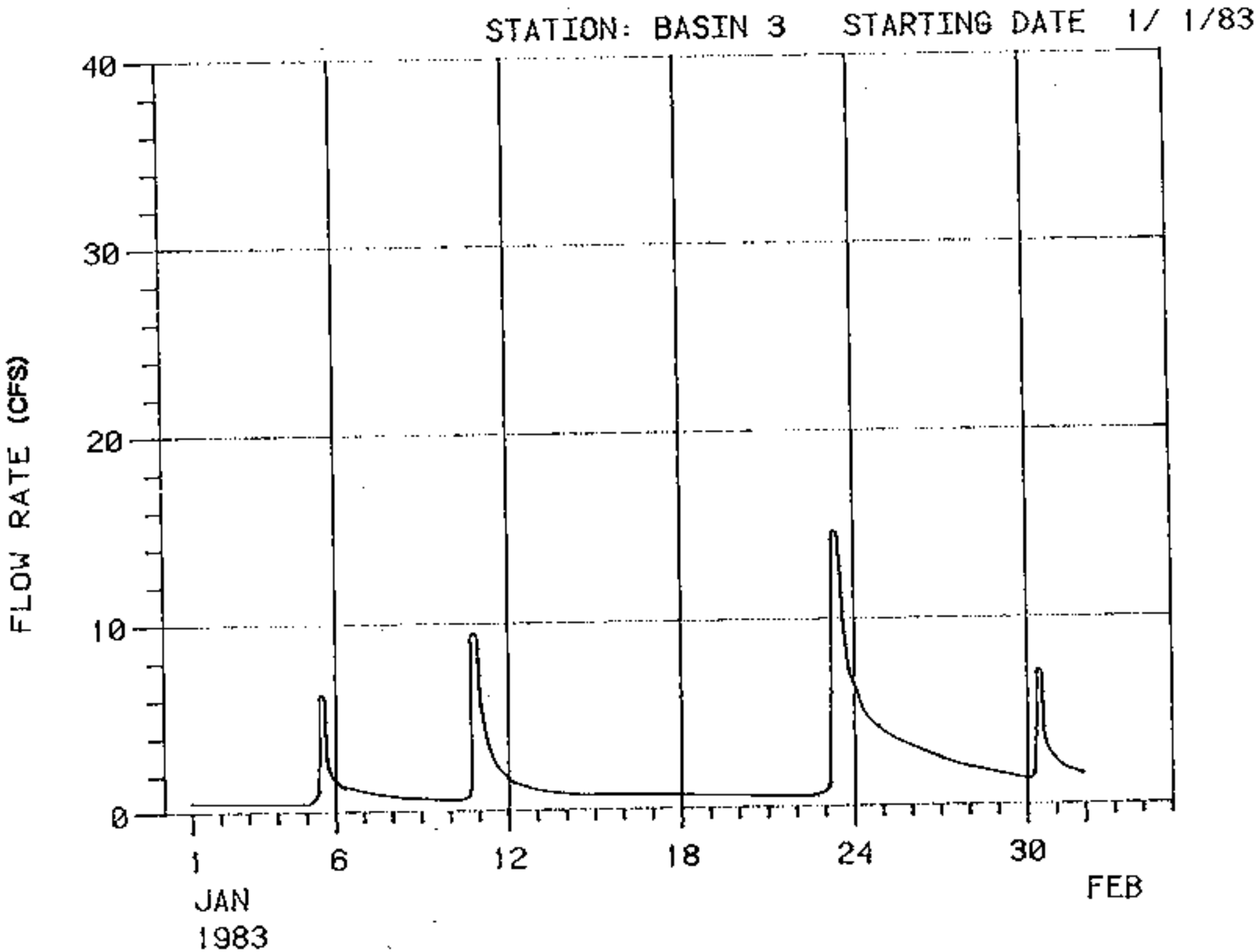
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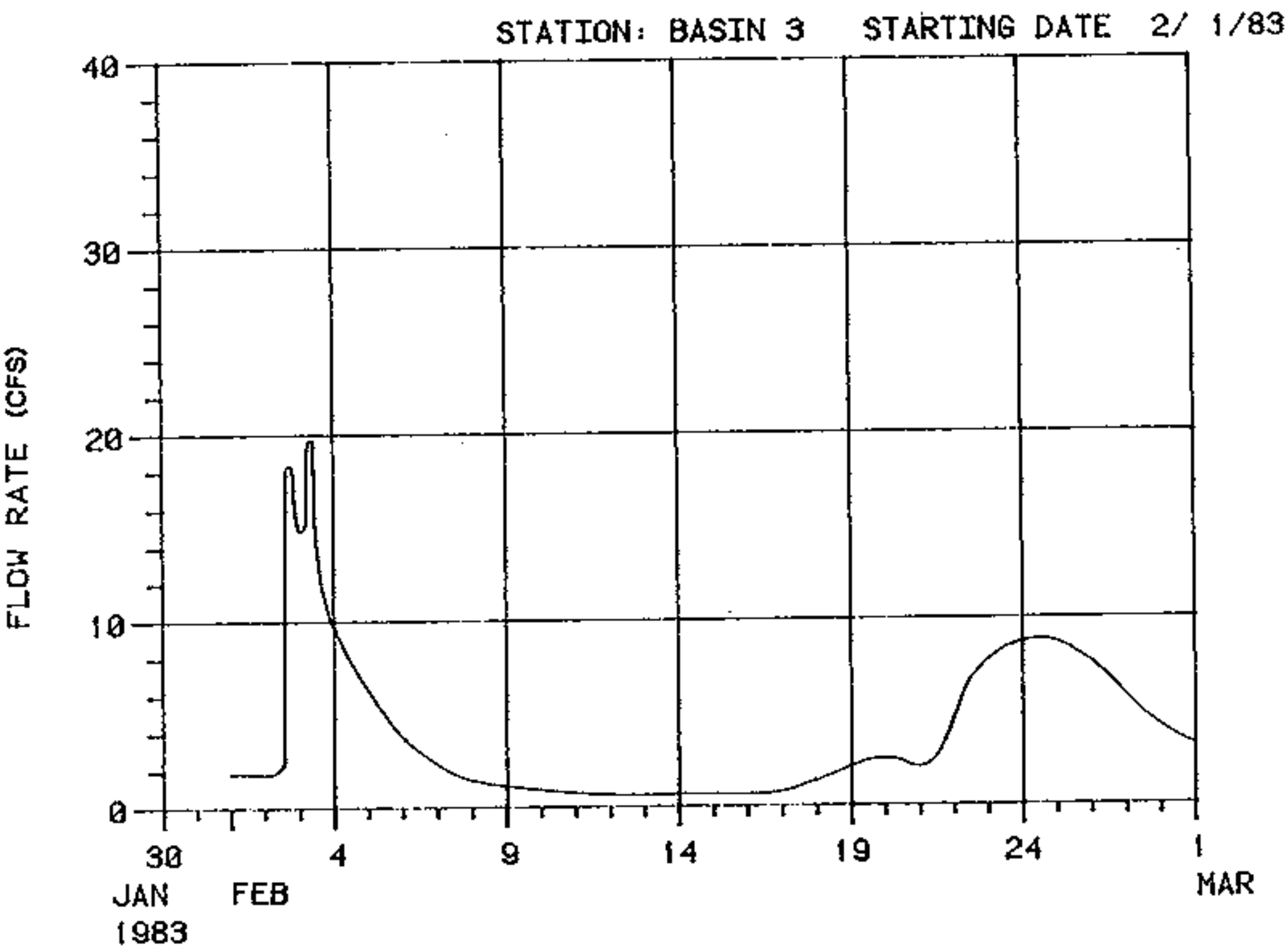
