SHORT TERM VARIATION OF RUNOFF-RAINFALL RATIOS IN NOVA SCOTIA IHD WATERSHEDS

by

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ABSTRACT

Runoff-rainfall ratios are estimated from streamflow hydrographs using precipitation and streamflow data for three IHD watersheds in Nova Scotia. The study watersheds are located in eastern, central and western Nova Scotia. Instrumentation for the measurement of precipitation, temperature and streamflow was installed in the watersheds as part of the International Hydrological Decade program.

Annual hydrographs were plotted and separated into their direct runoff and groundwater runoff components. Average annual direct runoff varied from 20 to 29.8 inches and groundwater runoff varied from 11.3 to 28.7 inches.

Individual and largest storms were selected for each month from the meteorological records (Fraser Brook 3 years, April Brook 2 years, Sharpe Brook 1 year of period). Storm hydrographs were also plotted and separated into their two components of direct and groundwater runoff. Ratios of direct runoff to average weighted rainfall were determined for each watershed. Estimates revealed that these ratios varied from 0.03 to 29% for the period of study.

Annual runoff-rainfall ratio in the watersheds varied from 66 to 97%.

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INTRODUCTION

Purpose and Scope of the Investigation

The purpose of the studies described in this report is to better understand the variation of total runoff-rainfall ratios of the streams in Nova Scotia.

For a given stream, runoff-rainfall ratios must be estimated for the investigation of public water supplies, irrigation, drainage, flood protection, river regulation, etc. This study becomes more important due to the increased demand for water by industry and population. Therefore, representative watersheds have been established as part of the IHD (International Hydrological Decade) program in Nova Scotia. These watersheds are located at Fraser Brook, April Brook, and Sharpe Brook as shown in Figure 10 on page 34.

The specific aim of the study was to determine the total quantity of flow, its seasonal variation, and investigate relations between storm rainfall and direct runoff.

The results of this study of small representative IHD watersheds may be useful in comparing similar but larger basins in Nova Scotia.

Previous Investigations

The first detailed study for IHD watersheds in Nova Scotia has been done by Pinder and Jones (1969). In that study the groundwater component of peak discharge was determined from the chemical analysis of total runoff. The groundwater component at the peak stage for a single storm, October 9, 1967, was calculated to be 42% of total runoff for April Brook, 40% for Fraser Brook, and 32% for Sharpe Brook.

No other work has been carried out on the hydrogeology of the watersheds prior to this report, although meteorological, physiographical and geological investigations have been done which are mentioned later in this report.

Acknowledgments

I wish to thank Mr. J. F. Jones, Chief, Groundwater Section, Nova Scotia Department of Mines, for his continuing guidance throughout the investigation, and for discussion and clarification of the text during the compilation of the thesis.

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I wish to thank Mr. J. Peters, Mr. D. McBride, and Mr. J. W. Byers of the Canada Department of Energy, Mines and Resources, Inland Waters Branch, for their criticism and the Branch itself for providing me with the necessary runoff data.

Meteorological data was obtained from the Canada Department of Transport, Meteorological Branch.

The writer is indebted to K. S. Chan of the Computer Center, Dalhousie University, for writing the computer program.

FRASER BROOK WATERSHED

General Description of the Area

Location and Extent of Area

Fraser Brook Watershed, about 4 miles east of Truro, Colchester County, is located in the north-central part of the province. Geographically, the area is enclosed between 63°11'56" and 63°08'32" west longitude and 45°20'48" and 45°18'03" north latitude.

The Fraser Brook Watershed is a small part of the larger Salmon River Watershed which has a drainage area of about 140 square miles (Hennigar, 1968). The drainage area* of the Fraser Brook Watershed is 3.51 square miles, with drainage northward into Christie Brook which ultimately discharges into the Salmon River above the Water Survey of Canada gauging station at Murray and about half a mile below the bridge at Valley village.

Physiography

The Fraser Brook Watershed lies on the Hants and Colchester County Lowland physiographic region of Nova Scotia (Goldthwait, 1924). These lowlands

* After the work on this thesis was completed, maps of watersheds scale 1" = 400' became available to the Canada Dept. of Energy, Mines and Resources, Inland Waters Branch, and N. S. Dept. of Mines.

are underlain by Mississippian and Pennsylvanian marine and continental sediments.

Relief within the watershed is about 300 feet. Altitudes at the watershed are between 340 and 640 feet from north to south. The shapes of the hills are very generally rounded or oval, after the fashion of hills of glacial drift.

The stream profile is given in Figure 1, which shows the elevation of the bed of the main stream as a function of its distance from the lower most point in the watershed. The gross slope of the stream between any two points is the total fall between the points divided by the stream length. The mean slope may be constructed by drawing a straight line so that the areas enclosed above and below the stream profile are equal (DeWiest, 1965).

Soils

The three main soils mapped are called the Harmony, Londonderry and Hebert Associations (Wicklund and Smith, 1948).

The soil map shown in Figure 2 and Table 1 gives summarized data for soils of the watershed.

Forest Types

A forest inventory of the woodlands within the watershed was carried out by the Nova Scotia Department of Lands and Forests in 1966. Over 30 miles of cruise lines were surveyed, measuring trees in 61 acres of the watershed and giving a 2 percent sample of the area. Table 2 summarizes data for forest types of the Fraser Brook Watershed Area.

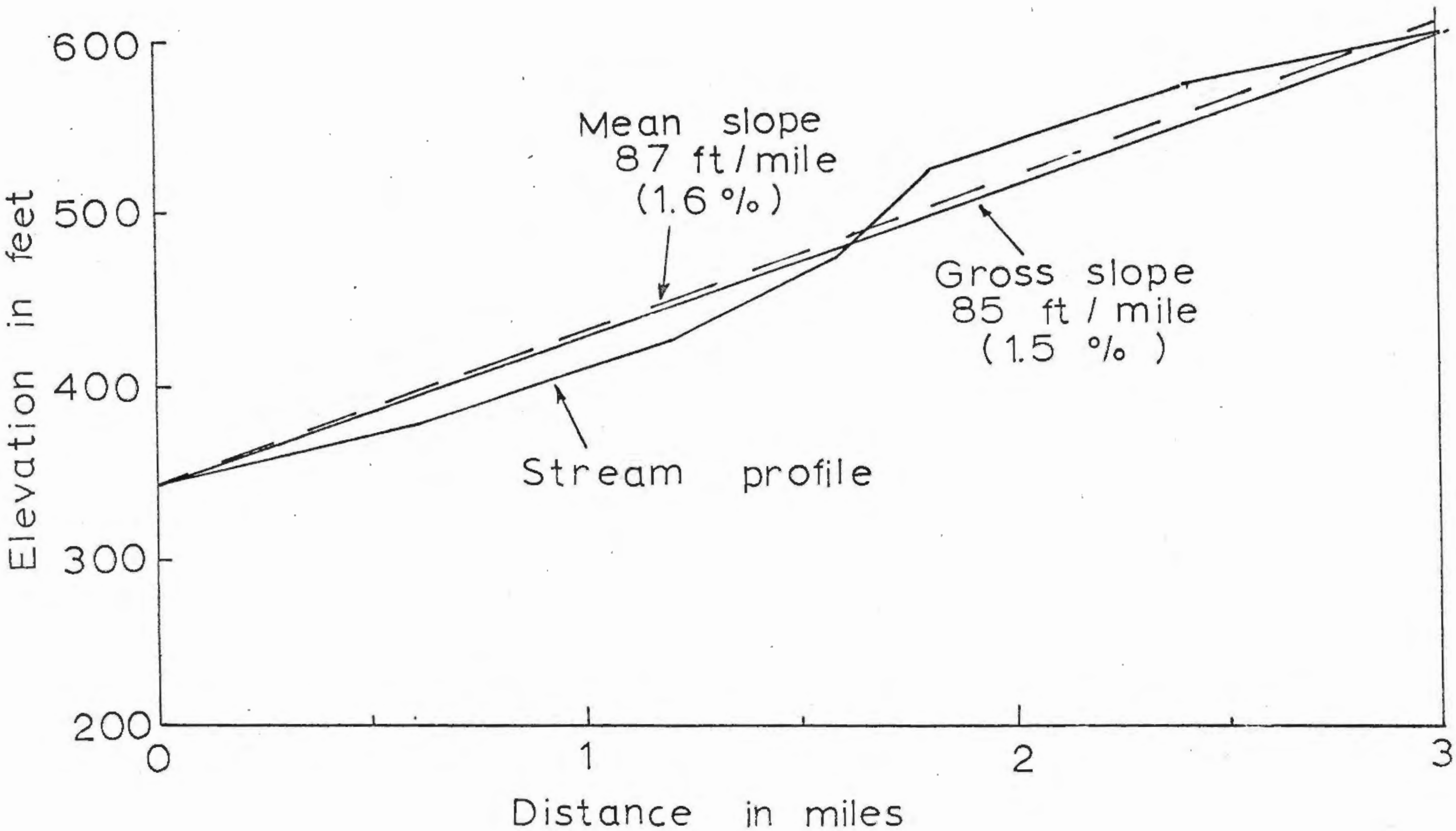

Figure 1. Stream Profile of Fraser Brook.

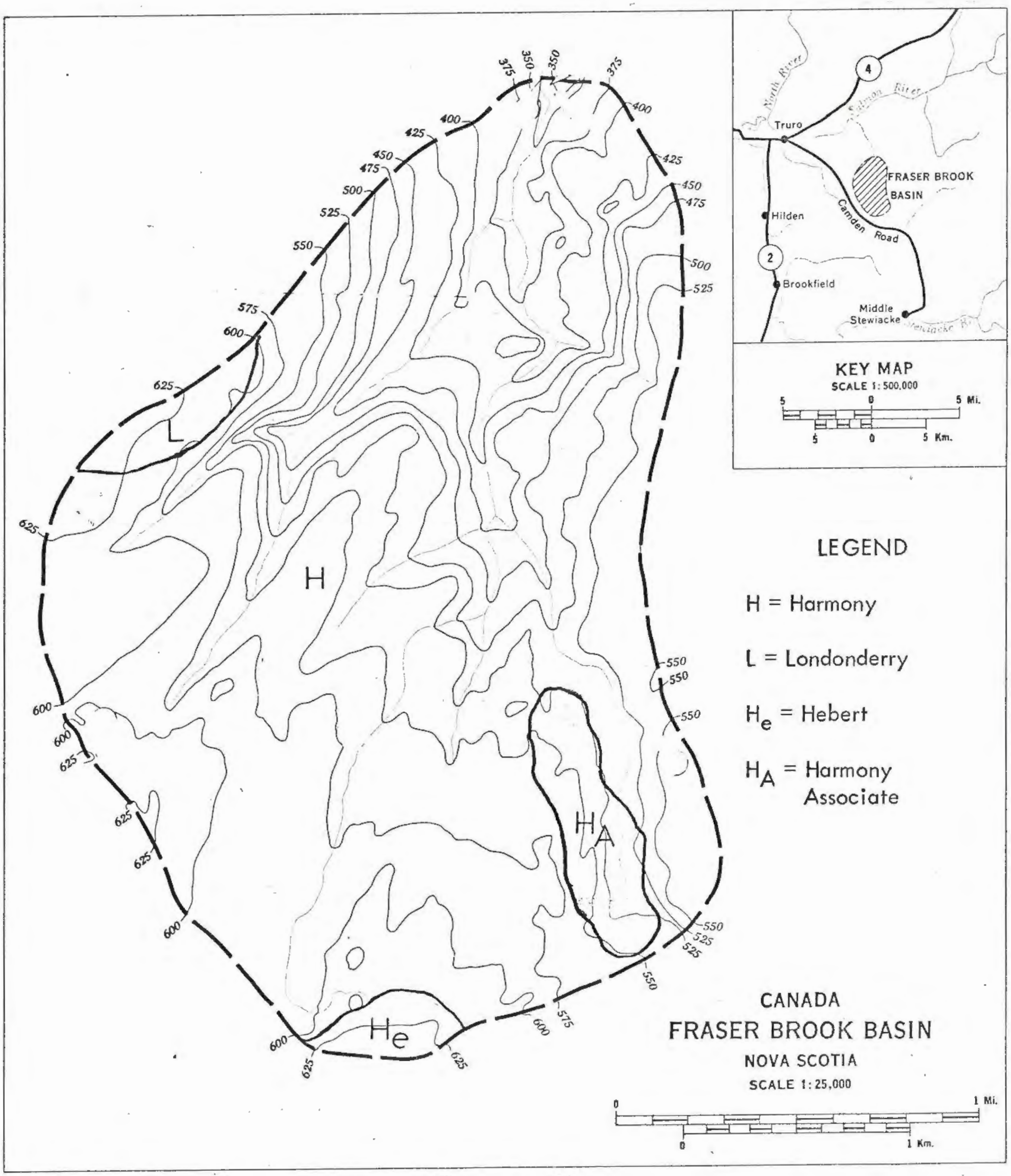

Figure 2. Soil map of Fraser Brook Watershed

Table 1. Description of Soils for Fraser Brook Watershed*

Name of Soil	Harmony	Londonderry	Hebert	Harmony Associate
Description of surface and subsoil	Brown gravelly sandy loam, light brown gravelly sandy clay loam. Gravel content ranges from 39 to 60 percent	Light brown clay loam over light brown clay loam.	Brown gravelly sandy loam over yellowish brown stony sandy loam.	Soil exhibiting deeply leached layers and strongly mottled profiles.
Parent Material	Dark brown gravelly clay loam till derived from dark brown sandstone.	Purplish brown clay loam till derived from dark red shale and sandstone	Water deposited material consisting of gravel and cobblestones	Similar to the imperfect and well drained associates.
Topography and Drainage	Moderately to roughly undulating. Good drainage.	Moderately undulating. Fair external and internal drainage	Level to undulating. Excessively drained.	Level to gently undulating Poor drainage.

* Adapted from Wicklund and Smith, 1948

Table 2. Forest Types in Fraser Brook Watershed Area

Type	Area in square miles	Area in acres	Percent area
Softwood	2.020	1280	58
Hardwood	0.190	122	5
Mixedwood	1.013	647	29
Alders	0.067	43	2
Blueberry	0.040	26	1
Cleared land	0.170	110	5
Totals	3.500*	2541	100

* Forest inventory includes a slightly less area than the actual watershed area.

Climate

The climate is described in general terms as humid and temperate for the watershed area. Extremes in temperature and precipitation seldom occur. Precipitation is usually ample during the growing season (Canada Land Inventory, 1966). Most of it is produced by cyclonic storms; thunderstorms in summer are not frequent. Usually, precipitation is heaviest in late fall and early winter.

Winters are cold, raw, and snowy. The ground is usually frozen and impervious at this time so that a great portion of the precipitation eventually passes directly into the streams as surface runoff. The length of the frost free period is from 100 to 120 days (Wicklund and Smith, 1948).

The spring season is late because of the prevalence of northeasterly winds and frequent precipitation. Changes in precipitation and temperature in the watershed are described in Figures 11 and 12 on pages 35 and 36.

The average annual potential evapotranspiration is 21 inches of water (Chapman and Brown, 1966).

Geology

Fraser Brook area is underlain by nonmarine sedimentary rock units. In this region sandstone, grit, shale, and conglomerate of the Horton Group, and sandstone and shale of the Canso Group are found. The rock units found in the watershed are of Mississippian age.

Surficial deposits are of three main types:
Ice-content material; sandy till and clay till, which cover most of the watershed; and other materials such as swamp, bog and recent alluvium, which cover only a minor portion of the area.

Bedrock Geology

Horton Group

Rocks of the Horton Group are fossiliferous and consist of red sandstone, grit, shale and conglomerate (Stevenson, 1958).

Bell (1958) estimated the Horton Group has a maximum combined thickness of 4,000 feet.

Canso Group

The sedimentary rocks of the Canso formation are nonmarine and reach a thickness of over 1800 feet. The formation consists of red and grey shales and sandstones that overlie the Windsor Group.

The Canso sediments found within the Fraser Brook Watershed were separated into 8 distinct mappable lithologic units (Hennigar, 1967). These are described in order from the bottom of the section to the top in Table 3.

Surficial Geology

Sandy glacial till covers about 80 percent of the watershed and in some areas overlies a clay till exposed over approximately 15 percent of the drainage area; the drift varies from 5 to 45 feet in thickness, (Hennigar, 1967).

The soil grain properties of the sandy till unit are very similar to the soil grain properties of the siltstone and sandstone units making up the bedrock geology. It follows that the source, or parent, material is most likely to be bedrock very near or within the watershed area.

The clay till mapped in the area is relatively cohesive and compact. Also, pebble size fragments in the material are sparse; the major portion of the till is silt and clay components.

Table 3. Lithology of Units of Canso Group

Unit number	Lithology
8	Reddish brown, micaceous siltstone.
7	Greyish brown and green, fine-grained sandstone.
6	Reddish brown laminated micaceous siltstone, showing cross bedding.
5	Thin, platy, brick-red shale.
4	Medium-grained, massive, grey sandstone.
3	Reddish brown siltstone.
2	Greyish green siltstone, well consolidated.
1	Brown sandstone, high content of mica.

In general, the surficial deposits are of a granular nature which is favourable for a high rate of infiltration of precipitation and surface water to the groundwater table.

Structure

Within the map area, folding has resulted in formation of an anticline and two synclines, all trending northeast. The anticline passes through Camden, the center of the watershed, and continues northeastward. The Archibald syncline lies northwest and the Greenfield syncline lies southeast of the central anticline.

The watershed area was studied by Hennigar (1967), who indicated that the beds are right side up and folding is continuous, with no overturning or major faulting. The regional strike of the strata is about N 35°E, deviating as much as 15° over the area.

APRIL BROOK WATERSHED

General Description of the Area

Location and Extent of Area

April Brook Watershed about 2 miles west of Upper Margaree, Inverness County, is located in the northwest part of the Cape Breton Island. Geographically, the area is enclosed between 61°11'00" and 61°07'50" west longitude, and 46°15'50" and 46°12'40" north latitude.

April Brook is approximately two miles in length and the drainage area is 2.14 square miles, with drainage eastward into Southwest Margaree River.

Physiography

The greater part of the watershed lies on the Cape Breton Island Lowland physiographic region of Nova Scotia (Goldthwait, 1924). These lowlands are underlain by sandstones, shales and limestones.

Relief within the watershed reaches about 980 feet. Altitudes at the watershed are between 180 and 1160 feet.

The stream profile is given in Figure 3, which shows the elevation of the bed of the main stream as a function of its distance from the lowermost point in the watershed.

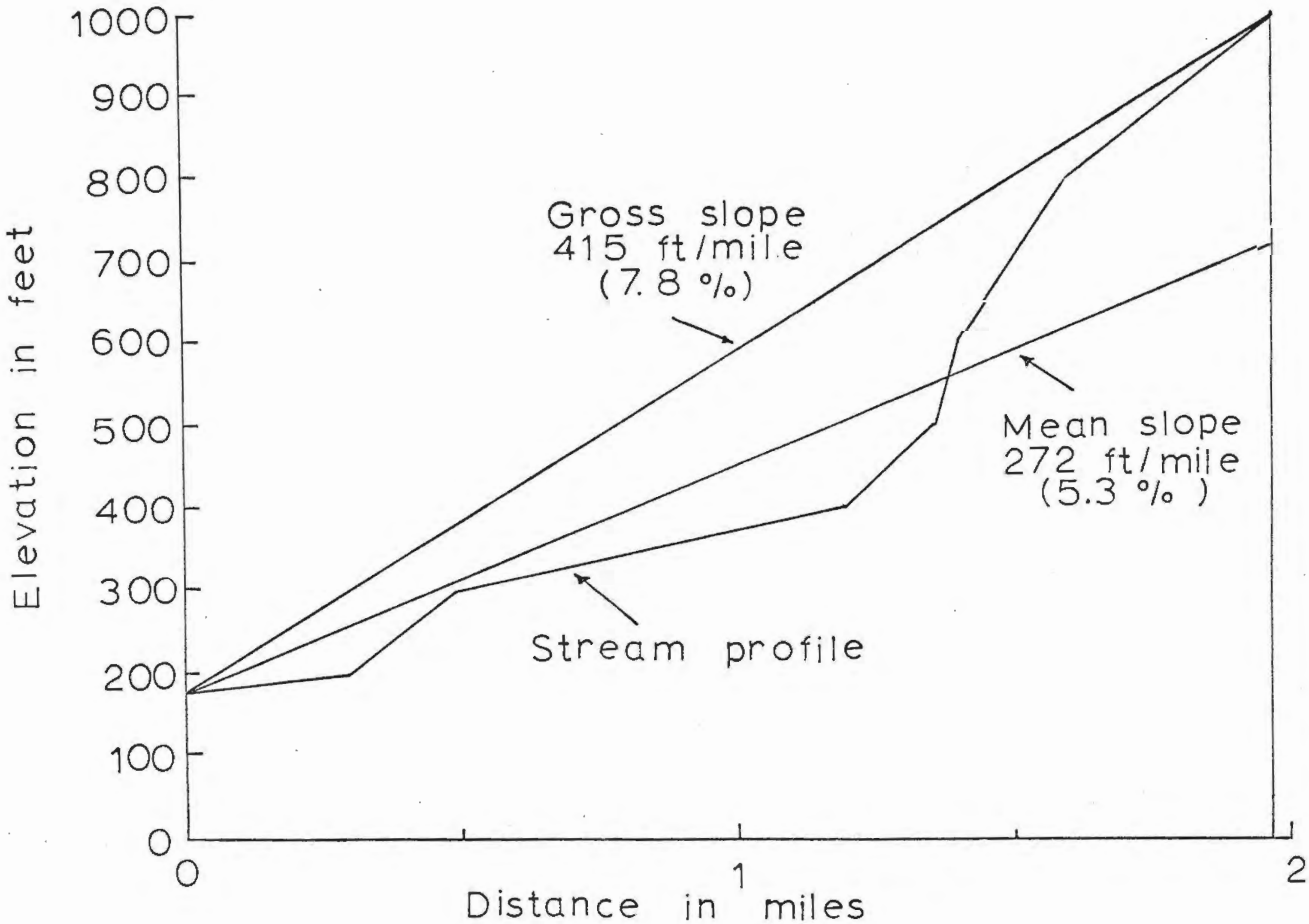

Figure 3. Stream Profile of April Brook

Soils

The soils within the watershed have been classified into soil series (Cann, MacDougall and Hilchey, 1963). However there are a few miscellaneous soils, such as "Rough Mountain Land", for which the place in the classification scheme is not yet fixed. The three main soils mapped in the drainage area are called the Rough Mountain Land, Hebert Series and Queens Series.

