Rainfall and runoff: hydrological studies in Weardale

Shaw, E. M.

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Rainfall and Runoff:

Hydrological Studies in Weardale.

Elizabeth M. Shaw. B.Sc. London.

Thesis for M.Sc. Dunelm 1957.

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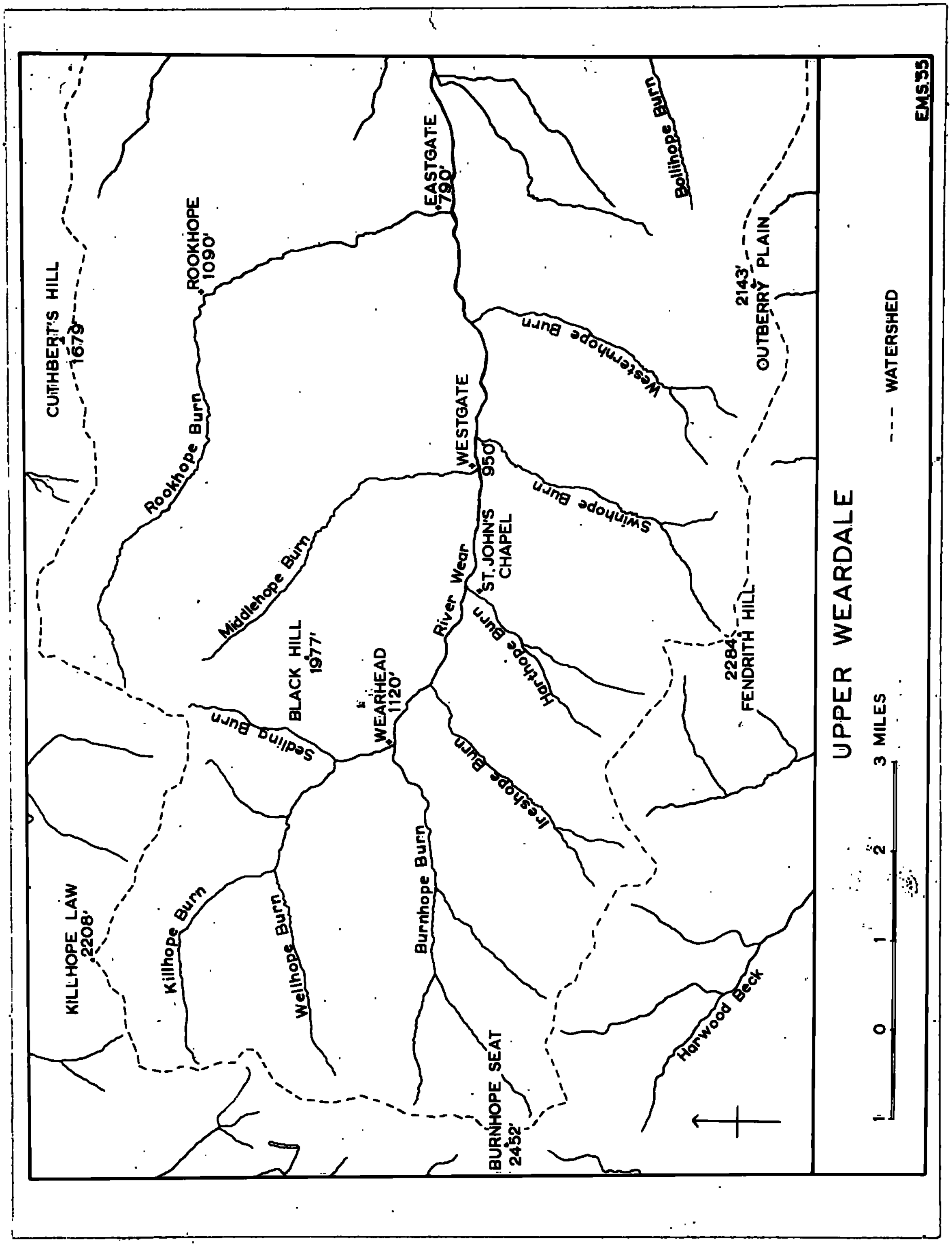
UPPER WEARDALE
EASTGATE
790'
ROOKHOPE
1090'
CUTHBERT'S HILL
1679'
Bollihope Burn
2143'
OUTBERRY PLAIN
Westernhope Burn
WESTGATE
950
Rookhope Burn
Swinhope Burn
ST. JOHN'S CHAPEL
Middlehope Burn
River Wear
Harthope Burn
BLACK HILL
1977'
WEARHEAD
1120'
2284'
FENDRITH HILL
Sedling Burn
Ireshope Burn
Burnhope Burn
KILLHOPE LAW
2208'
Killhope Burn
Wellhope Burn
Harwood Beck
BURNHOPE SEAT
2452'
3 MILES
0
1
2
3
1
WATERSHED
EMS'55

Fig. 1

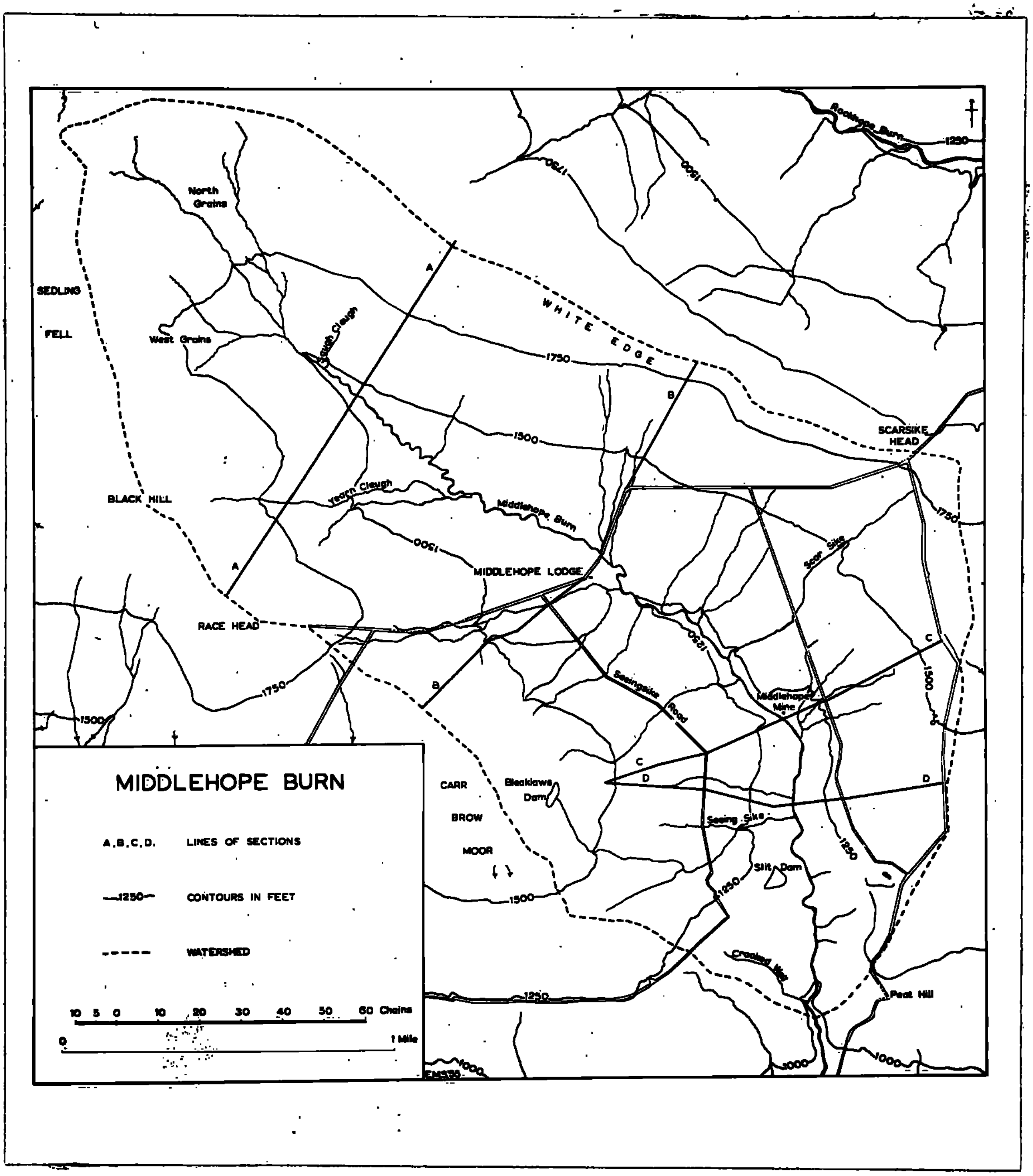
Rookhope Burn
1250
1750
1500
North Grains
SEDLING
FELL
West Grains
Slough Cleugh
A
WHITE EDGE
1750
B
SCARSIKE HEAD
1500
BLACK HILL
Yearn Clough
Middlehope Burn
1500
1750
MIDDLEHOPE LODGE
Scar Sike
A
RACE HEAD
1250
C
1750
B
Seeingsike Road
Middlehope Mine
1500
1500
C
D
D
CARR
BROW
MOOR
Bleaklaws Dam
Seeing Sike
1250
Silt Dam
1250
1500
Crooked Well
1250
Peat Hill
1000
1000
1000
MIDDLEHOPE BURN
A, B, C, D. LINES OF SECTIONS
1250 CONTOURS IN FEET
WATERSHED
10 5 0 10 20 30 40 50 60 Chains
0 1 Mile

Fig. 2

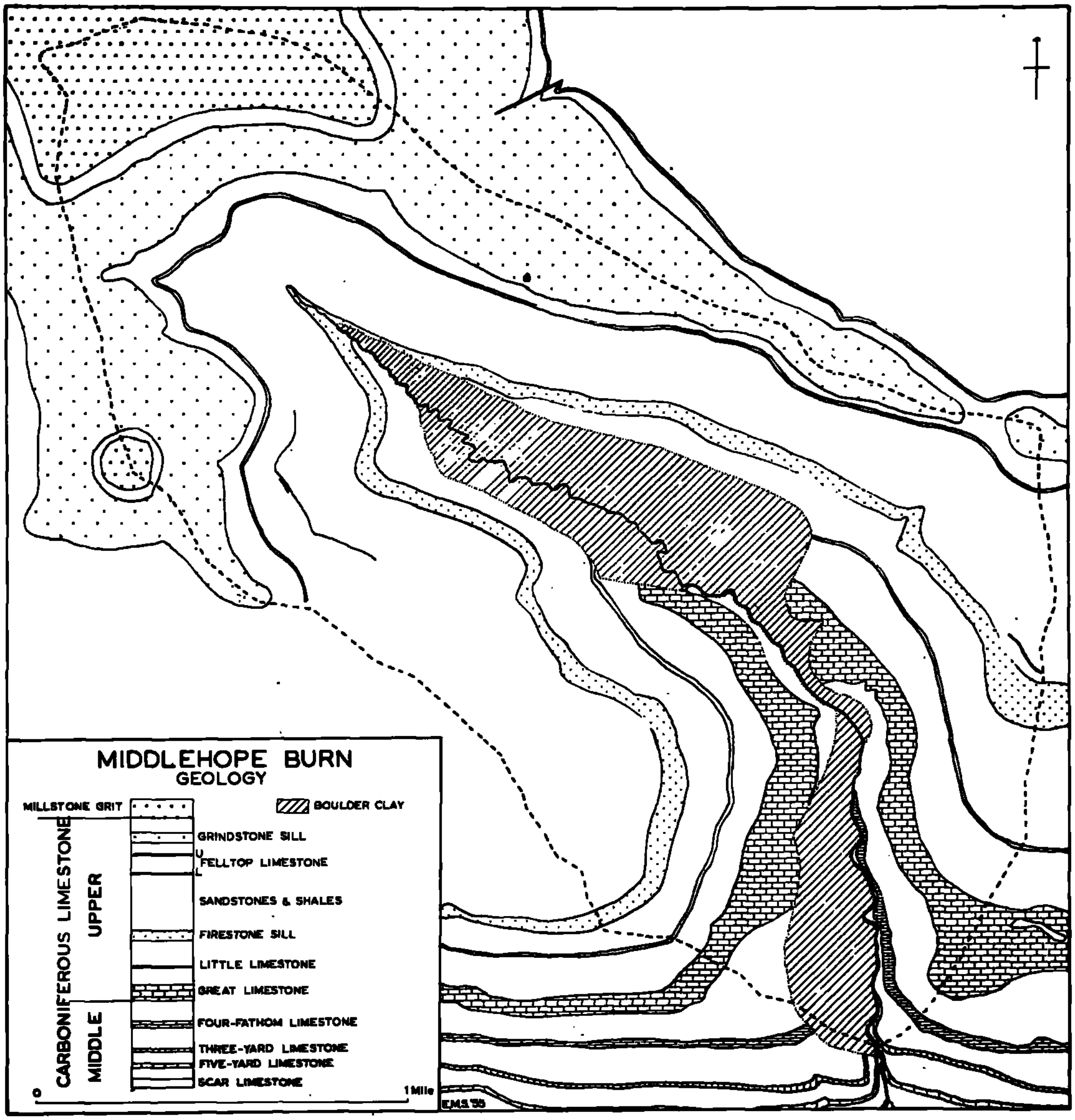
MIDDLEHOPE BURN
GEOLOGY
MILLSTONE GRIT
BOULDER CLAY
CARBONIFEROUS LIMESTONE
UPPER
GRINDSTONE SILL
U
FELLTOP LIMESTONE
L
SANDSTONES & SHALES
FIRESTONE SILL
LITTLE LIMESTONE
GREAT LIMESTONE
MIDDLE
FOUR-FATHOM LIMESTONE
THREE-YARD LIMESTONE
FIVE-YARD LIMESTONE
SCAR LIMESTONE
0
1 Mile
EMS 35

Fig. 3

the other hand, the Middlehope Burn is bordered by a pathway leading from Westgate, and there are several possible gauging points easy of access. Supporting the choice of this valley is also the fact that a good roadway leads round to the upper reaches of the stream, so that rainfall observations can be made comparatively easily in the upper part of the valley to give some indications of the precipitation falling on the catchment area.

Position

The Middlehope Burn is the first major left bank tributary of the Wear. Numerous small streams originating on the broad level stretches of Middlehope Moor join together to flow south-eastwards and then southwards as the Middlehope Burn into the Wear at Westgate (Fig.1). On the west side of the upper part of the valley is the Sedling Burn draining to one of the headwaters of the Wear, the Killhope Burn, while to the north and north-east is the valley of the Rookhope Burn. Only to the extreme north-west of the moor are there streams flowing away from the Wear system and those drain to the River Allen, a tributary of the Tyne.

Structure and Relief

The whole of the drainage basin is composed of Palaeozoic Carboniferous strata (Fig.3). The most representative series is that of the Carboniferous Limestone, but there are two outliers of the Millstone Grit. The smaller forms an obvious capping on Black Hill with a diameter of approximately 15 chains. The larger outlier covers the highest parts of Middlehope Moor, and extends beyond the drainage basin into the catchment areas of the Rookhope Burn and the Sedling Burn. The Millstone Grit, resistant to erosion, lies protectively on top of a shale, the highest formation of the Carboniferous Limestone, and so forms a plateau-like surface on which the only changes in gradient are caused by steep sided gullies eroded in the thick peat near the headwaters of the streams.

The Carboniferous Limestone formations outcrop successively down the valley sides. The Grindstone Sill outcrop covers the extensive area along White Edge, the watershed between the Middlehope Burn and the Rookhope Burn, and reaches a breadth of ¼ mile on the north-eastern slopes of Black Hill. The edge of the Grindstone Sill shows markedly as a very steep slope along the valley sides especially above Saugh Cleugh. The base of the formation, which forms the steep gradient occurs at 1918' at Race Head, but along White Edge it is found at 1750'. This illustrates the general easterly dip of the strata.

The greater proportion of the valley sides in the upper reaches of the burn is composed of sandstones and shales in alternate beds of varying thicknesses. A particularly thick resistant sandstone has made a ten-foot high waterfall at 1620' along the course of the West Grains. For about 300 yards upstream from their confluence at Middlehope Head, the two principal headstreams, of which the West Grains is one, have eroded steep sided gorges 10-20 feet deep. The upper and to a much lesser extent the lower Felltop Limestones are represented also in the series of strata and a very small outcrop of a thin coal is found in Yearn Cleugh. The Firestone Sill outcrops continuously round both sides of the valley, and its lower edge forms a very steep slope especially near Middlehope Head, and so the upper part of the main valley is narrow and steep sided (Fig.4 Section A). Between the Firestone Sill and the Little Limestone, the highest of the main succession of limestones, are further formations of sandstones and shales.

The central part of the Middlehope Burn valley may be considered to begin at the outcrop of the Great Limestone above Middlehope Bridge near the confluence of the large right bank tributary Yearn Cleugh. The valley here begins to develop a more open character (Section B). Irregularities in the cross section illustrate minor features caused by the dissection of tributary streams, but the higher slopes are still determined by the differential resistence of the same series of rocks as those found in the upper part of the valley. At Scarsike Head 1770', there is a col between the Middlehope and Rookhope drainage basins, a feature emphasised on the Geological map by the portrayal of an outlier of the Grindstone Sill separated from the continuous outcrop along White Edge. It is utilised by a minor road leading from Westgate to Rookhope (NG. 35/911413). The Great Limestone influences the landscape most noticeably north of Middlehope Mine, where the burn has cut a deep gorge through the rock, above which the top of the formation makes a broad nearly level shelf.

South of Middlehope Mine, the valley narrows again, and the stream enters the main gorge approximately $\frac{3}{4}$ mile in length. On both banks lower formations are exposed. The 4 fathom limestone, the 3 yard limestone, the 5 yard limestone and the Scar Limestone can be identified each in their turn with intervening sandstones and shales. The eastern valley side is

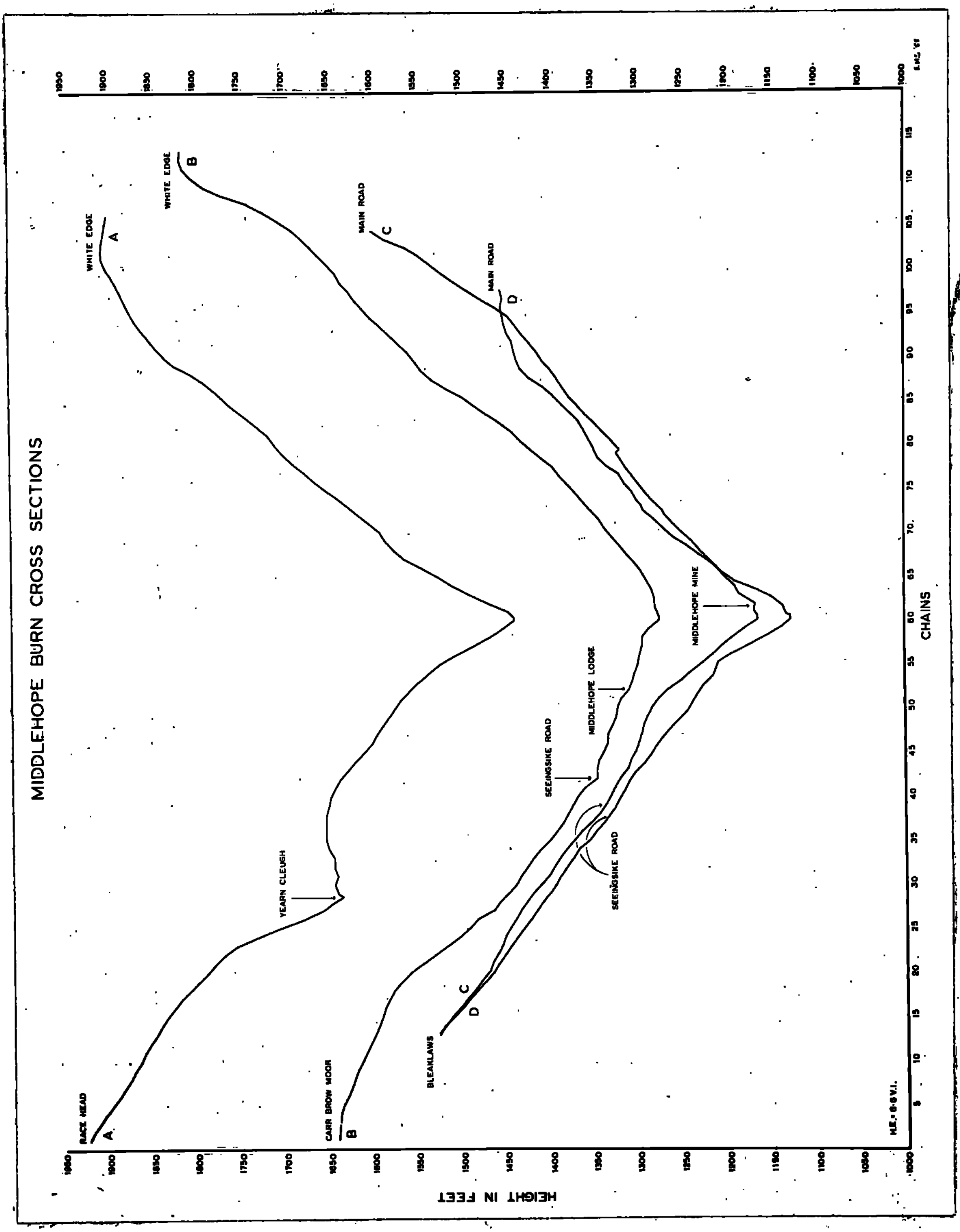
MIDDLEHOPE BURN CROSS SECTIONS
HEIGHT IN FEET
CHAINS
1950
1900
1850
1800
1750
1700
1650
1600
1550
1500
1450
1400
1350
1300
1250
1200
1150
1100
1050
1000
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
A
B
C
D
RACE HEAD
WHITE EDGE
CARR BROW MOOR
WHITE EDGE
BLEAKLAWS
MAIN ROAD
MAIN ROAD
YEARN CLEUGH
SEEINGSIKE ROAD
SEEINGSIKE ROAD
MIDDLEHOPE LODGE
MIDDLEHOPE MINE
H.E. = 6·6 V.I.
G.M.S. '55

Fig. 4

very steep and sometimes vertical with overhanging cliffs. The western flank has a much more gentle slope and only in a few instances near the bed of the stream, or where a right bank tributary such as the Seeing Sike joins the main stream, does the solid rock outcrop (Fig.5). The asymmetrical cross section of the valley in this stretch is largely obliterated by a covering of boulder clay which can be seen in many places where land slips have occurred. South of Slit Dam is found the section of maximum relief. The gorge is here about 100' deep, the east bank cliffs are at their greatest height, the most notable being Robin Hill's Crag and the landslips on the west side are most numerous (Fig.6). In one instance, a large block of the solid rocks including limestones, sandstones and shales, has been tilted out of the general line of dip, and it is supposed that this is the result of a land slip on a large scale possibly along a line of weakness. Unfortunately, it was not practicable to survey a cross section here, but some idea of the form of the valley sides may be obtained from the accompanying photograph. Above the gorge, the land slopes gently upwards with some minor undulations on the west side before rising steeply to the rounded summits.