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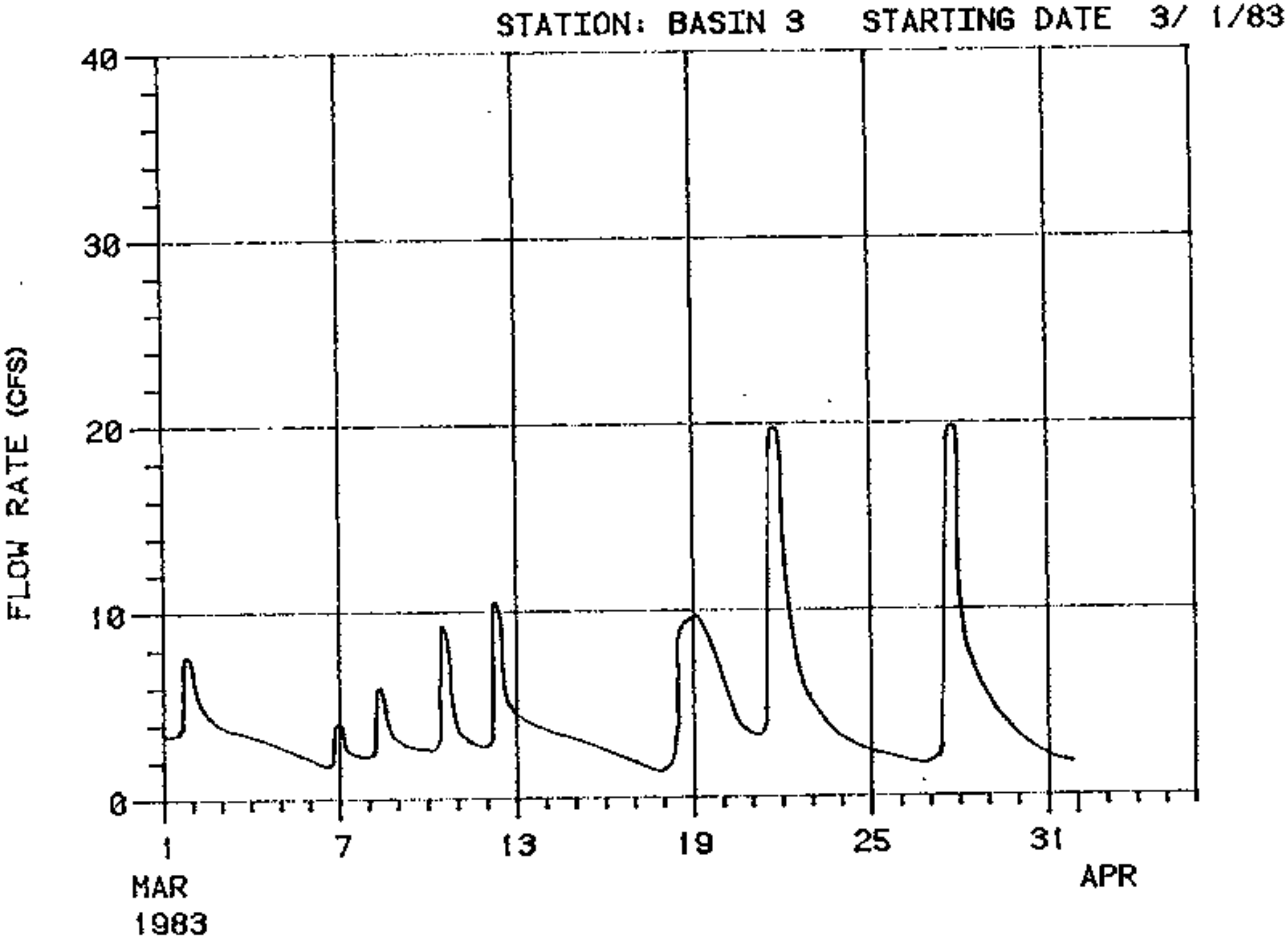
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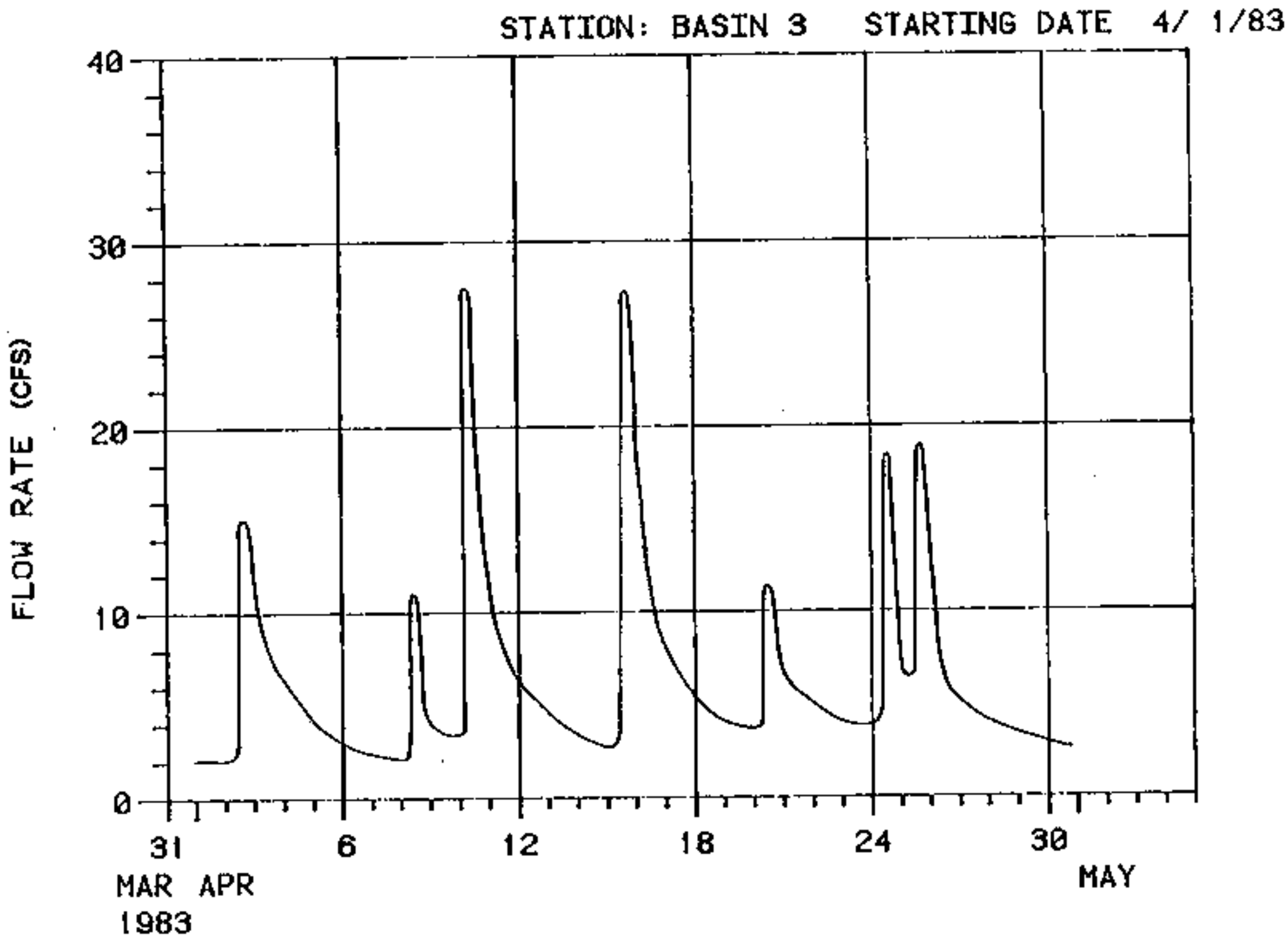