The soil map shown in Figure 4 and Table 5 gives summarized data for soils of the watershed.

Forest types

A forest inventory of the woodlands within the watershed was carried out by the Nova Scotia Department of Lands and Forests in 1966.

Table 4 gives summarized data for forest types of April Brook Watershed area.

Table 4. Forest Types in April Brook Watershed Area

Type	Area in square miles	Area in acres	Percent area
Softwood	0.49	314	19
Hardwood	0.70	447	27
Mixedwood	1.31	839	51
Non-Forested	0.07	46	3
Totals	2.57*	1,646	100

* Forest inventory includes a slightly greater area than the actual watershed area.

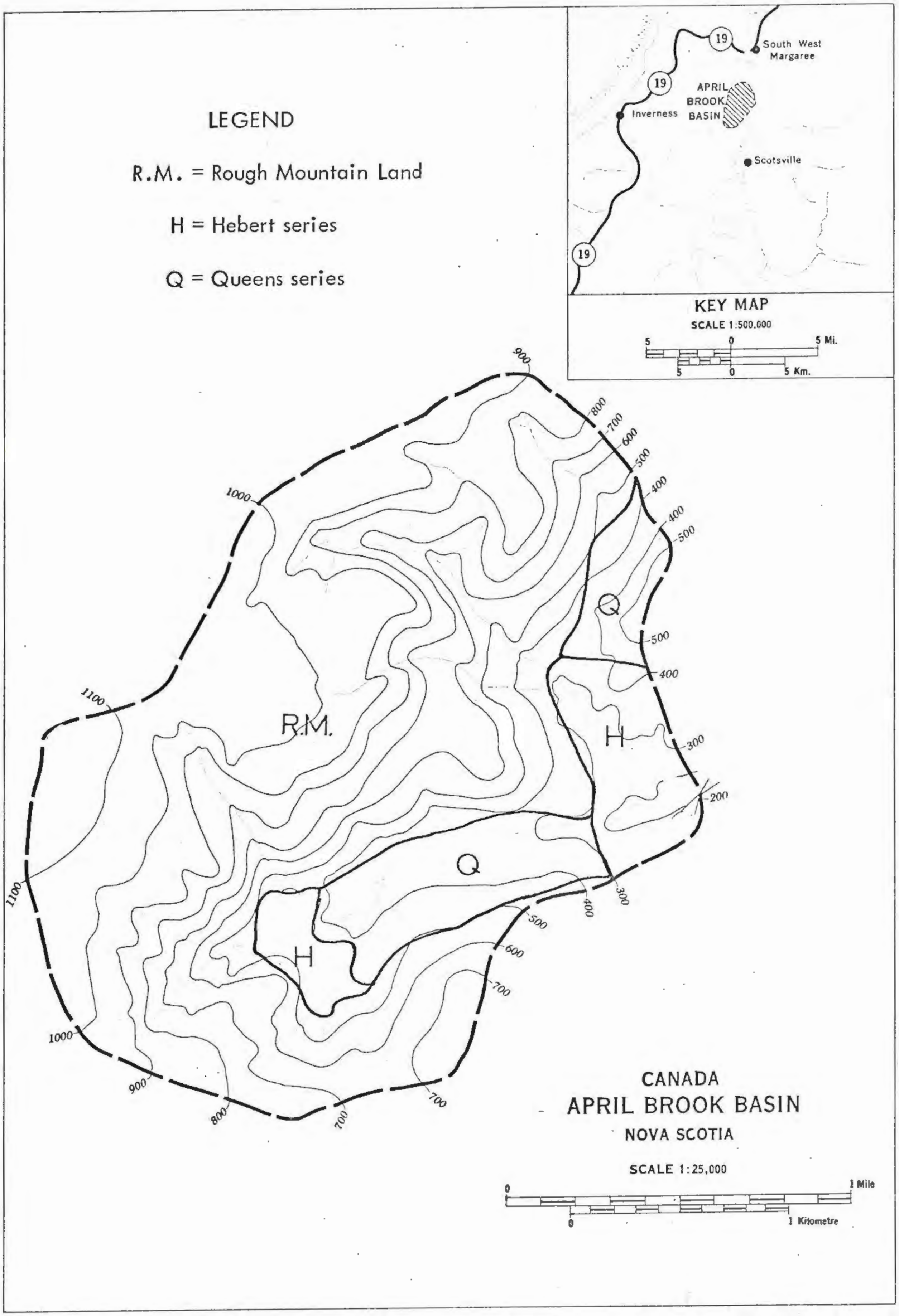

Figure 4. Soil map of April Brook Watershed

Table 5. Description of Soils for April Brook Watershed*

Name of Soil	Rough Mountain Land	Hebert Series	Queens Series
Description of surface and subsoil	Weakly developed or have been disturbed by man. (Classification is still in doubt)	Ranges from a loamy sand to sandy loam.	Reddish-brown clay loam and very pale brown loam.
Parent Material	Stony, sandy loam till.	Coarse-textured, stratified sand and gravel deposit of glacial streams.	Moderately plastic, reddish-brown, clay loam glacial till.
Topography and Drainage	Variable	Level to nearly level land, strongly rolling to hilly land. Well drained.	Level to nearly level land, strongly rolling to hilly land. Imperfect drainage.

* Adapted from Hilchey, 1963.

Climate

The watershed area has a humid and temperate climate. Extremes in temperatures and precipitation seldom occur. Precipitation is usually ample during the growing season.

Mention must also be made of the fogs along the coast, which is 15 miles from April Brook, where up to ninety days a year are foggy. Usually fogs occur in the morning, clearing up before noon (Canada Land Inventory, 1966).

Winters are cold, raw and snowy. Average frost free period is about 120 days (Chapman and Brown, 1966). During the summer, evapotranspiration usually exceeds rainfall; average annual potential evapotranspiration is 21 inches of water.

Changes in precipitation and temperature in the watershed are shown in Figures 13 and 14 on pages 38 and 39.

Geology

The geology of April Brook Watershed area consists of marine and nonmarine sedimentary rock units. In this region the conglomerate, sandstone, siltstone and shale of the Horton Group and the siltstone, sandstone, limestone, gypsum and anhydrite of the Windsor Group and the siltstone, sandstone and limestone of Canso Group are found. The rock units found in the watershed are of Mississippian age.

General information concerning the bedrock geology within the area of watershed is given in Table 6.

Table 6. Table of Formation of Bedrock Geology*

Era	Period or Epoch	Group or Formation and thickness (feet)	Formation or Member	Lithology
Paleozoic	Mississippian	Canso Group (7,000 ±)		Nonmarine sedimentary rocks; red and grey shales and sandstones
		Windsor Group (2,500 ±)	Gypsum Member	Gypsum (Sinkholes are filled with water).
			Limestone Member	Limestone. Abundant shell fragments. (The partly or wholly dissolved fossils cause the porosity)
		Horton Group (10,000 ±)	Strathlorne-Ainslie Formation	Red and grey sandstone, siltstone, conglomerate, grey siltstone, sandstone, shale
			Craignish Formation	Grey arkosic sandstone and conglomerate, some grey siltstone & sandstone

* Modified from Murray (1960), Pinder (1966), and Kelly (1967).

Surficial Geology

Surficial deposits are of two main types:
Glacial till covers most of the drainage area. Other material such as recent alluvium, covers only a minor portion of the area.

Sandy glacial till varies in thickness from a few feet on the highland areas up to at least 30 feet in the central region of the watershed.

Structure

Within the map area, folding produced an anticline and syncline. The anticline is overturned to the east plunging to the northeast in the central of the watershed area. The syncline is on the eastern side of the anticline. Small folds have developed between the anticline and syncline in the Strathlorne-Ainslie Formation (Pinder, 1966).

SHARPE BROOK WATERSHED

General Description of the Area

Location and Extent of Area

Sharpe Brook Watershed about 3 miles south of Cambridge Station is located about 10 miles west of Kentville, Kings County. Geographically, the area is enclosed between 64°39'00" and 64°36'00" west longitude, and 45°02'00" and 44°58'45" north latitude.

Sharpe Brook is approximately 2.5 miles in length and has two main branches. The drainage area is 3.27 square miles, with drainage northward into the Cornwallis River.

Physiography

The Sharpe Brook Watershed lies on the South Mountain physiographic region of Nova Scotia (Goldthwait, 1924). This highland is underlain by early Paleozoic slates and quartzites intruded by Devonian granite.

Relief within the watershed reaches about 500 feet. Altitudes in the area are between 300 and 800 feet from north to south.

The stream profile is given in Figure 5, which shows the elevation of the bed of the main stream as a function of its distance from the lowermost point in the watershed.

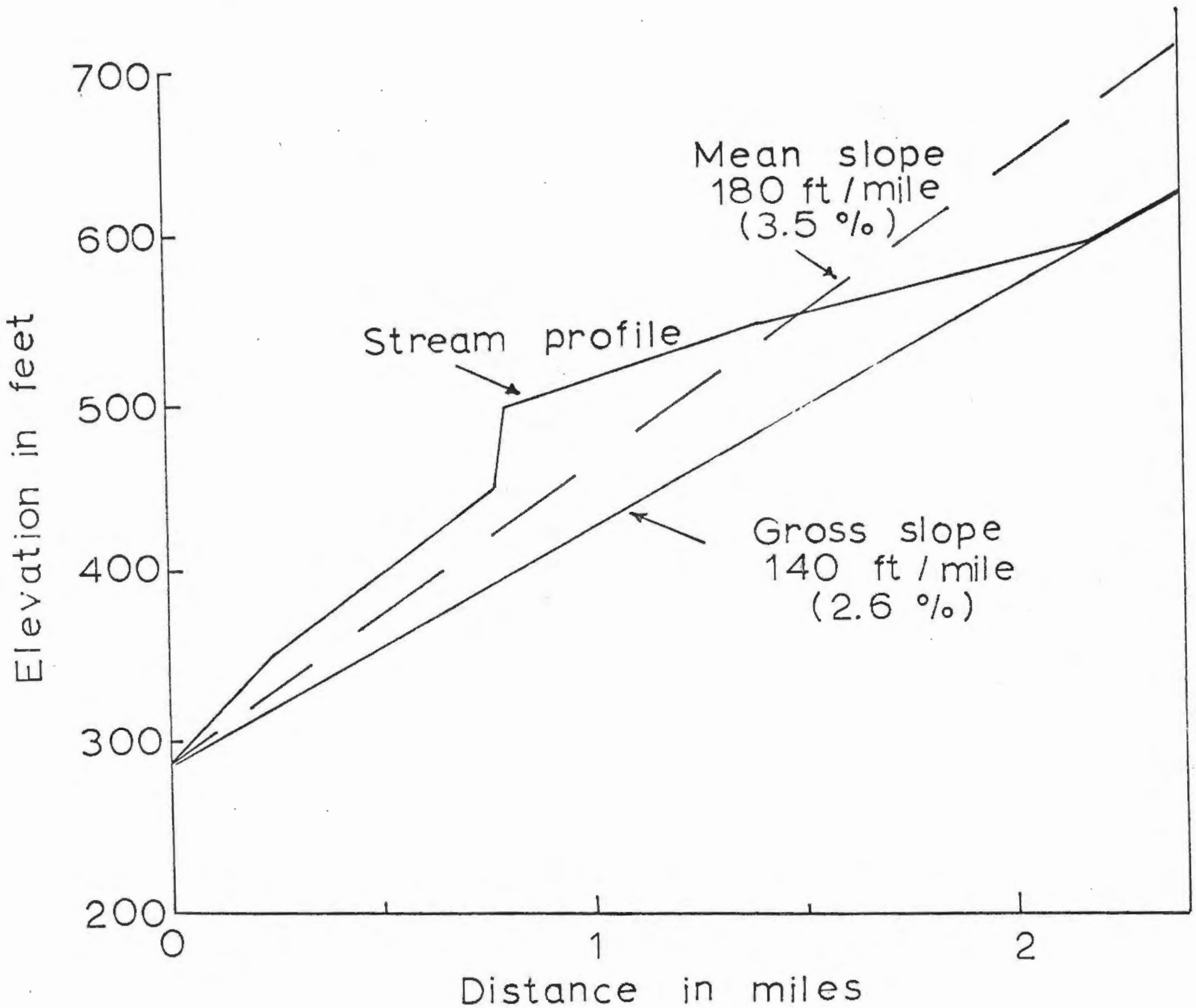

Figure 5. Stream Profile of Sharpe Brook

Soils

On the Watershed the four main soil series mapped are called the Halifax, Gibraltar, Morristown and Torbrook Series (Cann, MacDougall and Hilchey, 1965).

The soil map is shown in Figure 6, and Table 8 gives summarized data for soils.

Forest types

A forest inventory of the watershed within the drainage area was carried out by the Nova Scotia Department of Lands and Forests in 1966.

The watershed is covered mainly by second-growth forest, but the lower part of the watershed includes some areas that are farmed. Table 7 gives summarized data.

Table 7. Forest Types in Sharpe Brook Watershed Area

Type	Area in square miles	Area in acres	Percent area
Softwood	0.31	202	11
Hardwood	0.37	237	13
Mixedwood	2.08	1,332	72
Non-Forested	0.13	85	4
Totals	2.89*	1,856	100

* Forest inventory includes a slightly smaller area than the actual watershed area.

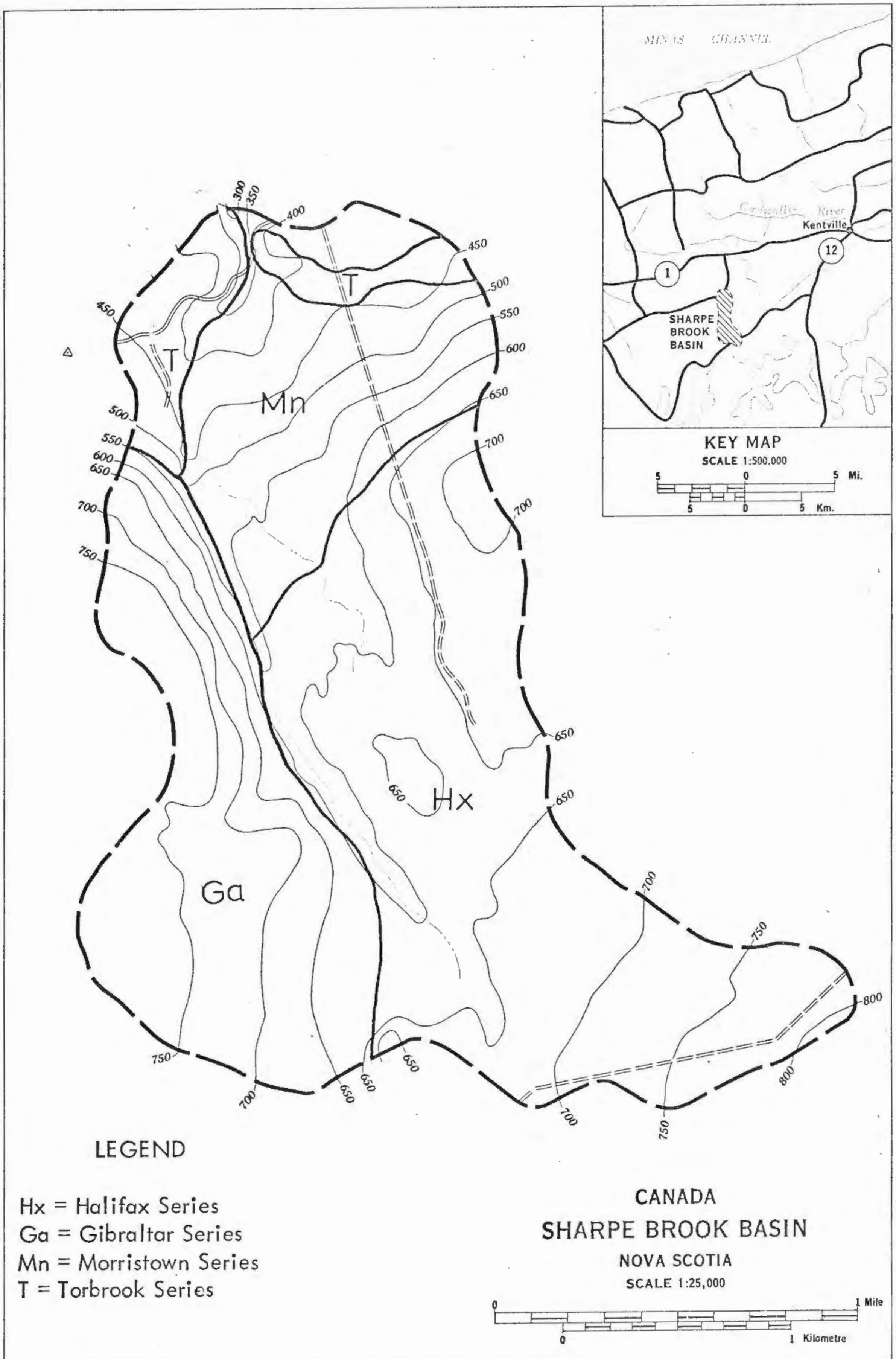

Figure 6. Soil map of Sharpe Brook Watershed

Table 8. Description of Soils for Sharpe Brook Watershed*

Name of Soil	Halifax Series	Gilbraltar Series	Morristown Series	Torbrook Series
Description of surface and subsoil	Dark grayish brown sandy loam over strong-brown stony sandy loam.	Grayish-brown to brown coarse sandy loam over yellow-sandy loam	Dark grayish brown loam over reddish-brown loam.	Brown friable sandy loam over yellowish-red gravelly sandy loam.
Parent material	Olive-gray stony sandy loam till derived from quartzite.	Light yellowish brown stony sandy loam till derived from granite.	Reddish-brown shaly loam to loam till derived from slate; often shallow.	Stratified slaty and cobbly gravel of variable depth, deposited as beach terraces.
Topography and Drainage	Undulating to rolling. Well drained.	Gently to moderately undulating. Well to rapidly drained.	Moderately undulating to strong rolling. Well drained.	Gently undulating to steeply sloping. Rapidly to excessively drained.

* Adapted from Cann, MacDougall and Hilchey, 1965

Climate

The watershed area has a humid, temperate climate. The precipitation during the winter months alternates between snow and rain. Average frost free period is about 130 days (Chapman and Brown, 1966). Wind speed records show that the most common speeds are in the 10 to 20 miles per hour range. The drainage area has about ten foggy days a year.

The average annual potential evapotranspiration is 22 inches of water (Chapman and Brown, 1966). Changes in precipitation and temperature in the watershed are shown in Figures 15 and 16 on pages 40 and 41.

Geology

In Sharpe Brook drainage area, granite, as well as greywacke, quartzite, slate and schist of the Meguma Group are found. The rock units found in the watershed are of Paleozoic age.

Surficial deposits are glacio-fluvial deposits and till.

Bedrock Geology

Meguma Group

The middle third of the drainage area is underlain by the Early Ordovician Meguma Group. Woodman (1904) divided the Meguma Group into two formations, the older Goldenville, and the younger Halifax.

The Goldenville Formation consists of greywacke and quartzites. The quartzite is metamorphosed and impure.

The Halifax Formation consists of slate, siltstone, and quartzite.

Granite

The upper part of the watershed is underlain mainly by Devonian porphyritic granite. Different types of granite are present. This rock consists of a coarse grained quartz, potash feldspar, plagioclase, and biotite crystals (Smitheringale, 1960).

Surficial Geology

Surficial deposits in the watershed are of glacial till, glaciofluvial deposits, stream alluvium, and peat and muck (Trescott, 1969).

Glacial till covers most of the watershed area. The thickness of the till ranges from 0 to 60 feet. The composition of the till depends on the nature of the bedrock.

The lower segment of the watershed is mantled by glaciofluvial deposits over 20 feet thick. Within the drainage area glaciofluvial deposits are kames and an esker.

A minor portion of the watershed area is covered by stream alluvium, and peat and muck.

PRECIPITATION

Precipitation (rain,sleet, snow, hail, dew, and fog drip) is essentially the source of all water on the earth's surface and is commonly considered the starting point of the hydrologic cycle. Within the area of the watersheds, rainfall accounts for a great part of the mean annual precipitation and is thus the main element of discussion in this report.

Measurement of Precipitation

Instrumentation was carried out by the Canada Department of Transport, Meteorological Branch, as part of the International Hydrological Decade program. Fraser Brook drainage area was selected in 1965, April Brook and Sharpe Brook watersheds were established in 1966.

Rainfall is measured with a rain gauge, in terms of depth, the values being expressed in inches. Standard and recording types rain gauges were used in the watersheds. The standard rain gauge in M.S.C.T.B. type with tipping bucket and its sensitivity is 0.01 inch.

Some differences in rainfall are observed in short distances in mountainous terrain or during showery rainfall in level country. It is therefore necessary to consider methods of computing the average rainfall over a given area. If the rainfall is nonuniform and the stations unevenly distributed within the area, the arithmetic mean may be incorrect. A common method of determining weighting factors is by the use of the Thiessen network.

> "The Thiessen method assumes that the amount at any station can be applied halfway to the next station in any direction. It is applied by constructing a Thiessen polygon network, the polygons being formed by the perpendicular bisector of the lines joining nearby stations. The area of each polygon is determined and is used to weight the rainfall amount of the station in the center of the polygon. The polygons must be changed each time a station is added to or taken from the network or each time the amount for any station is missing" (Chow, 1964, p. 9-28).

The average rainfall over the watersheds was determined by Thiessen network. Locations of the stations and Thiessen networks are shown in Figure 7 to 9.

Precipitation in the Watersheds

Precipitation records at Fraser Brook Watershed are available from 1966 to 1968, at April Brook Watershed from 1967 to 1968, and at Sharpe Brook Watershed for 1968. The periods of precipitation records for the watersheds are different and short. Therefore, some detailed comparisons are made with long term precipitation and temperature records available from climatic stations and watersheds are shown in Figure 10. Mean monthly and annual temperature and precipitation long term records near Fraser Brook Watershed are schematically shown in Figure 11 and 12. Similar comparisons for April Brook and Sharpe Brook Watersheds are shown in Figures 13, 14, 15 and 16. The data were obtained from the Canada Department of Transport, Climatology Division, Meteorological Branch, 1965: Temperature and precipitation normals, preliminary listing. Types of normals are shown in Table 9.