Masking the solid geological formations over a large area are glacial deposits. They may be considered in two parts. The upper one extends from the confluence of Saugh Cleugh downstream to below Middlehope Lodge where it covers part of the Great Limestone outcrop. This 'boulder clay' varies in character from a fine yellow clay seen on the surface in a sheepfold at 1415' on the left bank, to a coarse material of a more

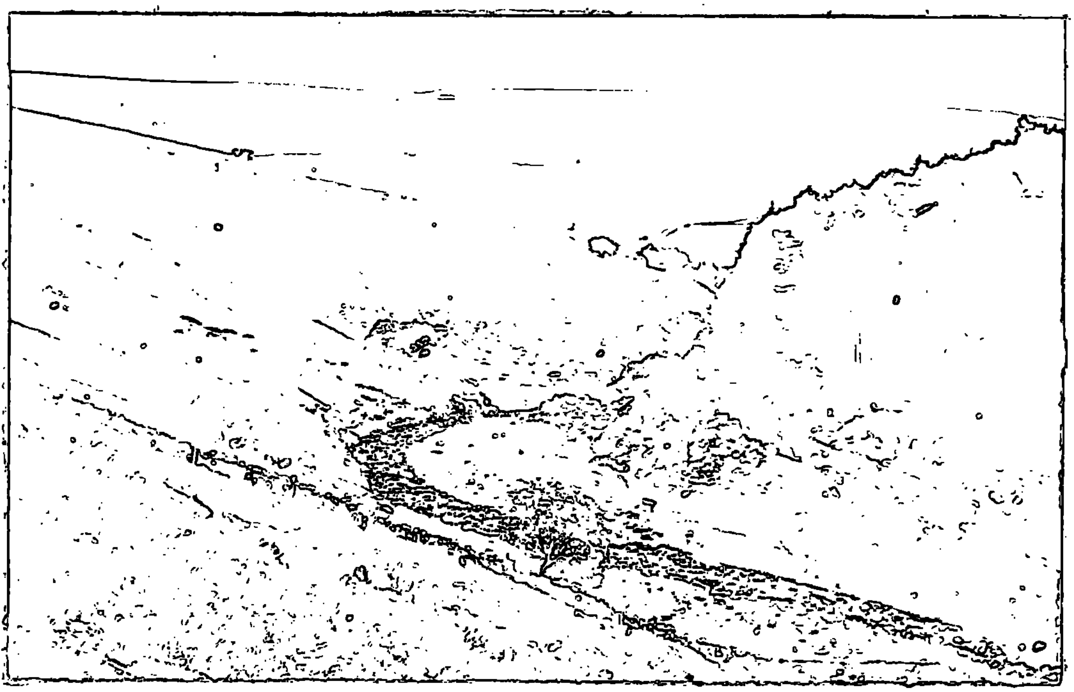

Fig. 5 The valley S. of Middlehope Mine looking N.E.

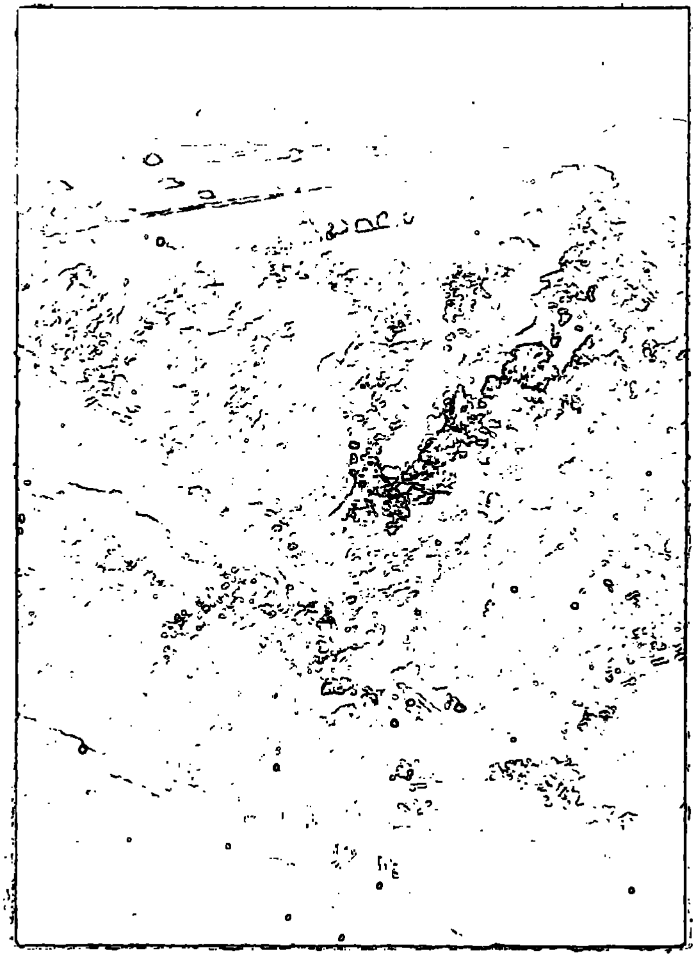

Fig. 6 The Lower Gorge looking N.N.E. Robin Hill's Crag on the E. bank.

sandy nature containing large boulders, found in the exposures along the main stream near the confluence of Yearn Cleugh. The clay at Middlehope Lodge 1315' below the vegetative cover was found to be a pale bluey-grey colour, and of a very fine nature. The second area of "boulder clay" lower downstream lies on the right bank and extends from Middlehope Mine (1160') to Crooked Well (1000'). Along the burn this patch of deposits can be observed below Slit Dam lying on top of the 4 fathom limestone. The deposits are coarse and sandy and contain many boulders of assorted sizes.

In addition to the glacial deposits there are deposits of more recent formation along the middle course of the stream. These are stratified gravels, and coarse and fine sands of the river terrace, and the boulders and gravels of the flood plain. The river terrace is seen clearly both above and below Middlehope Bridge, but it diminishes downstream to the Great Limestone gorge where it cannot be identified and it is not definitely observed again until Crooked Well is reached. In many places, it is difficult to distinguish the terrace with accuracy owing to much disturbance of the land during the prosperous lead mining periods of the nineteenth and early twentieth centuries.

In a general description of the structural features of the Middlehope Burn valley, mention must be made of the many unnatural, man-made features without exception connected with the extensive lead mining operations. Most prominent are the old tip-heaps, the largest group being above the lower gorge opposite Slit Dam. These are composed of mining refuse from the rich Slit vein and are now for the most part grass covered. Smaller heaps are found near all the old workings, and in some places there are old tramway embankments. The main one runs from Peat Hill along to Middlehope Mine, and then round to Slit Dam. Where the old tramway crosses a small tributary valley the height of the embankment is considerable (about 25' across Seeing Sike) and in such instances the stream is led underneath through a culvert. In addition the spoil heaps around old shaft holes form distinctive hillocks. These are most numerous ¾ mile south-east of Middlehope Lodge. The hillocks are bell-shaped with a diameter of the order of ten yards, but very rarely do they contain water. Other man-made irregularities include earth dams, two of which still impound a body of water, and small quarries providing sheer rock faces devoid of vegetation.

Soils

It is difficult to obtain a complete detailed picture of the soil pattern of the drainage basin. There is a wide range in the characteristics of the underlying rocks which form the parent material. Since it is a mountain region, where the presence of the solid geological formations is so widely evident, a large proportion of the soils is composed of boulders, and very coarse material. The depth of the soils is also affected by the varying parent materials.

Several borings have been made to determine the depth in selected parts of the catchment area. The first set of borings was at the south-eastern end of White Edge near Scarsike Head. On top of the Grindstone Sill, the depth varies between 6 and 10 inches, and most of it is a fine, black peaty soil. On the slopes at about 1700' O.D. below the outcrop of the Felltop Limestone, the depth increases to 15 inches. This represents a greater accumulation below the very steep slopes of the edge of the Grindstone Sill, on which the soil formation is very meagre. The second group of borings was on the left bank slopes above Saugh Cleugh, and among the North Grains headwaters. It is noticeable that the depth of soil varies with the degree of slope. This leads to considerations of a very detailed and complex nature outside the scope of the present work, but which would form the basis of further investigations. Depths of 14 and 18 inches occur on the shelf above Saugh Cleugh, and the soil consists of partially developed peat on top of fine light grey silt, the latter causing poorly drained patches. With increasing altitude, there is a greater thickness of peat, for example, at 1825', 34 inches of peat and fine grained clayey soil, and at 1880' near the watershed 6 feet of material mostly peat. These are on the flaggy sandstones of the Grindstone Sill. The light-grey clayey silt may be of glacial origin comparable with the high altitude drift mentioned by Dr. Raistrick in his paper on the "Glaciation of Wensleydale and Swaledale".[1] The maximum depth of peat measured is found on the highest parts of the catchment area on the Millstone Grit formations where 9 feet of peat lie on the surface of the solid rocks. The inter-relationship between peat formation, degree of slope and rainfall offers a further subject of enquiry.

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[1] "The Glaciation of Wensleydale, Swaledale, and adjoining parts of the Pennines". A. Raistrick, Proc.Yorks.Geol.Soc., 1926, vol.20.

In the lower parts of the area along the valley floor the soils are coarse, and their depth varies with the characteristics and extent of the underlying glacial and alluvial deposits. On the whole, it appears that the resistant qualities of the rocks, and limited chemical weathering have prevented the development of deep soil, and their often impervious nature has affected the leached and sometimes waterlogged soil characteristics so widely found.

Vegetation and Land Use

The natural vegetation has developed as a direct result of the various influencing factors, the high exposed locality with its associated climatic features, considerable rainfall and low temperatures, the hard resistant rocks with their predominating sandstones and shales, and the resulting poor soils. The different types of vegetation in the area are described fully by F.J. Lewis in his paper on the "Geographical distribution of vegetation of the Basins of the Rivers Eden, Tees, Wear and Tyne".[1] According to his detailed map, the vegetation of the Middlehope Burn valley is divided into four main types under the general classification of Sub-Alpine Moorland which corresponds with W.H. Pearsall's[2] sub-montane type under 2000' O.D. The first type covering the highest parts of Middlehope Moor is Heather with Cotton Grass. A smaller area with this type is found also south of Scarsike Head on the Grindstone Sill outlier. By far

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[1] "Geographical distribution of Vegetation of the Basins of the Rivers Eden, Tees, Wear and Tyne". F.J. Lewis, Geog.Journ. 1904.

[2] "Mountains and Moorlands". W.H. Pearsall.

the largest area of the drainage basin is classified as Grass Heath: grasses with a general Heath flora, though there are patches of Cotton Grass to be found. The third type covering the lower parts of the catchment area is called Upland Cultivation. This type was meant to include all developed land, but many changes have been made since the area was delimited, and it now includes much rough pasturage which cannot truly be called cultivated. The last type covers the smallest area. It is the woodland bordering the lower course of the stream. The natural deciduous woods have the greatest extent with Silver Birch, Willow, Sycamore and Mountain Ash trees predominating. Underneath these taller trees, the sides of the gorge are covered with thick undergrowth, and smaller trees and bushes are represented by the Thorn, Wild Rose, Sloe and Hazel. Near Middlehope Mine on the left bank, there is a conifer plantation of Scots Pine, Spruce and Fir. This was planted about 50 years ago by the Ecclesiastical Commissioners.

The accompanying Land Use map has been compiled for 1954-55. The rough pasture land representing 95.3% of the drainage area supports sheep all the year round, and cattle during the summer months. Since the 1939-45 war some experimental ploughing and reseeding has been carried out. Approximately 90 acres have been planted with mixed grasses including Italian Rye Grass, Timothy, Rape and Clover. Generally, this is used as improved pasture for cattle grazing but in one instance the crop was cut for hay for winter fodder. 3.0% of the area is meadow land providing the bulk of the hay crop. Permanent Pasture grazed regularly represents

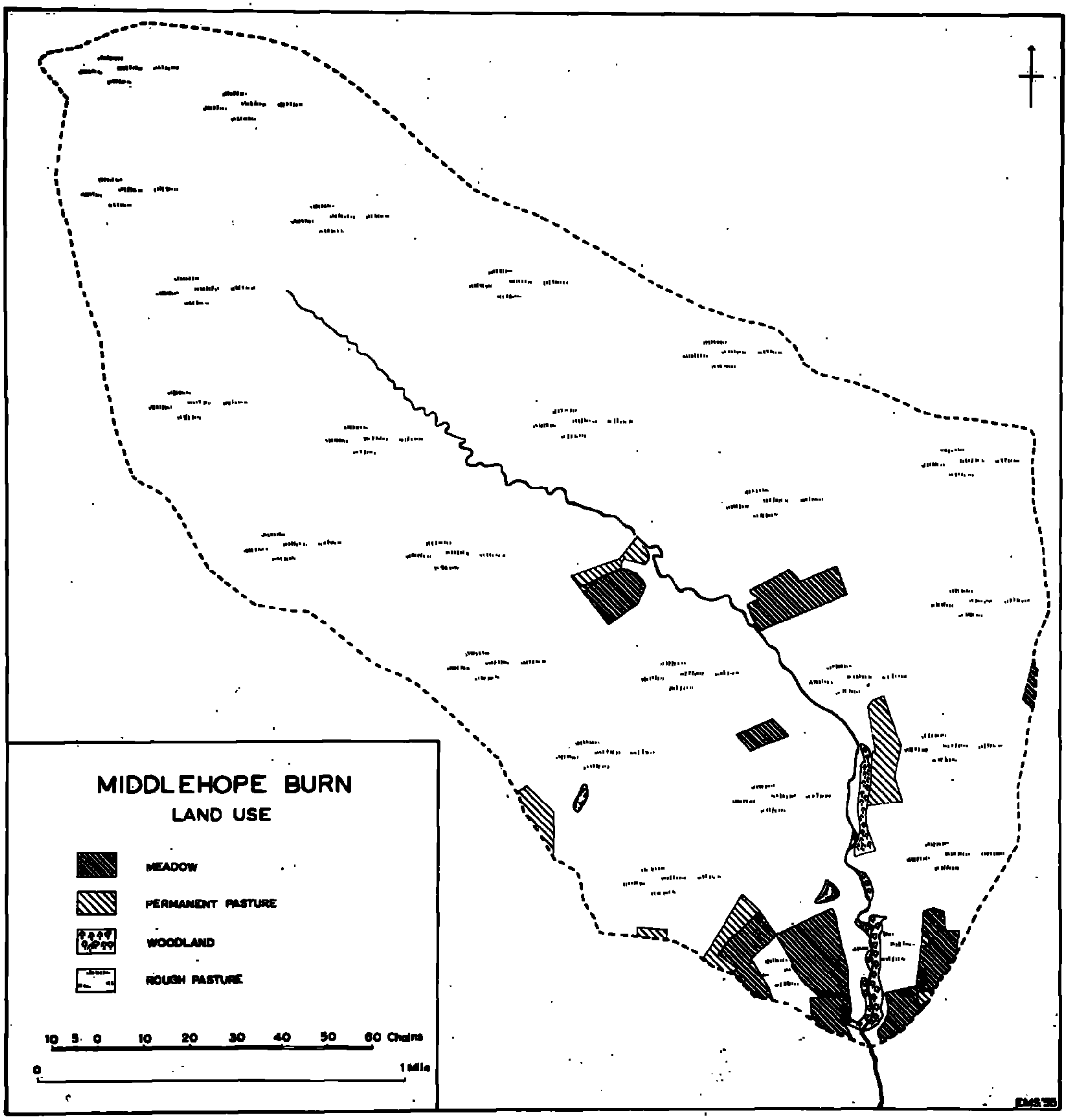
MIDDLEHOPE BURN
LAND USE
MEADOW
PERMANENT PASTURE
WOODLAND
ROUGH PASTURE
10 5 0 10 20 30 40 50 60 Chains
0
1 Mile
EMS '55

Fig. 7

1.1% of the total catchment area and the remaining 0.6% is woodland. The Middlehope Burn valley is thus representative of Upper Weardale as a whole, in that it supports a farming economy based on animal husbandry, where conditions are quite unsuitable for arable crop production.

Drainage Pattern

The headwaters of the Middlehope Burn are numerous small streams rising on the highest parts of the moor. Near the watershed, the courses of the streams are ill-defined, and where there are stagnant pools in the peat, sometimes isolated and sometimes connected by small channels, it is difficult to determine the direction of flow. However two groups of streams, the North Grains and the West Grains, have deeply scoured channels in the peat, and both sets eventually combine together to form streams in well-defined valleys before joining together at Middlehope Burn Head. These headstreams are also joined by water seeping from springs in marshy areas below the Upper Felltop Limestone. Much of the land is permanently waterlogged, and the thick layer of peat forms a vast reservoir constantly feeding the streams. (Even during the exceptionally dry summer of 1955 the lower layers of the peat were still damp, although their contribution to the stream flow was practically negligible.) The right bank tributary Yearn Cleugh rises on the slopes of Black Hill, and it is joined by water carried by drainage ditches on both sides. Some of these ditches were associated with the old lead workings, but others have been cut more recently to improve the pastures. Along the floor of the valley in this upper tract ditches have been dug from the foot of the steep valley sides to the stream bed to prevent small tributaries from taking winding courses across the more level land. These trenches facilitate runoff, but there are still many swampy places between them, and their effect is extremely localised, and on a very small scale.

In the central part of the valley, which is more open, are found the majority of the longer tributaries. Those on the left bank which include Scar Sike, rise about 1700' O.D., and pursue fairly straight courses down to the main stream, except where they suffer diversions by man-made features. The right bank tributaries in this section drain from the level top of Carr Brow Moor. Nearly all of them are affected by old mine workings along some stretch of their courses, but nowhere is the flow restricted. The Middlehope Burn itself pursues a meandering course along the middle tract. From Saugh Cleugh to Middlehope Mine its bed is strewn with large boulders, and only along the straighter reaches, and occasionally where the steepness of the profile is least, is there much fine material to be found. The stream is eroding its bed actively, especially on the convex curves of the meanders, which cut into the old river terraces, and into the boulder clay deposits in many places. The banks, varying from two feet to about six feet high bording the largest meanders, gradually become undermined, and periodically the soil and vegetative cover collapses into the stream. There is corresponding accumulation of material owing to lower velocities, and hence deposition, on the concave banks of the meanders. In one instance, below Middlehope Lodge, the land on the inside bend of a meander is stepped from the present bed of the stream to the flood plain level and up again to the river terrace.

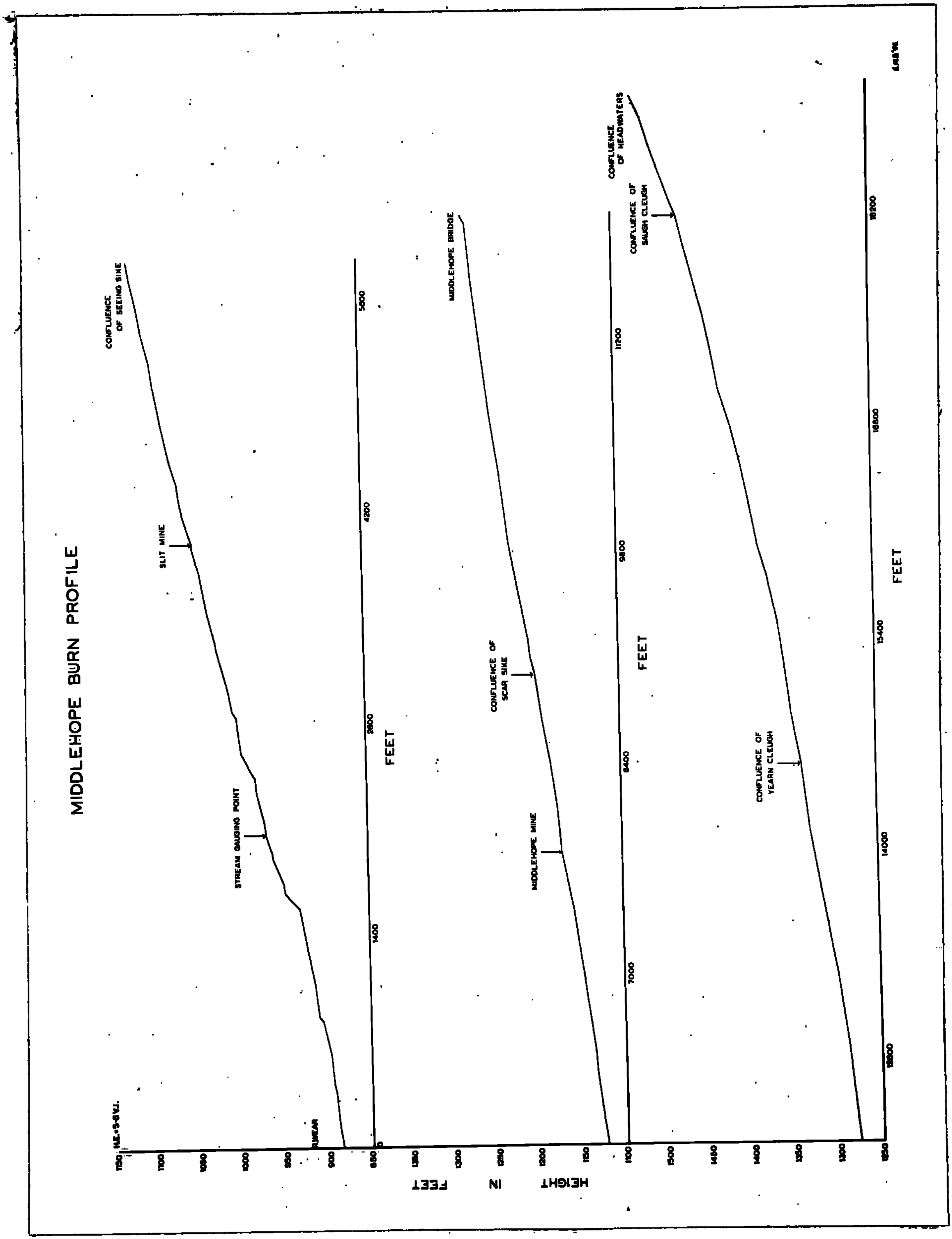
MIDDLEHOPE BURN PROFILE
HEIGHT IN FEET
FEET
CONFLUENCE OF SEEING SIKE
SLIT MINE
STREAM GAUGING POINT
WEAR
MIDDLEHOPE BRIDGE
CONFLUENCE OF SCAR SIKE
MIDDLEHOPE MINE
CONFLUENCE OF HEADWATERS
CONFLUENCE OF SAUGH CLEUGH
CONFLUENCE OF YEARN CLEUGH
1150
1100
1050
1000
950
900
850
1350
1300
1250
1200
1150
1100
1500
1450
1400
1350
1300
1250
0
1400
2800
4200
5600
7000
8400
9800
11200
12600
14000
15400
16800
18200

Fig. 8

The tributaries joining the Middlehope Burn in the main gorge are shorter and more swiftly flowing. On the eastern side of the valley they pour over the edge of the cliffs forming high waterfalls, but on the opposite bank they cut steep-sided V-shaped valleys in the boulder clay cover, and only fall into the main stream from a lesser height, as for example, the Seeing Sike, which has a fall of six feet over the outcrop of the 4 fathom limestone near the confluence. The burn flows swiftly through the gorge, and its bed is composed alternatively of boulders and coarse gravel, and smooth rock ledges. Above the gorge on the right bank are two artificially formed lakes. Bleaklaws Dam, the higher, is drained by an overflow stream which joins the Seeing Sike. The larger, known as Slit Dam, receives very little water from inflowing streams, and has a very small overflow channel; thus it plays a very minor part in the changing volume of the stream. These lakes were formerly dammed up for the lead mining.