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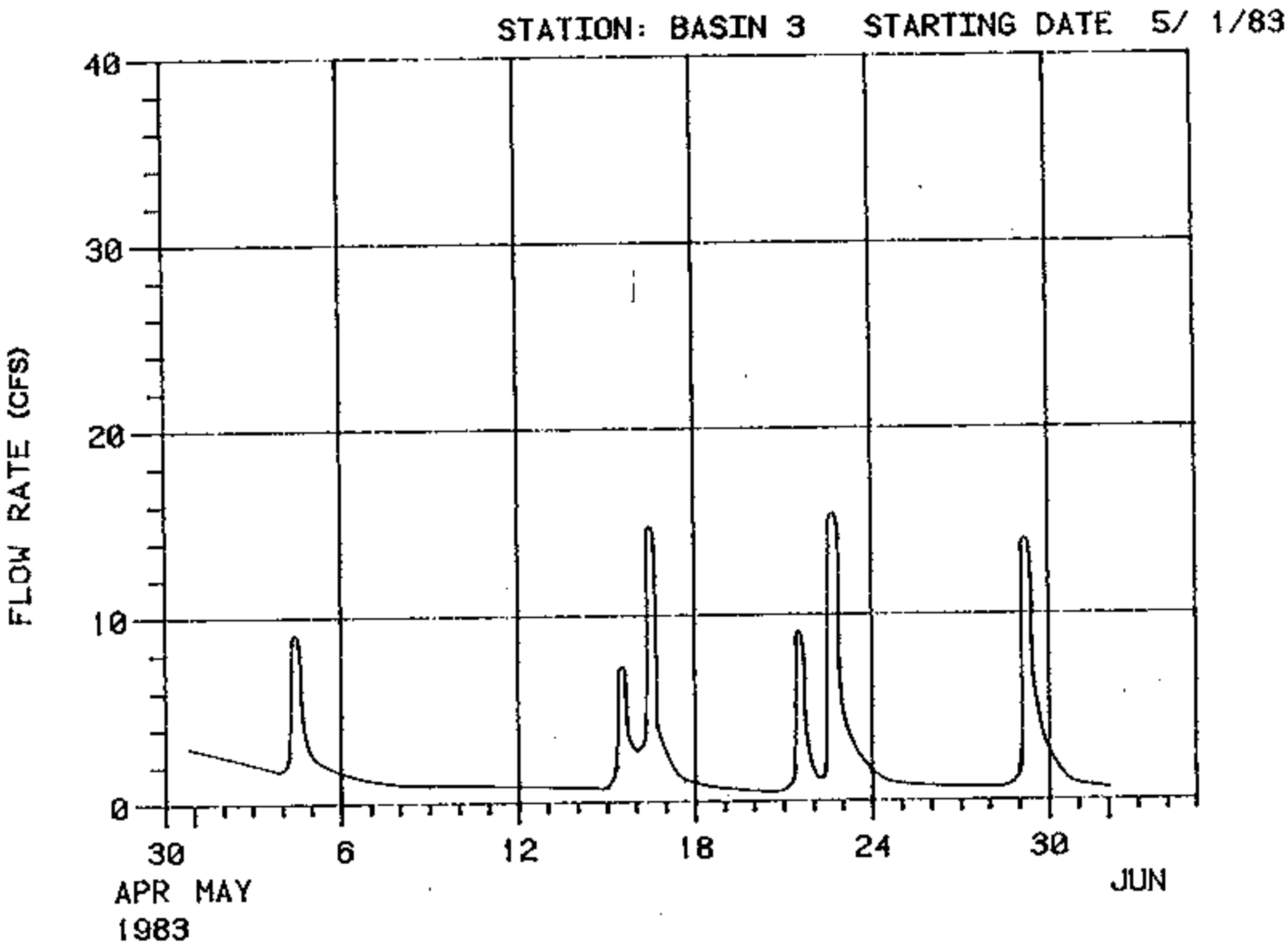
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