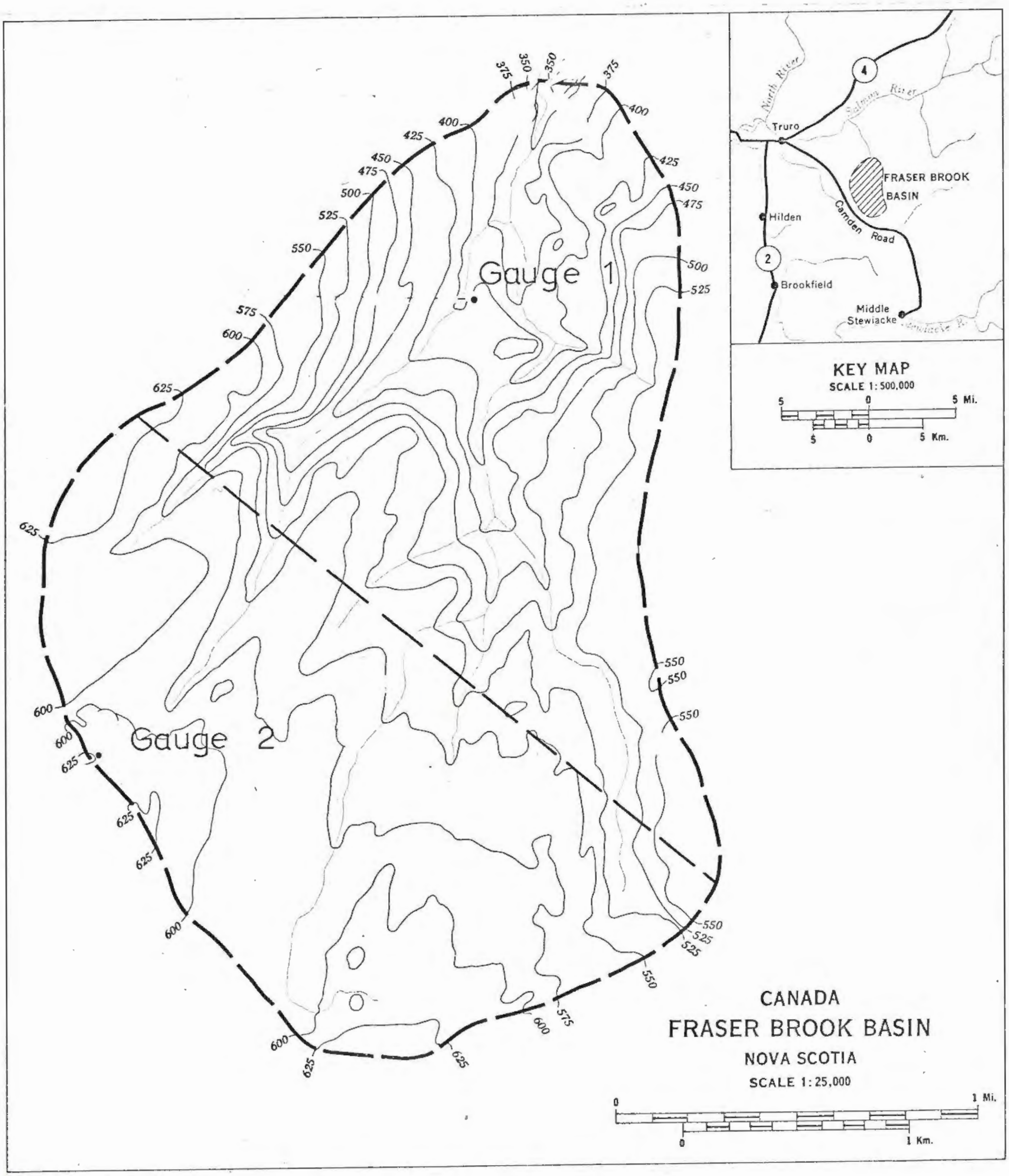

Figure 7. Precipitation gauges in Fraser Brook Watershed

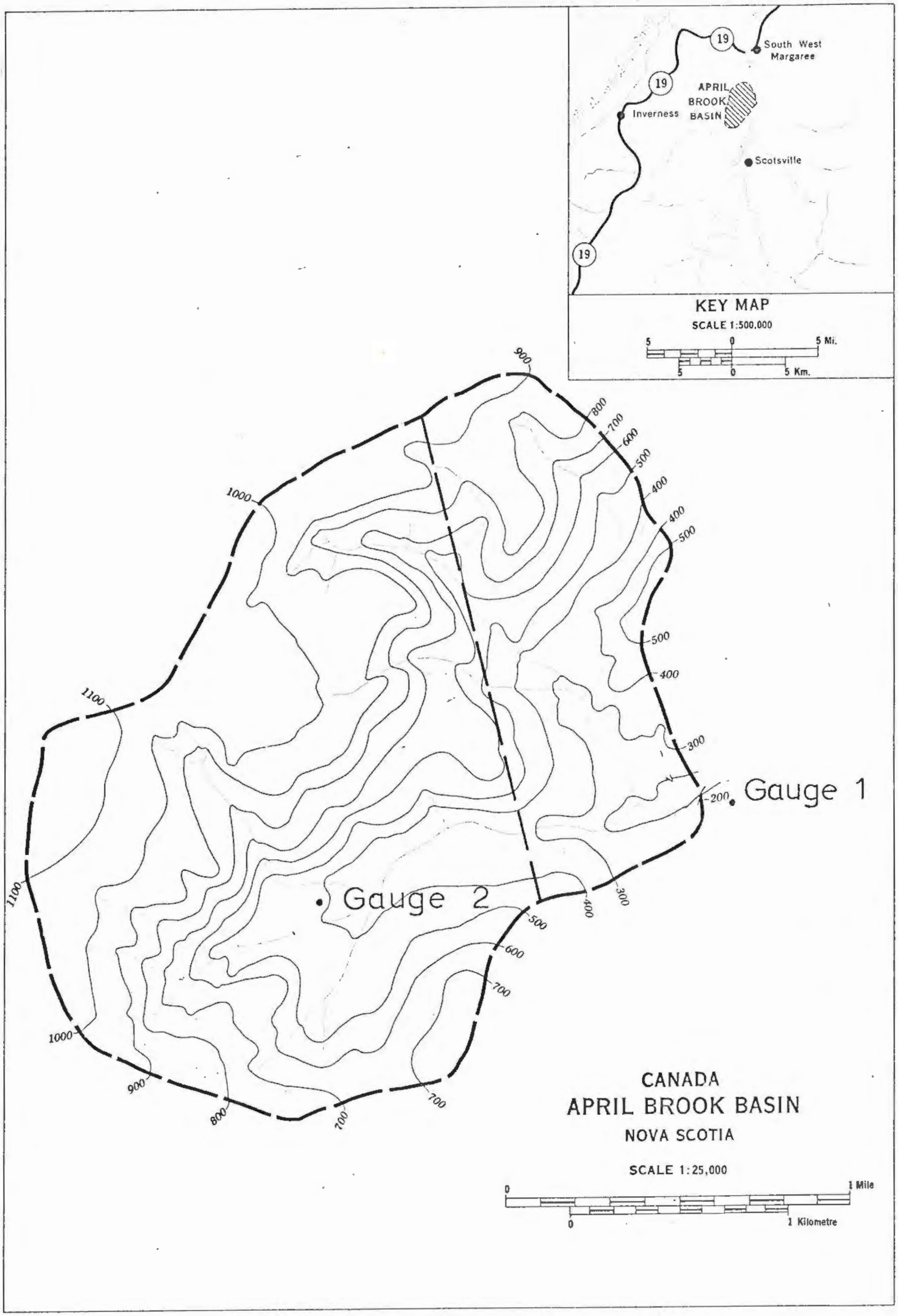

Figure 8. Precipitation gauges in April Brook Watershed

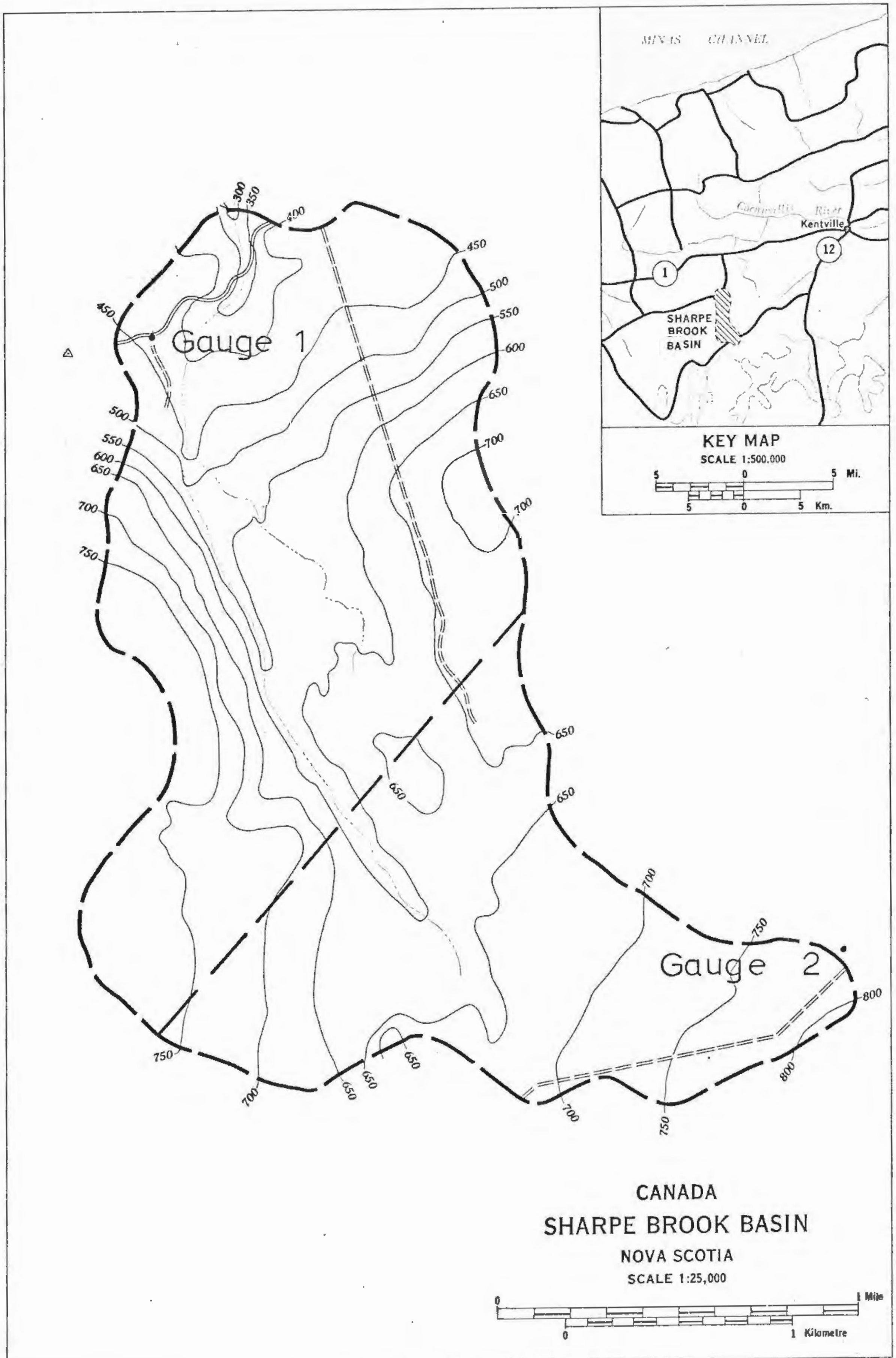

Figure 9. Precipitation gauges in Sharpe Brook Watershed

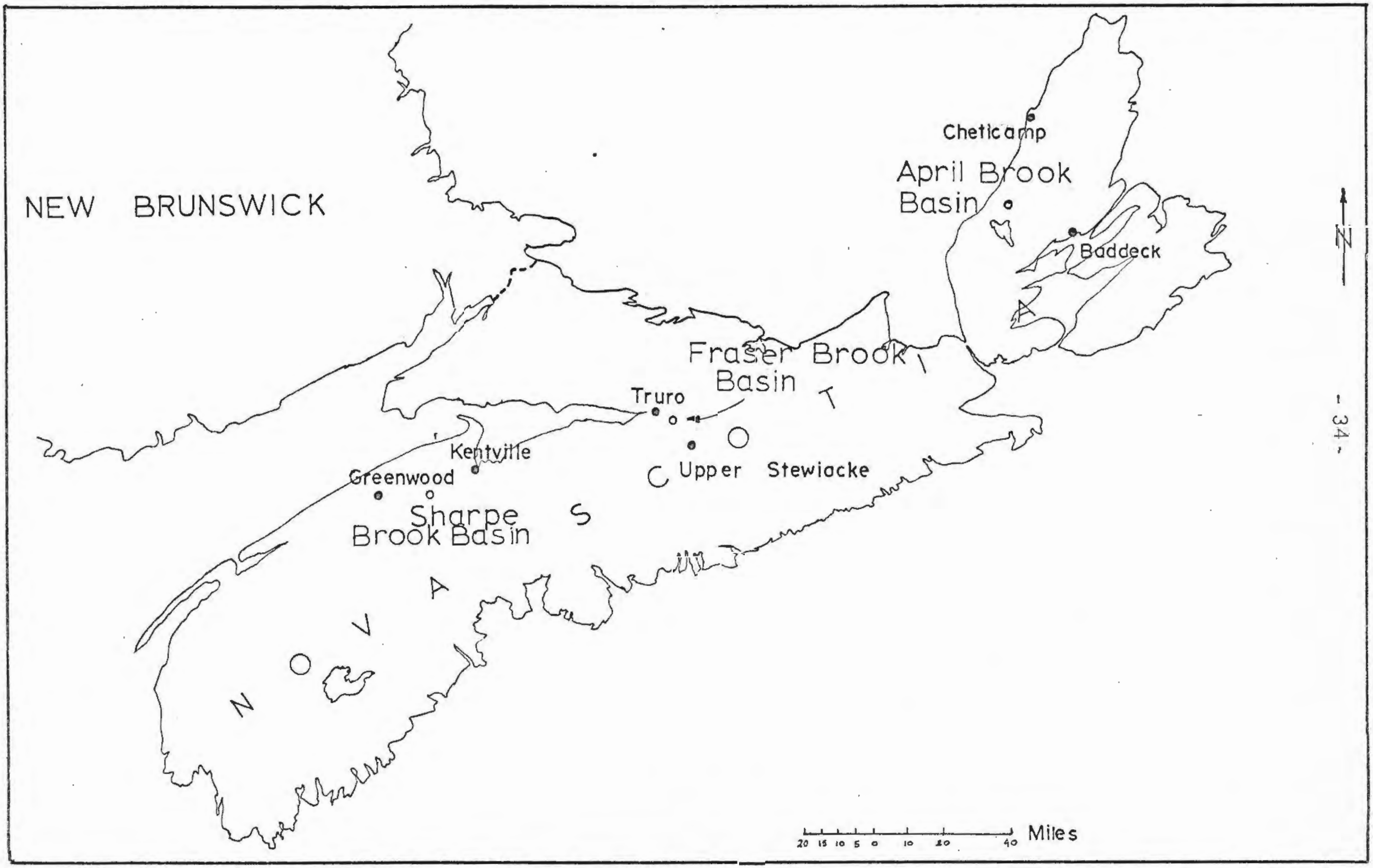

Figure 10. Locations of the Watersheds and nearby climatic stations.

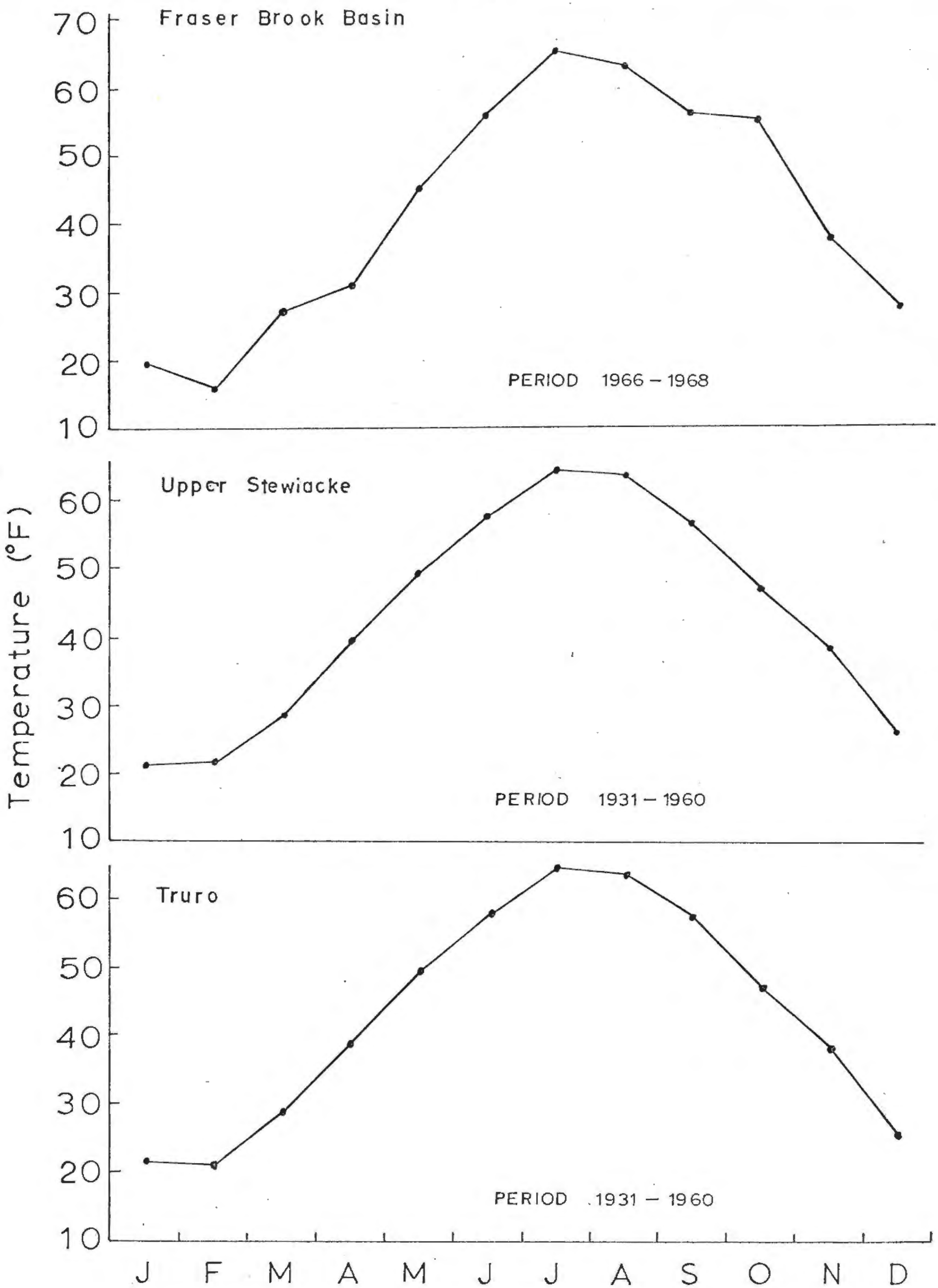

Figure 11. Temperature normals for Fraser Brook and nearby climatic stations.

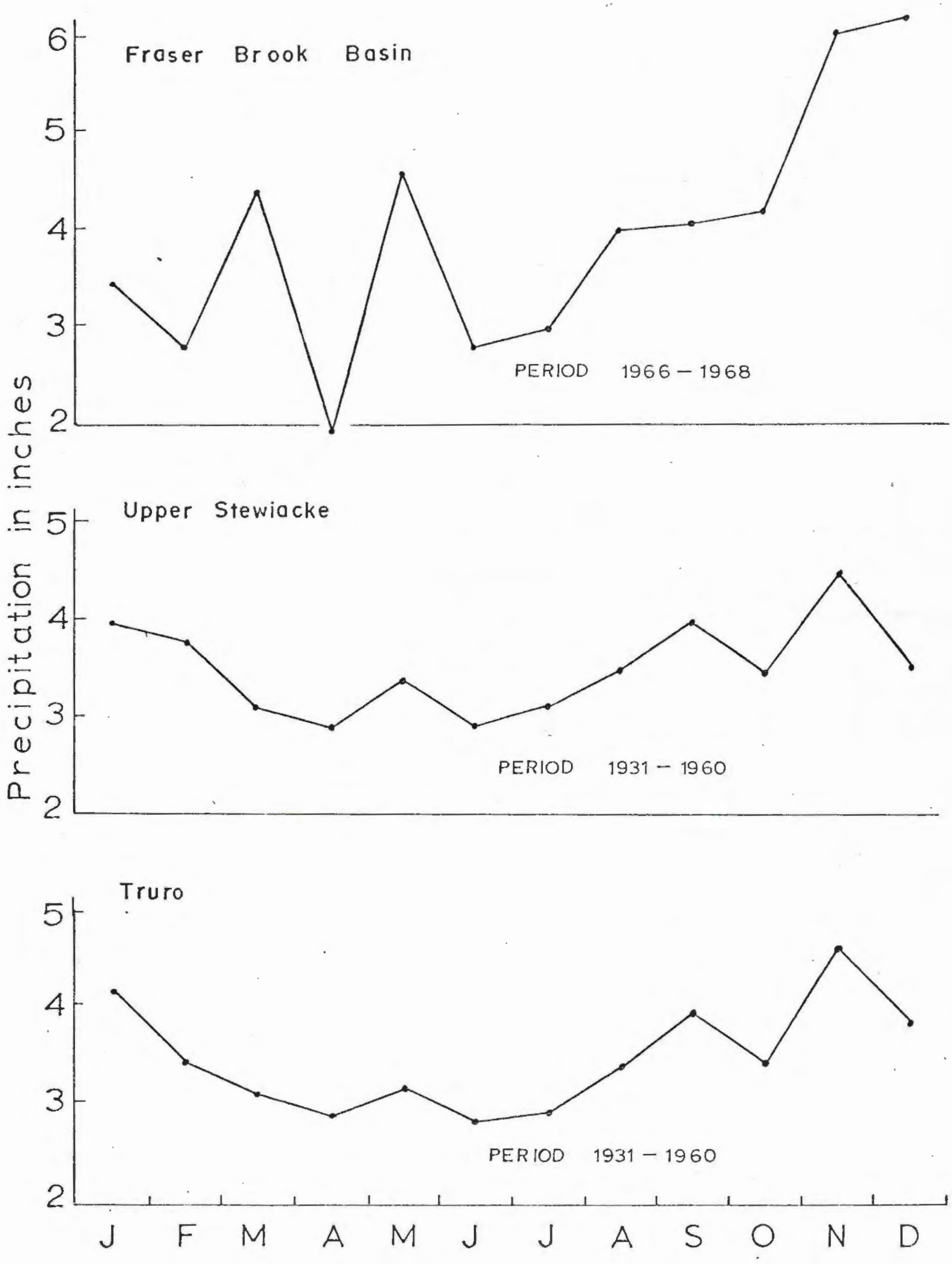

Figure 12. Precipitation normals for Fraser Brook and nearby climatic stations.