Unfortunately for this present investigation, the past commercial activities already mentioned have affected the flow of the Middlehope Burn more seriously. The old entrances to the mines known as levels have also been left as they were when mining was carried out. These levels are now important channels leading from the workings in the Great Limestone formations. An examination of copies of the old maps revealed that they do not extend for very far, but the existence of such conduits may influence seepage through the limestone joints from beyond the determined watershed. It has not been possible to explore these old levels, and therefore the effect of this drainage remains unknown. There are three such water levels flowing into the burn. This continuously flowing water keeps the stream free from ice below their confluences during very cold periods, and also helps to maintain the stream flow during dry spells. The fact that the exit of the right bank level is $\frac{3}{4}$ mile from the watershed, and that the other two from the left bank are flowing against the dip of the strata, partially justifies neglecting their influence in the following consideration of the discharge measurements.

Determination of the Watershed

The watershed was drawn on the 6 inch O.S. map by inspection of stream flow directions, contours and spot heights. The lower parts of the basin below the site of the stream gauge were not considered. This procedure did not seem entirely satisfactory, since drainage ditches running round the hillsides are shown on Carr Brow Moor, and it was decided that a check should be made on the present condition of these artificial features. In consequence, the watershed was redrawn in the field, incorporating amendments due to irregularities among the small streams, and also due to relief features not shown on the 6 inch maps. Great difficulty was found in determining the line of the watershed on the broad expanses of the peat at the head of the valley. It is most likely that the actual watershed is a variable line fluctuating in a sinuous zone across the moor according to the nature of the precipitation. Nevertheless, a line was drawn on the map, and the area of the drainage basin determined planimetrically.

Chapter 2. Precipitation

Site of Gauges

Three sites were chosen for rain gauges in the valley. Their general positions were determined primarily by ease of access, so that there was as short an interval of time as possible between the readings of the first visited and the last. Thus, one gauge was placed in the lowest part of the area in the valley near the stream gauging point, the second at the highest point near the road up the valley, and the third at an intermediate height, approximately in the centre of the catchment area, and also near the road. With favourable conditions, it was found that the observations could be completed in half an hour, but there were occasions when it was not possible to have transport, and then two hours elapsed between the beginning and the completion of the readings. Unfortunately, on several days it was quite impossible to reach the higher gauges owing to severe blizzards. Other criteria considered in placing the gauges were the exposure of the instruments, influencing the actual readings, and the finding of sites where the instruments would not be disturbed. In the latter case, the local land-owners and farmers were consulted.

1) The Westgate gauge. This was a 5" diameter Snowdon pattern zinc gauge, and it was placed on a level patch of ground provided by the river terrace about ¼ mile upstream from the village of Westgate, on the right bank. Here the valley sides rise steeply, and the position is sheltered

from very strong winds. Care was taken to see that the gauge was protected neither by neighbouring trees nor by the valley sides, and a round of angles on to probable obstructions was taken with an Abney level. In all cases, angles of under 30° were recorded, so that it was felt that the site was not overshadowed in any direction. The rain gauge was placed so that the rim was one foot above the ground, and a protective barbed wire enclosure six feet square was erected. The grass in the enclosure was kept cut during the summer months. The height of the rim 982' was determined by precise levelling from a Bench Mark on the old Methodist Chapel in the village under ¼ mile away.

2) The Scarsike Head gauge. This was a 5" diameter, Snowdon pattern copper gauge. The actual site for such an exposed location was very difficult to select. Finally, a level piece of ground, out of sight of the road, was found on the north-western slopes of the col. A certain amount of shelter from strong prevailing westerly winds was afforded by a stone wall aligned approximately N.W. - S.E., and the land rose gently to the north and north-west. The gauge was placed about 30 feet from the wall, and it was also enclosed by a barbed wire fence. Precise levelling from a Bench Mark 200 yards away determined the height of the rim of the gauge, 1792', and this was one foot above ground level.

3) The Middlehope Lodge gauge (Fig. 9.). This was of a similar pattern to the Westgate gauge. Its site was in a permanent pasture field 25 yards due west of the Middlehope Lodge farmstead. It was ascertained carefully that a line of trees to the south did not have any sheltering effect on the site. The gauge was fixed with its rim one foot above the ground, and

Fig. 9 The Middlehope Lodge Rain Gauge

the height of the rim was found to be 1315' O.D. from a Bench Mark on the house. This gauge was also surrounded by a barbed wire fence, and it was noticeable that the grass here and at Scarsike Head did not need to be cut as frequently as at the lower site of Westgate.

Observations

At each station, in addition to measuring the amount of precipitation, the wet and dry bulb temperatures were measured and the wind direction, estimated force and state of the sky were recorded. The rainfall was measured in a graduated glass jar of the "Camden type", and the method adopted was that recommended in the Meteorological Observers' Handbook.[1] When the water in the glass bottle was frozen, or when snow was found in the funnel, a known quantity of hot water was added, and this amount deducted from the total water measured. If there was snow lying, an average depth was obtained from several measurements around the gauge site, for purposes of comparison.

Difficulties were encountered in obtaining a wet bulb temperature reading during the winter months when the air temperature was 32° and below. As this occurred when the ground was snow covered and transport between the stations was not practicable, time could not be afforded to make a satisfactory reading, and these observations were discontinued. The air temperature measurements were continued however with the whirling hygrometer.

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[1] Meteorological Observer' Handbook 1942. H.M.S.O.

The observations were made daily at 0900 hrs. G.M.T., this time, of course, referring to the Westgate gauge. The readings at the Scarsike Head gauge were taken usually between 0920 hrs. and 0940 hrs., and those at Middlehope Lodge between 0930 hrs. and 0950 hrs. During the snowy weather, the time of the last two sets of readings averaged 1 - 1½ hrs. later, but even under exceptional circumstances, if it were at all possible to reach the stations, the observations were always completed before midday.

The daily observations were started on March 27th, 1954, and terminated on May 29th, 1955, from which date weekly records were kept until September 25th, 1955. However, for the purposes of this thesis, it is proposed to consider in detail only the records between April 1st, 1954, and March 31st, 1955.

The Records

A complete list of all the observations made is included in the appendix in table form. The first item of interest is the total precipitation measured at the three stations. The Westgate gauge at 982' recorded 52.64 ins., the Scarsike Head gauge at 1792', 47.29 ins. and the Middlehope Lodge gauge at 1315', 55.61 ins. Only for two months, April and July, relatively dry months, are the totals for Scarsike Head, the highest, and in the autumn months, October, November and December, the amount of rainfall measured at the highest station was much lower than at the other two places. Immediately the question of over exposure is suggested as a possible explanation of this unusual state of affairs. The siting of the gauge has been considered most carefully, and the placing

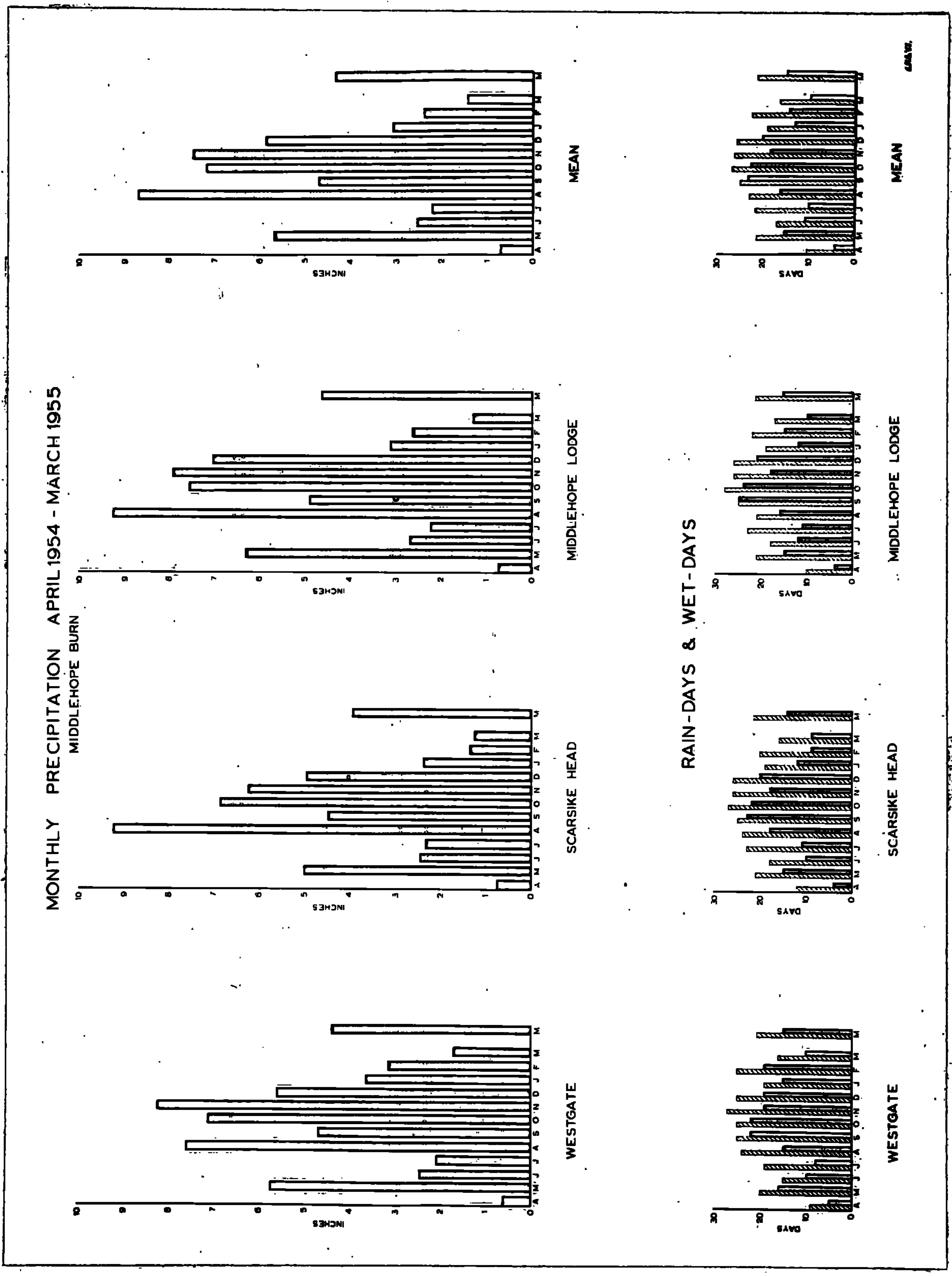
MONTHLY PRECIPITATION APRIL 1954 - MARCH 1955
MIDDLEHOPE BURN
WESTGATE
SCARSIKE HEAD
MIDDLEHOPE LODGE
MEAN
INCHES
0 1 2 3 4 5 6 7 8 9 10
A M J J A S O N D J F M
RAIN-DAYS & WET-DAYS
DAYS
0 10 20 30

Fig. 10

of it on the lea side of the N.W. - S.E. aligned wall was thought to be an adequate protection from the severe westerly winds. However since Scarsike Head is in the form of a col, between the Middlehope and Rookhope valleys, with a wind from the west and south-west, the air is obliged to rise on reaching White Edge, and in this way, the rain is perhaps carried over the col. In such an event, the existence of the wall is just magnifying the upward sweep of the air and rain.

Another explanation may lie in the fact that when overcast conditions with continuous low stratus clouds prevail, the tops of the hills are hidden. It has been noticed that on such occasions the average height of the cloud base is about 1600', so that when continuous rain is falling, it could be suggested that more would be precipitated from the clouds as a whole on stations below the cloud base, than on land within the clouds.

During the periods of snow fall, it was very difficult to obtain satisfactory readings. There was no occasion on which snow fell without strong winds persisting at the time. Fortunately, none of the gauges was ever buried, but the most accurate readings were obtained at the Westgate site. At Scarsike Head, most of the snow drifted against the wall leaving very little on the ground, and in many cases there were bare patches in the large pastures. The records at 1792' for January and February are poor, 26.1% of the January total for the three gauges, and only 18.9% of the February total being measured there. It must be remembered, however, that the gauge was not visited every day, and there may be considerable ablation losses.

An analysis of the rainfall, and wind directions was made for the period April 1954 to March 1955. The falls at the three stations were averaged, and percentages of this daily mean were computed for each place. Only those days which had a daily mean of 0.1 ins. and over were considered. Days on which snow fell were also omitted. Eight points of the compass for wind direction were used, and the proportions of rainfall were listed, according to the wind direction. These were then averaged in the eight columns and the following table resulted.

Mean percentages of the daily averages.

	N	NE	E	SE	S	SW	W	NW
WESTGATE	99.9	92.4	108.6	103.0	112.7	101.0	86.6	90.7
SCARSIKE HEAD	85.0	105.1	85.7	96.2	89.8	93.1	95.6	101.1
MIDDLEHOPE LODGE	115.0	102.5	105.5	100.8	96.9	105.9	117.8	109.9
No. OF DAYS	6	12	2	7	10	30	17	28

Scarsike Head has the greatest rainfall when the wind is from the north-east, and it has over a third of the total measured fall, when a north-westerly wind is blowing. The results at Westgate are quite in accordance with what might be expected since the valley where the gauge is situated is open to the direction of its dominant rainbearing winds. It is also remarkable that Middlehope Lodge in the open central part of the valley receives over one third of the total rainfall seven times out of the eight. From this, it can be seen that the direction of the rainbearing winds has a marked effect on the amounts over 0.1 ins. measured at each station. Thus it remains a matter for conjecture whether or not more rain would have been 'caught' at Scarsike Head if the gauge had been placed away from the 'sheltering' wall.

A similar problem in the siting of a rain gauge has been considered in the moorland area of West Yorkshire. In this case, a gauge site near the crest of a ridge at 1450' was moved to a position just below 1400' to the leeward side of the ridge in a little valley sheltered from the wind. The two gauges were read for comparison purposes and it was found that the over-exposed gauge on the ridge showed an average deficit of 23% from the newly installed protected gauge over the five months June to October 1954.[1] It seems probable therefore that a similar re-siting of the Scarsike Head gauge would have produced a more satisfactory series of observations.

Further investigation into the precipitation records was carried out on the correlation of the three stations using only the falls when the mean was 0.1 ins. and over. Reitz's[2] method was adopted to find the correlation coefficients from the formula

$$r = \frac{\frac{1}{n}\sum XY - \bar{X}\bar{Y}}{6x\,6y}$$

where n is the number of days, $\bar{X}$ and $\bar{Y}$ are the arithmetic means of the two sets of observations X and Y, and 6x and 6y are the standard deviations. (A sample of the method used for the calculations is to be found in the appendix.) The following results were obtained:-

A. Westgate and Scarsike Head $r = 0.83 \pm 0.03$

B. Scarsike Head and Middlehope Lodge $r = 0.90 \pm 0.02$

C. Westgate and Middlehope Lodge $r = 0.87 \pm 0.02$

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[1] The Assessment of Rainfall & Evaporation. A.Bleasdale. Journ.Instit. Water Eng. 1955, vol.9 no.6.

[2] "Rainfall & Runoff". E.E. Foster. Macmillan.

The three coefficients are all of the same order of magnitude, which should be expected when the three stations are all within the same climatic régime. There is no significant irregularity in the correlation of Scarsike Head and the other two stations, in fact, the highest coefficient is that of the relationship between Scarsike Head and Middlehope Lodge, when the difference between the two annual totals is 8.32 ins.

The numbers of rain days, i.e. days on which 0.01 or more inches of precipitation are measured, has a range of 8 between the highest and lowest. Westgate records 249, Scarsike Head 257 and Middlehope Lodge 256 rain days. Here, Scarsike Head has the greatest total, but as might be expected from the comparative amounts of precipitation measured, the number of wet days (days with 0.04 ins. and over) is considerably fewer. Scarsike Head has 171 wet days compared with Westgate 180 and Middlehope Lodge 183. The major differences occur during the snowy months, in particular February, (Westgate 19 wet days, Scarsike Head 9, Middlehope Lodge 15), showing the decreased reliability of the observations, for although values were obtained proportionately for the days when the higher gauges were missed, the accumulation of several days was much lower than the totals for a similar number of days at Westgate. There could have been considerable loss of snow out of the gauge funnel by wind removal or evaporation, after the snow fell and before the reading was made. A more detailed comparison of the rain days and wet days for the individual months may be obtained from the diagram of Monthly Precipitation April 1954 - March 1955.

From the number of rain days per month and the monthly precipitation records may be calculated the rainfall intensity. This is obtained from the formula $I = \frac{P}{R}$ where P is the precipitation and R the number of of rain days. Thus the intensity for each month is the average rate of precipitation. In considering rainfall and runoff, the study of rainfall intensity is important for the prediction of floods. For this purpose, the intensities are usually obtained for a shorter interval of time and are expressed in inches per hour units. Recording raingauges are necessary to obtain these detailed intensities, and therefore such measurements have not been taken in the Middlehope Burn valley. However, the more generalised rainfall intensities calculated for the three stations serve to demonstrate their comparative wetness. It is notable that the figure for Scarsike Head in August much exceeds that for Westgate (0.38 compared with 0.32). This is due mainly to the very heavy falls which occurred over the higher land during an exceptionally wet month, during which the highest daily total during the year's observations, 1.72 ins., was recorded at Scarsike Head on August 21st. During the week ending August 21st, 6.81 ins. of rain fell at Scarsike Head and 6.85 ins. at Middlehope Lodge. These readings give a rainfall intensity of nearly 1 inch per day, which is a high figure to be sustained for so many days. The weather conditions at the beginning of this very wet spell are depicted in the extracts from the Daily Weather Report. A complex low pressure area moved east-north-eastwards across the British Isles deepening as it progressed towards the North Sea area. On August 19th it reached the North Sea and became slower moving, becoming stationary on August 20th, before turning to move south-westwards towards the English channel. During this time, unstable air conditions persisted over N.E. England, giving the heavy falls of rain.(Fig. 11 + 12.)

The rainfall intensity for November is highest at Westgate, for November is the wettest month at this station. There are a number of heavy falls among the 27 rain days, although the highest fall here was 1.61 ins. on August 17th at the beginning of the atmospheric developments described above.