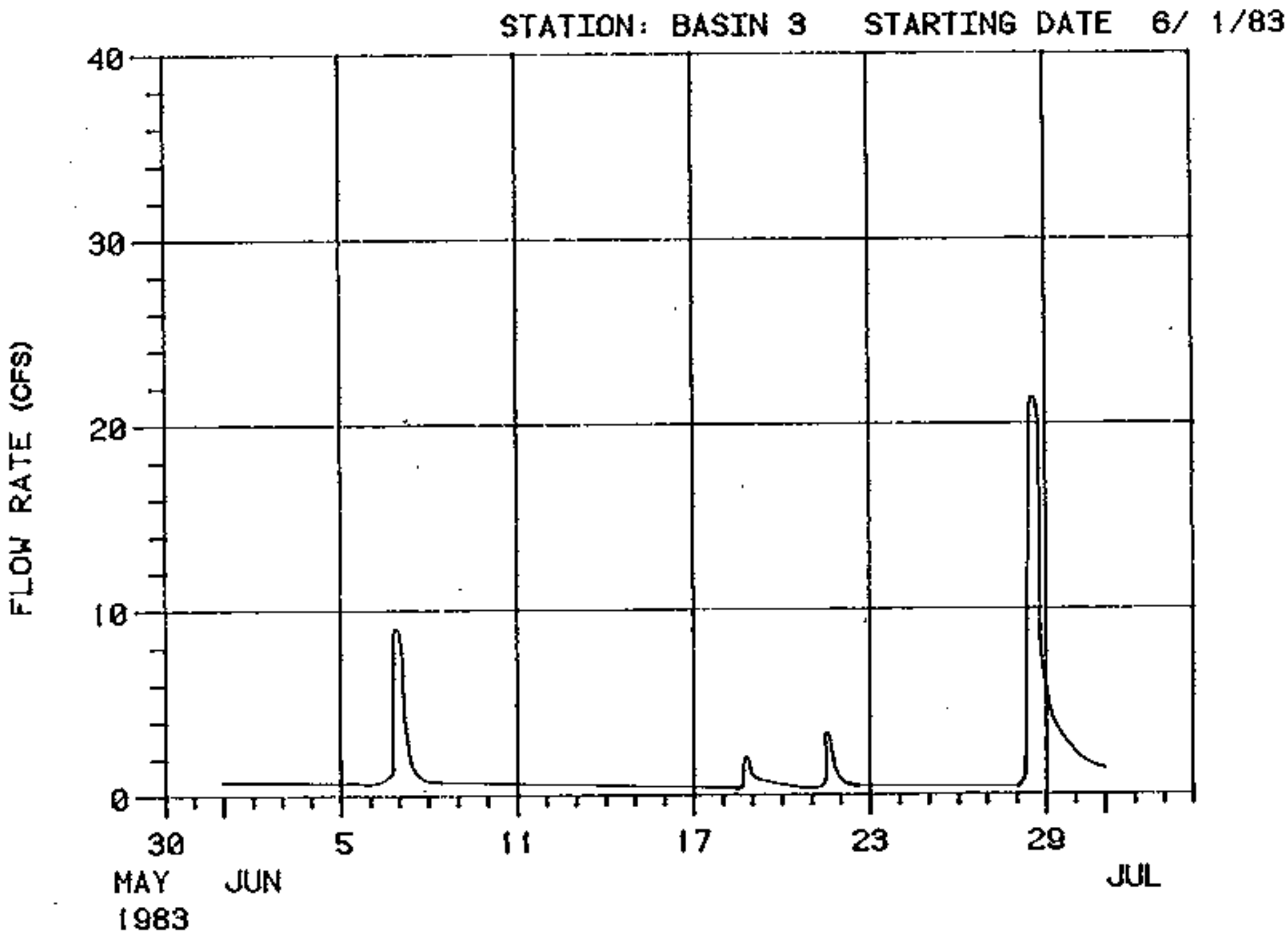
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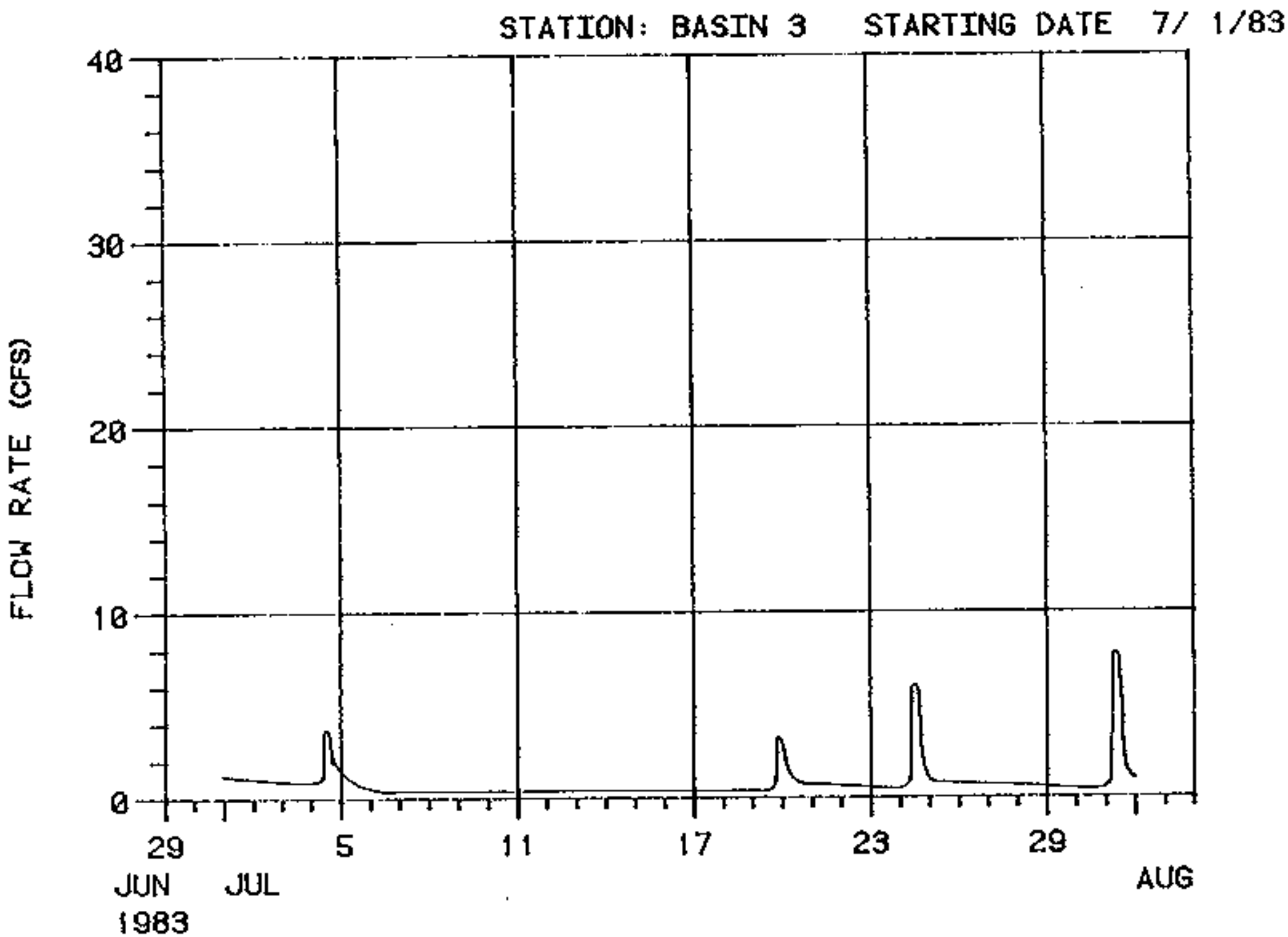