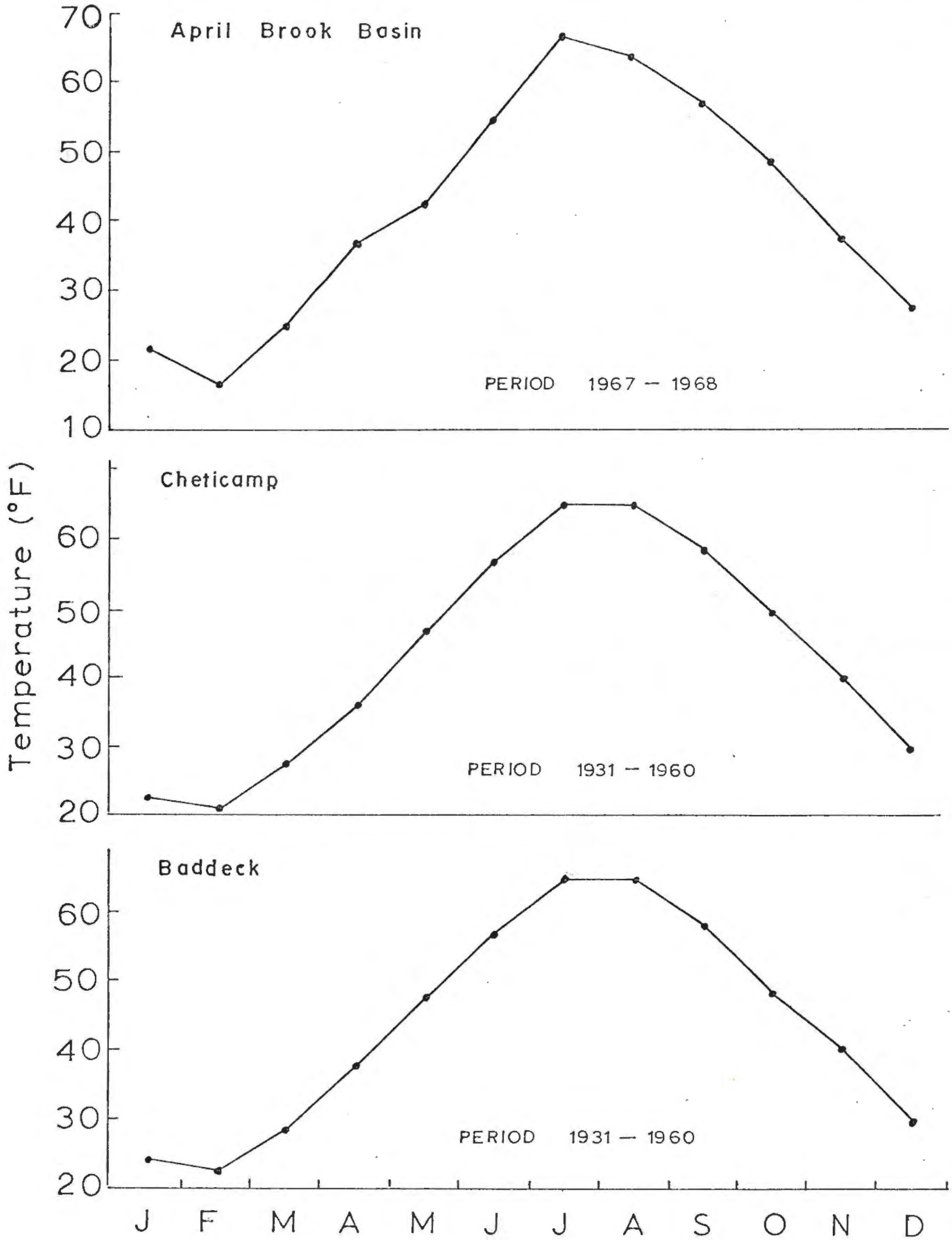

Figure 13. Temperature normals for April Brook and nearby climatic stations.

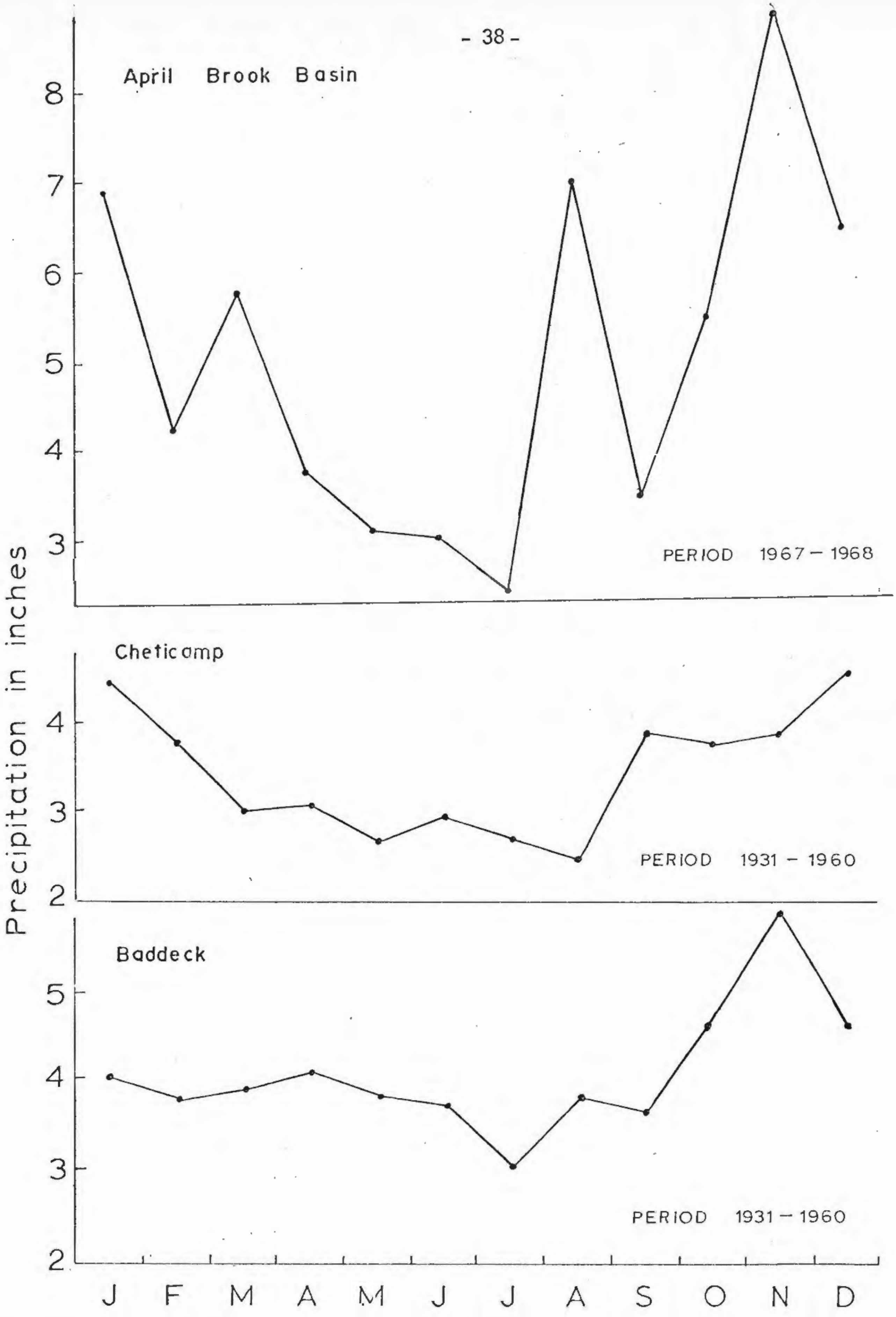

Figure 14. Precipitation normals for April Brook and nearby climatic stations.

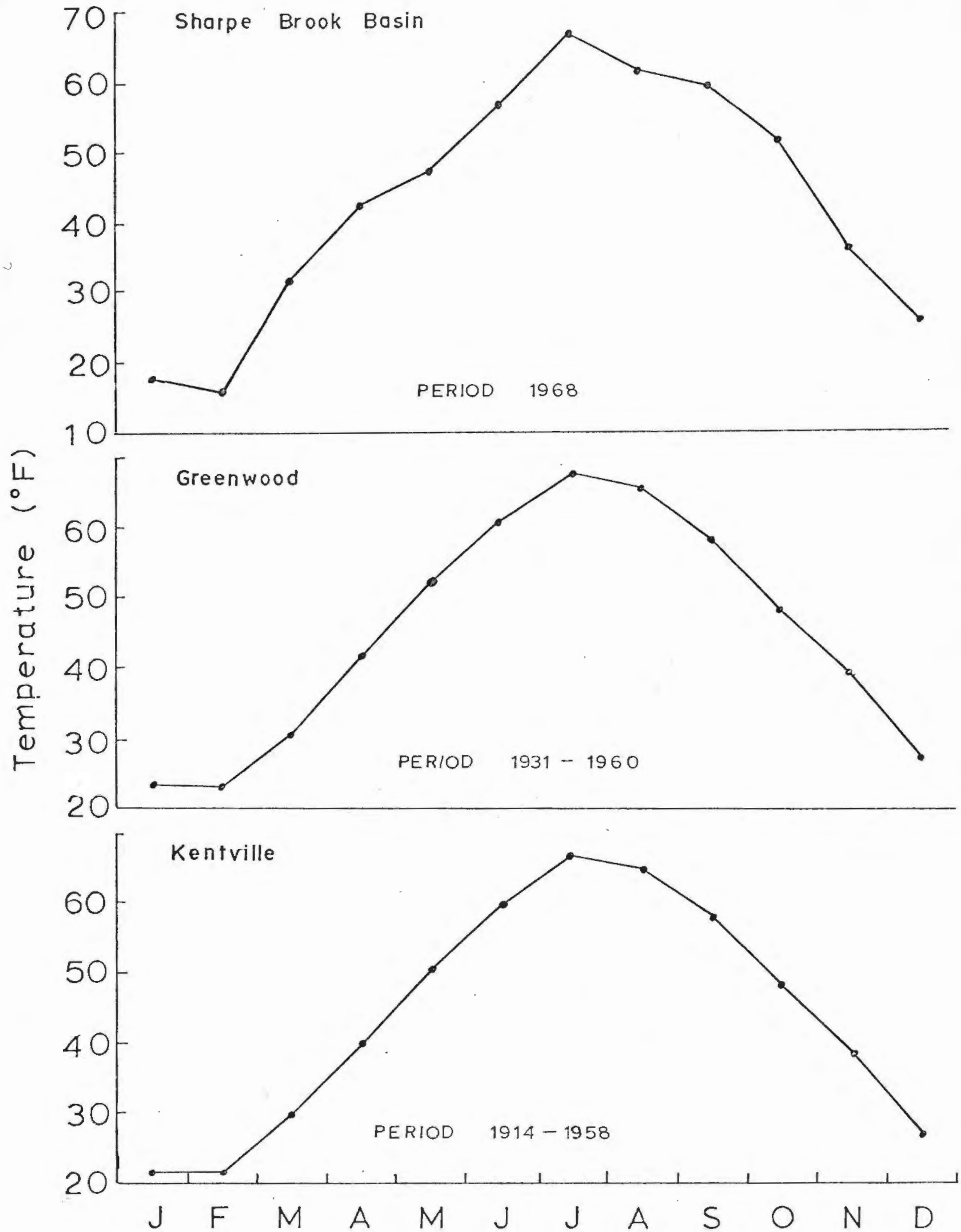

Figure 15. Temperature normals for Sharpe Brook and nearby climatic stations.

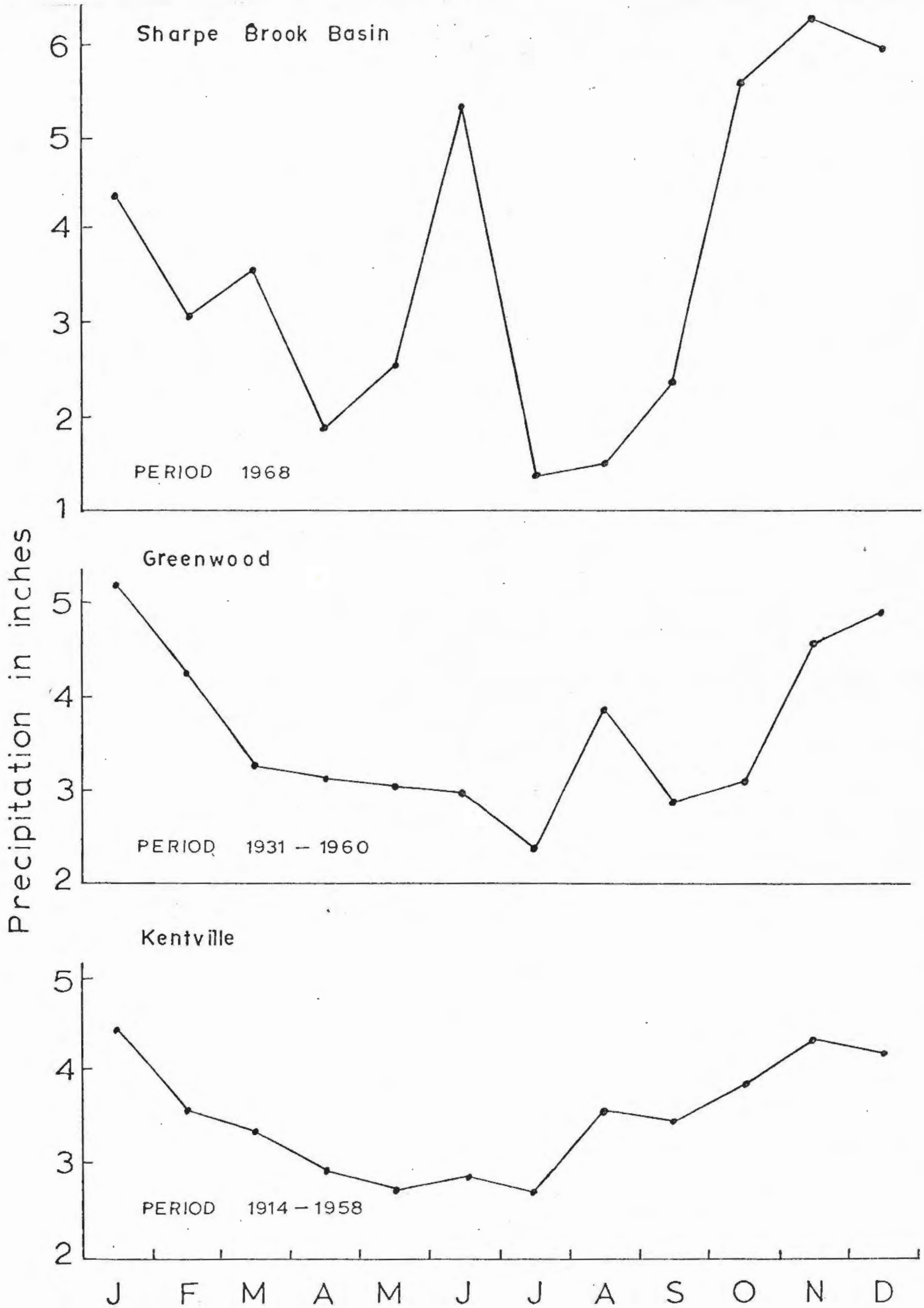

Figure 16. Precipitation normals for Sharpe Brook and nearby climatic stations.

Table 9. Types of Normals for Climatic Stations

Station	Type of Normals
Baddeck Cheticamp	These averages are based on the period of record of 10 to 24 years during the period 1931 to 1960. No adjustment factor has been used.
Truro Upper Stewiacke	Normals were computed directly from a period of record of 25 to 30 years within the period 1931-1960.
Greenwood	The data for temperature normals were from the full ten year period 1951-1960, adjusted to the standard normal period 1931-1960.
	Precipitation averages are based on the period of record of 10 to 24 years during the period 1931 to 1960. No adjustment factors have been used.
Kentville	Normals were from the full 45 year period 1914-1958. (Date obtained from Canada Dept. of Agriculture, Publication 1029, 1961)

It appears from the figures that variations of temperature normals for the basins are comparable with long term records of the other stations.

In the three watersheds greater variations of precipitation take place than in the long term records from nearby stations. These discrepancies in the precipitation records of the watersheds are based on only a few year's records, but study of available records for all the stations indicates that precipitation patterns are quite complicated. For example, long term precipitation records near April Brook

Watershed indicate a different pattern from the stations of Cheticamp to Baddeck in such a short distance.

Another indication of the variability of precipitation is shown in comparison of average weighted daily precipitation records for the three IHD watersheds under study in Nova Scotia. Such a comparison is presented in Table 10, where the weighted daily precipitation records for the months of January and July, 1968, are given for the watersheds. It can be seen at a glance that uniform precipitation, such as January 7, 1968, is the exception rather than the rule both in the winter and in the summer. Heavy precipitation in particular (such as January 3 and July 28, 1968) is likely to be irregularly distributed.

Annual precipitation weighted for area is shown in Table 11. The figures were obtained by multiplying the annual precipitation by the area of influence of each precipitation gauge in square miles, adding the products, and dividing the sum by the are of the watershed in square miles.

Table 10. Weighted Daily Precipitation Records for Three Basins for January and July, 1968

	January			July		
	Fraser Brook	April Brook	Sharpe Brook	Fraser Brook	April Brook	Sharpe Brook
1	0.17	0.07	0.30			
2		1.00				
3	0.09	0.61	0.30	0.04		
4	0.75	0.13	0.45		0.15	0.18
5		0.39	Tr*			
6		0.12	0.31		0.17	
7	0.74	0.60	0.70			
8	Tr	0.47				
9		0.51				
10		0.07				
11		0.57		0.05		
12		0.27		0.22	0.01	
13	Tr	0.20		0.92		
14	0.03	Tr	0.05			
15	0.52	Tr	0.81		0.36	
16	0.02	0.35	0.12	Tr		
17		0.29		0.82		
18	Tr			0.02	Tr	Tr
19	0.01	Tr	0.03			0.09
20	Tr			0.48	0.22	0.25
21	0.09	Tr	0.06	0.35	0.21	
22				0.01	Tr	
23	0.17		0.53	Tr	0.04	
24	0.59	0.43	0.26	Tr	0.10	0.05
25	0.22	Tr	0.06	0.11	0.02	0.45
26	0.01	Tr				
27						
28		Tr	0.02	0.56	Tr	0.20
29	Tr	0.39		0.37		
30	0.34		0.24			
31						

* Less than 0.01 inch

Table 11. Weighted Annual Precipitation for the Watersheds*

Year	Watersheds		
	Fraser Brook	April Brook	Sharpe Brook
	inches	inches	inches
1966	43.11		
1967	55.23	61.39	
1968	43.73	63.88	43.70

* Includes all precipitation in the watersheds.

RUNOFF

The water flowing in streams depends upon the rainfall and the many physical conditions of the drainage area.

If rainfall intensity is less than the infiltration rate, all the water will enter the soil. Conversely, when the rainfall intensity is in excess of the soil infiltration capacity, it ultimately produces surface runoff, which is the principal cause of sudden increase in streamflow, and of floods. Rather extreme variations in the percentage of precipitation which occurs as direct runoff is evident in different parts of Nova Scotia (Hennigar, 1968).

Table 12 summarizes the available flow data for the three watersheds of this study. This table seems to indicate runoff variations are comparable with precipitation variations (see Table 11). Monthly runoff in the watersheds for the water year 1968 is shown in Table 13. Mean daily runoff in cubic feet per second per square mile is shown in the same table. Maximum runoff occurred in April Brook during the water year 1968 (4.58 cfs/sq. mile). Precipitation was also at a maximum in April Brook Watershed during the same year, as shown in Table 11, (63.88 inches).

The totol annual runoff-rainfall ratio is calculated to be 66% for Fraser Brook, 97% for April Brook, and 72% for Sharpe Brook during the water year 1968.

Separation of Annual Streamflow Hydrographs

In quantitative studies of annual streamflow it becomes desirable to separate runoff into its direct runoff and groundwater runoff components. The Russians have

Table 12. Annual Runoff for the Watersheds, in Inches

Year	Fraser Brook	April Brook	Sharpe Brook
	Watersheds		
1966	25.0		
1967	39.9	55.1	
1968	29.0	62.0	31.3

Table 13. Monthly Runoff in the Watersheds for Water Year 1968

Months	Fraser Brook	April Brook	Sharpe Brook
	Watersheds		
		cfs - days	
January	218.7	279.0	204.0
February	91.9	226.4	148.5
March	698.1	717.3	683.9
April	351.1	637.1	261.9
May	131.1	219.6	123.9
June	111.2	117.6	202.11
July	21.32	73.2	39.95
August	33.03	179.2	2.81
September	18.56	173.2	2.64
October	72.93	113.5	136.25
November	428.8	395.3	518.7
December	559.2	470.8	439.8
Total (cfs - days)	2735.92	3602.2	2764.46
Mean daily (cfs)	7.50	9.8	7.60
Mean daily (cfs/sq. mile)	2.14	4.58	2.40

presented several methods for separation of streamflow hydrographs.

Two types of groundwater runoff were determined by Chernaya (1964): the backwater and the descending type. The "backwater type" of groundwoter feeding of the river is hydraulically connected to the river. During flood periods the river forces the water to enter into bank storage, thus the groundwater runoff decreases. When the river level drops below the water table, the stream becomes effluent and water in bank storage is discharged into the river. In this case, the groundwater runoff increases.