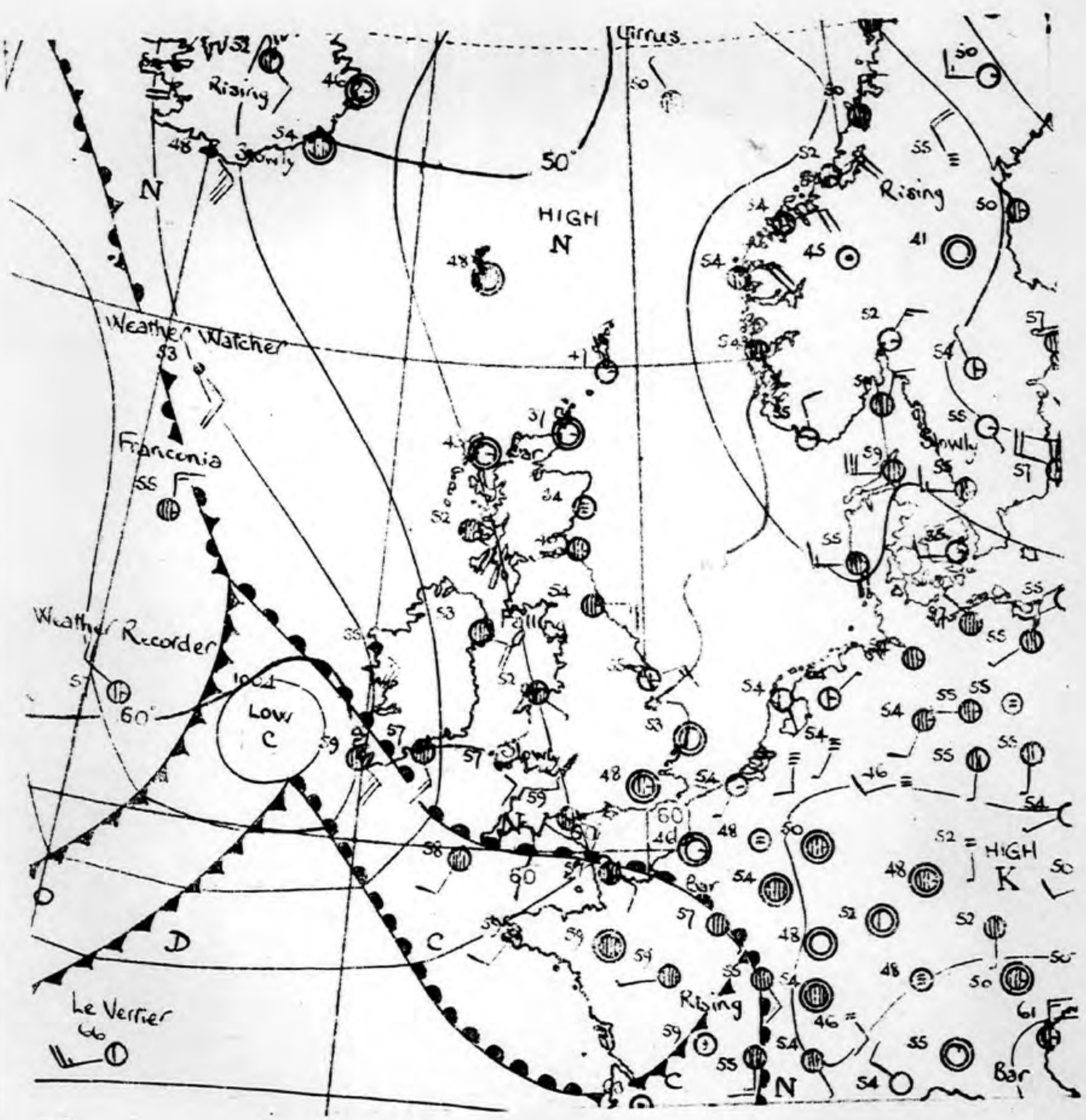
The table of rainfall intensity also illustrates the irregularity between the stations during the cold months. The figures for Middlehope Lodge are however quite comparable with those of Westgate even though the gauge was not visited with the same promptness, which suggests that the lower readings at Scarsike Head may not be due to the shortcomings in the compilation of the record.

Rainfall Intensity. Inches per day.

	Westgate	Scarsike Head	Middlehope Lodge
April 1954	0.07	0.06	0.07
May	0.29	0.24	0.30
June	0.16	0.14	0.15
July	0.11	0.10	0.10
August	0.32	0.38	0.44
September	0.19	0.18	0.20
October	0.28	0.25	0.27
November	0.31	0.24	0.30
December	0.22	0.19	0.27
January 1955	0.20	0.13	0.16
February	0.13	0.07	0.12
March	0.11	0.08	0.08

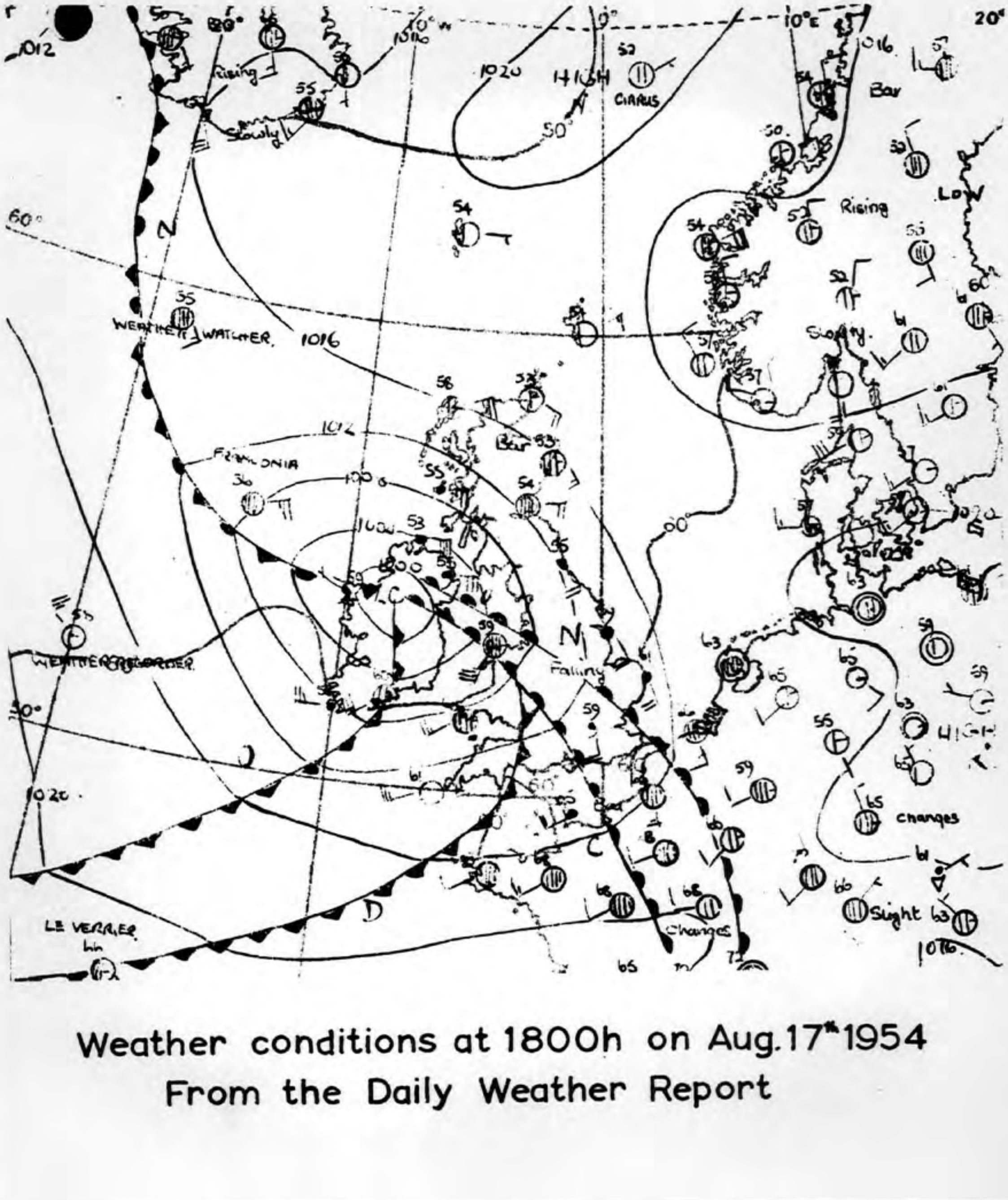
Mean Rainfall

It is necessary to determine the mean rainfall over the catchment



Weather conditions at 0600h on Aug.17th 1954
From the Daily Weather Report

Fig. 11



Weather conditions at 1800h on Aug.17th 1954
From the Daily Weather Report

Fig. 12

area for a hydrological analysis. This figure may be obtained in three ways:-

1) By taking the straightforward averages of the precipitation measurements;

2) By computing a mean by the Thiessen Method[1]. This takes into account the area of the catchment, which is subdivided by the perpendicular bisectors of the distances between the sites of each rain gauge. Thus a proportionate area is allotted to each gauge, and the mean precipitation is multiplied by this factor, thus giving what is known as an area-weighted mean;

3) By drawing isohyetal maps of the area for each period of time to be considered, and obtaining the rainfall over the area by planimetric measuring of the areas enclosed by each isohyet, and then summing the product of the proportionate areas and the values of the corresponding isohyets.

The first two methods have been used in calculating the average precipitation of the Middlehope Burn drainage area, and the monthly and annual values are shown in the table below.

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[1] "Elements of Applied Hydrology". D. Johnstone & W.P. Cross. Ronald.

	Method 1. Mean of 3 gauges				Method 2. Thiessen Method			
					Area Weights			
					0.148	0.142	0.710	
	W	S.H.	M.L.	MEAN	W	S.H.	M.L.	MEAN
APR 1954	0.61	0.75	0.73	0.697	0.090	0.107	0.518	0.715
MAY	5.75	5.01	6.29	5.683	0.851	0.711	4.466	6.028
JUNE	2.47	2.46	2.70	2.543	0.366	0.349	1.917	2.632
JULY	2.08	2.33	2.23	2.213	0.308	0.331	1.583	2.222
AUG	7.59	9.22	9.24	8.683	1.123	1.309	6.561	8.993
SEPT	4.69	4.48	4.89	4.687	0.694	0.636	3.472	4.802
OCT	7.12	6.85	7.55	7.173	1.054	0.973	5.360	7.387
NOV	8.25	6.23	7.92	7.467	1.221	0.885	5.623	7.729
DEC	5.59	4.97	7.02	5.860	0.827	0.706	4.984	6.517
JAN 1955	3.65	2.39	3.11	3.050	0.540	0.340	2.208	3.088
FEB	3.14	1.35	2.64	2.377	0.465	0.192	1.874	2.531
MAR	1.70	1.25	1.29	1.413	0.252	0.177	0.916	1.345
YEAR	52.64	47.29	55.61	51.85	7.790	6.715	39.482	53.987

It will be observed that the values given by Method 2 - the Thiessen method - are greater than those obtained by Method 1. This is due to the relative position of the rain gauge stations within the drainage basin. In the area-weight method, Middlehope Lodge has by far the largest factor 0.710, i.e. this gauge is taken to represent 71% of the total area, and in half the months it has the maximum rainfall. Using these values of the mean precipitation may be justified by considering the nature of this large area. Most of the land within the Middlehope Lodge section is above the height of the gauge, and indeed, it includes the greater part of the high enclosing moorland, and the whole of the upper part of the valley where it is expected that the rainfall will be greater. Scarsike Head, on the other hand, has the lowest proportion of the drainage basin, only 14.2%, and therefore this station, where some doubt on the reliability of the measurements has already been indicated, plays a smaller part in the evaluation of the mean by this method than it does in Method 1.

The values obtained by both methods will be used in comparing rainfall and runoff in a later chapter.

Chapter 3. Stream Flow

The stream gauging site was chosen along the accessible lower reaches of the burn. Two fundamental conditions needed to be fulfilled. Firstly, there should be a fall in the bed of the stream to form a control of the flow, above which a quiet pool with even flow and a relatively smooth water surface is found. Secondly, the enclosing banks and the bed of the stream should be as regular as possible, and not liable to undue erosion in the event of flood flows. A place was found where it appeared that these conditions prevailed (Fig.13). Above a series of waterfalls, the greatest height of which is 9 feet, there is a bed of limestone about 12 inches thick which dips upstream. This forms a small waterfall, and above the crest the ponded back pool deepens gradually. The jointed limestone provides a relatively smooth boulder-free stream bed. The left bank is a six feet high stone wall built against the path, and the right bank rises three feet above the bed of the stream. A hollow scaffolding pole was painted, graduated to 0.05 feet, and fixed against the wall on the left bank in the pool, with its base resting on the limestone floor (Fig.14). The datum of the gauge was determined by precise levelling from a bench mark to be 967.2 feet O.D.

Observations

The stage height was read daily at 0900 hrs. G.M.T. and the observations began on March 27th, 1954, continuing until September 25th, 1955. Additional readings were taken after severe storms whenever possible. The first reading was 0.45 feet, an average height. The measurements could

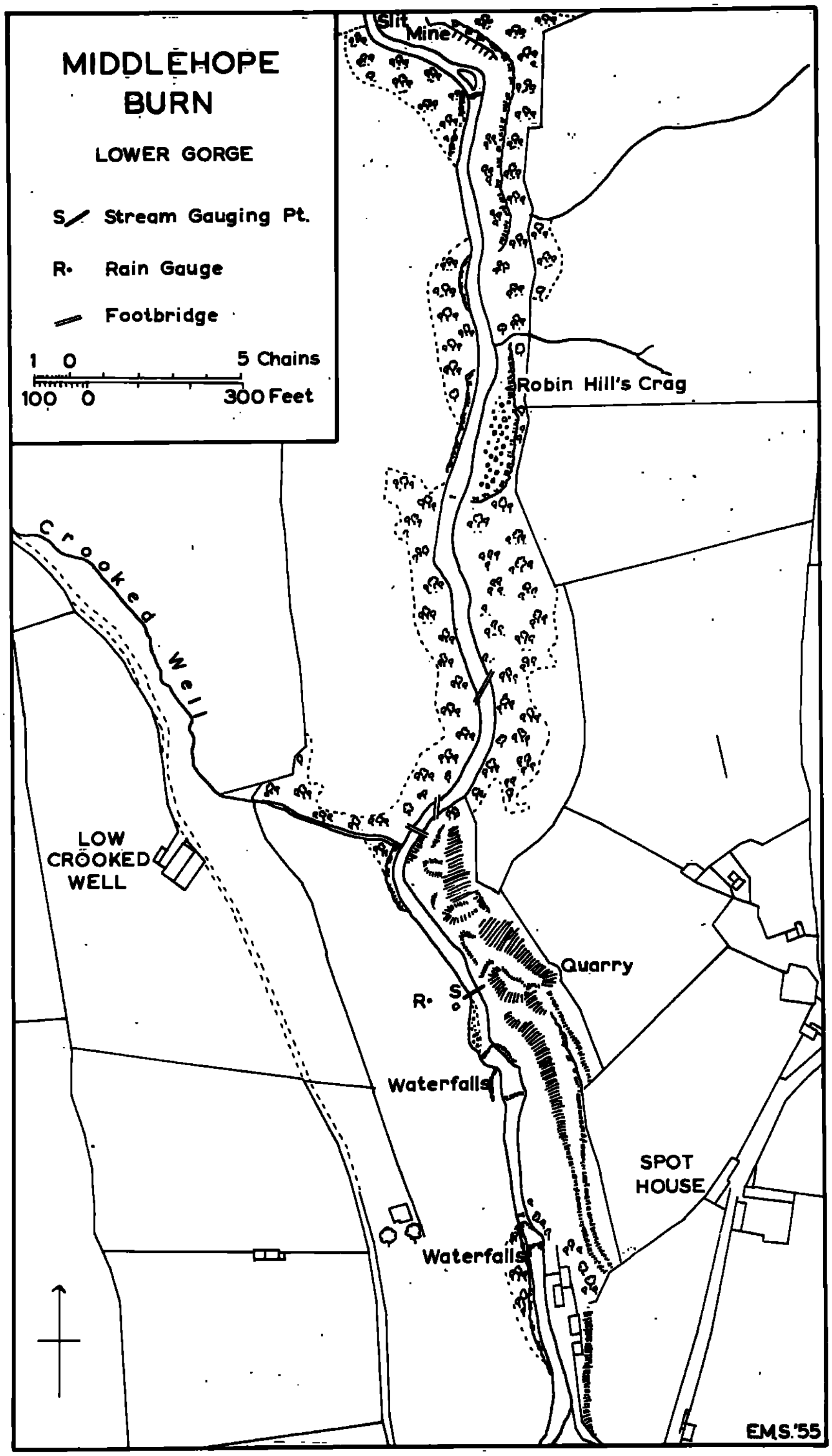
MIDDLEHOPE BURN
LOWER GORGE
S Stream Gauging Pt.
R· Rain Gauge
Footbridge
1 0 5 Chains
100 0 300 Feet
Slit
Mine
Robin Hill's Crag
Crooked Well
LOW CROOKED WELL
Quarry
R·
S
Waterfalls
SPOT HOUSE
Waterfalls
EMS.'55

Fig. 13

Fig. 14 The Middlehope Burn Stage Gauge

be made to 0.01 feet by careful estimation up to about 1.00 feet, but above that height, the velocity of the stream was too great to permit approaching the gauge post, and the surging of the water did not allow an accurate reading to be made. In these instances, a mean was taken between the highest and lowest readings over a period of a minute or two. The maximum stage reading was 2.30 feet on January 10th, 1955. This flood flow was caused by sudden amelioration of the weather accompanied by heavy rainfall, (1.49 ins. in about 13 hrs. at Middlehope Lodge), on top of melting snow. The lowest reading on the stream gauge was 0.33, which occurred on several days in July and August, 1954. Such a reading represents an extremely low flow, and it is doubtful whether there could be a lower measurement under present conditions owing to the water draining from the old mining levels, mentioned previously.

On three days in January, the stream was found to be frozen over when the site was visited at 0900 hrs. The readings were made after breaking the ice round the gauge post, but these did not bear any relation to the previous measurements. It was discovered finally that the control of the waterfall had been modified by the piling up of ice, and it was not until this was cleared that valid readings were obtained. Since no appreciable precipitation had been recorded, estimated values were entered in the records.

Discharge Measurements

In order to relate the continuous series of stage measurements to the precipitation, it is necessary to convert the stage readings into amounts of discharge, i.e. quantities of water flowing past the gauging point, at the times of observation. The method adopted for this purpose utilises the basic formula $Q = A.V.$ where Q is the discharge in cubic feet per second, A is the cross sectional area at the gauging point in square feet and V is the average velocity of the stream in feet per second. Many modifications of this fundamental hydraulic formula have been devised, usually attempts to simplify and perfect the determination of the velocity under widely different conditions found in natural streams.

In this investigation, the velocity was obtained by direct measurement with a current meter. Since the Middlehope Burn is a small stream, and consequently the depths at the gauging point are small, it was felt that the velocity measurements would be most satisfactory with a U.S. Geological Survey cup-type pygmy current meter. Unfortunately, these instruments were unobtainable in this country at the time of requirement, and a standard size small Price-type current meter was acquired instead. The instrument was fitted with batteries and headphones so that it could be operated single-handed, and a stop watch was used to time a fixed number of revolutions. The rod which carries the current meter was graduated in feet to 0.05 feet, to facilitate the measurement of the water depths.

The velocity readings were taken across the stream between the stage gauge and the crest of the waterfall control. At this point, the stream is 20 feet wide, and a Chesterman tape stretched taut from the wall to the right bank defined the gauging line, and could be fixed in the same position during each series of measurements. The stage reading was taken at the beginning and end of each set of observations, and if they differed, the mean was calculated to relate to the discharge obtained. The velocity of the stream was measured at intervals of one foot except near each bank where readings were made at 0.5 feet and 19.5 feet, i.e. six inches from the left and right banks respectively. The procedure at each point in the stream was as follows:- 1) The distance from the bank was recorded; 2) The depth of water was noted from the current meter rod; 3) According to the state of the stream, a fixed number of revolutions was timed; 4) The same number of revolutions was timed again. If there was any major discrepancy between the two times, a third reading was made. The velocity measurements were taken at 21 points across the stream, and the whole operation lasted about an hour.

Owing to the extreme delicacy of the measurements and to the accuracy required, it will be seen that ideal weather conditions were necessary at the time of observation. It was found that the weather must be nearly calm, since quite soft winds, especially those aligned downstream, affected the velocity measurements, and of course strong winds were detrimental to the manipulation of the instruments and other equipment. Even with perfect conditions, other factors added to the difficulties. The velocities were measured at 0.6 of the depth, the point at which the average velocity occurs in the vertical. When the stream was low, the top of the cups of the current meter were above the water surface near the left bank of the stream, even when the current meter was at its minimum height position on the rod. To check the results on these occasions, several series of readings were made in deeper water about 20 feet upstream. The velocities were amended experimentally by applying correction coefficients supplied by C.H. Pierce in his paper on "The Performance of Current Meters in

Water of shallow depth",[1] but the resulting difference in the final discharge total was too small to justify amendments to the other series of measurements in view of other practical errors. When the stream was high, current meter measurements of velocity were impossible, and thus discharge figures corresponding to stage heights within the very small range of 0.33 to 0.90 only, have been obtained. On one occasion, the interval between the measurements had to be increased suddenly from one foot to two feet in mid-stream as the stream rose quickly.

During the period of the investigations, 15 series of velocity measurements were made, the resultant discharges varying from 0.466 cusecs at 0.36 feet to 45.979 cusecs at 0.90 feet. It is regretted that further modifications of the method in order to obtain further readings, especially some at stages above 0.90 feet were not possible. A complete set of the observations and details of the calculation of the discharges from the velocities and cross sectional areas are to be found in the appendix.

The stage-discharge curve

In order to obtain discharge figures for every value of the stage measured, it is necessary to draw a curve of the stage-discharge relationship. Plotted directly, with the discharges in cusecs along the x-axis, the curve is convex resembling a parabola in its lower portion, and smoothing out with increasing discharges. When plotted logarithmically,

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[1] "Performance of Current Meters in water of shallow depth". C.H. Pierce. U.S. Water Supply paper 868.A 1941

a stage-discharge curve is a straight line, and this can be extended beyond the range of measured discharges to give discharges at lower or higher stages. Many difficulties were encountered in using this method especially in attempting to align the curve through the fixed measured points, and also a long extension in the upper stages was required to reach the maximum stage of 2.30 feet. When the curve was drawn, the maximum discharge deduced was over 1,000 cusecs, and all the values of the resulting rating table seemed wildly exaggerated. This fact was demonstrated also when monthly runoff figures were calculated, since they were far in excess of the rainfall totals. Even after neglecting several of the suspect discharge measurements at the low stages, there was little improvement.

After considering several methods, it was decided finally to improve upon the straight logarithmic plot by determining the equation of the required curve following the method demonstrated by C.O. Wisler and E.F. Brater in "Hydrology".[1] The cross section of the stream at the gauging point is reasonably uniform, and therefore the following relationship pertains:-

$Q = C\,(G - a)^n$ where Q is the discharge in cusecs, G is the gauge height in feet, 'a' is the gauge height corresponding to zero discharge, and C & n are constants. In the logarithmic form this becomes:-

$$\log Q = n \log (G - a) + \log C.$$

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[1] "Hydrology". C.O. Wisler and E.F. Brater. John Wiley, 1951.