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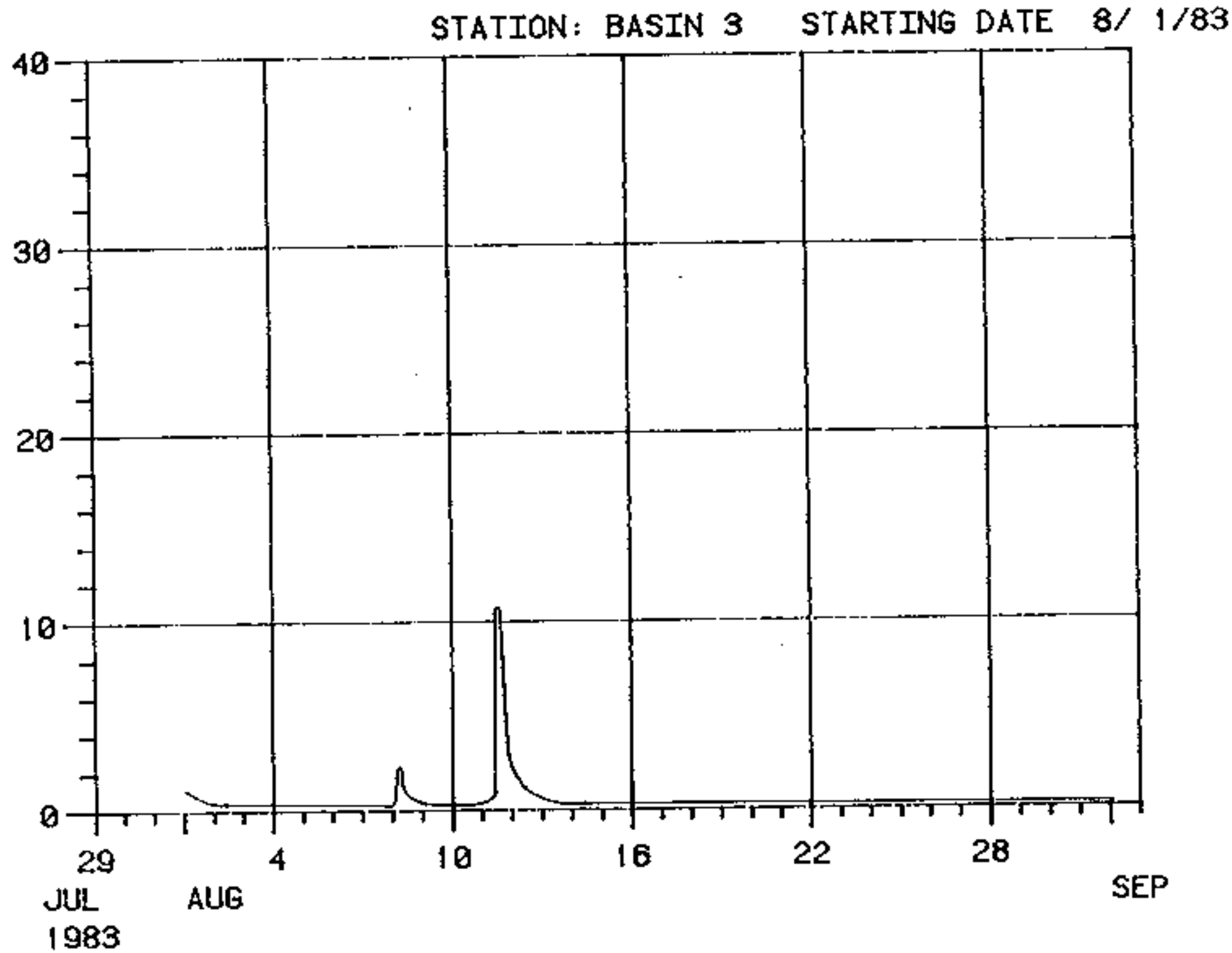
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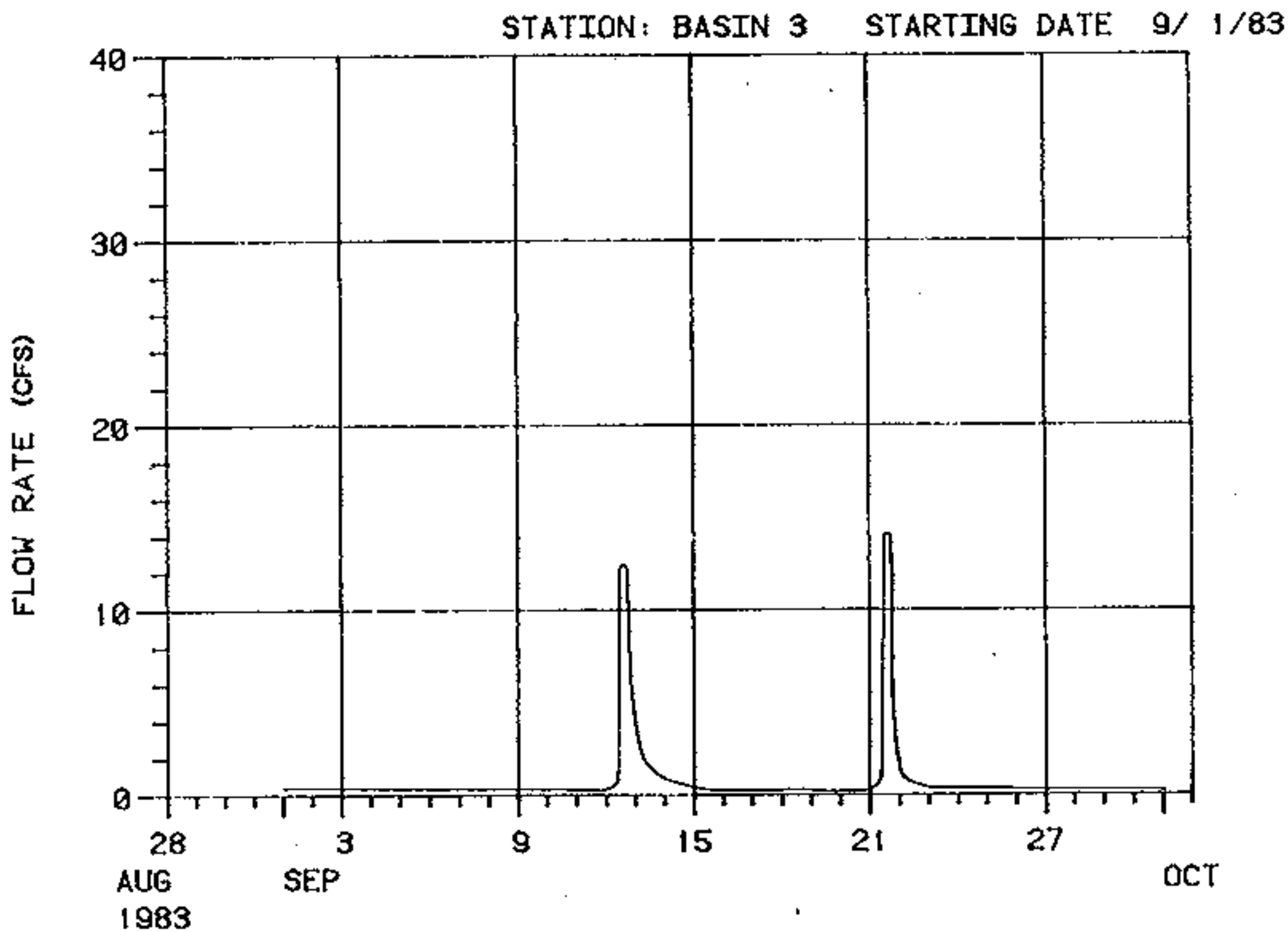