The "descending type" of groundwater runoff occurs in the steep slopes of upper river zones where much of the groundwater runoff is above the stream line. The descending type of groundwater discharge hydrograph follows a smoothed form of river hydrograph (see the plates in the pocket).

The three representative watersheds are characterized by descending type of basin hydrology, where groundwater runoff commonly occurs as springs above the stream surface (Pinder and Jones, 1969).

Numerous methods for separating the groundwater runoff component of streamflow hydrographs are cited by Chernaya (1964), and Amus'ya and Ratner (1964). F. A. Makarenko's method is considered to be most precise. However, when the observations of spring regimes are lacking Makarenko's method cannot be used.

The principle of separation of hydrographs given by Frederick is the "envelope method" (see Amus'ya and Ratner, 1964). Frederick established segments on the hydrograph where surface runoff has already passed from the river. These segments are connected by a continuous smooth curve and the total amount of groundwater runoff will be obtained. This method for large drainage areas overestimates the groundwater runoff. For small watersheds where the periods of surface runoff are quite insignificant (1-2 days), the envelope method of separation may give satisfactory results.

It seems logical, therefore, to apply this method to the three small watersheds in Nova Scotia. Plates 1 to 6 show the separation of annual hydrographs for the watersheds.

Hydrograph Analysis

A "hydrograph" is a graph showing stage (water level), discharge, velocity, or other properties of water flow with respect to time. When the stage is plotted against time, the graph is a "stage hydrograph", which is usually shown on the recorder chart from a recording-gauge station. When the discharge is shown against time the graph is a "discharge hydrograph", or it is commonly called simply a "hydrograph".

In these watersheds, streamflow instrumentation was installed by the Water Survey of Canada under the International Hydrological Decade program, with water-stage recorders used to give stage hydrographs. In this report, discharge hydrographs were drawn from stage hydrographs by using a rating table for the gauging stations obtained from the Water Survey of Canada. Individual and largest storms were selected for each month from the precipitation records (Canada Department of Transport, Meteorological Branch). A simple hydrograph of the type selected for study, has a simply peak and a normal unsustained recession flow.

The area under the hydrograph curve was calculated by using the IBM Model 360/50 digital computer at Dalhousie University. The program was written for dividing the total interval of the discharge hydrograph into many smaller intervals and calculating the area under the hydrograph curve (see Appendix). The idea for applying this method of rapid calculation to hydrograph separation suggested itself after reading "Numerical Methods and Fortran Programming", (McCracken and Dorn, 1964). In this study over 60 storm hydrographs were analyzed from Fraser, April, Sharpe Brooks and the Salmon River.

Hydrograph Shape

The shape of the hydrograph for a single storm follows a general triangular pattern which consists of a rising limb, peak and recession (see figure 21 on page 56). This pattern shows a period of rise and increasing discharge which culminates in a peak. The recession represents the withdrawal of water stored in the stream channel during the period of rise. Double, or several, peaks are sometimes caused by two or more periods of rainfall separated by periods of little or no rain.

Factors Affecting Hydrograph Shape

The rising limb extends from the time of beginning of the surface runoff to the first inflection point on the hydrograph. The shape of the rising limb depends on the duration and intensity distribution of the rainfall, and the antecedent condition and shape of the drainage basins.

The recession limb represents the withdrawal of water from storage after excess rainfall has ceased. The shape of the curve is independent of time variations in rainfall and infiltration and is dependent on areal rainfall distribution and ground condition.

The time distribution of runoff or the shape of the hydrograph is influenced by climate and physiographic factors. Climatic factors are distribution of rainfall on the basin, rainfall intensity and duration, and type of precipitation and type of storm.

The areal distribution of rainfall can cause variations in the hydrograph shape. If large amounts of rainfall occur in the region most remote from the basin outflow, the hydrograph is marked by a uniform slope of the rising limb. Figure 17 shows an example of this type of hydrograph, in April Brook Basin, 1968. For this hydrograph, rainfall recorded was 0.37 inch at gauge site 2 (see Fig. 7 on page 31) while it was 0.32 inch at gauge site 1. If most of the rainfall occurs near the outflow, the hydrograph shows rapid rise of the rising limb. In April Brook Basin, during the October 21/22 measured rainfall was 1.37 inches near the outflow, while it was 1.00 inch remote from the outflow. This storm hydrograph is shown in Figure 18.

The rainfall intensity affects the shape of the hydrograph. Figure 19 shows double peak which indicates a varying intensity in April Brook on June 14, 1967.

The type of precipitation also affects the shape of the hydrograph. The snowmelt hydrograph usually tends to exhibit a lower, broader runoff pattern than

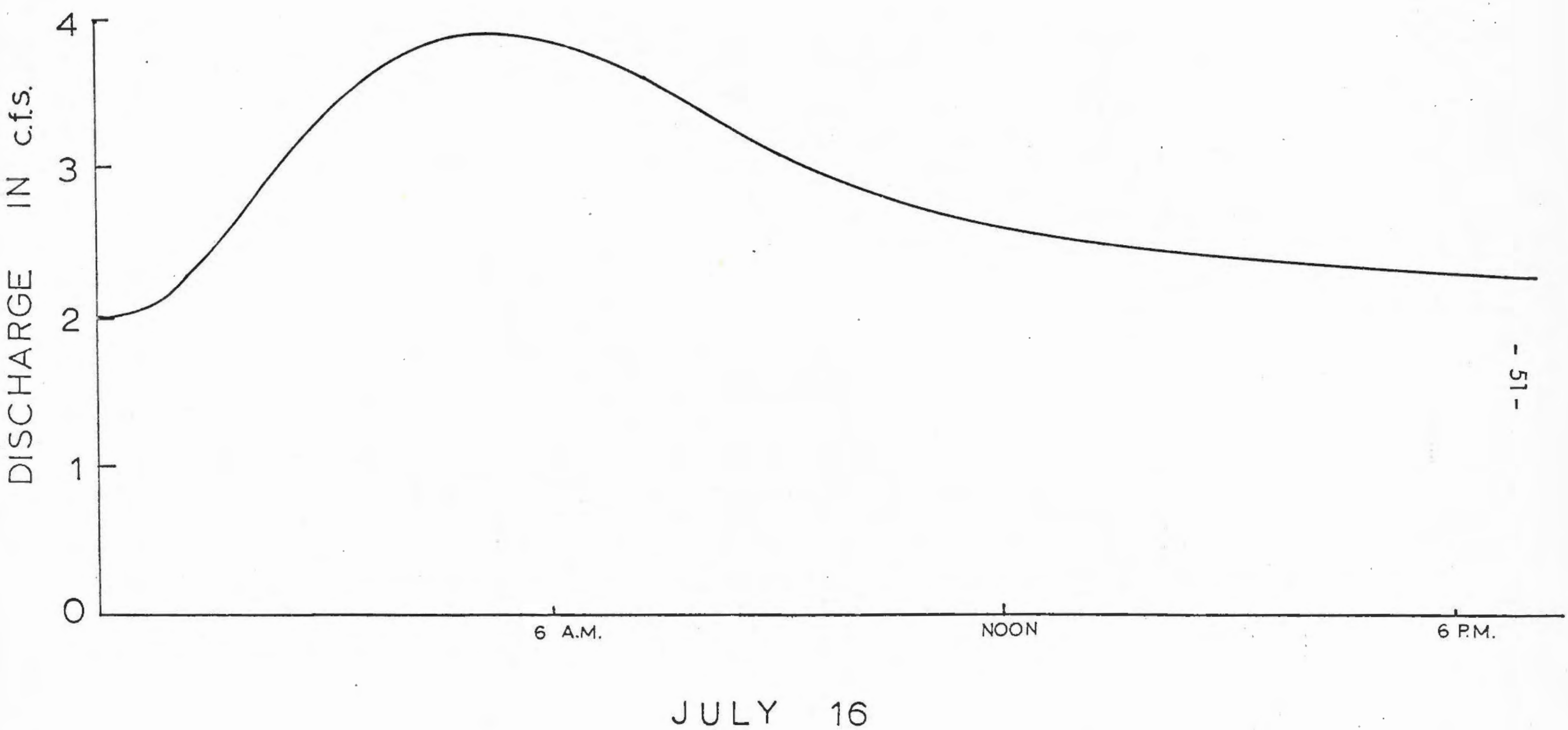

Figure 17. Hydrograph shape affected by distribution of rainfall, April Brook Watershed, 1968.

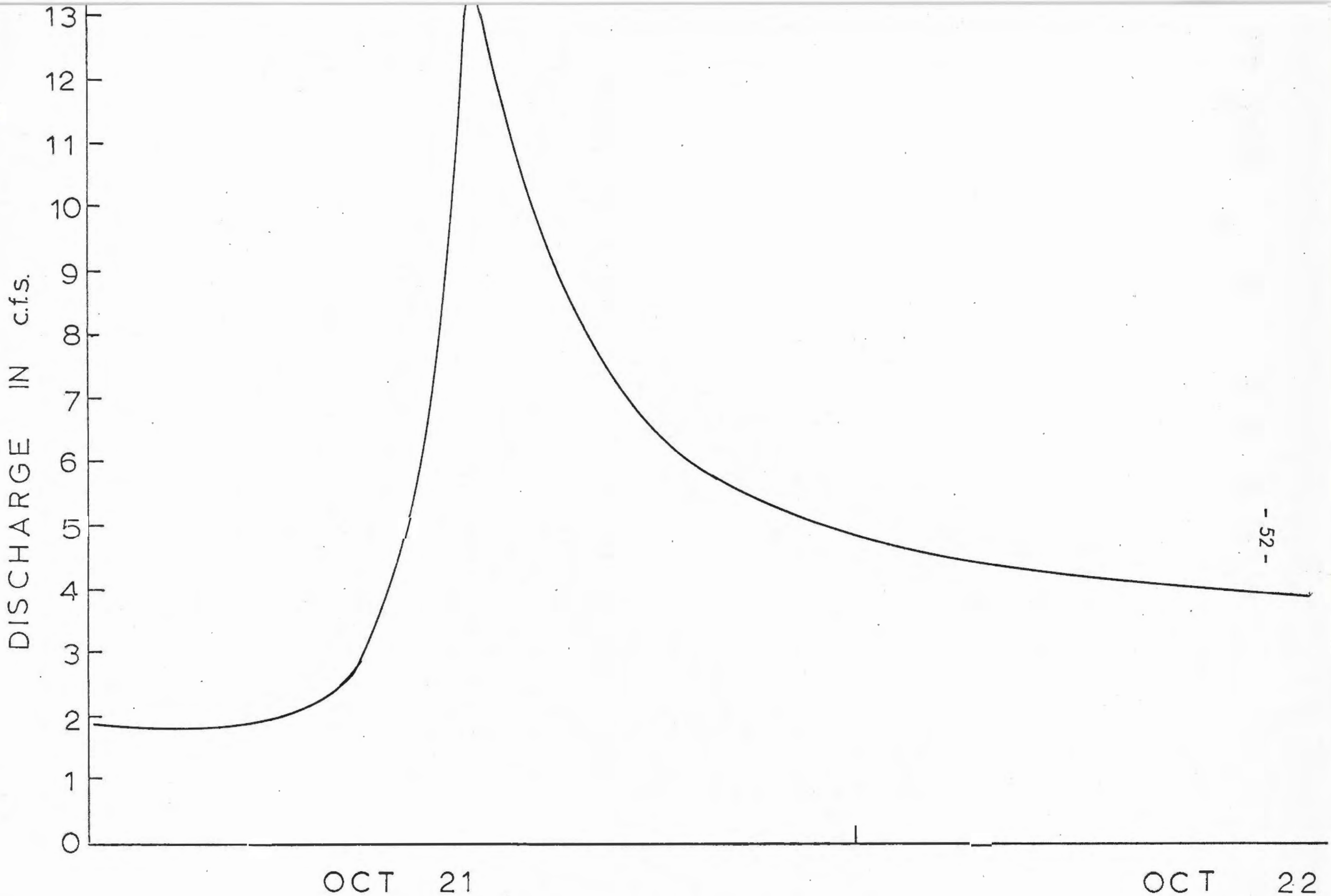

Figure 18. Hydrograph shape affected by distribution of rainfall, April Brook Watershed, 1968.

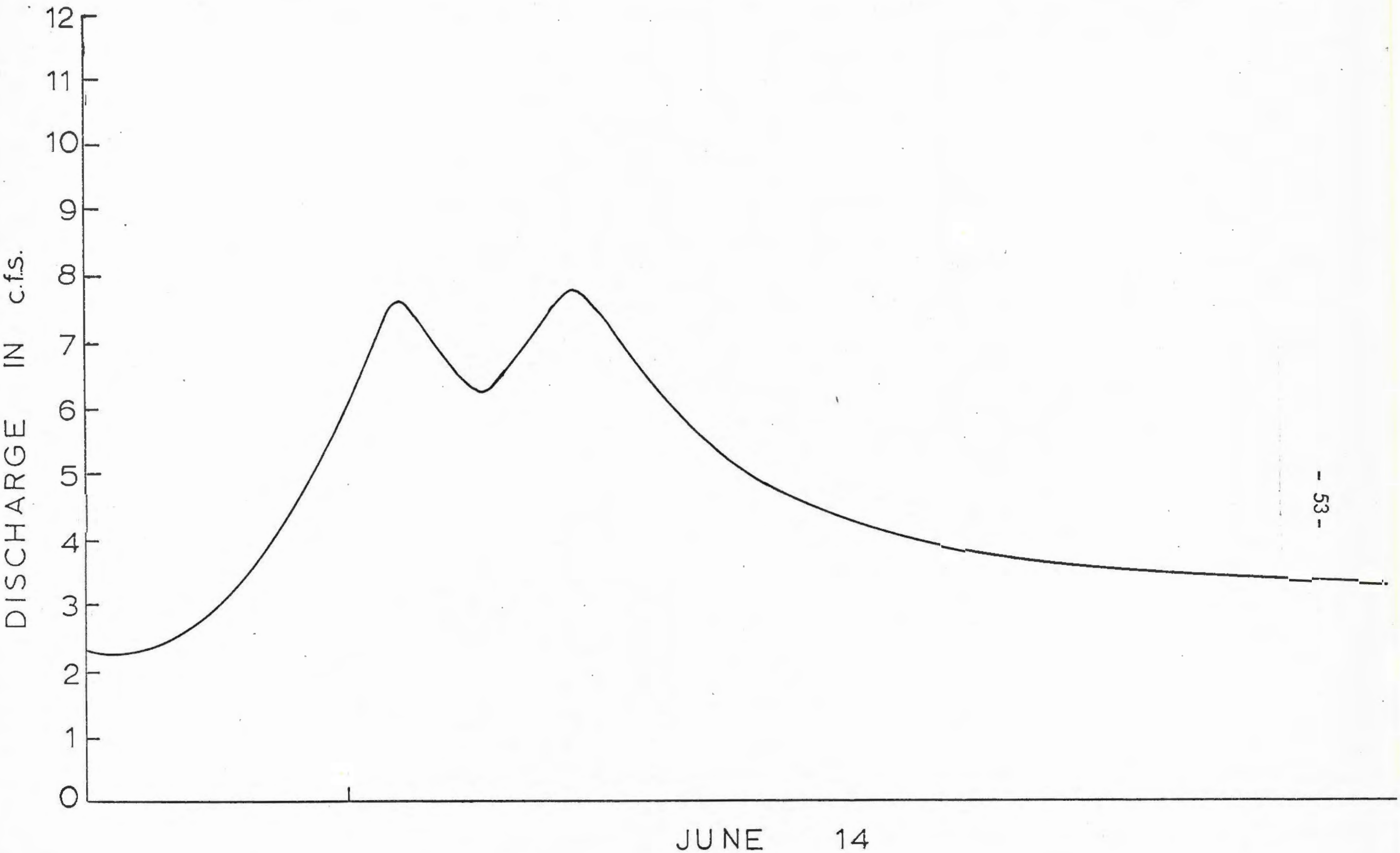

Figure 19. Hydrograph shape affected by intensity of rainfall, April Brook Watershed, 1967.

the rainfall hydrograph. An example of snowmelt hydrograph from Fraser Brook is shown in Figure 20.

Hydrogroph shape is affected by physiographic factors and is related to hydraulic properties of the channel which govern the movement of streamflow.

It should be noted, that the factors interact with one another. The final hydrograph will depend on the cumulative affect of all of the factors.

Separation of Storm Hydrographs

In order to recognize the direct runoff portion of a storm hydrograph, it is necessary to estimate the groundwater runoff and subtract it from the total runoff. Several methods of hydrograph separation have been used. One method devised by Gray and Wigham, 1966, was easily applied to the hydrographs in this report.

This method consists of extending the groundwater runoff curve, occurring after surface runoff, back to a point beneath the peak and then drawing a straight line to the point representing the beginning of direct runoff (Figure 21). This method of separation may have some advantage where descending type of groundwater occurs, (Chernaya, 1964).

This method of hydrograph separation may not be used for Salmon River near Fraser Brook, where backwater and descending types of groundwater feeding occur. Another method devised by Gray and Wigham, 1966, was suitable for a river where both types of groundwater fedding occur. In this method of separation, the separation of groundwater runoff is accomplished by simply joining the beginning of

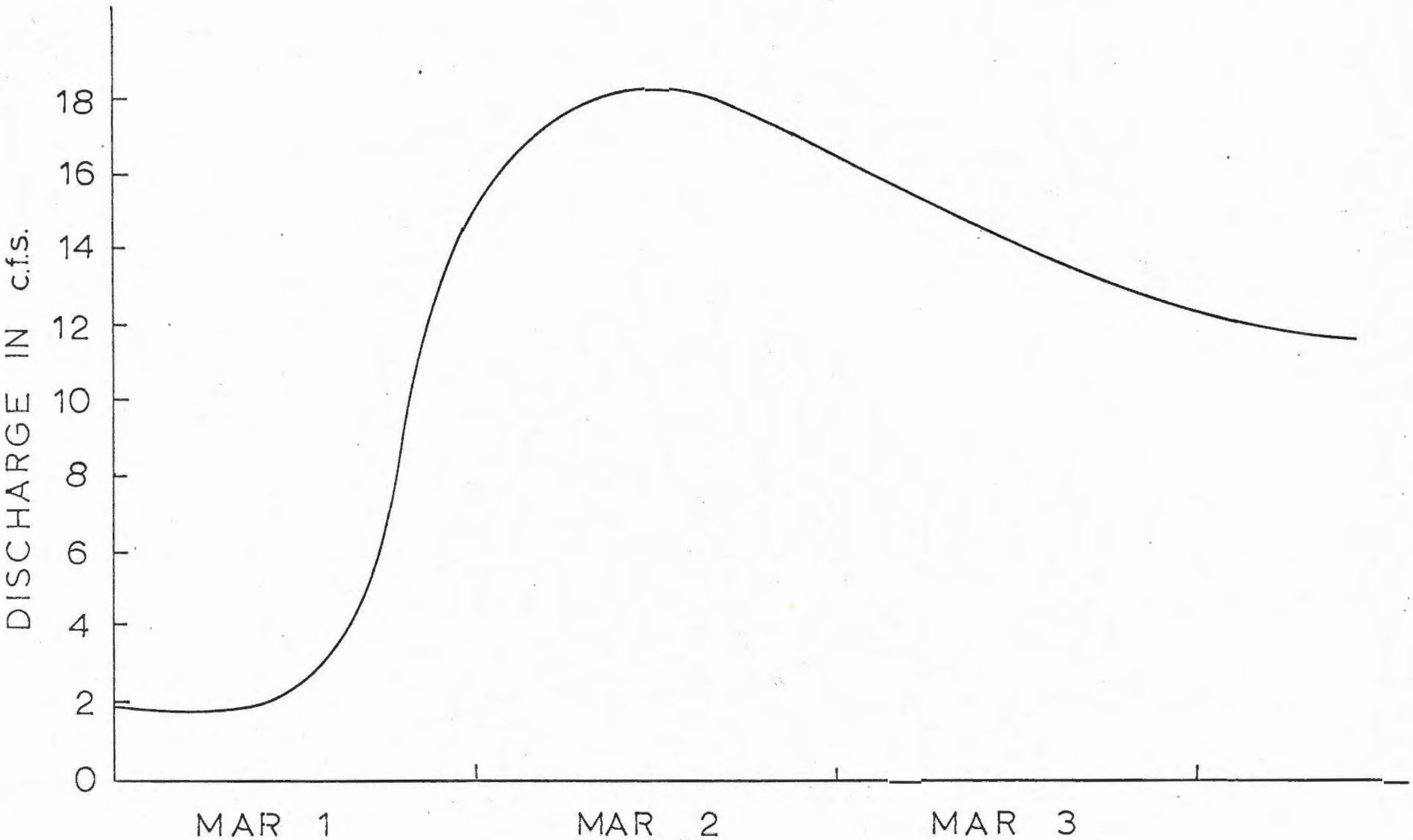

Figure 20. Hydrograph shape affected by snowmelt,

Fraser Brook Watershed, 1966.