Before the constants can be evaluated to obtain a direct relationship between Q and G, the value of 'a' must be determined. This is done graphically, and it is assumed that the lower part of the simple discharge curve is a parabola. Three discharge values in geometric series are selected, in this instance $7\frac{1}{2}$, 15 and 30 cusecs. These are within the range of the fairly reliable measurements. At these points on the curve, vertical and horizontal lines are drawn, and a line through their points of intersection is produced to meet a straight line through the points $7\frac{1}{2}$ and 15 on the curve. The point of intersection of the two produced lines represents the stage value of zero discharge on the stage axis. The construction is shown clearly on the accompanying diagram. (Fig. 15)

The zero flow gauge height was found to be 0.33 feet. A discharge measurement was made at this level, and under considerable difficulty and with the disadvantage of extremely low velocities, when the accuracy of the current meter measurements may be doubtful, a value of 0.787 cusecs. was obtained. Thus it does not appear unreasonable to accept the value of 0.33 feet as the stage of the imaginary zero discharge. Substituting 0.33 feet for 'a', the equation becomes:-

$$\log Q = n \log (G - 0.33) + \log C.$$

Putting $Q = 7.5$, then $G = 0.5$

$$\log 7.5 = n \log (0.5 - 0.33) + \log C$$

$$0.87506 = - n. 0.76955 + \log C \qquad \text{eq. (1)}$$

Putting $Q = 30$, then $G = 0.77$

$$\log 30 = n \log (0.77 - 0.33) + \log C$$

$$1.47712 = - n.\ 0.35655 + \log C \qquad \text{eq. (2)}$$
$$0.87506 = - n.\ 0.76955 + \log C \qquad \text{eq. (1)}$$

Eq.(2)-eq.(1) $0.60206 = 0.413n$

$$n = \frac{0.60206}{0.413}$$

$$n = 1.458$$

From eq.(2) $\log C = 1.47712 + 1.458 \times 0.35655$

$$= 1.47712 + 0.5198$$

$$= 1.99692$$

$$\therefore C = 99.3$$

Therefore, the equation of the logarithmic stage-discharge curve for the gauging point on Middlehope Burn is:-

$$\log Q = 1.458 \log (G - 0.33) + \log 99.3.$$

Five points were calculated for plotting the straight line, and these are given in the table below.

G	G-a	log(G-a)	log Q
0.5	0.17	1.23045	0.87492
0.7	0.37	1.56820	1.36736
0.9	0.57	1.75587	1.64098
1.0	0.67	1.82607	1.74333
1.5	1.17	0.06819	2.09634

The curve is illustrated in the accompanying diagram.(Fig.16)

The Rating Table

From the stage-discharge curve, it was possible to obtain values of the discharge for any of the measured stages. To facilitate the

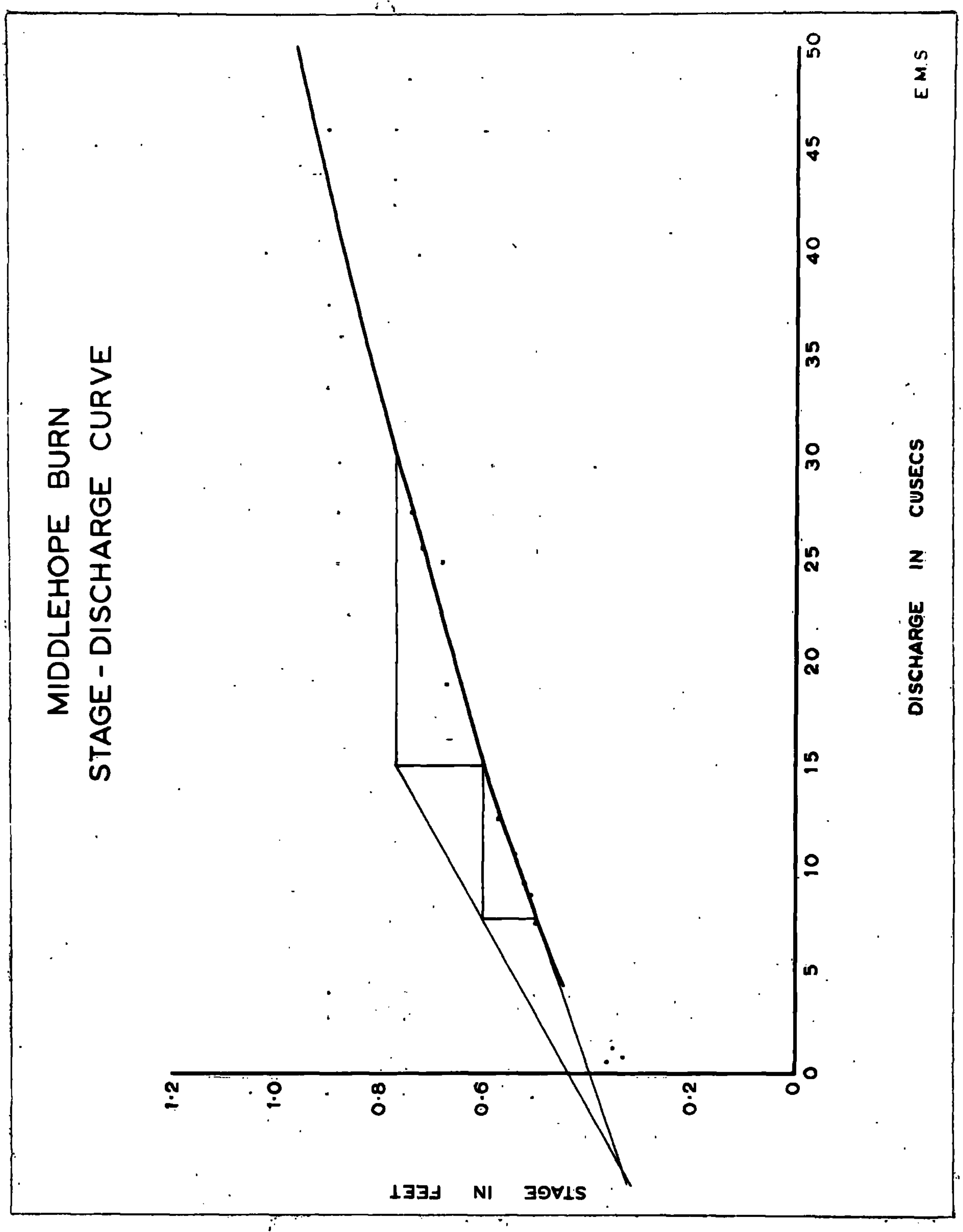
MIDDLEHOPE BURN
STAGE - DISCHARGE CURVE
STAGE IN FEET
1·2
1·0
0·8
0·6
0·2
0
0
5
10
15
20
25
30
35
40
45
50
DISCHARGE IN CUSECS
E M S

Fig. 15

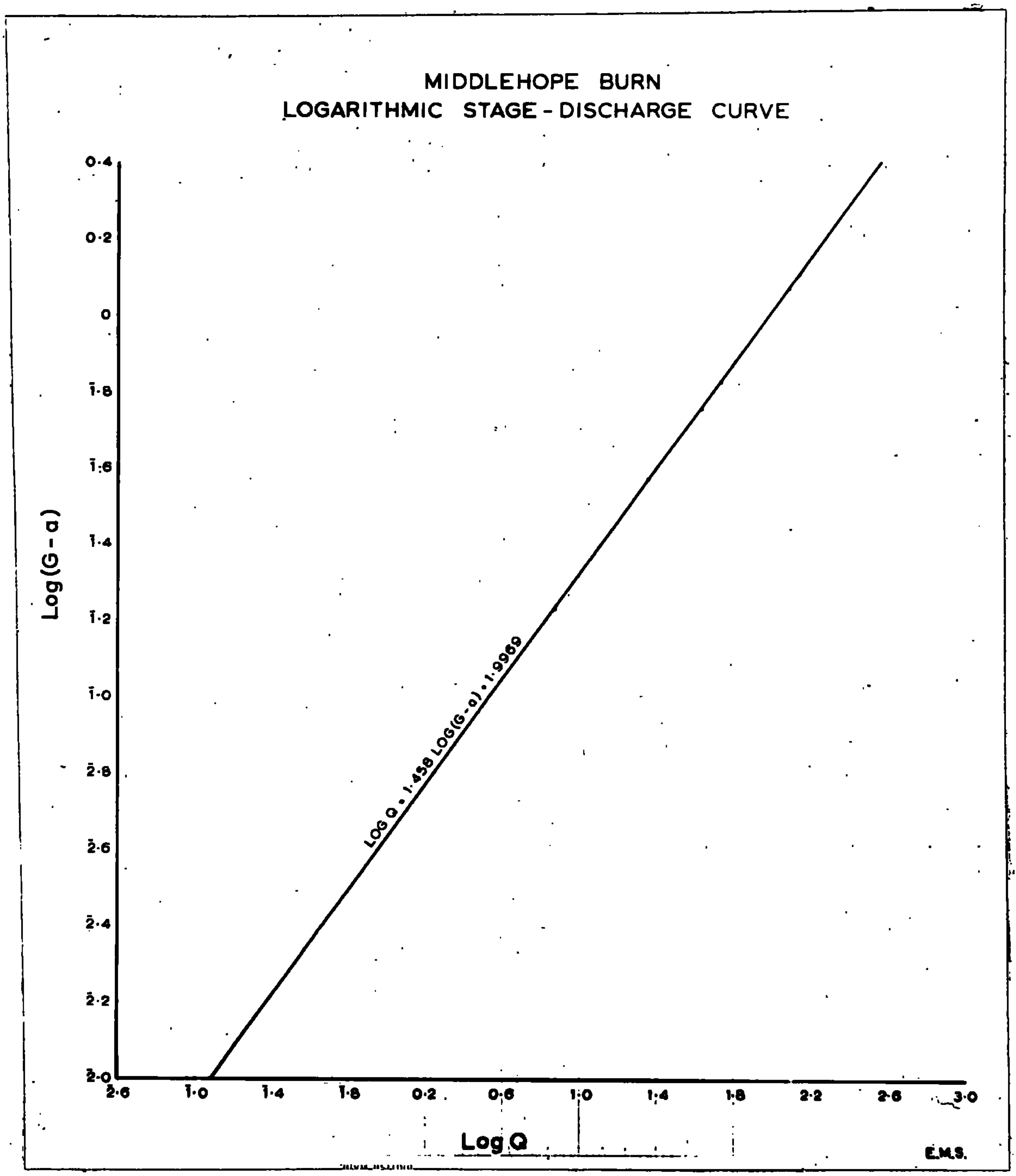
MIDDLEHOPE BURN
LOGARITHMIC STAGE - DISCHARGE CURVE
Log (G - a)
0·4
0·2
0
$\bar{1}$·8
$\bar{1}$·6
$\bar{1}$·4
$\bar{1}$·2
$\bar{1}$·0
$\bar{2}$·8
$\bar{2}$·6
$\bar{2}$·4
$\bar{2}$·2
$\bar{2}$·0
$\bar{2}$·6
$\bar{1}$·0
$\bar{1}$·4
$\bar{1}$·8
0·2
0·6
1·0
1·4
1·8
2·2
2·6
3·0
Log Q
LOG Q = 1·458 LOG(G-a) + 1·9969
E.M.S.

Fig. 16

later computations, a rating table was prepared, and this is included in the text in its simplest form. G is the stage in feet and Q the corresponding discharge in cusecs. The complete table showing the determination of each value, is to be found in the appendix.

The Rating Table

G	Q	G	Q	G	Q	G	Q	G	Q	G	Q
0.33		0.51	8.13	0.69	22.34	0.87	40.18	1.05	61.38	1.25	88.11
0.34	0.12	0.52	8.81	0.70	23.28	0.88	41.40	1.06	62.66		
0.35	0.33	0.53	9.46	0.71	24.15	0.89	42.66	1.07	63.97	1.35	102.57
0.36	0.59	0.54	10.12	0.72	25.12	0.90	43.75	1.08	65.16		
0.37	0.91	0.55	10.84	0.73	26.12	0.91	44.87	1.09	66.53	1.40	109.65
0.38	1.26	0.56	11.61	0.74	27.10	0.92	46.03	1.10	67.92		
0.39	1.64	0.57	12.33	0.75	27.86	0.93	47.10	1.11	69.02	1.43	114.02
0.40	2.04	0.58	13.18	0.76	28.91	0.94	48.08	1.12	70.63	1.44	115.61
0.41	2.49	0.59	13.90	0.77	30.76	0.95	49.32	1.13	71.95		
0.42	2.95	0.60	14.65	0.78	30.97	0.96	50.47	1.14	72.95	1.60	140.60
0.43	3.44	0.61	15.49	0.79	32.06	0.97	51.76	1.15	74.47		
0.44	3.96	0.62	16.29	0.80	32.89	0.98	53.09			1.63	145.55
0.45	4.49	0.63	17.10	0.81	34.04	0.99	54.20	1.18	78.16		
0.46	5.05	0.64	17.91	0.82	34.99	1.00	55.34	1.19	79.62	1.80	173.78
0.47	5.64	0.65	18.75	0.83	36.14	1.01	56.62	1.20	81.28		
0.48	6.24	0.66	19.72	0.84	37.24	1.02	57.81	1.21	82.41	2.30	264.85
0.49	6.84	0.67	20.51	0.85	38.28	1.03	59.02	1.22	83.56		
0.50	7.50	0.68	21.43	0.86	39.17	1.04	60.26	1.23	85.11		

Runoff

The final procedure in the study of the Middlehope Burn flow is the calculation of the runoff from the catchment area in a specified time using the daily stage measurements and the corresponding discharge determinations. The unit of time chosen was the month, since the daily frequency of the rainfall and stage readings did not justify the consideration of a shorter period. In each month, beginning with April 1954, the discharges in cusecs for all the stage readings were taken from the rating table. The mean discharge for each day was computed by taking the average of two successive readings, and this was allotted to the day of the first reading. Consequently, at the end of a month, the average discharge of the last day was taken as the mean of the reading on the last day and the reading on the first day of the next month. The total of the mean discharges for the month gave a figure for the discharge, in cusec-days, of the drainage basin. (A cusec-day is 1 cusec flowing for 1 day.) Tables showing the calculation of the monthly discharges are to be found in the appendix.

In order to have the runoff values in a form convenient for comparison with the precipitation, the monthly discharge totals must be converted into inches of runoff. For example: in April, 1954, the total discharge was 39.80 cusecs. The area of the drainage basin is 4.126 square miles or 2640 acres.

Since 1 cusec. flowing for 24 hrs. = 0.03719 ins. of runoff on 1 sq.mile[1]
∴ 39.80 cusecs. " " " = 0.03719 x 39.80 ins. " "
$$= \frac{0.03719 \times 39.80}{4.126} \text{ ins. " " } 4.126 \text{ sq.miles}$$
= 0.36 ins. of runoff.

The other monthly figures were treated in a similar way, and the following values resulted.

	1954 April	May	June	July	Aug.	Sept.
Discharge in cusec-days	39.80	341.86	52.26	29.18	587.26	257.47
Runoff in inches	0.36	3.08	0.47	0.26	5.29	2.32

	Oct.	Nov.	Dec.	1955 Jan.	Feb.	March
Discharge in cusec-days	821.99	531.58	601.57	521.62	164.91	186.86
Runoff in inches	7.41	4.79	5.42	4.70	1.49	1.68

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[1] "Surface Water Year Book of Great Britain 1937-45". H.M.S.O. 1952.

The annual runoff value was determined from the monthly discharge totals. The sum for the twelve months was 4,136.36 cusec-days, and therefore the runoff was 37.28 ins. over the catchment area.

This set of values of the runoff of Middlehope Burn for the period April, 1954, to March, 1955 appear to have reasonable proportions. With due regard to the shortcomings of the methods by which they have been determined, to which attention has been brought at all controversial points in the procedure, the figures are presented as being fairly representative of the natural conditions prevailing at the place in question, and for the period considered.

Part II The Burnhope Burn

Chapter 1. General description.

The Burnhope Burn is one of the two main headwaters of the River Wear. It rises near the extreme western boundary of Durham County, of which the highest point is Burnhope Seat 2452 ft. O.D., at the head of the valley. From this high moorland area (most of the watershed is over 2000 ft.), the stream flows in a general easterly direction to join the Killhope Burn at Wearhead. The asymmetrical valley slopes, steep on the northern side and much more gentle on the southern, are dissected by many small tributary streams. These are more numerous on the right bank, and their courses are not so incised as those of the main feeders, the Scraith Burn and Salley Grain. NG 35/8138.

No detailed field work was attempted in this valley, but from the 1" and 6" Geological Survey maps, it is apparent that its structure resembles that of the Middlehope Burn. The major difference lies in the fact that the rocks are lower in the Carboniferous sequence, which might be expected from the more westerly location. Thus the Millstone Grit is not found in the Burnhope drainage basin, and in the lower parts of the valley, older strata such as the Tyne Bottom limestone occur in the Carboniferous Limestone Series. Otherwise all the same formations are represented in succession along the valley sides. The continuity of the outcrops is disturbed by numerous faults running usually in a N.E. to S.W. direction, and more seriously near the dam of the reservoir by a disturbance associated with the Burtree Ford Dyke. Mineral veins once worked for lead, e.g. at Scraith Head Mine and Lodgegill Mine, are found in the south-west part of the basin.

There is another geological difference distinguishing the Burnhope valley from that of the Middlehope. Boulder clay covers a very wide area of Burnhope, perhaps as much as two thirds of the drainage basin. Most of it is found on the southern, or right bank, and very notably, it extends up Salley Grain and Scraith Burn to 2000 ft. On the southern slopes, it is found at Lodgegill at 1980 ft. and at 1750 ft. near Grassmeres, but on the northern side 1600 ft. is the maximum height, and only 1500 ft. near the reservoir.

The Burnhope valley as a whole is wide and open and its height varies from 1200 ft. to over 2400 ft., i.e. a range in the relief of over 1200 ft., compared with about 900 ft. in the Middlehope Burn valley. A comparison in the areal extent of the two valleys can be seen in the accompanying maps (Fig. 1 & 20). The greater part of the area is open moorland, and only near the reservoir are there enclosed meadows and permanent pastures. A comparatively small section on the northern side has been planted with coniferous trees by the Durham County Water Board to assist in regulating the runoff. It is expected that further parcels of land will be similarly planted in the future.

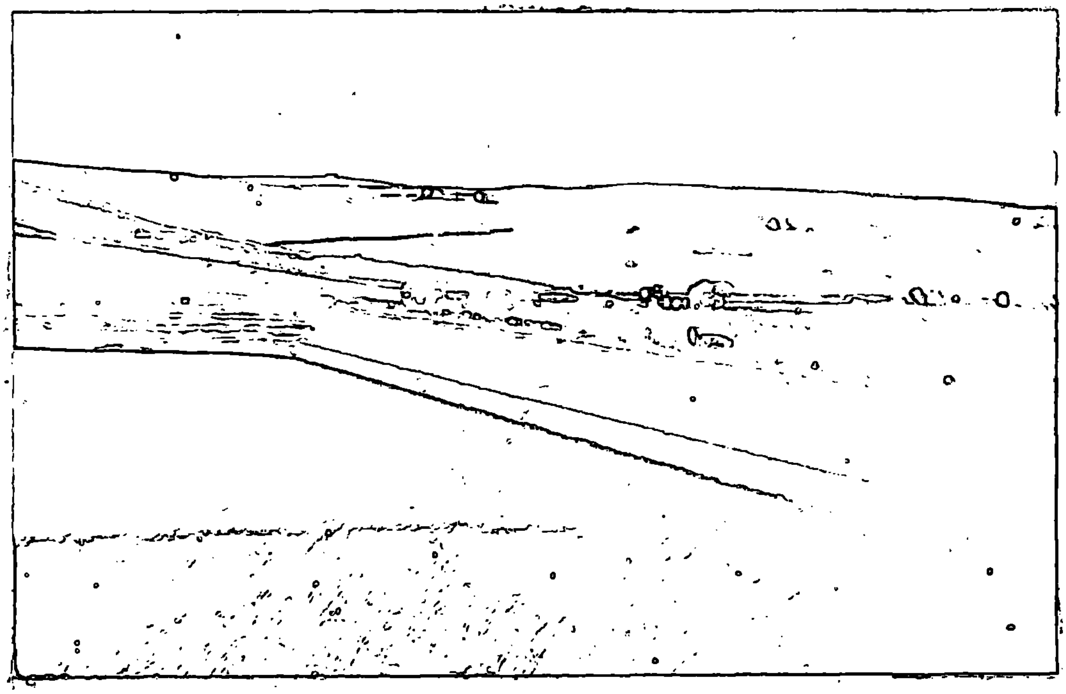

Fig.17. Burnhope Reservoir and the head of Weardale.

Chapter 2. Precipitation.

The rain gauges in the Burnhope Burn valley were set up by the Weardale and Consett Water company in 1902. There are two high sites where readings are made monthly, at Lodgegill Mine 1950 ft. and Grassmeres 1850 ft. on the right bank, i.e. on the southern slopes of the valley. The daily gauge at Burnhope was noted originally to be at 1200 ft., but in 1930 its height changes to 1160 ft. in the records. The site of the gauge was moved presumably when construction of the reservoir was begun, but this does not detract from the value of such a long continuous series of rainfall measurements in nearly the same location. The Burnhope gauge is now on the left bank of the stream below the reservoir dam. The three gauges are maintained by the Durham County Water Board, and the observations are made by their Water Bailiff at the reservoir.

The observations at Lodgegill Mine, Grassmeres and Burnhope are complete from the beginning of 1903 up to the present time. On occasions when it was impossible to visit the high gauges at the end of the month during particularly snowy winters, or when a gauge had not registered correctly probably because of the need for replacements, an estimated value was supplied by the British Rainfall Organisation or the Meteorological Office, and this figure has been incorporated in the series of observations.

Annual Precipitation

The fifty years continuous record of daily rainfall observations at Burnhope is of great value, and the effects of the small change of location can be neglected. For an upland region such a long series of records is rarely found, and it provides significant evidence of precipitation fluctuations. Unfortunately, it is not advisable to study the statistics for the higher gauges in detail, owing to their unreliability during the winter months. This is apparent at once, on examining the totals for the year 1917. Burnhope registers 55.66 ins., i.e. 105% of the record mean, whereas at Lodgegill Mine, 73.30 ins. and Grassmeres 73.75 ins. are well above their respective means, and indeed these "falls" could be included among those of the wettest years. Such an anomaly is very unlikely with regard to stations less than 3 miles apart. The irregularity, thus demonstrated, diminishes the confidence which might be placed in the whole series of measurements of the two monthly gauges. Suffice it to say that the means for the 50 yrs. are 63.47 ins. at Lodgegill Mine and 59.71 ins. at Grassmeres, and it is suspected that these are both too high. The wettest year is 1903, and Grassmeres at 1850 ft. O.D. is claimed to have had 93.20 ins. during that year, with 78.26 ins. at Burnhope for comparison.