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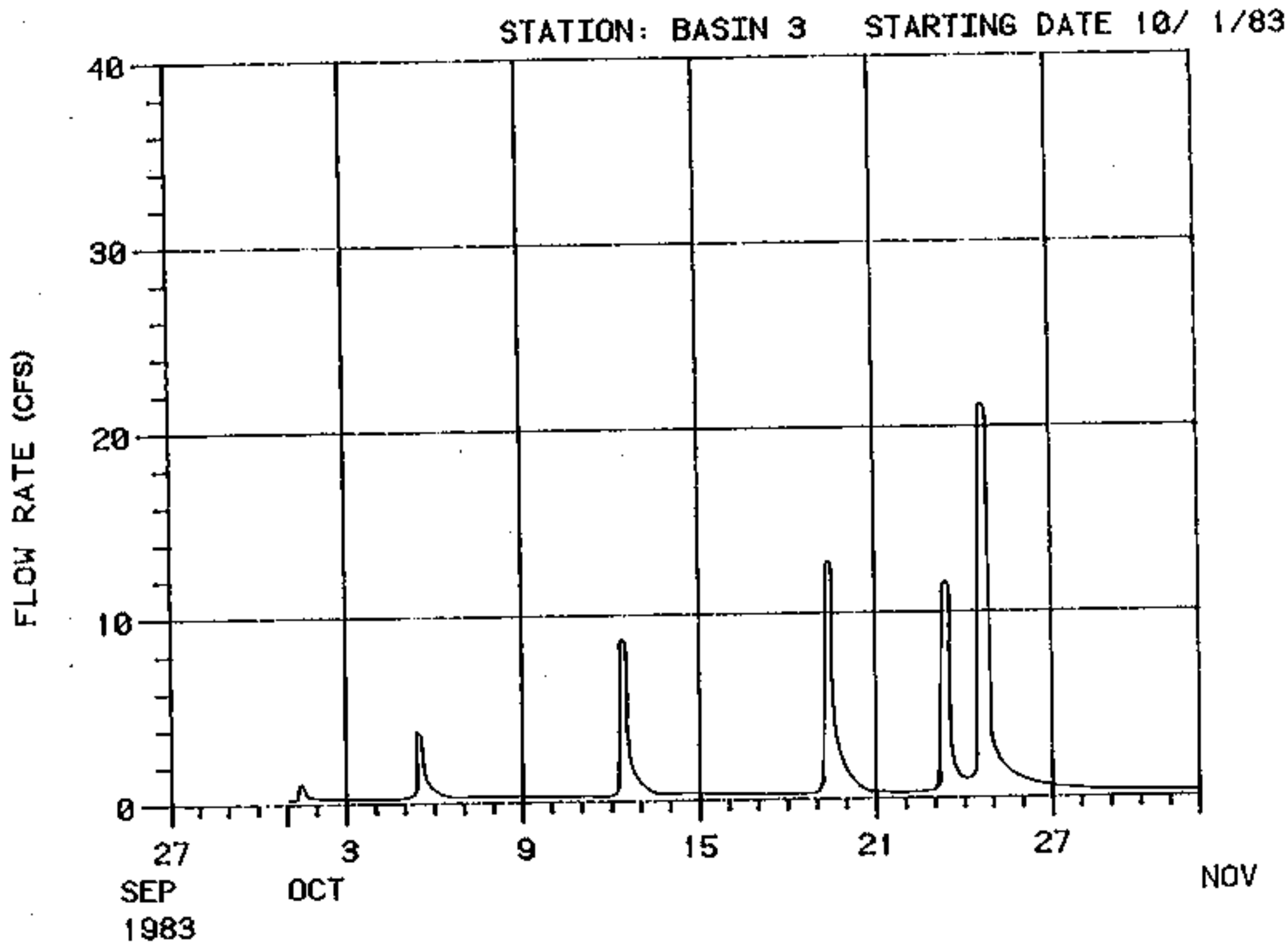
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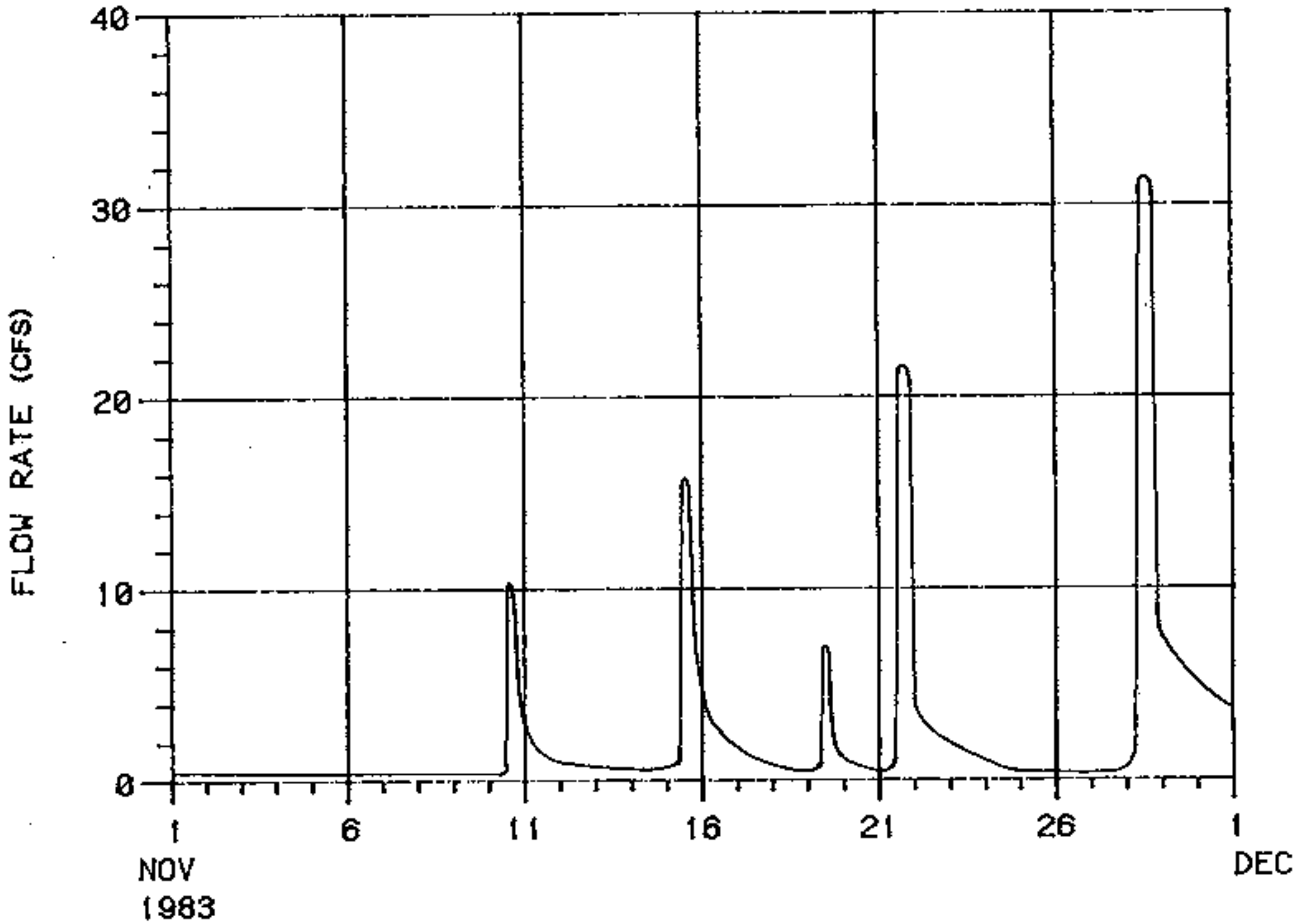