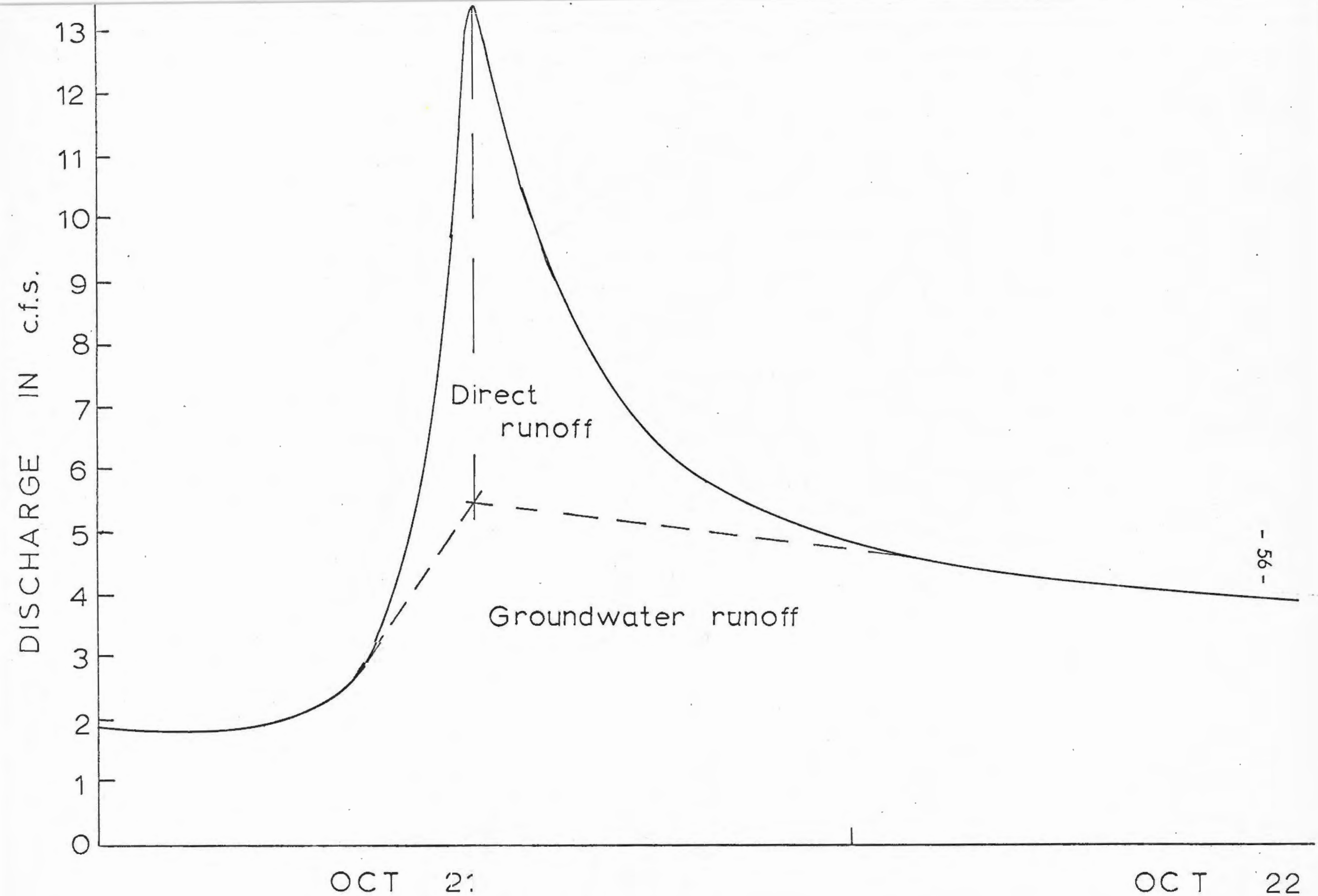

Figure 21. Example of the method of separation of the storm hydrograph for the watersheds.

surface runoff (pt A, Figure 22) to a point on the recession curve representing the end of direct runoff (pt B) with a straight line. If the point B is not well defined, the time after the peak of the streamflow hydrograph at which direct runoff ends is given by the following equation, (Linsley and Franzini, 1964).

$$N = A_b^{0.2}$$

where:

A_b = drainage area of basin, in square mile,

N = time after the peak of the streamflow hydrograph when surface runoff ceases, in days.

Hydrographs resulting from isolated storms were not always available and it was necessary to analyse complex hydrographs which are caused by two or more closely spaced rainfall events. Gray and Wigham, 1966, devised a method which was used for complex hydrographs in this report.

In this method, the small portion of recession between the peaks was reconstructed from points A to B using a composite total recession curve (Figure 23). Lines BE and EF can then be drawn as a single peak hydrograph separation. Usually point B falls after the second peak in which case a straight line was drawn from point D to a point directly below the second peak on the recession curve AB.

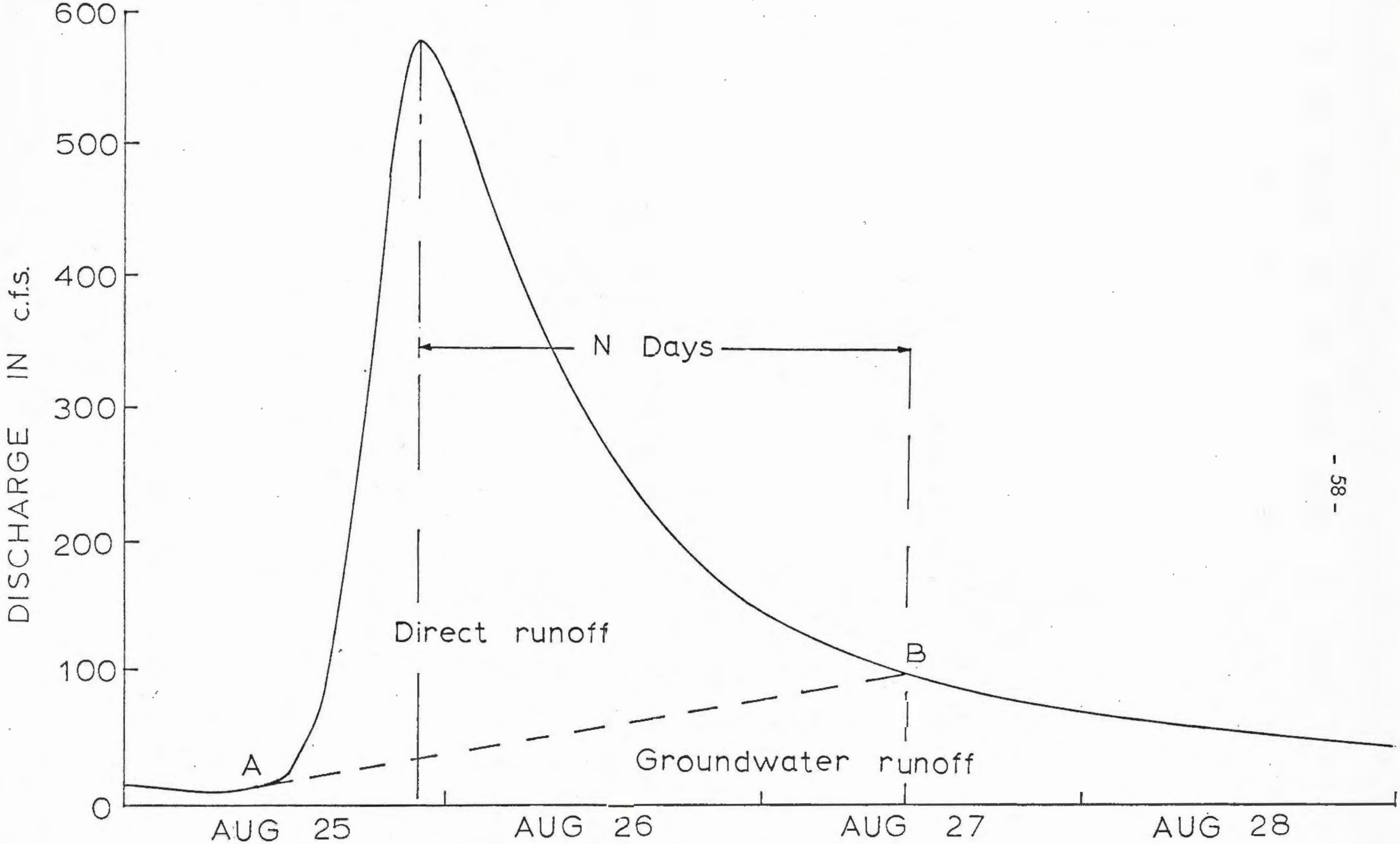

Figure 22. Separation of storm hydrograph

for Salmon River, 1968.

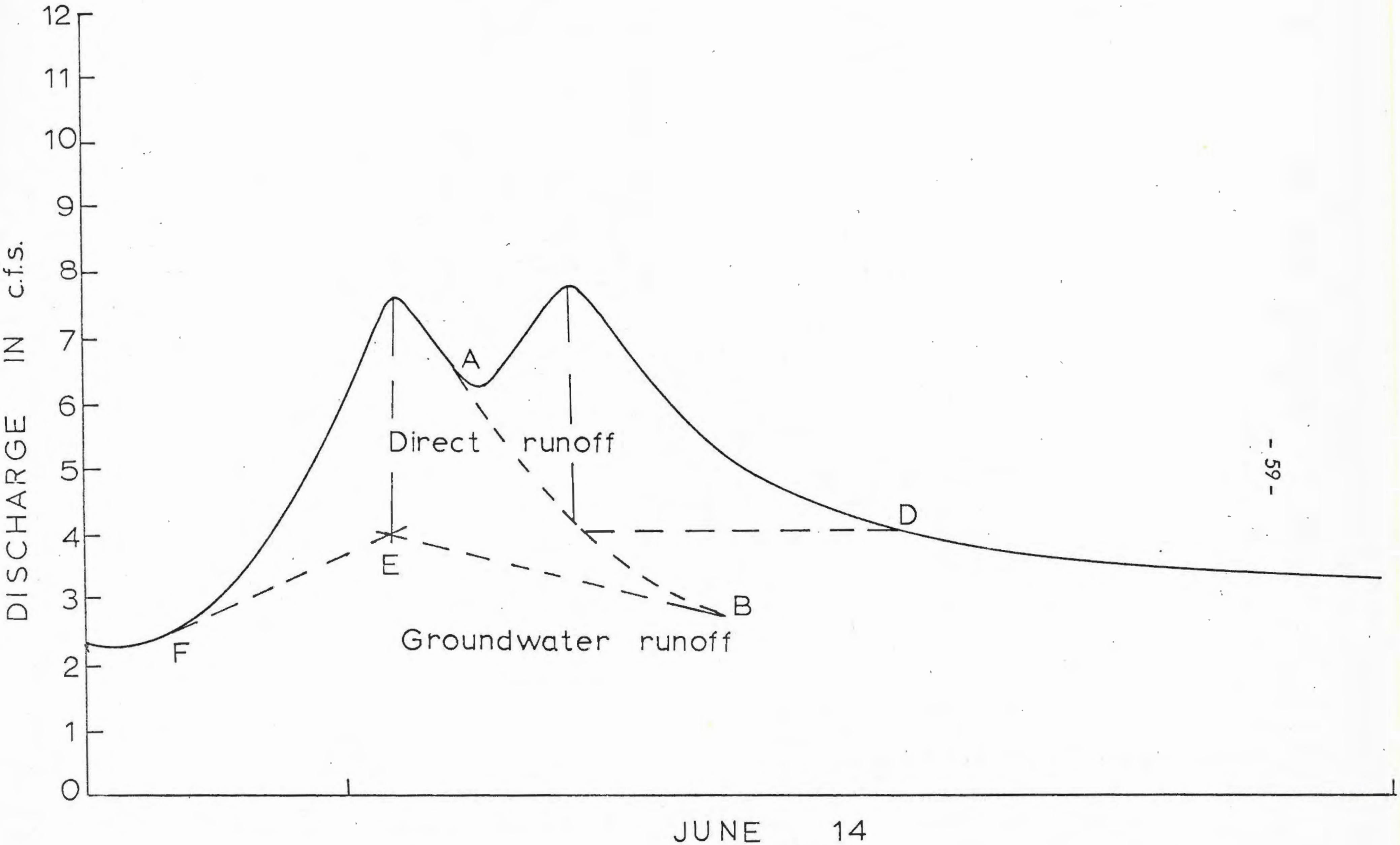

Figure 23. Separation of complex hydrograph for the watershed.

Direct Runoff Component

Table 14 shows, for three watersheds, an estimate of the annual direct runoff expressed in inches and as a percentage of precipitation. All the figures were obtained by subtracting from the total runoff the groundwater runoff as estimated from the plotted annual hydrographs of streamflow.

Table 14. Annual Direct Runoff for Watersheds

Watershed	Precipitation (inches)	Direct Runoff		
		inches	Percent of Total runoff	Percent of Precipitation
Fraser Brook				
1966	43	14.5	58	34
1967	55	24.4	61	44
1968	44	20.3	70	46
April Brook				
1967	61	31.6	58	52
1968	64	28.0	45	44
Sharpe Brook				
1968	44	20.0	64	46

Average total direct runoff in Fraser Brook was 20 inches while in April Brook 29.8 inches and in Sharpe Brook 20 inches. The direct runoff values indicate that over the watersheds variations on the basis of a period of a few years are not large. Changes of direct runoff in the watersheds are affected by basin and precipitation characteristics. Some of these characteristics are determined from available information in earlier parts of this report.

Groundwater Runoff Component

Groundwoter runoff in the three watersheds is shown in Table 15. An estimate of the annual groundwater runoff is expressed in inches. All figures were obtained through a study of the plotted annual hydrographs of total streamflow and are based on a general envelope separation line. These estimates are rough approximations of the amount of infiltration that reaches the stream channels as groundwater runoff.

Average annual groundwater runoff was 11.5 inches for Fraser Brook, 28.7 inches for April Brook, and 11.3 inches for Sharpe Brook.

Table 15. Annual Groundwater Runoff for Watersheds

Watershed	Precipitation (inches)	Groundwater runoff	
		Inches	Percent of total runoff
Fraser Brook			
1966	43	10.5	42
1967	55	15.5	39
1968	44	8.7	30
April Brook			
1967	61	23.5	43
1968	64	34.0	55
Sharpe Brook			
1968	44	11.3	41

RUNOFF - RAINFALL RATIOS

Table 16 gives the groundwater runoff, and direct runoff from selected storms with an approximation of the precipitation that caused the runoff for the three watersheds and for Salmon River.

Runoff from Fraser Brook and Salmon River, which are in the Salmon River drainage system, was compared for each storm. The same storms were selected and estimates revealed that approximately the same amount of total runoff (in inches) occurred for both rivers. Comparison of the direct runoff indicates that amount of direct runoff increases in the Salmon River. This difference is due to bank storage of the lower part of Salmon River which causes the back water type of groundwater feeding of the river where the fluid potential of water in bank storage during periods of high flow decreases groundwater discharge into the stream (Chernaya, 1964).

Table 16. Runoff-Rainfall Ratios for the Watersheds

Fraser Brook

Storm	Weighted rainfall (inches)	Direct runoff (inches)	Ground-water runoff (inches)	Ratio of direct runoff to weighted rainfall
May 28, 1966	1.81	0.25	0.39	0.14
June 19, 1966	0.72	0.04	0.09	0.06
July 20, 1966	0.62	0.003	0.01	0.005
Aug 23, 1966	1.28	0.03	0.04	0.02
Sep 29, 1966	0.95	0.05	0.07	0.05

(Table 16. Continued)

Storm	Weighted rainfall (inches)	Direct runoff (inches)	Ground-water runoff (inches)	Ratio of direct runoff to weighted rainfall
Oct 24, 1966	0.66	0.05	0.24	0.08
May 19, 1967	0.51	0.03	0.23	0.06
June 15, 1967	0.86	0.04	0.12	0.05
July 3, 1967	2.06	0.17	0.21	0.08
Aug 27, 1967	1.03	0.02	0.10	0.02
Sep 10, 1967	0.96	0.06	0.26	0.06
Oct 18, 1967	1.34	0.06	0.40	0.04
May 30, 1968	0.70	0.04	0.09	0.06
June 13, 1968	1.19	0.05	0.11	0.04
July 21, 1968	0.43	0.003	0.01	0.01
Aug 25, 1968	1.65	0.10	0.09	0.06
Sep 27, 1968	1.21	0.03	0.04	0.01

Salmon River

Storm	Weighted rainfall (inches)	Direct runoff (inches)	Ground-water runoff (inches)	Ratio of direct runoff to weighted rainfall
May 28, 1966	1.45	0.51	0.22	0.35
June 19, 1966	0.69	0.06	0.06	0.09
July 20, 1966	0.58	Neg.	Neg.	Neg.

(Table 16. Continued)

Storm	Weighted rainfall (inches)	Direct runoff (inches)	Ground-water runoff (inches)	Ratio of direct runoff to weighted rainfall
Aug 23, 1966	1.36	0.055	0.03	0.04
Sep 29, 1966	0.95	0.08	0.04	0.08
Oct 24, 1966	0.81	0.12	0.17	0.15
May 19, 1967	0.48	0.08	0.45	0.17
June 15, 1967	0.81	0.05	0.07	0.06
July 3, 1967	1.47	0.21	0.09	0.14
Aug 27, 1967	0.70	0.035	0.045	0.05
Sep 10, 1967	1.07	0.18	0.12	0.17
Oct 18, 1967	1.05	0.31	0.27	0.29
May 30, 1968	0.48	0.04	0.05	0.08
June 13, 1968	1.02	0.06	0.05	0.06
July 21, 1968	0.33	Neg.	Neg.	Neg.
Aug 25, 1968	1.64	0.11	0.03	0.07
Sep 27, 1968	1.25	0.04	0.03	0.03
Oct 25, 1968	0.92	0.12	0.10	0.13

(Table 16. Continued)

April Brook

Storm	Weighted rainfall (inches)	Direct runoff (inches)	Ground-water runoff (inches)	Ratio of direct runoff to weighted rainfall
May 9, 1967	0.28	0.08	0.96	0.29
June 7, 1967	0.37	0.01	0.08	0.03
July 30, 1967	0.86	0.02	0.03	0.02
Aug 6, 1967	0.74	0.01	0.06	0.01
Sep 10, 1967	0.86	0.03	0.08	0.04
Oct 29, 1967	0.82	0.03	0.33	0.04
May 1, 1968	0.25	0.02	0.20	0.08
June 13, 1968	0.95	0.03	0.05	0.03
July 15, 1968	0.37	0.007	0.03	0.02
Aug 20, 1968	1.49	0.06	0.08	0.03
Sep 11, 1968	0.53	0.006	0.06	0.01
Oct 20, 1968	1.27	0.02	0.10	0.02

Sharpe Brook

Storm	Weighted rainfall (inches)	Direct runoff (inches)	Ground-water runoff (inches)	Ratio of direct runoff to weighted rainfall
May 20, 1968	0.72	0.11	0.26	0.15
June 13, 1968	1.96	0.14	0.25	0.07
July 19, 1968	0.33	0.001	0.005	0.003

(Table 16. Continued)

Storm	Weighted rainfall (inches)	Direct runoff (inches)	Ground-water runoff (inches)	Ratio of direct runoff to weighted rainfall
Aug 20, 1968	0.62	0.0002	0.0003	0.0003
Oct 25, 1968	1.08	0.04	0.24	0.04

Comparison of Ratios for Watersheds

Comparison of the results for Fraser, April, and Sharpe Brook watersheds is given in Table 17. The comparison shows that direct runoff is greatest in the April Brook watershed, although variations of direct runoff are not great from watershed to watershed. A comparison of characteristics of the watersheds is given in Table 18. During periods of soil moisture deficiency and high rates of evapotranspirotion direct runoff is at a minimum.

Conclusions

The three watersheds under study are fairly representative of many parts of Novo Scotia in climate, soils, forest cover and unconsolidated deposits. Runoff is affected by many natural influences including climate, geology, topography ond vegetation. The forest inventory indicates that more than 90 percent of the three watersheds is covered by forests. Experiments of Hoover (1944) showed that trees transpire large quantities of water and so reduce the volume of runoff.

The variation of runoff-rainfall ratio in general depends upon the distribution of rainfall during the year in each watershed.

During the period January to May, the ratio of runoff to precipitation in general increases due to the occurrence of heavy rainfall or rising temperature and the discharge of waters from snowmelt and, in many cases, combination of both causes, and frozen ground. During June to September, evapotranspiration and soil moisture deficiency are at their maximum and the runoff-rainfall ratio decreases.

Table 17. Comparison of Hydrologic Data in Watersheds

for Water year 1968

Ratio factors	Watershed		
	Fraser Brook	April Brook	Sharpe Brook
Annuol values		inches	
Temperature (in °F)	40.60	41.60	42.60
Precipitation (weighted)	43.73	63.88	43.70
Streamflow	28.90	52.50	29.40
Direct runoff	20.30	28.00	20.00
Groundwater runoff	8.70	34.00	11.30
Storm runoff values		inches	
Maximum direct runoff	0.10	0.06	0.14
Minimum direct runoff	0.003	0.006	0.0002

Table 18. Comparison of characteristics of watersheds

Watershed characteristics	Watershed		
	Fraser Brook	April Brook	Sharpe Brook
Topography	Rolling topography of lowlands	Well rounded hilly lowlands	Highlands with smooth surface
Mean stream slope in feet per mile	87	415	180
Soil	Brown sandy and clay loam	Loamy sand, sandy loam and clay loam	Grayish-brown sandy loam
Forest cover	94% forest; 6% cleared land	97% forest; 3% non-forested	96% forest; 4% non-forested
Unconsolidated deposits	From 5 to 45 feet of sandy and clay till	From few feet to 30 feet of sandy till	Over 50 feet of glaciofluvial deposits
Bedrock formations	Sandstone, grit, shale, and conglomerate of Mississippian age	Conglomerate, sandstone, siltstone, shale, limestone, gypsum, and anhydrite of Mississippian age	Greywacke, quartzite, slate, schist and granite of Paleozoic age
North latitude	45°20'-45°18'	46°15'-46°12'	45°02'-44°58'

For October to December, the ratio of runoff to precipitation in general again increases on account of the reduction of evapotranspiration.

Comparable discharge (direct and groundwater runoff) occurs at the three IHD watersheds in Nova Scotia. The physical conditions of the drainage areas are not greatly different, but stream slope varies from 87 to 415 feet per mile among the watersheds. In April Brook watershed, steep slope causes quick direct runoff and is unfavourable to seepage.

Runoff of Salmon River and Fraser Brook was compared for selected storms at the same time. Comparison indicates that total runoff (in inches) is similar for both rivers. However, direct and groundwater runoff components of storm runoff cannot be compared for Fraser Brook and Salmon River, because the type of groundwater feeding affects the amount of groundwater runoff in the drainage areas. The descending type of groundwater feeding occurs in Fraser Brook where the groundwater runaff component increases, while direct runoff decreases. In contrast, the backwater type of groundwater discharge occurs in the lower part of Salmon River and, during periods of high flow, this causes a decrease of groundwater discharge inta the stream. Available direct runoff-rainfall ratios from Fraser Brook Watershed cannot be used for the Salmon River Basin. The Salmon River and other larger basins need more instrumentation to study direct runoff-rainfall ratios.

In this report the "envelope method" was used for separating annual streamflow hydrographs, because of lack of observations of spring regimes. Makarenko's method is considered to be most precise (Chernaya, 1964) if spring records are available. Therefore, it is necessary to collect spring records for a better estimation of the annual hydrograph components and also possibly water samples to separate the streamflow components by chemical analysis of total runoff (Pinder and Jones, 1969).