It is considered that much more confidence can be placed in the measurements of the daily gauge, where snowfall, the form of precipitation which gives most difficulty, is dealt with at shorter intervals, and therefore with greater accuracy. Therefore, any mention of the record hereafter, refers to the series of daily observations made with an 8-inch diameter gauge at Burnhope. The mean of the 50 yrs. readings is 53.22 ins., and the standard deviation ± 7.30 ins. The new standard mean for the years 1916-1950 is 53.32 ins., and since the difference between the two is only 0.10 ins. and the new standard mean has not as yet been generally adopted, all calculations and inferences are based on the average for the whole period (1903-1952). 78.26 inches in 1903 is the greatest annual total, and the driest year is 1933 with 40.75 inches (77%). This gives a range of 70% of the record mean. It is interesting to note that 1903 stands out as a particularly wet year in the Wrexham District[1] where it has the highest total in a 63 years record from 1880 onwards. In the Central Pennines at Malham Tarn 1297 ft. O.D., 1923 is the wettest year with 78.22 inches (136% of the old standard mean 1881-1915) but only 45 miles to the north in a similar environment, Burnhope has an average year with 53.48 ins. It is also noteworthy that the value of 77% of the average for the driest year is unusually high; values below 70% are commonly instanced elsewhere in long term records.

There are 26 years above the average 53.22 ins. and 24 years below. This distribution, like many others elsewhere, is slightly skew, but not sufficiently to demand discussion, for a large proportion of the totals, 43 out of 50, are within a departure of 20% of the mean. Of the remaining, extreme values, three are wet years and four dry years. It is often useful to consider the precipitation of periods greater

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[1] "The Rainfall of the Wrexham District", S.E. Ashmore. Q.J.R.Met.S.1944.

than a year especially in connection with water-supply requirements, and hence the following table has been prepared.

PERIODS OF DRY AND WET YEARS

No. of YEARS	PERIOD	Average fall in ins.	% of Mean	No. of YEARS	PERIOD	Average fall in ins.	% of Mean
1	1933	40.75	77	1	1903	78.26	147
2	1904-05	42.81	80	2	1916-17	63.80	120
3	1940-42	44.51	84	3	1916-18	60.69	114
4	1940-43	46.55	87	4	1925-28	57.98	109
5	1904-08	47.40	89	5	1947-51	57.15	107
10	1937-46	50.28	94	10	1909-18	55.07	103

One very important point emerges from an inspection of this table. Although the wettest year has a much larger departure from the mean than the driest year, 47% as against 23%, and then for the sequence of two years the departures are equal, after that, the departures of the percentages of the driest 3, 4, 5 and 10 years gradually become greater than those for the corresponding sequences of wet years. Thus for the decade, the departure of the dry years is 6% of the mean, while the departure is 3% for the wet years. This has greater significance when inches of rainfall and hence quantities of water are considered.

An analysis of dry and wet periods leads naturally to a study of the outstanding periods in relationship to each other, or otherwise, to the determination of rainfall fluctuations and trends. The first method adopted was by accumulative deviations, shown in the accompanying diagram (Fig. 18). It is rather unfortunate that the first year was so outstandingly wet, since it causes the initial point to have an

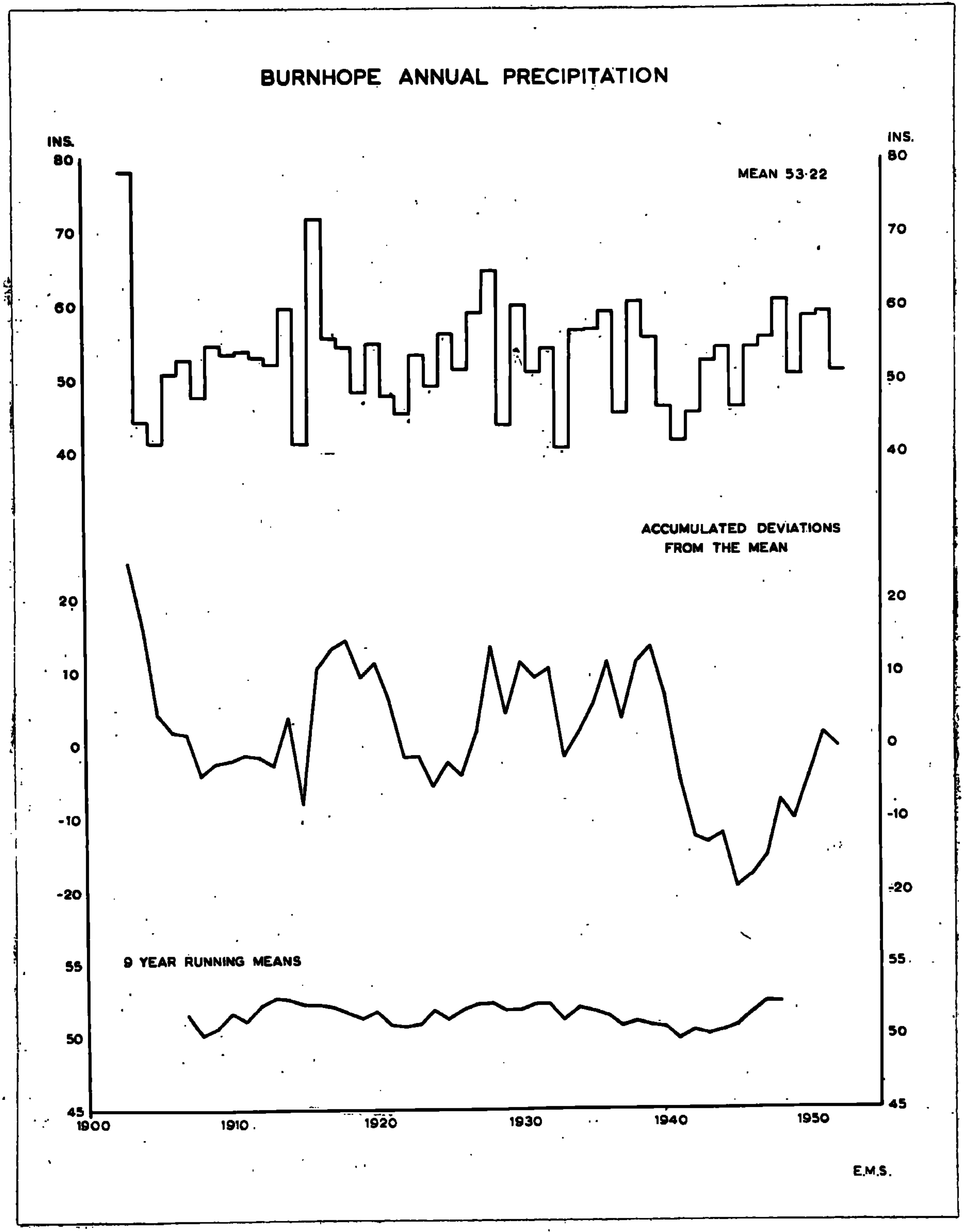
BURNHOPE ANNUAL PRECIPITATION
INS.
80
70
60
50
40
MEAN 53·22
ACCUMULATED DEVIATIONS FROM THE MEAN
20
10
0
-10
-20
9 YEAR RUNNING MEANS
55
50
45
1900
1910
1920
1930
1940
1950
E.M.S.

Fig. 18

unusual departure from the mean. However, it does help to emphasise the dry period immediately following, which is comparable to the dry spell about 1940. The blocks of wet years are easily identified by the persistent rising of the curve, e.g. after 1945. The residual mass diagram first drawn by A.A. Barnes [1,2], produces a very similar curve when applied to the Burnhope record, and adds little to the impressions of fluctuations given by the diagram of accumulative deviations. It is noteworthy that no indications of symmetry over the years are given by the curve for the period 1903-1950, as found by Barnes and Ashmore; though of course, their studies did not cover the same period and took into account earlier years. Nevertheless, no obvious agreement exists between those parts of the curves which do overlap. A simpler and perhaps more realistic picture of the trends is given by a series of running means. The diagram illustrates a curve of 9 years running means plotted centrally. These values are unrelated to the overall average for the period, and do not appear to exaggerate the effects of extreme years such as that (1903) with which the series begins. The rise in precipitation over the later years is represented in a truer relationship to the rest of the period, since the peak centred on 1947 and 1948 has a comparable value to that centred on 1913 and 1914, a fact shown in the table of periods of wet

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1 "Rainfall in England: the true long-average as deduced from symmetry", A.A. Barnes. Q.J.R.Met.S. 1919.

2 "Rainfall reviewed: A common long-average period for each country of the British Isles", A.A. Barnes. Q.J.R.Met.S. 1932.

years but not apparent on the diagram of accumulative deviations. As a further point of interest, the figures for a straight trend line were computed by the method of least squares.[1] (The computations are to be found in the appendix.) The results, for T = 0, P = 53.39, and for T = 50, P = 53.04, show a very slight downward trend over the 50 yrs., so that with the addition of but one or two years with rainfall above the average, the slope of the line could be reversed. It does not therefore appear justifiable to claim that any significant overall trend really exists, based on the period studied.

Monthly Precipitation

The important features of the record of monthly observations are summarised in the accompanying diagram (Fig. 19) and a corresponding table is to be found in the appendix. The absolute maximum fall recorded in a month totals 13.72 ins. in January 1948, and the absolute minimum, 0.19 ins. in June 1925. These extreme values are indicative of the relative wetness and dryness of the months, for considering the monthly means, January is the wettest month with 6.18 ins. and June the driest with 2.78 ins. The absolute maximum and absolute minimum values do not represent the greatest deviations from the means of their respective months. In April 1947, a total of 10.95 ins. is 301% of the mean for that month (3.64 ins.) whereas the maximum in January 1948 is only 222% of the January mean (6.18 ins.). The month of July has the

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[1] "Rainfall and Runoff", E.E. Foster 1949. p.144.

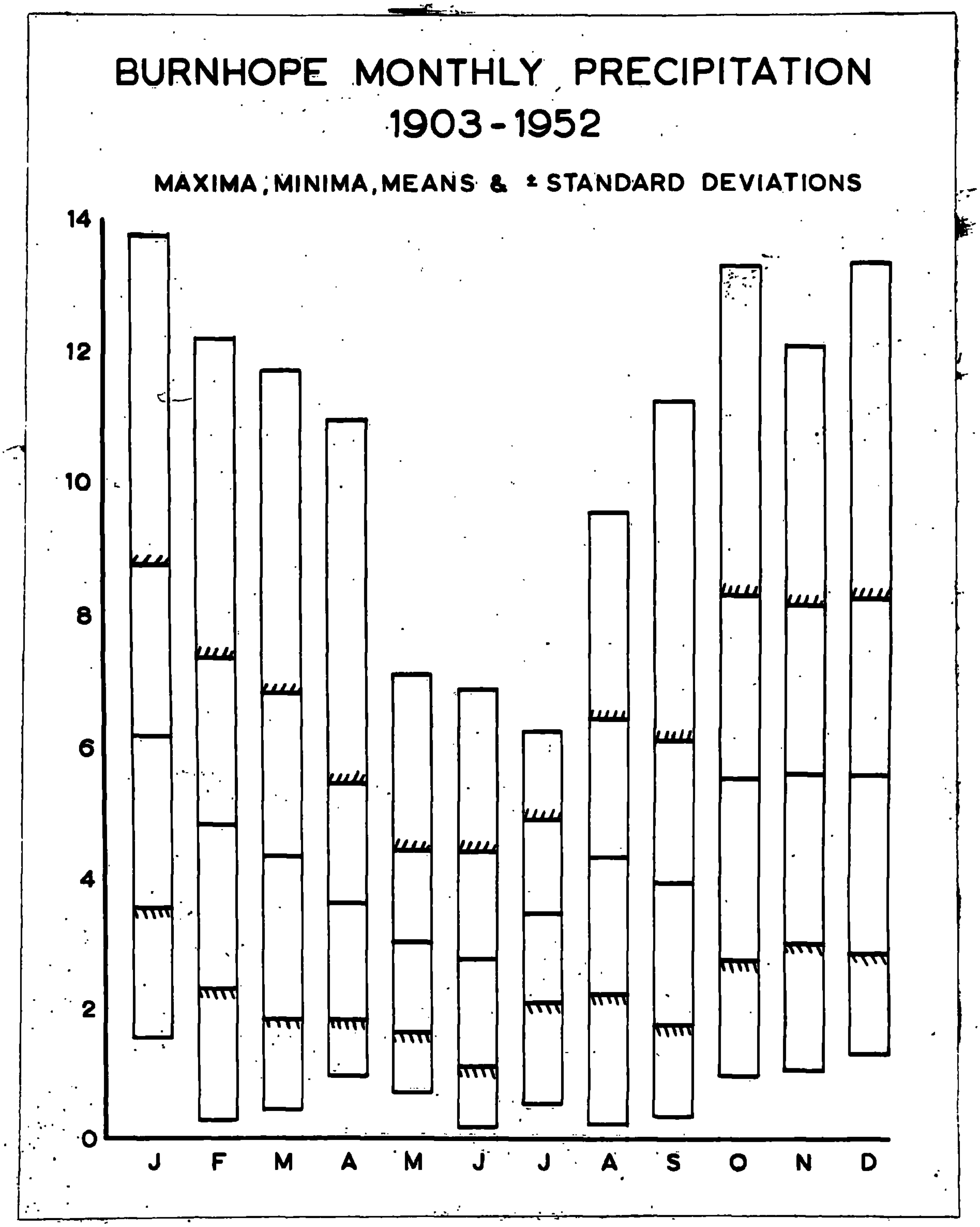
BURNHOPE MONTHLY PRECIPITATION
1903 - 1952
MAXIMA, MINIMA, MEANS & ± STANDARD DEVIATIONS
14
12
10
8
6
4
2
0
J
F
M
A
M
J
J
A
S
O
N
D

Fig. 19

lowest positive deviation from the mean, (179% in 1930) among the maximum values. Among the minimum monthly totals, 0.21 ins. in August 1947 is 5% of the average for the month. The next in extreme dryness is February 1921 with 0.29 ins., 6% of the mean, while the absolute minimum fall 0.19 ins. in June 1925 is 7% of the June mean. The lowest negative deviation from the monthly normal occurs in January 1929 (1.57 ins. i.e. 25%). To summarise the variability of the monthly precipitation figures for the period 1903-1952, the deviation from the monthly means (100%) ranges from 201% (April 1947) to 95% (August 1947).

Some idea of the effectiveness of the individual monthly falls within the years is given in the following table, which shows the frequencies of the wettest and driest months.

NO. OF YEARS EACH MONTH WAS DRIEST OR WETTEST

	FREQUENCY			FREQUENCY	
MONTH	DRIEST	WETTEST	MONTH	DRIEST	WETTEST
Jan.	-	11	July	3	-
Feb.	4	4	Aug.	3	3
Mar.	5	3	Sept.	4	1
April	5	1	Oct.	3	9
May	7	1	Nov.	3	6
June	11	-	Dec.	3	11

1946 APRIL & OCTOBER EQUAL DRIEST.

Within the 50 years of the record, there is the expected pattern of the winter months being most often the wettest, and the summer months most often the driest in the year. The table also reflects the values of the mean monthly precipitation, for in addition to the outstanding significance of the January and June frequencies the four driest and one wettest months for September corroborate the secondary minimum in the autumn. July stands out as a most insignificant month, and it seems remarkable that it has never been the wettest month of the year during the period.

Sequences of months with abnormal rainfall amounts are shown in the following table of driest and wettest periods of consecutive months.

DRIEST AND WETTEST PERIODS OF CONSECUTIVE MONTHS

No. of months	PERIOD	TOTAL FALL IN INCHES	% OF MEAN ANNUAL	No. of months	PERIOD	TOTAL FALL IN INCHES	% OF MEAN ANNUAL
1	June 1925	0.19	0.36	1	Jan. 1948	13.72	25.78
2	Feb-Mar.'29	1.36	2.56	2	Nov.-Dec.1914	23.39	43.94
3	Jan-Mar.'29	2.93	5.51	3	Jan.-Mar.1903	32.10	60.32
4	Jan-Apr.'29	4.64	8.72	4	Oct.'38-Jan.'39	37.32	70.12
5	Jan-May '29	7.10	13.34	5	Oct.'38-Feb.'39	42.81	80.44
6	Jan-June'29	8.90	16.72	6	Oct.'38-Mar.'39	48.61	91.34
7	Dec'28-June'29	12.32	23.15	7	Oct.'38-Apr.'39	52.26	98.20
8	Dec'28-July'29	16.53	31.06	8	Sept.'38-Apr.'39	54.35	102.12
9	Dec'28-Aug.'29	20.26	38.07	9	Feb.'03-Oct.'03	61.17	114.94
10	Dec'28-Sept.'29	21.91	41.17	10	Jan.-Oct. 1903	70.03	131.59

This table does not demonstrate the same characteristics of variability as those shown in the comparable table for annual precipitation. The fall for the driest month June 1925 represents 4.3% of the mean monthly precipitation (4.43 ins.) while the wettest month January 1948 with 13.72 ins. has the much greater departure with 310% of the monthly mean. However, at the lower end of the table where a number of consecutive months is considered, the wettest period continues to have the greater departure from the mean. This is not apparent at once from an examination of the values since the proportions have been evaluated from the annual mean. It is considered that the use of, for example, the mean for 10 months, i.e. 44.3 ins., tends to be unrealistic since it neglects the effects of the seasons. Consequently the presentation of the driest 10-monthly period December 1928 to September 1929 as 41% of the mean annual precipitation and the wettest 10-monthly period January 1903 to October 1903 as 132% is of much more value. This shows that there is a greater negative departure from the mean 59% as against 32%, and thus that the lack of rain in such a period with regard to what might be normally expected in a year, is much more serious than a surplus over a comparable period.

It is also interesting to consider the combination of the appropriate monthly means forming the seasons.

SEASONAL DISTRIBUTION 1903-1952

	INS.	% of Mean Annual		INS.	% of Mean Annual		INS.	% of Mean Annual		INS.	% of Mean Annual
DEC.	5.57	10.47	MAR.	4.33	8.14	JUNE	2.78	5.22	SEPT.	3.92	7.37
JAN.	6.18	11.61	APR.	3.64	6.84	JULY	3.48	6.54	OCT.	5.52	10.37
FEB.	4.85	9.11	MAY	3.04	5.71	AUG.	4.32	8.12	NOV.	5.58	10.48
WINTER		31%	SPRING		21%	SUMMER		20%	AUTUMN		28%

The seasons as defined above do not illustrate the maximum range within quarterly periods, which would be as much as 15% of the annual mean if summer was considered to be the months May to July and winter November to January. It might be expected too that Spring and Autumn would show more similarity, but the accepted definition of the seasons does not provide for the equinoxes, the periods of expected maximum cyclonic activity over the British Isles, coming into the centre of their respective quarters.

The division of the year into two seasons, the winter season (Oct. to March) and the summer (April to Sept.) is much more accommodating. In the Burnhope record the percentage of the mean annual precipitation falling in winter is 60%, and therefore in the summer is 40%.

It is not proposed to attempt more detailed studies of the Burnhope rainfall records. Considering the nature of the investigations as a whole, an analysis of rainfall frequency, although of great interest to the water engineer, is a major study in itself, and from exploratory experiments with the Burnhope statistics, it seems that a longer period of time than that of the available 50 years of records, needs to be used to provide a basis upon which frequencies and probabilities may be determined. Further fields of study lie also in the analysis of rain days and wet days, there being on an average about 220 rain days per year. These would link up appropriately with the evaluation of intensity of rainfall, which is hydrologically important, but for which no satisfactory data is available in this area.

Average Precipitation

The principal aim of the investigations in Upper Weardale was to find the rainfall - runoff relationships, but unfortunately the runoff data for the Burnhope valley did not cover such an extensive period of time as was first hoped. However, values of runoff for several years have been computed and a full account of the method will follow in the next chapter. At present, it is sufficient to state that the years are divided into three groups 1916-1920, 1937-1940 and 1951-1953, a total of twelve individual years. The determination of the average rainfall over the Burnhope valley was made by the two methods adopted in Part I, firstly the straightforward arithmetical mean of the values recorded at the gauges in the catchment area, and secondly by the Thiessen method. The first set of values was obtained by averaging the annual totals at Grassmeres and Lodgegill Mine, the two gauges read monthly, and Burnhope, the daily gauge.