APPENDIX B

EXAMPLE RECHARGE CALCULATIONS

BASIN-I

1440
43

4320
5760

61,920

86,452 Ave daily (gals/day)

31 | 2,689,216 = Total base flow.
248

200
186

140
124

160
155

66

cfs = gpd.

APPENDIX B

BASEFLOW METHOD

December 1982

Total Baseflow = 2,689,216 gallons

Average Daily Baseflow = 86,749 gallons/day

Basin Area = 0.1968 square miles

Groundwater Recharge = 441,000 gallons/day/square mile

January 1983

Total Baseflow = 4,298,006 Gallons

Average Daily Baseflow = 138,645 gallons/day

Basin Area = 0.1968 square miles

Groundwater Recharge = 704,000 gallons/day/square mile

February 1983

Total Baseflow = 6,080,224 gallons

Average Daily Baseflow = 217,151 gallons/day

Basin Area = 0.1968 square miles

Groundwater Recharge = 1,103,000 gallons/day/square mile

March 1983

Total Baseflow = 9,495,469 gallons

Average Daily Baseflow = 306,305 gallons/day

Basin Area = 0.1968 square miles

Groundwater Recharge = 1,556,000 gallons/day/square mile

April 1983

Total Baseflow = 4,840,104 gallons

Average Daily Baseflow = 161,337 gallons/day

Basin Area = 0.1968 square miles

Groundwater Recharge = 820,000 gallons/day/square mile

May 1983

Total Baseflow = 2,206,902 gallons

Average Daily Baseflow = 71,190 gallons/day

Basin Area = 0.1968 square miles

Groundwater Recharge = 362,000 gallons/day/square mile

June 1983

Total Baseflow = 454,307 gallons

Average Daily Baseflow = 15,144 gallons/day

Basin Area = 0.1968 square miles

Groundwater Recharge = 77,000 gallons/day/square mile

July 1983

Total Baseflow = 0 gallons

August 1983

Total Baseflow = 0 gallons

September 1983

Total Baseflow = 0 gallons

October 1983

Total Baseflow = 0 gallons

November 1983

Total Baseflow = 1,367,229 gallons

Average Daily Baseflow = 45,574 gallons/day

Basin Area = 0.1968 square miles

Groundwater Recharge = 232,000 gallons/day/square mile

Average Annual Recharge = 441,000 gallons/day/square mile

HYDROLOGIC BUDGET METHOD

Potential Evapotranspiration - Thornthwaite (1948)

$$e = 1.6\ (10t/I)^{a}$$

$$i = (t/5)^{1.514} \qquad :t>0°C$$

$$I = \ i$$

$$a = 6.75 \times 10^{-7}\ (I^3) - 7.71 \times 10^{-5}(I^2) + 0.01792\ (I) + 0.49239$$

Where:

e = monthly evapotranspiration (cm)

t = mean monthly temperature (°C)

i = monthly heat index

DECEMBER 1982 $i = (4.3/5)^{1.514} = 0.80520$

JANUARY 1983 $i = (-0.022/5)^{1.514} = 0$

FEBRUARY 1983 $i = (0.24/5)^{1.514} = 0.01008$

MARCH 1983 $i = (6.26/5)^{1.514} = 1.40531$

APRIL 1983 $i = (10.42/5)^{1.514} = 3.03956$

MAY 1983 $i = (16.35/5)^{1.514} = 6.01209$

JUNE 1983 $i = (21.74/5)^{1.514} = 9.24587$

JULY 1983 $i = (24.58/5)^{1.514} = 11.14552$

AUGUST 1983 $i = (24.27/5)^{1.514} = 10.93339$

SEPTEMBER 1983 $i = (19.88/5)^{1.514} = 8.08280$

OCTOBER 1983 $i = (13.14/5)^{1.514} = 4.31830$

NOVEMBER 1983 $i = (6.51/5)^{1.514} = 1.49115$

$I = \quad i = 56.49827$

$a = 6.75 \times 10^{-7} (180,345.56) - 7.71 \times 10^{-5} (3,192.05) - 0.01792 (56.49827) + 0.49239$

$a = 0.1217333 - 0.2461 + 1.01245 + 0.49239$

$a = 1.3805$

$e = 1.6 (10t/I)^{a}$

$$\text{DECEMBER 1982} = 1.6\ (10(4.3)/56.49827)^{1.3805} = 1.09\ \text{cm} = 0.44\ \text{in}$$

$$\text{JANUARY 1983} = 1.6\ (10(-0.022)/56.49827)^{1.3805} = 0\ \text{cm} = 0\ \text{in}$$

$$\text{FEBRUARY 1983} = 1.6\ (10(0.24)/56.49827)^{1.3805} = 0.0204\ \text{cm} = 0.01\ \text{in}$$

$$\text{MARCH 1983} = 1.6\ (10(6.26)/56.49827)^{1.3805} = 1.8433\ \text{cm} = 0.73\ \text{in}$$

$$\text{APRIL 1983} = 1.6\ (10(10.42)/56.49827)^{1.3805} = 3.7248\ \text{cm} = 1.47\ \text{in}$$

$$\text{MAY 1983} = 1.6\ (10(16.35)/56.49827)^{1.3805} = 6.9375\ \text{cm} = 2.73\ \text{in}$$

$$\text{JUNE 1983} = 1.6\ (10(21.74)/56.49827)^{1.3805} = 10.2807\ \text{cm} = 4.05\ \text{in}$$

$$\text{JULY 1983} = 1.6\ (10(24.58)/56.49827)^{1.3805} = 12.1796\ \text{cm} = 4.80\ \text{in}$$

$$\text{AUGUST 1983} = 1.6\ (10(24.27)/56.49827)^{1.3805} = 11.9681\ \text{cm} = 4.71\ \text{in}$$

$$\text{SEPTEMBER 1983} = 1.6\ (10(19.88)/56.49827)^{1.3805} = 9.0866\ \text{cm} = 3.58\ \text{in}$$

$$\text{OCTOBER 1983} = 1.6\ (10(13.14)/56.49827)^{1.3805} = 5.1305\ \text{cm} = 2.02\ \text{in}$$

$$\text{NOVEMBER 1983} = 1.6\ (10(6.51)/56.49827)^{1.3805} = 1.9457\ \text{cm} = 0.77\ \text{in}$$

Potential Evapotranspiration - Eagleman (1967)

$$E_T = C\ (0.035\ e_s)\ (100-RH)^{1/2}$$

$$C = 0.20 + 0.0133\ t$$

Where: E_T = Monthly potential evapotranspiration (in)

e_s = Saturation vapor pressure (mb)

RH = Mean monthly percent relative humidity

t = Mean monthly temperature (°F)

December 1982

$C = 0.20 + 0.0133\ (39.8\ °F)$

$C = 0.72934$

$E_T = 0.72934\ (0.035\ (9mb))\ (100-75)^{1/2}$

$E_T = 0.72934\ (0.315)\ (5.0)$

$E_T = 1.15$ in

January 1983

$C = 0.20 + 0.0133\ (31.96\ °F)$

$C = 0.625068$

$E_T = 0.625068\ (0.035\ (6mb))\ (100-69)^{1/2}$

$E_T = 0.625068\ (0.21)\ (5.568)$

$E_T = 0.73$ in

February 1983

$C = 0.20 + 0.0133\ (32.43\ °F)$

$C = 0.631319$

$E_T = 0.631319\ (0.035\ (7mb))\ (100-65)^{1/2}$

$E_T = 0.631319\ (0.245)\ (5.916)$

$E_T = 0.92$ in

March 1983

$C = 0.20 + 0.0133\ (43.26\ °F)$

$C = 0.775358$

$E_T = 0.775358\ (0.035\ (10mb))\ (100-63)^{1/2}$

$E_T = 0.775358\ (0.35)\ (6.085)$

$E_T = 1.65$ in

April 1983

$C = 0.20 + 0.0133\ (50.75\ °F)$

$C = 0.874975$

$E_T = 0.874975\ (0.035\ (14mb))\ (100-66)^{1/2}$

$E_T = 0.874975\ (0.49)\ (5.831)$

$E_T = 2.50$ in

May 1983

$C = 0.20 + 0.0133\ (61.43\ °F)$

$C = 1.017019$

$E_T = 1.017019\ (0.035\ (20mb))\ (100-67)^{1/2}$

$E_T = 1.017019\ (0.70)\ (5.745)$

$E_T = 4.09$ in

June 1983

Mean Monthly Temperature = 71.13°F

THUS C = 1.13

E_T = 1.13 (0.035) (26mb)) $(100-66)^{1/2}$

E_T = 1.13 (0.91) (5.831)