Soil moisture plays a very important role in runoff-rainfall ratio. In this study, independent storms have been selected, therefore, antecedent precipitation condition may be considered to be at a minimum. Future studies must place more emphasis on accurate determination of soil moisture.

The precipitation, temperature, and runoff records that are presented in this report cover a relatively short period of time, which indicate larger variations than the long term records. These larger variations give a better indication of the extreme values of records than the nearby long term precipitation normals. However, short term records might not always give useful indication of the extreme values. Consequently, short term records should not be compared with long term records. In general, occurrence of a series of wet or dry years is purely random. Therefore, long term records are necessary for a statistical estimation of precipitation and runoff. To obtain a full knowledge of the variation in the flow of a stream it is essential to study its hydrographs for a long term of years (e.g. for 30 or more years).

Variations of runoff-rainfall ratios for three watersheds have been estimated, the results of studies described in this report permit a better understanding of stream discharges in Nova Scotia.

APPENDIX

Computer Program for Calculation of Runoff Volumes

Direct and groundwater runoff volumes of storm hydrographs are calculated by IBM Model 360/50 Digital Computer.

1 - Calculations for backwater type of groundwater discharge hydrographs:

a) The total runoff area under the hydrograph curve is divided into rectangular and triangular sub-areas (Figure 24). The sum of the divided areas gives total runoff area in cubic feet.

b) The groundwater runoff area under the separation line is divided into rectangular and triangular sub-areas (Figure 25). The sum of the divided areas gives groundwater runoff area in cubic feet.

c) The groundwater runoff area is subtracted from the total runoff area which gives direct runoff area in cubic feet.

d) The areas are multiplied by 0.083 conversion factor and volumes in acre-feet can be obtained.

Table 19 shows the program for backwater type of groundwater discharge hydrographs. An example for set of data is given in Table 20.

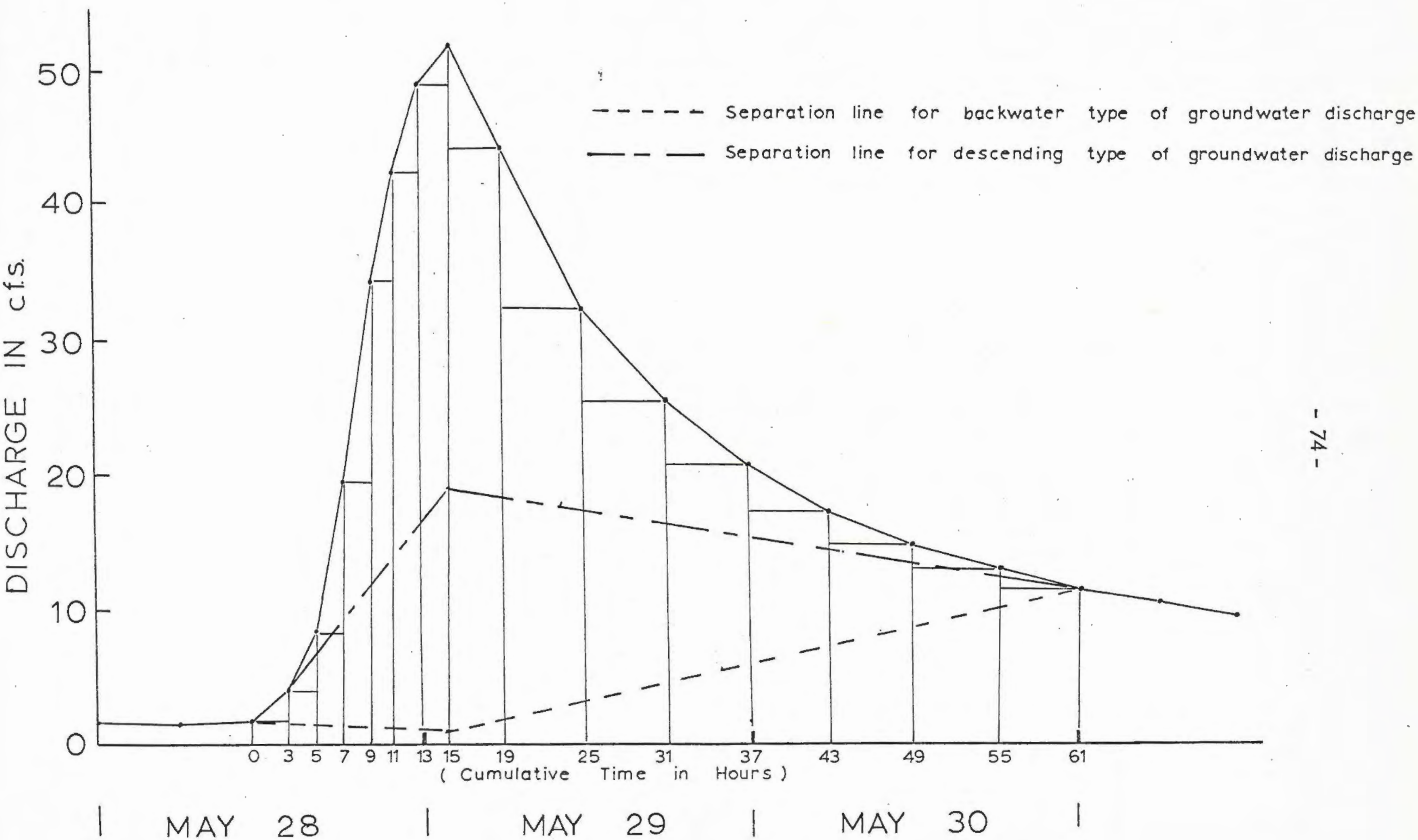

Figure 24. Division of total runoff area under the hydrograph curve (Fraser Brook, May 28, 1966).

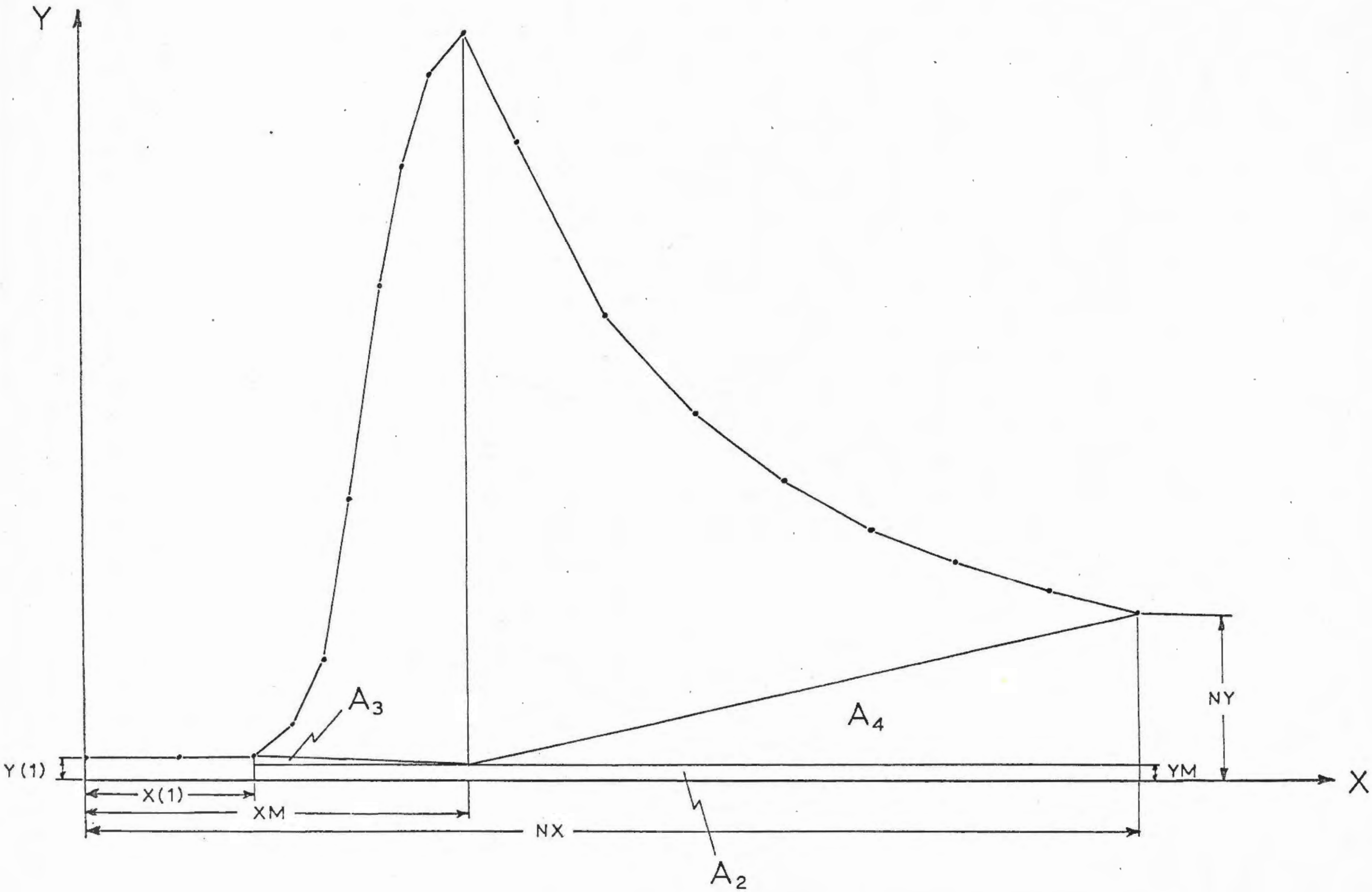

Figure 25. Division of groundwater runoff area under the separation line for backwater type of groundwater discharge hydrograph.

Table 19. Computer Program for Backwater

Type of Groundwater Discharge.

```
C     THIS PRØGRAM CØMPUTES THE AREA UNDS
C     THIS PRØGRAM CØMPUTES THE AREA UNDER THE CURVE
      BETWEEN TWØ PØINTS
C     THIS PRØGRAM CØMPUTES THE VØL UNDER THE CURVE
      BETWEEN TWØ PØINTS
C     A AND B AND A NUMBER ØF PØINTS IN BETWEEN
C     IT IS ASSUMED THAT THESE PØINTS ARE PØINTS ØF THAT
C     SEGMENT ØF THE CURVE THAT IS CØNTINUØUS
C
C
      DIMENSIØN X(100),Y(100),NERR(4)
      DATA NX,NY/2*0/,NERR/4*0/,NUMBER/0,A1/0.0/
C
    1 DØ 20 I=1,100,10
      K=I+9
      IF (K.GT.100) GØ TØ 25
      READ(5,1000,END=9999) (X(J),J=I,K)
      DØ 10 L=I,K
      IF (X(L).EQ.99999.99) GØ TØ 25
   10 NX=NX+1
   20 CØNTINUE
C
   25 DØ 40 I=1,100,10
      K=I+9
      IF(K.GT.100) GØ TØ 45
      READ(5,1000) (Y(J),J=I,K)
      DØ 30 L=I,K
      IF(Y(L).EQ.99999.99) GØ TØ 45
   30 NY=NY+1
   40 CØNTINUE
C
   45 READ(5,1010) YM
C
C
      IF(Y(1)-YM) 100,100,110
  100 NERR(1)=1
  110 IF(Y(NY)-YM) 120,120,130
  120 NERR(2)=1
```

```
      130 IF(NY-NX) 140,150,140
      140 NERR(3)=1
      150 DØ 160 I=2,NX
          IF(X(I-1).GT.X(I)) NERR(4)=NERR(4)+1
      160 CØNTINUE
C
C
          IF (NERR(3).EQ.1) GØ TØ 9000
          IF (NERR(4).GT.0) GØ TØ 9000
C
C         SEARCH FØR XM
          M=1
          DØ 180 I=2,NY
          IF(Y(I-1)-Y(I)) 180,180,170
      170 M=I-1
          GØ TØ 190
      180 CØNTINUE
C
      190 XM=X(M)
C
C         CØMPUTE AREA A1
C
          NXBD=NX-1
          DØ 200 I=1, NXBD
          XW=X(I+1)-X(I)
          YW=Y(I+1)+Y(I)
          A1=A1+(XW*YW)/2.0
      200 CØNTINUE
C
C         CØMPUTE AREA A2
C
          A2=(X(NX)-X(1))*YM
C
C         CØMPUTE AREA A3
C
          A3=((XM-X(1))*(Y(1)-YM))/2.0
C
C         CØMPUTE AREA A4
C
          A4=((X(NX)-XM)*(Y(NY)-YM))/2.0
C
C         PRINT ØUTPUT
C
          NUMBER=NUMBER+1
```

```
        WRITE(6,1100) NUMBER
  1100  FØRMAT(1H1,35X,'GRAPH #',13/' X CØ-ØRD        Y CØ-ØRD'/' ')
C
        DØ 210 I=1,NX
        WRITE(6,1110) X(I), Y(I)
   210  CØNTINUE
        WRITE(6,1120) XM,YM
  1120  FØRMAT(1H0 ,'XM=',F8.2,'       YM',F8.2)
C
        IF (NERR(1).EQ.1) WRITE(6,1200) Y(1),YM
        IF (NERR(2).EQ.1) WRITE(6,1210) Y(NY),YM
C
        AS=A2+A3+A4
        A=A1-AS
C
        WRITE(6,1300) A1,A2,A3,A4,AS,A
  1300  FØRMAT (1H0 ,'A1=',F8.2,'       A2=',F8.2,'       A3=',F8.2,'
                                                           A4=',F8.2,/,
       1' AS=',F8.2,/'0****** NET AREA=',F8.2)
C
C       VØL IN ACRE-FT
C
        VØL1=A1*0.083
        VØLS=AS*0.083
        VØL=A*0.083
        WRITE(6,1600) VØL1,VØLS,VØL
  1600  FØRMAT(1H0 ,'VØL1=',F10.4,2X,'VØLS=',F10.4/'0
                                                   ******NET VØLUME=',
       1F10.4)
C
C
C
   220  A1=0.0
        NX=0
        NY=0
        DØ 250 I-1,4
   250  NERR(I)=0
C
        GØ TØ 1
C
C
  9000  WRITE(6,1400) NERR(3),NERR(4)
  1400  FØRMAT(1H1,' INPUT ERROR; NERR(3)=',I1,'       NERR(4)',13)
        GØ TØ 220
```

```
C
C
  9999 WRITE(6,1500)
  1500 FØRMAT(1H0,'END OF RUN')
C
C
       STOP
C
  1000 FØRMAT(10F8.2)
  1010 FØRMAT(F8.2)
  1110 FØRMAT(1H  ,F8.2,5X,F8.2)
  1200 FØRMAT(1H0,' Y(A) LESS THAN YM; Y(A)=',F8.2,'
                                       YM=',F8.2)
  1210 FØRMAT(1H0,' Y(B) LESS THAN YM; Y(B)=',F8.2,'
                                       YM=',F8.2)
C
       END
```

Table 20. An Example for Set of Data from Fraser Brook, 1966.

Date	Hour	Cumulative time in hours (X-axis)	Flow (cfs) (Y-axis)	YM (cfs)
May 28, 1966	00:00	-	1.50	1.0
28	06:00	-	1.50	
28	11:00	0.00	1.80	
28	14:00	3.00	3.80	
28	16:00	5.00	9.50	
28	18:00	7.00	17.60	
28	20:00	9.00	34.70	
28	22:00	11.00	42.30	
29	00:00	13.00	49.20	
29	02:00	15.00	51.70	
29	06:00	19.00	42.30	
29	12:00	25.00	31.80	
29	18:00	31.00	24.50	
30	00:00	37.00	20.40	
30	06:00	43.00	19.50	
30	12:00	49.00	14.70	
30	18:00	55.00	12.30	
31	00:00	61.00	11.20	
June 1	06:00	-	10.30	
2	12:00	-	9.50	

These data should be written on fortran coding form paper as shown in Table 21.

2- Calculations for descending type of groundwater discharge hydrographs:

According to Figure 26 (on page 82) few changes are necessary on computer program of backwater type of groundwater discharge hydrograph. Cards # 44, 45, 46, 57, 59 and 60 are written and one more card is added as shown in Table 22.

Table 21. Fortran Statement of the Example

0.00	3.00	5.00	7.00	9.00	11.00	13.00	15.00	19.00	25.00
31.00	37.00	43.00	49.00	55.00	61.0099999.99				
1.80	3.80	9.50	17.60	34.70	42.30	49.20	51.70	42.30	31.80
24.50	20.40	19.50	14.70	12.30	11.2099999.99				
1.00									

(Note that end of X and Y values must be placed by the 99999.99 numbers as a rule of this program)

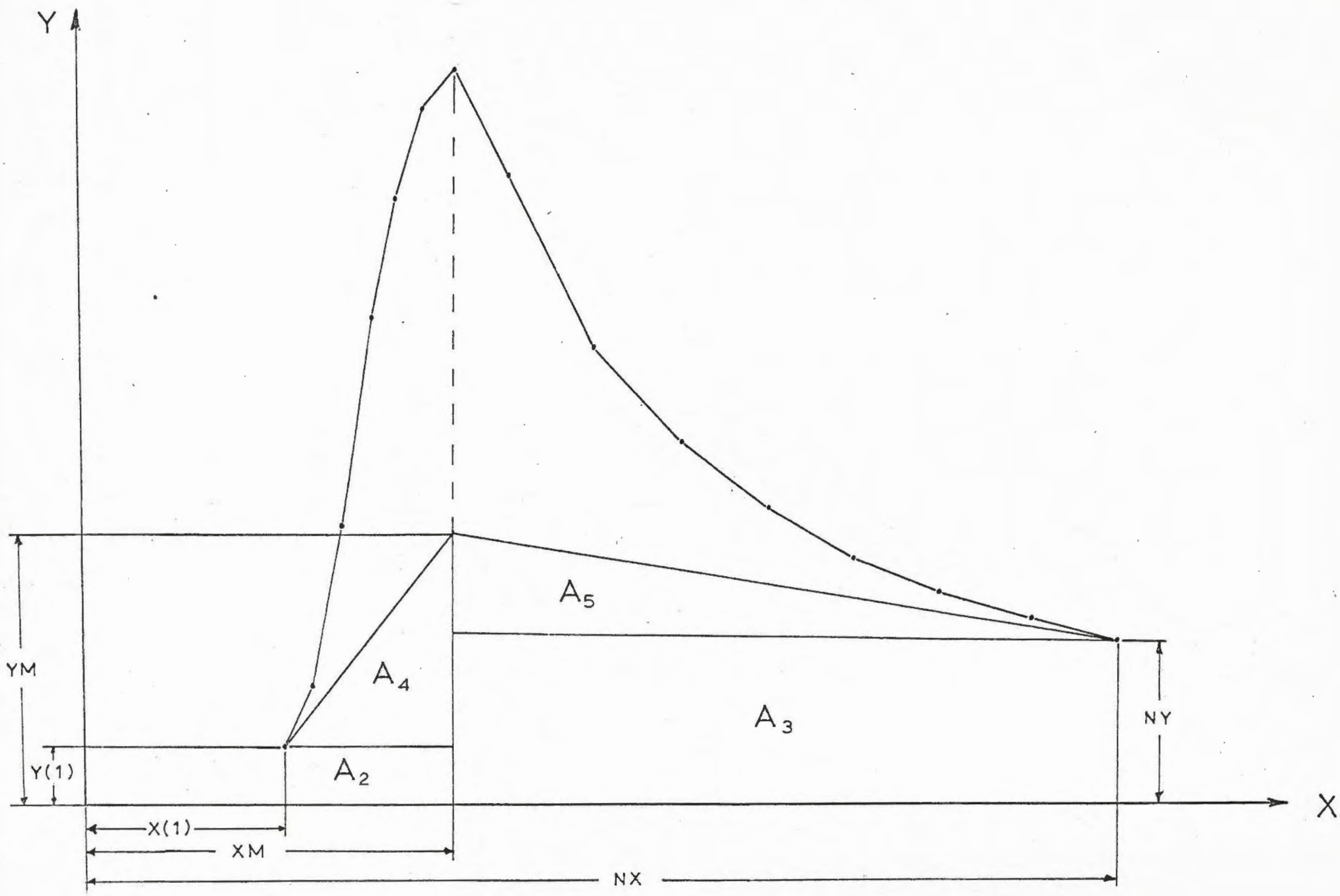

Figure 26. Division of groundwater runoff area under the separation line for descending type of groundwater discharge hydrograph.