The calculations for the Thiessen method had to be subdivided into two groups. This was found to be necessary because the stream flow measurements were related to two different points along the stream, and therefore would refer to a catchment area of two different sizes. For the years 1916-1920, the amount of water flowing from the drainage basin was measured further upstream from the site of the reservoir dam, and so a smaller area was involved. The watersheds of the two catchment areas were drawn on the 6-inch maps, and the area values obtained by measurement with a planimeter. The boundaries, and extent of these areas are shown in Fig. 20. They are 4302 acres for the first group of years and 4480 acres for the rest. The proportional areas awarded to the three different raingauge sites were measured for both area values, and hence these proportional factors were applied to the annual rainfall totals, and figures for the average

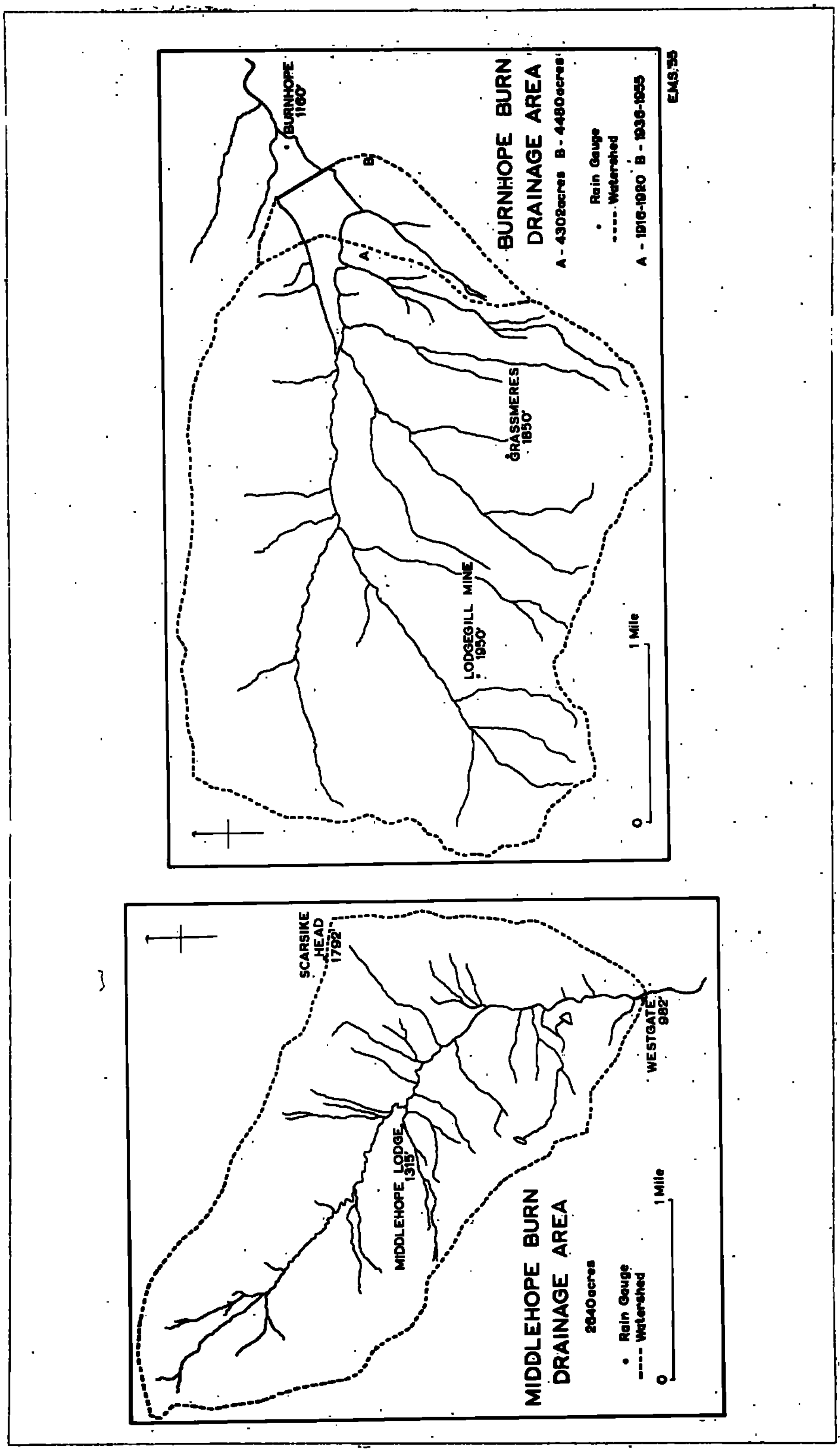
BURNHOPE BURN DRAINAGE AREA
A - 4302acres B - 4480acres
• Rain Gauge
---- Watershed
A - 1916-1920 B - 1936-1955
EJMS.56
BURNHOPE 1160'
B
A
GRASSMERES 1850'
LODGEGILL MINE 1950'
0
1 Mile
MIDDLEHOPE BURN DRAINAGE AREA
2640acres
• Rain Gauge
---- Watershed
SCARSIKE HEAD 1792'
WESTGATE 982'
MIDDLEHOPE LODGE 1315'
0
1 Mile

Fig. 20

rainfall over the catchment area were obtained. The results of these computations are given below.

THIESSEN METHOD

Area A. 4302 acres

GAUGE	AREA PROPORTIONS
LODGEGILL MINE	47.5
GRASSMERES	42.8
BURNHOPE	9.7

Area B. 4480 acres

GAUGE	AREA PROPORTIONS
LODGEGILL MINE	43.8
GRASSMERES	40.6
BURNHOPE	15.6

AVERAGE PRECIPITATION IN THE BURNHOPE VALLEY

	1916	1917	1918	1919	1920	1937	1938	1939	1940	1951	1952	1953
Mean of 3 gauges	78.28	67.57	60.42	47.30	61.60	47.82	69.05	60.55	52.63	62.20	54.99	47.71
Thiessen Mean	80.47	71.79	62.60	47.02	64.13	48.51	71.36	61.92	54.39	62.96	56.04	49.30

There are two criticisms of the use of the Thiessen method which may by put forward in this instance, but as a result there may be a counter-balancing of effects. Firstly, the area weight of the Burnhope gauge i.e. the influence on the Burnhope values, is small compared with the other two gauges which are only read monthly. Secondly, however, there is a large part of the catchment area above the height of the highest gauge 1950 ft., which it is expected will receive a greater rainfall, and therefore it is not unreasonable to accept provisionally the apparently exaggerated figures for the average rainfall obtained by the application of the large areal factors to the higher rainfall totals.

measured at Lodgegill Mine and Grassmeres. This argument was used in Part I with regard to the Middlehope Burn rainfall. The reliability of upland gauges will always remain suspect unless they are inspected more frequently preferably daily, and in attempting to find a satisfactory value of average precipitation for hydrological purposes such shortcomings should always be considered. In using such values in the Burnhope valley in a later chapter, due regard is taken of abnormal measurements, and fluctuations are always to be noted in relationship to the readings of the Burnhope daily gauge.

The use of the isohyetal method for the determination of the average rainfall is the most generally accepted method. However, it is considered that, although there is another rain gauge beyond the N.E. boundary of the catchment area, there is not a sufficient number of gauges available to make possible good interpolations of the isohyetal lines. Given a satisfactory 'coverage' of gauges, the drawing of isohyets on 1:25,000 maps would be admirable, but it is debatable whether or not the runoff figures would have been sufficiently accurate to warrant such consideration.

Chapter 3. Runoff.

The data for the assessment of runoff in the valley of the Burnhope Burn were all supplied by the Durham County Water Board. They are clearly divided into two groups according to the methods used in the measurement of the amount of water flowing in the stream for particular periods.

The first set of values were obtained for the years 1916-1920 inclusive. A survey of the stream flow was carried out by a private firm for the Weardale and Consett Water Company with a view to constructing a reservoir in the valley. The records of these preliminaries state that a compound Lea Recorder was set up in the burn at a point indicated by the lowest extension of the watershed of drainage area A shown on Fig. 20. The quantities of water in millions of gallons that passed this site in each month of the five years were abstracted from the typed tables of these records. Knowing the extent of the drainage area from planimetric measurements mentioned in the last chapter, the runoff for each month was calculated as in the following example.

E.g. Jan. 1916. Total volume of water = 1002.55 million gallons

The area of the drainage basin = 4302 acres.

1 million gallons = 0.04423 ins. of runoff on 1,000 acres
1,002.55 " " = 0.04423 x 1002.55 ins. of runoff on 1,000 acres
= $\frac{0.04423 \times 1002.55}{4.302}$ " " " " 4302 acres

= 10.31 ins. of runoff.

In this way, sixty monthly values and five annual totals of runoff were obtained from the given volumes of water flowing from the drainage area. These are presented in table form below.

RUNOFF (INS.) FROM THE BURNHOPE VALLEY COMPUTED FROM
REGISTERED VOLUMES OF WATER

MONTH	1916	1917	1918	1919	1920
JAN.	10.31	3.20	17.92	2.14	7.13
FEB.	5.30	6.19	8.56	1.32	5.91
MAR.	4.12	2.90	3.59	3.95	6.15
APR.	9.31	6.45	1.68	6.86	5.25
MAY	4.30	2.88	0.52	3.17	4.90
JUNE	3.58	0.77	0.20	0.71	0.96
JULY	5.03	0.19	3.74	2.27	4.98
AUG.	1.44	3.96	1.43	2.05	3.84
SEPT.	3.69	2.79	5.19	2.66	2.79
OCT.	11.55	7.68	3.25	4.11	3.51
NOV.	5.12	9.99	2.17	5.94	4.71
DEC.	2.57	4.00	2.19	10.27	7.56
YEAR	66.31	51.00	50.43	45.45	57.67

The second group of runoff statistics pertain to periods after 1936 when the Burnhope Reservoir had been constructed. The site of the reservoir dam shown on Fig. 20 was assumed to be the 'gauging point' of the stream so that the drainage measurements refer to the area bounded by the watershed above this point, drainage area B. There were three principal sets of daily water measurements to be considered, and these are used in the computations on a weekly basis. The amount of water sent by pipeline to another reservoir further downstream in in the Wear drainage system, and the amount of water allowed to flow naturally into the burn below the reservoir are both measured accurately by meters in millions of gallons. The former comprises 'consumed' water, and the latter is known as compensation water, the flow of which by statute must not be allowed to fall below the rate of 2 million gallons per day. The third important measurement taken regularly is the difference in the height of the water level in the reservoir above or below top water mark. When the water level is at this mark, the reservoir is considered to be full and the capacity is 1357 million gallons. The values of consumed water, compensation water, and water level heights were abstracted from the reservoir records for consecutive weeks beginning at 9 a.m. on a Saturday morning and finishing at the same time on the following Saturday. Hence to determine the change in storage during one week, the difference between the amount of water in the reservoir at the measurement time of the first Saturday and the amount on the second Saturday was calculated. To do this, the height measurements had to be converted into millions of gallons first of all, and this was possible by using a table compiled by the Water Board for such a purpose. This table operated for height differences below top water mark. For positive anomalies, therefore, a smaller table was evaluated by adding a series of ½ inches of water (the finest degree of accuracy to which the measurements were made) on top of the top water surface area, 104.94 acres, and adding these amounts to the top water level capacity of 1357 million gallons. It will be observed at once that this represents a rather crude method, and neglects the change in surface area with increase in depth, along the margins of the reservoir.

However, it was rarely found that the height above top water level exceeded 3 inches, and therefore the method of compilation of the positive anomaly table appears justifiable.

The runoff for each week was obtained by summing algebraically the consumed water, compensation water and storage differences in millions of gallons, care being taken to see that the signs of the last figures were correct. The total runoff for the year was calculated subsequently, and amendments according to the day of the week on which the year began and ended were incorporated.

This procedure was followed with the statistics for the years 1937-1940, but in September 1941 were brought into operation the north and south catchwaters. This meant that further supplies of water were allowed to flow into the reservoir from valleys outside the Burnhope catchment basin, beyond the northern watershed from the Wellhope Burn and beyond the southern watershed from the headwaters of the Ireshopeburn. Measurements of the quantities from the catchwaters were made at the end of the pipes near the reservoir by recording depths of water in observation chambers, but unfortunately these daily linear values had not been converted into units of volume. Consequently, it was found impossible to obtain values for the quantity of water coming into the reservoir from these sources so that they could be subtracted from the computed runoff in the Burnhope valley. For the years 1951 and onwards, these necessary amounts had been evaluated in the records, and therefore from that year, the reservoir data could be used to determine runoff. Samples of the data and computations are to be found in the appendix.

Once the runoff totals in millions of gallons had been evaluated from the suitable data for the years 1937-1940 and 1951-1953, the number of inches of runoff were computed as previously demonstrated except that the larger catchment area of 4480 acres was employed.

RUNOFF (INS.) COMPUTED FROM BURNHOPE RESERVOIR DATA

1937	42.00	1951	43.95
1938	58.64	1952	38.73
1939	52.23	1953	34.39
1940	38.31		

These values must be treated with great reserve, for in addition to the inaccuracies already indicated in the method of computation, some of the original data is hardly suitable for such careful analysis. For example, in March 1939, there was a burst along the pipeline conveying the consumed water, and although no water was lost before it was measured, after the pipe was closed for repair, and on reopening the supply, the amount of water was not recorded for a day. Also in the reservoir returns, there are reports of leaks which may mean that some quantity of water escaped without being measured. Such discrepancies would result in lower runoff values.

In order to make a comparison with the work done in the valley of the Middlehope Burn, the reservoir data was abstracted for the corresponding period April 1954 to March 1955, and the value of the runoff was calculated for the Burnhope Valley for these twelve months. Unfortunately, the recorder measuring the compensation water allowed to run into the river was broken for two days, and thus, this important constituent of the Burnhope Burn discharge was unknown for one week. It is not known what caused the breakdown in the recorder, but during that week ending January 15 1955, the greatest flood noted flowed down the Middlehope Burn, and widespread flooding was reported in the Tyne valley at the same time. The sudden rush of water may have affected the mechanism of the recorder, but what is more important is that millions of gallons of water passed through unmeasured, and the absence of such a large quantity greatly influences the final runoff figure of 51.09 ins.

Part III The Relationship between Precipitation and Runoff

In all parts of the world, but especially in those countries with high densities of population, the difference between the precipitation and the natural runoff is of supreme importance. This value which is technically known as the 'loss' in precipitation, represents the amount of water which returns to the atmosphere by the process of direct evaporation from free water surfaces (including all wetted surfaces after precipitation as well as the more obvious larger bodies of water such as lakes, pools and streams), and by transpiration of moisture from the ground by all kinds of vegetation. The 'loss' also includes a largely unknown quantity of water which disappears underground. Sometimes, when small areas are considered, this can be assessed, but in regions of complex stratigraphy, it may be impossible to consider how much water returns to the natural hydrological cycle and how much is lost to the earth's surface.

One of the most important problems in the field of hydrology is the determination of this loss in precipitation since it has to be taken into account in any analysis of water resources for whatever purpose it may be required. This difference between precipitation and runoff varies enormously in different parts of the world according to the climatic régime. The type of climate experienced by an area has the greatest effect on the loss of precipitation over the earth's surface, but within a relatively homogeneous climatic region, it may have significant variations according to the structure and composition of the underlying rocks and soils. The latter, of course, are related to the climate as is too the natural vegetation which greatly affects the runoff.

Hence with the growing importance of adequate water supplies for agricultural, industrial and domestic purposes, many investigations into the determination of the loss of precipitation have been carried out. The evaluation of evaporation has attracted much attention. The most notable formula by Thornthwaite[1] devised originally for use in America has been applied by other workers to other parts of the world, and has found much favour in those areas with a tendency towards a continental type of climate. In this country, the formulae of Penman[2] and Lloyd[3] for evaporation have gained prominence among many detailed studies. The reliability of these mathematical methods, without considering the actual formulae, depends entirely on the value and accuracy of the meteorological statistics used, and since, for example in Penman's formula, measurements of dewpoints, duration of bright sunshine, and wind velocity as well as air temperature are required, the application of the formulae is limited to those areas possessing first-class meteorological stations. Thus by these methods, only generalised values of the evaporation can be obtained, and over restricted areas.

The direct measurement of evaporation is also made at many places, and indeed there are long records of the evaporation from a

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[1] "The climates of North America according to a new classification" C.Warren Thornthwaite. Geog.Review 1931.

[2] "A general survey of meteorology in agriculture and an account of the physics of irrigation control" H.L. Penman Q.J.R.Met.S. 1949.
"Evaporation over the British Isles" H.L. Penman Q.J.R.Met.S. 1950.

[3] "Evaporation over catchment areas" David Lloyd Q.J.R.Met.S. 1938.

water surface. Of more value to the hydrologist are the measurements of evaporation plus transpiration from ground covered with various types of vegetation. There are many methods in use, and improvements based on experience are always being made. The variety of methods, however, sometimes appears to exceed the number of stations at which the measurements are made, and since no standard procedure has been universally accepted as yet, the available statistics are limited in areal extent.

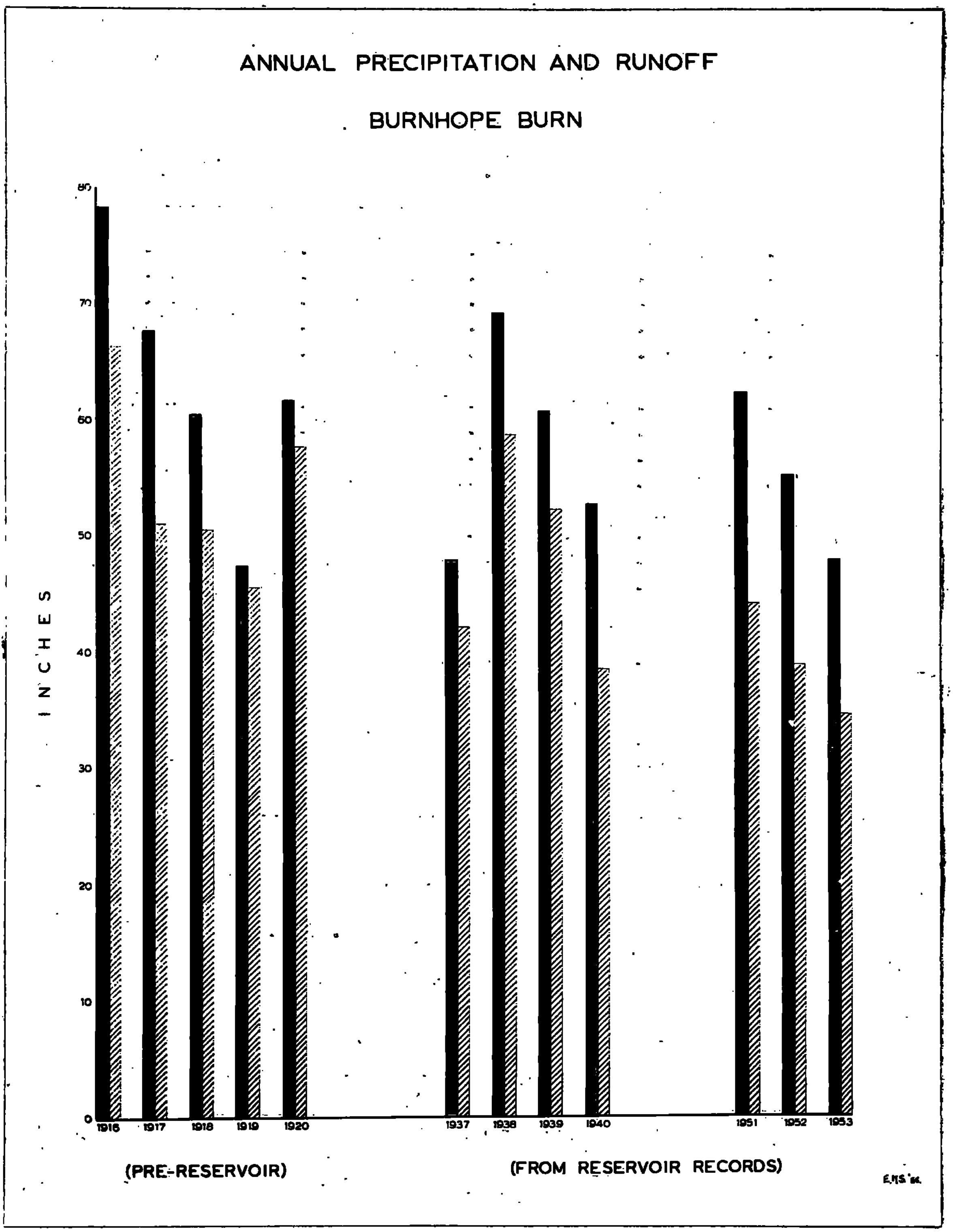
In the experiments carried out in Upper Weardale and described in the previous chapters, no attempt has been made to subdivide the values for the loss of precipitation, for reasons which are evident from the above introduction, and from the shortcomings of the precipitation and stream flow measurements explained previously. However, it is possible to present total values of the loss for annual periods. These are assembled in the following table, where both methods for the determination of the average rainfall over the area are used, giving two series of results.

ANNUAL LOSS OF PRECIPITATION IN UPPER WEARDALE

	PRECIPITATION INS.		RUNOFF INS.	LOSS OF PRECIPITATION INS.	
BURNHOPE	ARITHMETIC MEAN	THIESSEN MEAN		A.	T.
1916	78.28	80.47	66.31	11.97	14.16
1917	67.57	71.79	51.00	16.57	20.79
1918	60.42	62.60	50.43	9.99	12.17
1919	47.30	47.02	45.45	1.85	1.57
1920	61.60	64.13	57.67	3.93	6.46
1937	47.82	48.51	42.00	5.82	6.51
1938	69.05	71.36	58.64	10.41	12.72
1939	60.55	61.92	52.23	8.32	9.69
1940	52.63	54.39	38.31	14.32	16.08
1951	62.20	62.96	43.95	18.25	19.01
1952	54.99	56.04	38.73	16.26	17.31
1953	47.71	49.30	34.39	13.32	14.91
BURNHOPE APR.'54-MAR.'55.	73.45	75.00	51.09	22.36	23.91
MIDDLEHOPE APR.'54-MAR.'55.	51.85	53.99	37.28	14.57	16.71

Some of these figures are also represented graphically in the accompanying diagram (Fig. 21).

In considering the results for the twelve calendar years, it will be observed that there is a very wide range from 1.57 ins. in 1919 to 19.01 ins. in 1951. It is highly improbable that there would be a range of over eighteen inches in the loss of precipitation in such an exposed area with a comparatively equable climate, a part of the ever windy Northern Pennines. Thus it is necessary to examine the figures more closely, and to disregard those which may be faulty. In



ANNUAL PRECIPITATION AND RUNOFF

BURNHOPE BURN

Fig. 21

1919, when the runoff represents 97% of the precipitation, some of the monthly precipitation totals may be doubted, for example, during March of that year there were recorded 17 days on which snow fell, and the high gauges read monthly show a nearly 2-inch deficit on the readings of the daily Burnhope gauge. The October and November totals show similar discrepancies. Similarly in 1917 and 1918, although the proportion of runoff to precipitation is more reasonable, the figures for the month of January are to be suspected. Twenty-five days of snow were recorded at Burnhope in January 1917 where the total was 11.21 ins., but the monthly gauges were credited with 22 and 24 inches of precipitation by estimation. These amounts give unduly great differences particularly when there are no comparable large runoff figures even in the following months allowing for a late thaw. In the following year, the January totals give 5.23 ins. of precipitation and 17.92 ins. of runoff. It is probable that the monthly totals of runoff for January 1917 and 1918 may have been interchanged in error at some time, but careful scrutiny of the available records has not solved this problem (Fig. 22).