E_T = 6.00 in

July 1983

Mean Monthly Temperature = 76.24°F

THUS C = 1.13

E_T = 1.13 (0.035) (31mb)) $(100-62)^{1/2}$

E_T = 1.13 (1.085) (6.164)

E_T = 7.56 in

August 1983

Mean Monthly Temperature = 75.69°F

THUS C = 1.13

E_T = 1.13 (0.035) (30mb)) $(100-66)^{1/2}$

E_T = 1.13 (1.05) (5.831)

E_T = 6.92 in

September 1983

$C = 0.20 + 0.0133\ (67.78\ ^{\circ}F)$

$C = 1.101474$

$E_T = 1.101474\ (0.035\ (24mb))\ (100-64)^{1/2}$

$E_T = 1.101474\ (0.84)\ (6.0)$

$E_T = 5.55$ in

October 1983

$C = 0.20 + 0.0133\ (55.66\ ^{\circ}F)$

$C = 0.940278$

$E_T = 0.940278\ (0.035\ (17mb))\ (100-71)^{1/2}$

$E_T = 0.940278\ (0.595)\ (5.39)$

$E_T = 3.01$ in

November 1983

$C = 0.20 + 0.0133\ (43.72\ ^{\circ}F)$

$C = 0.781476$

$E_T = 0.781476\ (0.035\ (10mb))\ (100-74)^{1/2}$

$E_T = 0.781476\ (0.35)\ (5.099)$

$E_T = 1.39$ in

ACTUAL EVAPOTRANSPIRATION - EAGLEMAN (1967)

Actual Evapotranspiration - 72% of Potential Evapotranspiration

December 1982 = 1.15 in x 0.72 = 0.83 in

January 1983 = 0.73 in x 0.72 = 0.53 in

February 1983 = 0.92 in x 0.72 = 0.55 in

March 1983 = 1.65 in x 0.72 = 1.19 in

April 1983 = 2.50 in x 0.72 = 1.80 in

May 1983 = 4.09 in x 0.72 = 2.94 in

June 1983 = 6.00 in x 0.72 = 4.32 in

July 1983 = 7.56 in x 0.72 = 5.44 in

August 1983 = 6.92 in x 0.72 = 4.98 in

September 1983 = 5.55 in x 0.72 = 4.00 in

October 1983 = 3.01 x 0.72 = 2.17 in

November 1983 = 1.39 in x 0.72 = 1.00 in

Groundwater Recharge - Basin 1

$$R = P - E_T - Q$$

Where: R = groundwater recharge

P = precipitation

E_T = evapotranspiration

Q = storm runoff

December 1982

Precipitation = 4,309,368 gallons

Actual Evapotranspiration = 2,881,120 gallons

Storm Runoff = 344,702 gallons

Total Groundwater Recharge = 1,083,546 gallons

Average Daily Groundwater Recharge = 34,953 gallons/day

Basin Area = 0.1968 square miles

Groundwater Recharge = 178,000 gallons/day/square mile

January 1983

Precipitation = 10,465,608 gallons

Actual Evapotranspiration = 1,920,747 gallons

Storm Runoff = 807,896 gallons

Total Groundwater Recharge = 7,736,965 gallons

Average Daily Groundwater Recharge = 249,580 gallons/day

Basin Area = 0.1968 square miles

Groundwater Recharge = 1,268,000 gallons/day/square mile

February 1983

Precipitation = 10,465,608 gallons

Actual Evapotranspiration = 2,290,121 gallons

Storm Runoff = 3,953,303 gallons

Total Groundwater Recharge = 4,222,184 gallons

Average Daily Groundwater Recharge = 150,792 gallons/day

Basin Area = 0.1968 square miles

Groundwater Recharge = 766,000 gallons/day/square mile

March 1983

Precipitation = 20,393,994 gallons

Actual Evapotranspiration = 5,403,810 gallons

Storm Runoff = 5,560,477 gallons

Total Groundwater Recharge = 10,932,774 gallons

Average Daily Groundwater Recharge = 352,670 gallons/day

Basin Area = 0.1968 square miles

Groundwater Recharge = 1,792,000 gallons/day/square mile

April 1983

Precipitation = 27,429,468 gallons

Actual Evapotranspiration = 6,057,740 gallons

Storm Runoff = 4,002,047 gallons

Total Groundwater Recharge = 17,369,681 gallons

Average Daily Groundwater Recharge = 578,989 gallons/day

Basin Area = 0.1968 square miles

Groundwater Recharge = 2,942,000 gallons/day/square mile

May 1983

Precipitation = 15,869,418 gallons

Actual Evapotranspiration = 10,219,358 gallons

Storm Runoff = 0 gallons

Total Groundwater Recharge = 5,650,060 gallons

Average Daily Groundwater Recharge = 182,260 gallons/day

Basin Area = 0.1968 square miles

Groundwater Recharge = 926,000 gallons/day/square mile

June 1983

Precipitation = 7,524,293 gallons

Actual Evapotranspiration = 14,774,991 gallons

Storm Runoff = 0 gallons

Total Groundwater Recharge = -7,250,698 gallons

Average Daily Groundwater Recharge = -241,689 gallons/day

Basin Area = 0.1968 square miles

Groundwater Recharge = -1,228,000 gallons/day/square mile

July 1983

Precipitation = 3,249,127 gallons

Actual Evapotranspiration = 18,605,544 gallons

Storm Runoff = 0 gallons

Total Groundwater Recharge = -15,356,417 gallons

Average Daily Groundwater Recharge = -495,368 gallons/day

Basin Area = 0.1968 square miles

Groundwater Recharge = -2,517,000 gallons/day/square mile

August 1983

Precipitation = 5,472,213 gallons

Actual Evapotranspiration = 17,032,281 gallons

Storm Runoff = 0 gallons

Total Groundwater Recharge = -11,560,068 gallons

Average Daily Groundwater Recharge = -372,905 gallons/day

Basin Area = 0.1968 square miles

Groundwater Recharge = -1,895,000 gallons/day/square mile

September 1983

Precipitation = 6,737,662 gallons

Actual Evapotranspiration = 13,469,853 gallons

Storm Runoff = 0 gallons

Total Groundwater Recharge = -6,732,191 gallons

Average Daily Groundwater Recharge = -224,406 gallons/day

Basin Area = 0.1968 square miles

Groundwater Recharge = -1,140,000 gallons/day/square mile

October 1983

Precipitation = 15,459,002 gallons

Actual Evapotranspiration = 7,165,863 gallons

Storm Runoff = 0 gallons

Total Groundwater Recharge = 8,293,139 gallons

Average Daily Groundwater Recharge = 267,521 gallons/day

Basin Area = 0.1968 square miles

Groundwater Recharge = 1,139,000 gallons/day/square mile

November 1983

Precipitation = 19,802,571 gallons

Actual Evapotranspiration = 3,373,619 gallons

Storm Runoff = 0 gallons

Total Groundwater Recharge = 15,576,083 gallons

Average Daily Groundwater Recharge = 519,203 gallons/day

Basin Area = 0.1968 square miles

Groundwater Recharge = 2,638,000 gallons/day/square mile