Table 22. Changes of the Cards

Card #	
44	A2=(XM-X(1))*(Y(1))
45	A3=(X(NX)-XM)*(Y(NX))
46	A4=(XM-X(1))*(YM-Y(1))/2.0
Addition	A5=(X(NX)-XM)*(YM-Y(NX))/2.0
57	AS=A2+A3+A4+A5
59	WRITE(6,1300) A1,A2,A3,A4,A5,AS,A
60	1300 FORMAT(1H0,'A!=',F8.2,' A2=',F8.2,' A3=',F8.2,' A4=',F8.2,/, 1' A5=',F8.2,' AS=',F8.2,/'0******NET AREA=',F8.2)

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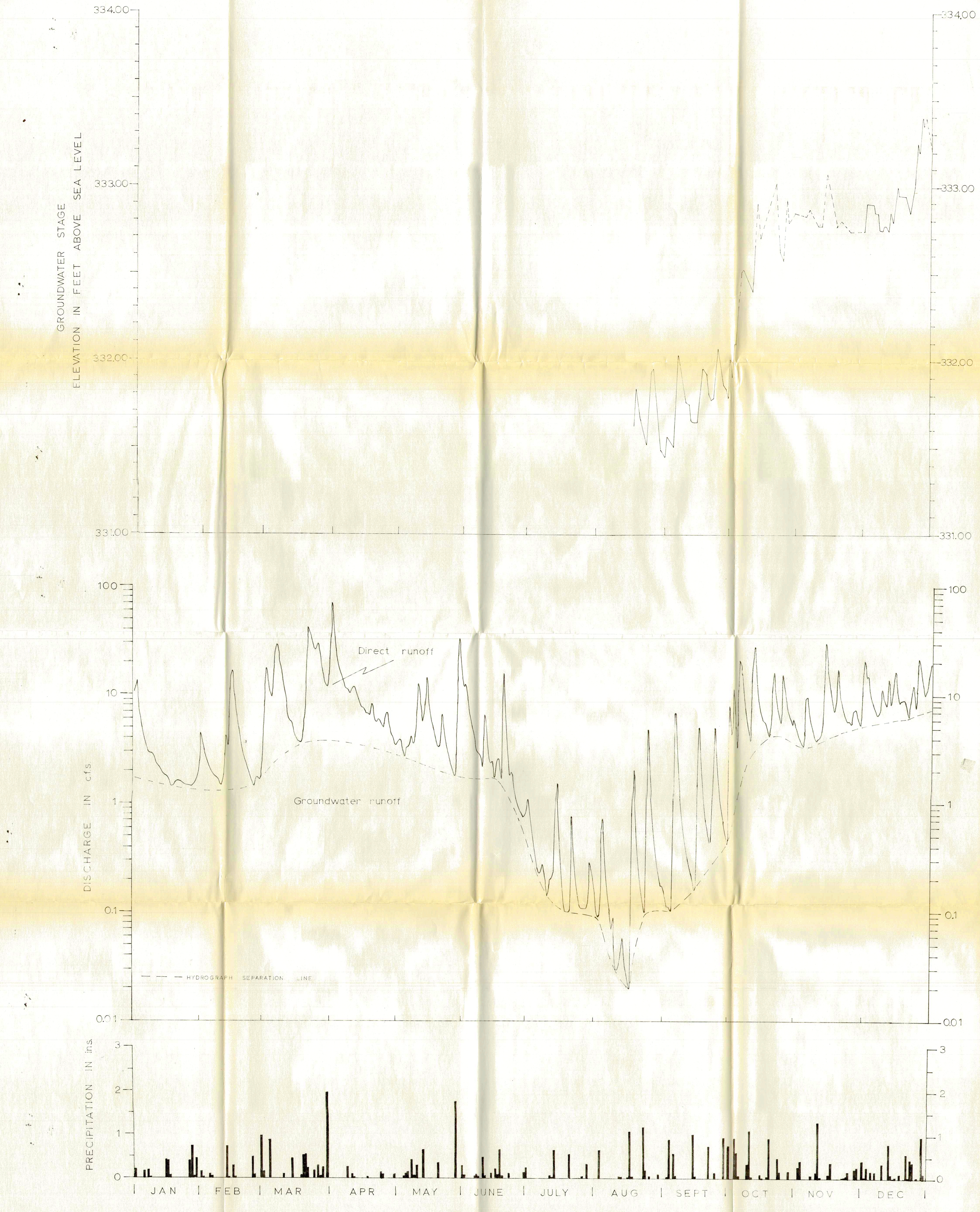

PLATE 1. MEAN GROUNDWATER STAGE AND MEAN DAILY DISCHARGE OF FRASER BROOK, AND DAILY PRECIPITATION FOR 1966

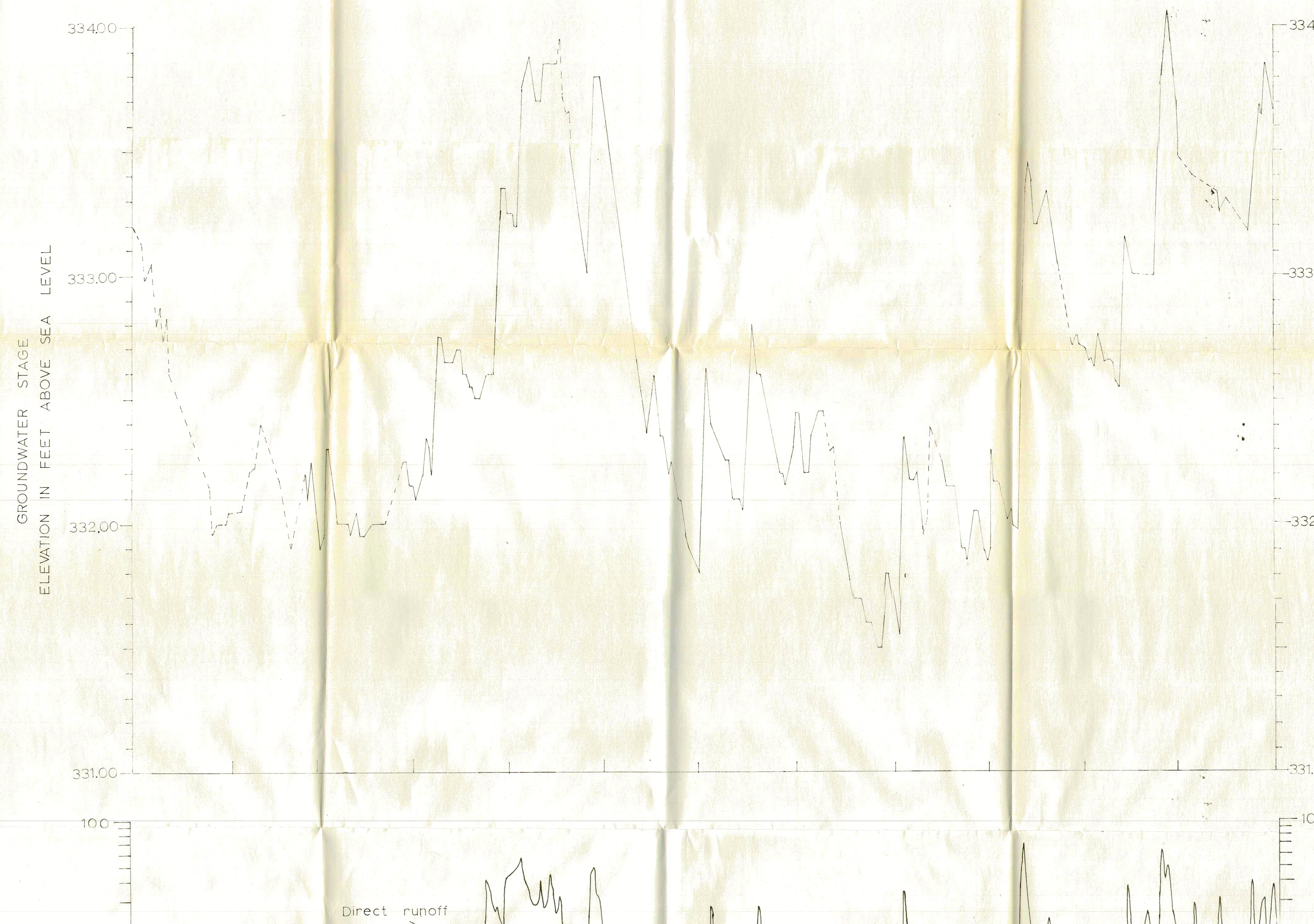

PLATE 2. MEAN GROUNDWATER STAGE AND MEAN DAILY DISCHARGE OF FRASER BROOK, AND DAILY PRECIPITATION FOR 1967

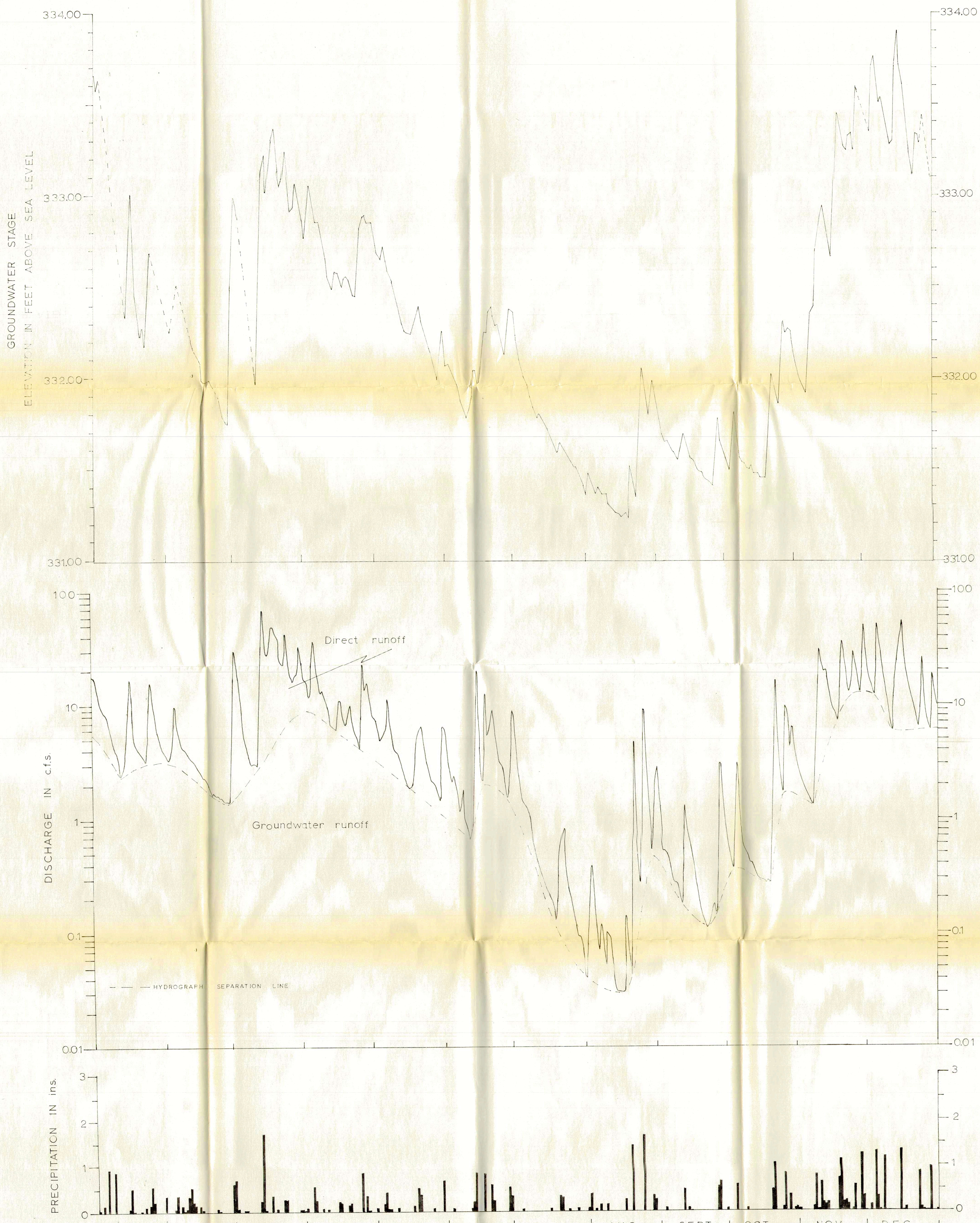

PLATE 3. MEAN GROUNDWATER STAGE AND MEAN DAILY DISCHARGE OF FRASER BROOK, AND DAILY PRECIPITATION FOR 1968

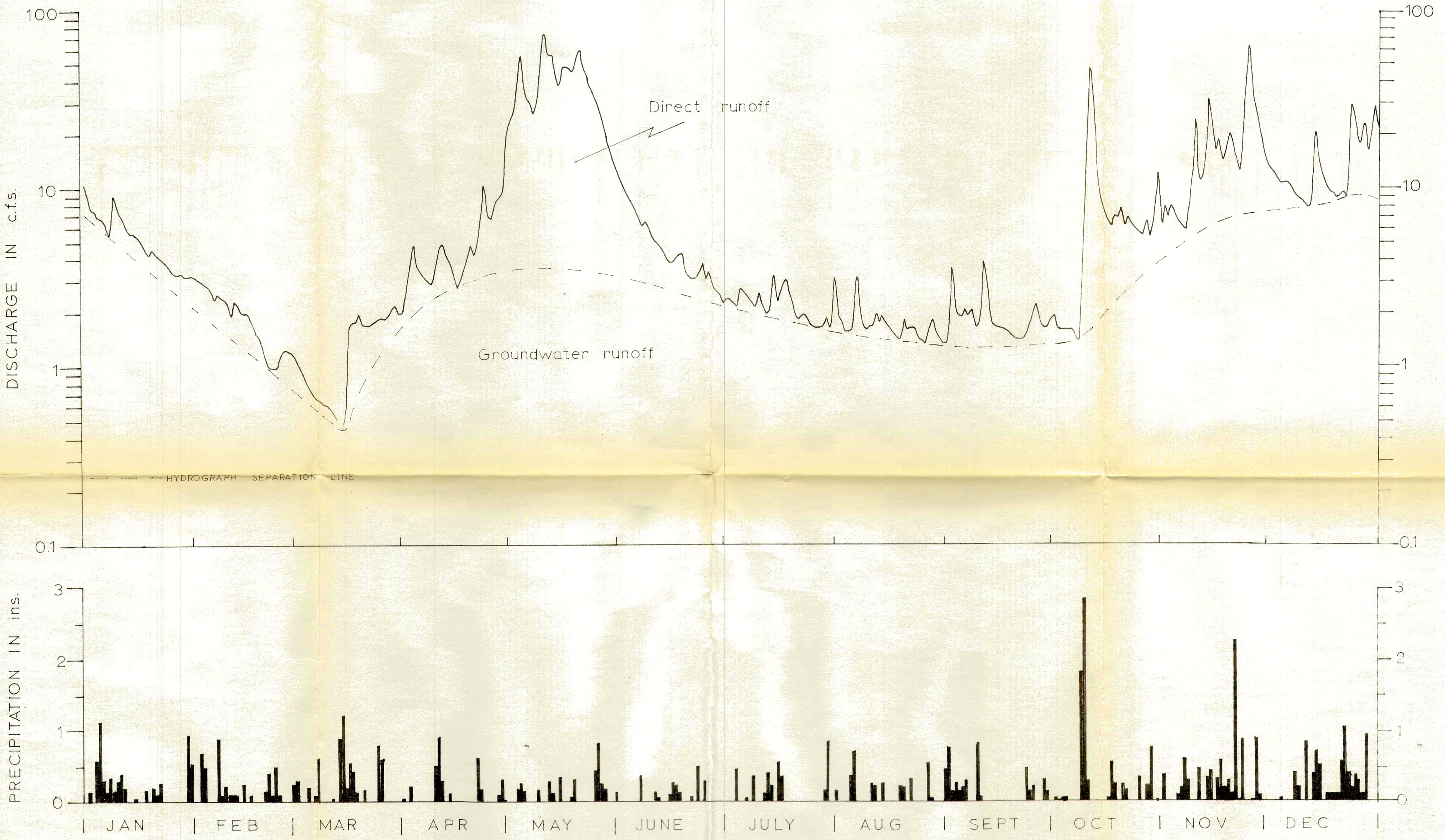

PLATE 4. MEAN DAILY DISCHARGE OF APRIL BROOK AND DAILY PRECIPITATION FOR 1967

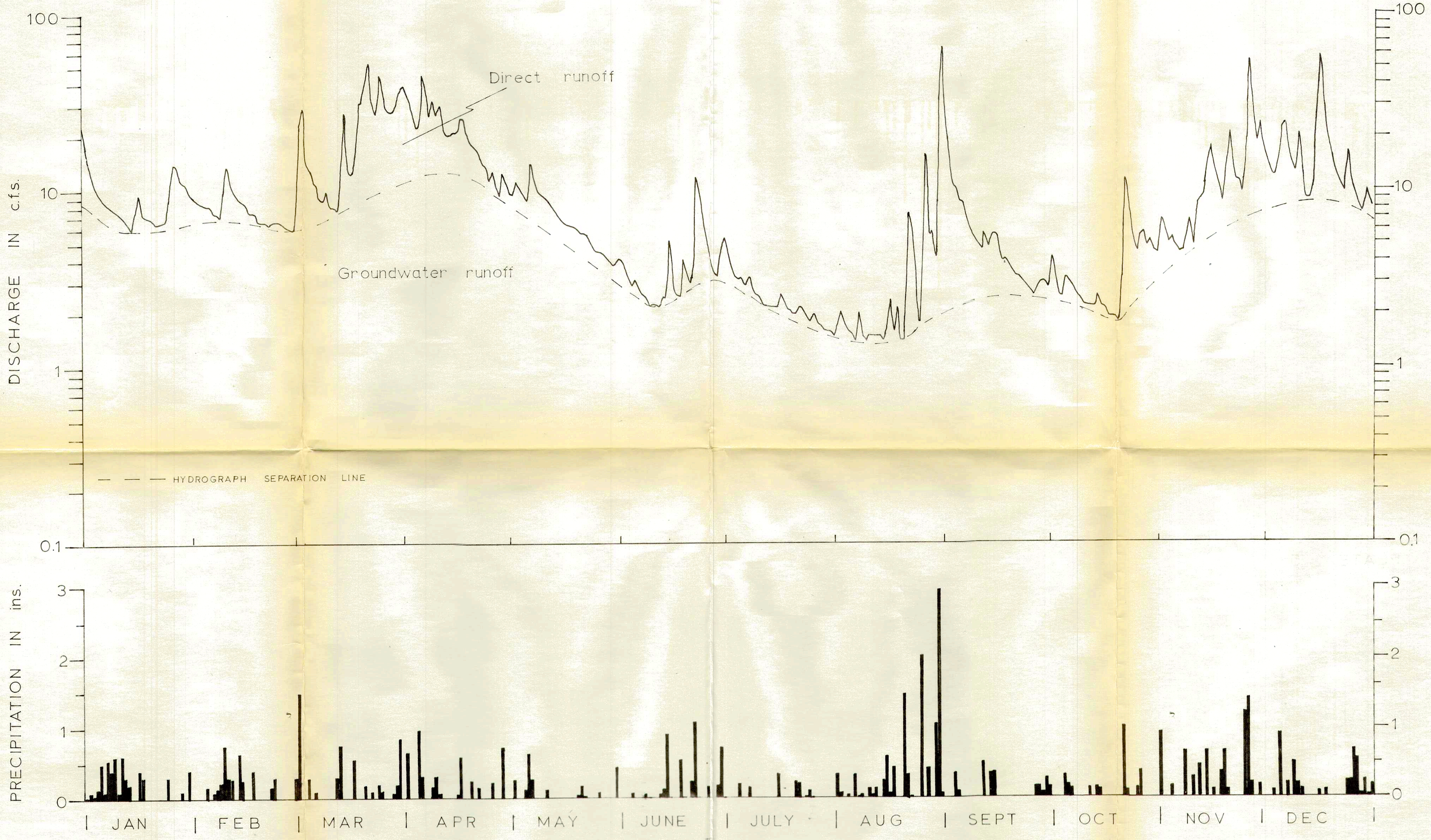

PLATE 5. MEAN DAILY DISCHARGE OF APRIL BROOK AND DAILY PRECIPITATION FOR 1968

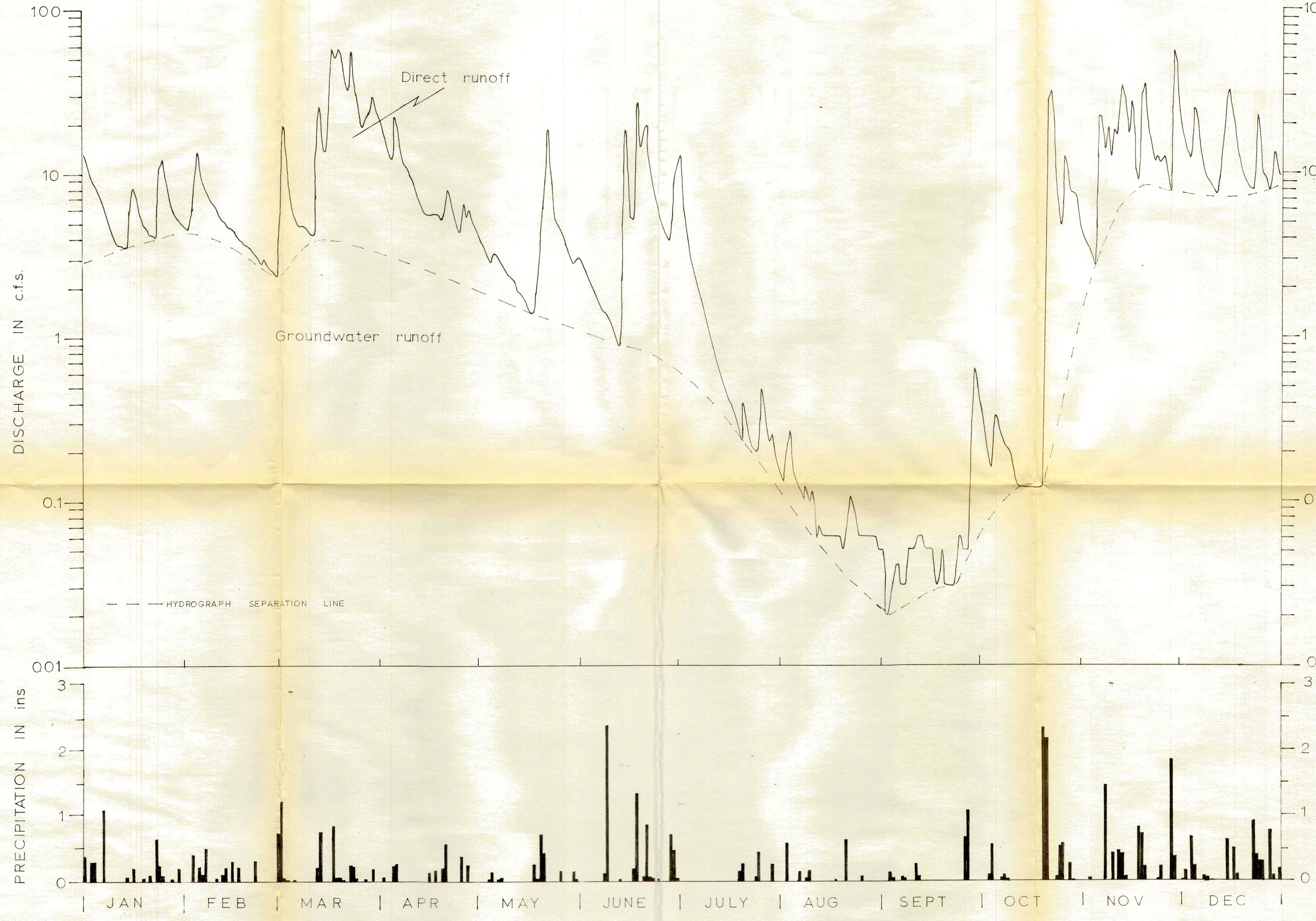

PLATE 6. MEAN DAILY DISCHARGE OF SHARPE BROOK AND DAILY PRECIPITATION FOR 1968