Thus it can be seen that no great reliance can be placed on the results for the earlier years. The later figures for the loss of precipitation evaluated from the reservoir records give a much more realistic picture, even though there are minor irregularities which have been indicated in previous chapters. The annual runoff totals have been plotted against the number of inches of precipitation, and the resulting graphs (Fig. 23) show the points falling into two

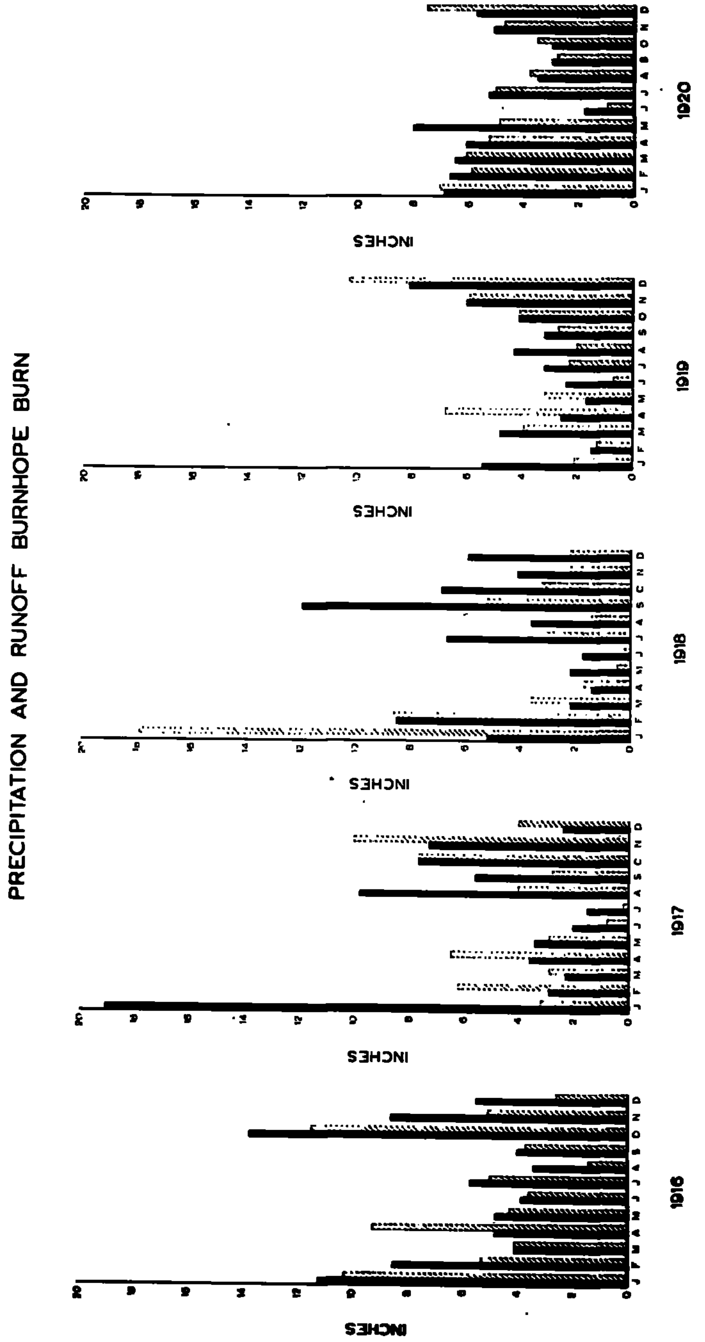

PRECIPITATION AND RUNOFF BURNHOPE BURN

Fig. 22

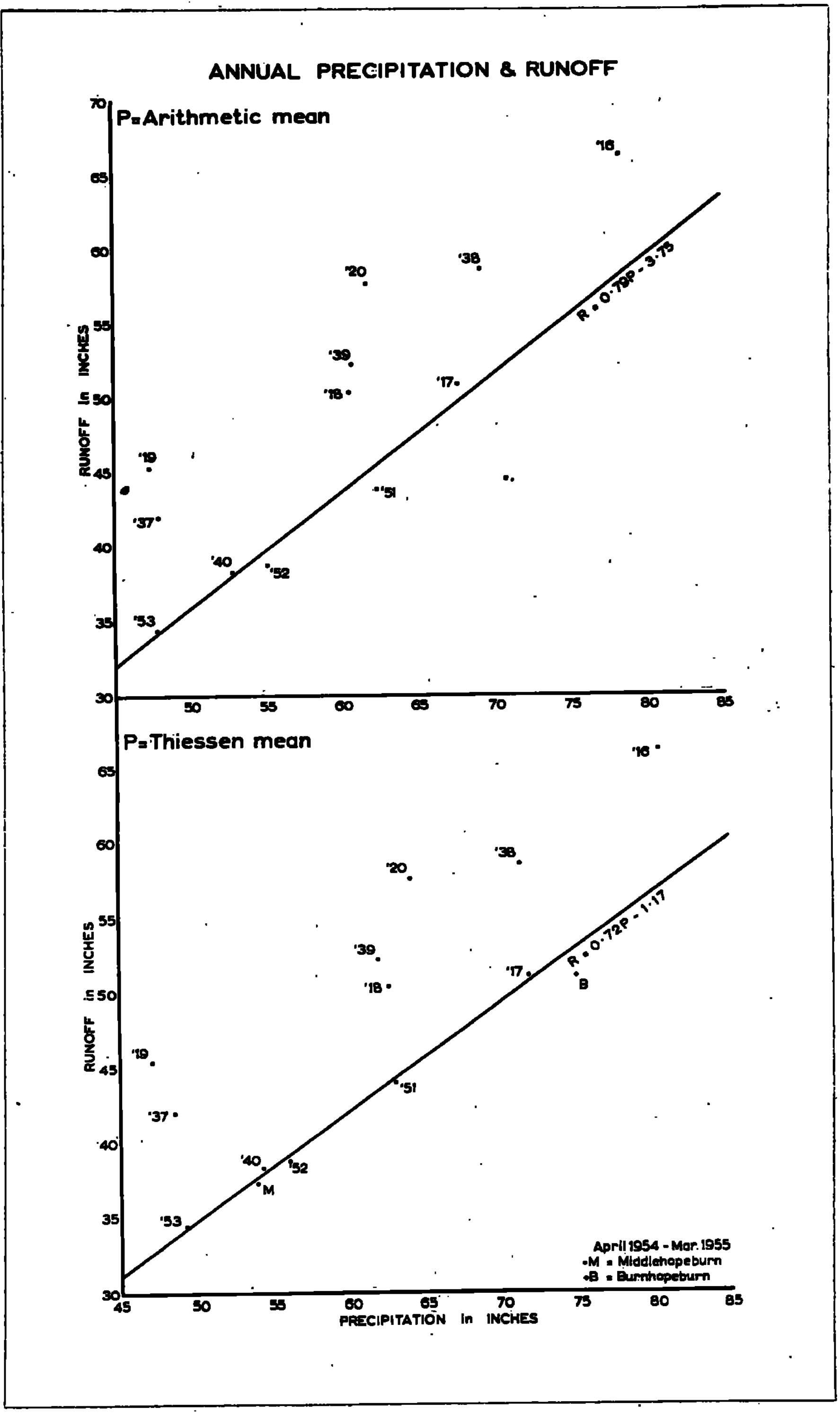

ANNUAL PRECIPITATION & RUNOFF
P=Arithmetic mean
R = 0·79P - 3·75
P=Thiessen mean
R = 0·72P - 1·17
RUNOFF in INCHES
PRECIPITATION in INCHES
30
35
40
45
50
55
60
65
70
45
50
55
60
65
70
75
80
85
'16
'20
'38
'39
'18
'17
'19
'37
'51
'40
'52
'53
M
B
April 1954 - Mar. 1955
•M = Middlehopeburn
•B = Burnhopeburn

Fig. 23

distinct groups, those of the earlier years and those from the more reliable statistics. Both series of results are shown, and in each instance, straight line curves have been drawn through the good points to give a simple precipitation - runoff relationship. The equation $R = 0.72P - 1.17$ ins. (where R = runoff and P = precipitation) from the graph of the Thiessen means is much more definite than the equation $R = 0.79P - 3.75$ ins. using the arithmetic means for average precipitation. These simple straight line equations are of a similar pattern to those quoted by Gold[1] for the Thames Valley. The slopes of the lines 0.72 and 0.79 are a little greater, and these larger proportions of the rainfall are reduced by the lesser amounts of the constants 1.17 and 3.75. This means that the proportion of the precipitation in Upper Weardale which forms measurable runoff is greater than that in the Thames Valley, which is a result that might be expected. The Thames Basin is rimmed with the highly absorbent chalk strata which leads surface moisture away to the deep natural underground reservoirs, while the harder rocks of the Pennines are much less permeable and provide a quicker runoff. Evaporation, especially during the warm summer months, is much higher in the south of the country than in the north, theoretically differing by as much as seven inches according to Penman.[2]

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[1] "The relation between runoff and quarterly values of rainfall in the Thames Valley" E. Gold. U.G.G.I. Assoc.Intern.d'Hydrologie Scientifique Brussels 1951 Tome III.

[2] See note 2, p.79.

The two values of the loss of precipitation for the twelve months April 1954 to March 1955, the period of the Middlehope Burn experiment, differ greatly as shown in the above table. The figures for Burnhope are too high, and plotted on the graphs they show the deficiency in the runoff explained earlier. The Middlehope Burn results are in accordance with the satisfactory Burnhope figures, although it must be remembered that they do not apply to an ordinary calendar year.

Since the runoff totals for the Middlehope Burn were compiled also on a monthly basis, the loss of precipitation has been evaluated for each month from April 1954 - March 1955.

MONTHLY LOSS IN PRECIPITATION IN MIDDLEHOPE BURN

	PRECIPITATION INS.		RUNOFF INS.	RUNOFF / PRECIPITATION (THIESSEN) %	LOSS IN PRECIPITATION INS.	
	ARITHMETIC MEAN	THIESSEN MEAN			A.	T.
1954 APR.	0.70	0.71	0.36	51	0.34	0.35
MAY	5.68	6.03	3.08	51	2.60	2.95
JUNE	2.54	2.63	0.47	18	2.07	2.16
JULY	2.21	2.22	0.26	12	1.95	1.96
AUG.	8.68	8.99	5.29	59	3.39	3.70
SEPT.	4.69	4.80	2.32	48	2.37	2.48
OCT.	7.17	7.39	7.41	100	-0.24	-0.02
NOV.	7.47	7.73	4.79	62	2.68	2.94
1954 DEC.	5.86	6.52	5.42	83	0.44	1.10
1955 JAN.	3.05	3.09	4.70	152	-1.65	-1.61
FEB.	2.38	2.53	1.49	59	0.89	1.04
1955 MAR.	1.41	1.35	1.68	124	-0.27	-0.33
YEAR	51.85	53.99	37.28	69	14.57	16.71

In a mountainous area, the response of a small stream to heavy rainfall is very rapid, so that the above table represents a broad generalisation of the actual conditions. Nevertheless, the figures do illustrate recognisable events associated with the various seasons of the year. June and July have low runoff values compared with the precipitation, when the average temperatures are approaching the maximum and evaporation is therefore greatest, and after these relatively dry months, the runoff for the wet August was still below the average for the year with 59% of the precipitation. This is due to the absorbency of the peat on the high moorland, and of the vegetation using the maximum amount of moisture at this time of the year. A distinct lapse in time between the occurrence of heavy rain and the rising of the stream occurred at the beginning of May, owing to the previous very dry month of April. Three quarters of an inch of rain fell on the 1st and 2nd of May, but it was not until the morning of the 3rd that a high reading of the stream gauge was recorded. During the autumn months of October and November and December when the mean temperature is decreasing, the proportion of runoff to rainfall rises. There were some heavy falls of rain during these months, but even during the dry spells the stream never fell to a low level. The ground became saturated, with the result that on December 1st a fall of under an inch produced flood conditions on the following day. January and February 1955 were very cold months, the mean temperature of the latter being below freezing point. There were considerable falls of snow with the consequent retarding of the effects on the stream. The remarkable flood of January 10th when over an inch of rain fell on the snow cover the previous day, and the temperature rose suddenly into the forties, has already been mentioned, and this greatly influences the high runoff - precipitation

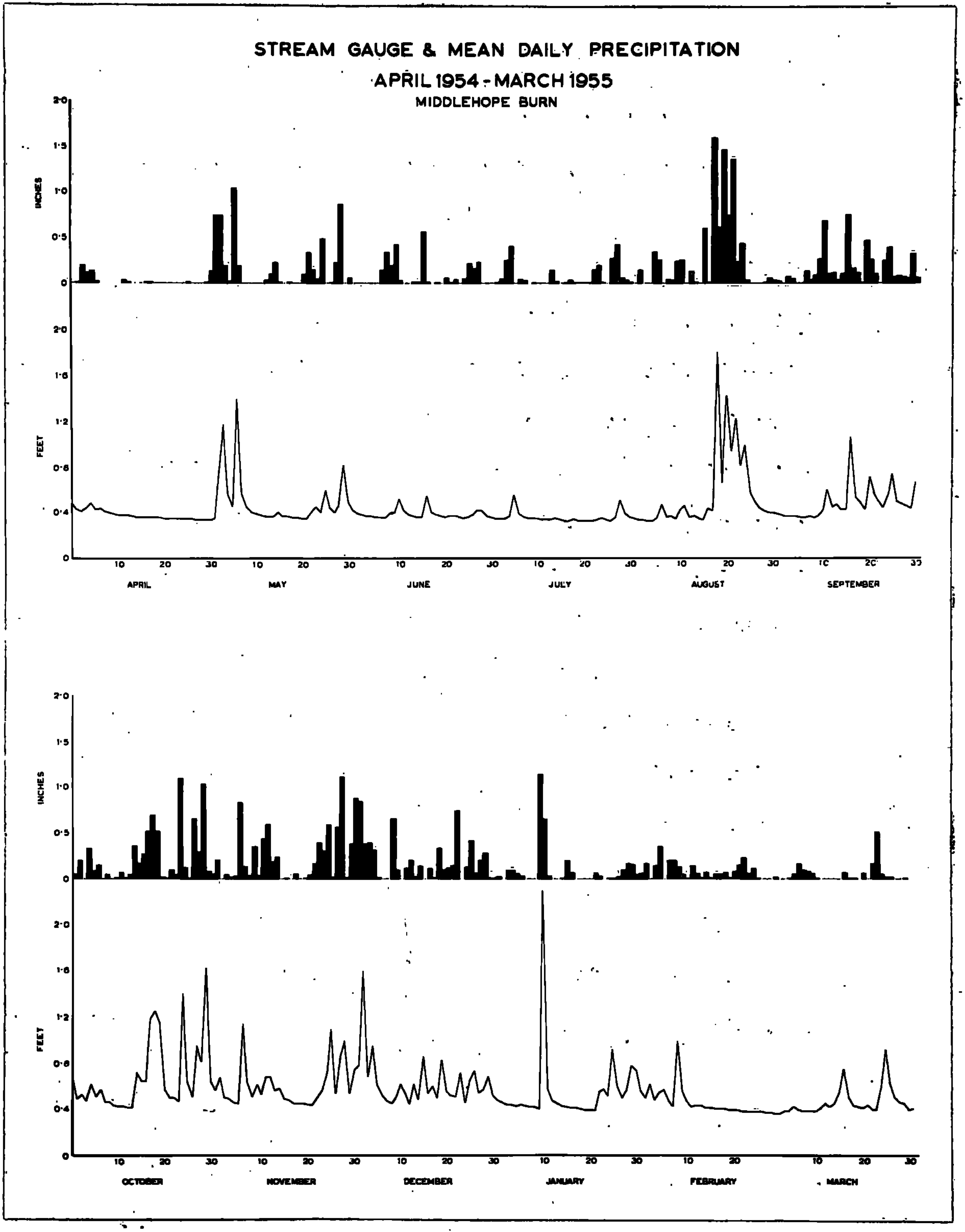
STREAM GAUGE & MEAN DAILY PRECIPITATION
APRIL 1954 - MARCH 1955
MIDDLEHOPE BURN
INCHES
2·0
1·5
1·0
0·5
0
FEET
2·0
1·6
1·2
0·8
0·4
0
10
20
30
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH

Fig. 24

proportion of 152%. The corresponding figure for February is much lower, for the temperature remained persistently low and snow fell on 18 days of the month. The final thaw began during the second week of March. The weather was dry, and the mean temperature rose gradually so that it was a gentle thaw, the maximum stream height of 0.75 ft. being recorded on the 16th of the month, but undoubtedly much of the February precipitation is contained in the March runoff (Fig. 24).

Conclusions

These hydrological investigations in Upper Weardale were directed towards the determination of the relationship between precipitation and runoff. To achieve this, the practical work was carried out in order to supplement and improve upon the existing information. It is debatable whether a lengthy series of unreliable records is more valuable than a short set of better observations. However, it cannot be stressed too strongly that unfailing accuracy and attention to detail are absolutely essential in taking hydrological measurements and compiling records. In addition, observations should be made completely continuous because conditions never remain static and events are never precisely repeated. The ideal is that all measurements should be continuous. The basic requirements in a study of this kind are recording raingauges and stream gauges, and the control section at the stream gauging point should be absolutely rigid; preferably a constructed weir. Even so, the stream should be watched carefully particularly in cold weather and the formation of ice prevented if possible to avoid finding the overflow choked so that several hours of readings are made unreliable. Of course, a constant vigil is something that is very rarely achieved, and much hydrological work is necessarily based on suppositions and assessments.

Some of these shortcomings have operated to a greater or lesser degree in the experiments in the Middlehope Burn catchment area. Although the stream has an uninterrupted natural flow, the geological structure makes the basin unsuitable for further detailed study of the outstanding hydrological problems indicated above. However, the results appear to be satisfactory from the standpoint of the methods employed, and from statistical scrutiny.

In dealing with the statistical results, attention must be drawn again to the inaccuracies explained earlier, which were brought about by adverse weather conditions. These would be overcome in larger scale investigations by more complex and improved equipment. The value of 14.6 ins. or 16.7 ins. for the difference between precipitation and runoff might have been a little higher if it had been possible to obtain the average precipitation by the isohyetal method, but as it stands it is of a reasonable order and magnitude. Comments on the reliability and value of individual measurements have been given in their appropriate contents.

The methods adopted in the Middlehope Burn investigations were the best that could have been used in the circumstances. Of course, the existence of a good natural stream gauging point is very rare, but it is considered that the best section of the Middlehope Burn was used, notwithstanding the difficulties that were encountered after it had been selected. The use of a pygmy type current meter would have given better velocity measurements at low flows, and it is difficult to know how readings could have been made at high velocities without the construction of a bridge over the stream at the gauging point. The siting of the highest raingauge on the col at Scarsike Head is most controversial; it is very probable that larger amounts of precipitation would have been recorded at a more sheltered site. It cannot be said whether or not the totals are a true measure of the precipitation reaching the ground at that point.

Finally, the experience gained during this series of experiments makes it possible to indicate several further lines of study. While some of these are well known in the field of hydrology it seems appropriate to re-emphasize them here:-

1) Improvement in the accuracy of measurement of precipitation in upland regions with special reference to the type of gauge of greatest practical use, preferably of a continuous recording pattern, and to the measurement of snow, the most difficult form of precipitation to measure satisfactorily.

2) The comparison of different criteria to be applied in arranging a good coverage of gauges with suitable sites over a catchment area to give reliable values of the average precipitation over that area.

3) The extension of evaporation and transpiration studies in mountain regions in this country where there is the greatest potential water supply.

4) The improvement in knowledge of water movement underground.

5) The intensive study of a small watertight catchment area in the mountains of Great Britain for a period of about 10 years would be extremely valuable in attempting to solve many of the problems connected with the determination of the relationships between precipitation, runoff, evaporation, transpiration and percolation.

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2) C. Clay, Esq., Chief Engineer to the Wear and Tees River Board, and his staff for their assistance in the selection of a current meter and for their demonstration of stream gauging procedure.

3) The landowners of Middlehope Burn for their permission to install the raingauges and the stream gauge on their property, and to the farmers of the valley for their help with transport especially during the snowy months.

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E.M. Shaw

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Appendix

Index

Middlehope Burn. Westgate. Precipitation.

	1954								1954	1955		1955	
	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	
1	Tr.	0.80	-	Tr.	0.09	Tr.	0.13	Tr.	0.90	-	0.24	0.01	
2	0.16	0.77	-	0.03	Tr.	0.07	Tr.	0.03	0.45	0.11	Tr.	Tr.	
3	0.12	0.18	-	0.25	-	0.02	0.22	0.01	0.42	0$\overset{s}{.}$19	0.14	-	
4	0.11	0.02	-	0.41	0.29	Tr.	0.07	0.03	0.28	0$\overset{s}{.}$16	0.46	0.01	
5	0.02	1.02	-	0.01	0.25	Tr.	0.15	0.93	0.01	0.07	0.01	0$\overset{s}{.}$09	
6	-	0.17	0.16	0.04	Tr.	0.13	Tr.	0.12	-	Tr.	0$\overset{s}{.}$26	0$\overset{s}{.}$27	
7	-	Tr.	0.38	0.03	0.03	0.03	0.04	0.03	-	-	0.14	0.08	
8	-	-	0.23	-	0.03	0.11	Tr.	0.42	1$\overset{s}{.}$18	Tr.	0.11	0.06	
9	-	-	0.43	0.01	0.29	0.31	-	0.05	0.09	1.05	0$\overset{s}{.}$04	0.09	
10	-	-	0.02	-	0.23	0.73	0.06	0.49	0.01	0$\overset{s}{.}$81	0$\overset{s}{.}$02	Tr.	
11	0.05	-	-	-	Tr.	0.07	Tr.	0.58	0$\overset{s}{.}$10	0$\overset{s}{.}$06	0$\overset{s}{.}$19	-	
12	0.01	0.04	-	Tr.	0.11	0.05	0.02	0.20	0.22	-	0$\overset{s}{.}$08	-	
13	-	0.10	0.05	0.10	0.01	0.01	0.36	0.18	Tr.	-	0$\overset{s}{.}$01	-	
14	-	0.23	0.01	0.02	0.01	0.15	0.15	-	0.16	-	0$\overset{s}{.}$13	-	
15	-	0.01	0.61	-	0.53	0.76	0.28	0.01	0.01	0$\overset{s}{.}$38	0$\overset{s}{.}$02	-	
16	0.01	Tr.	Tr.	Tr.	0.02	0.09	0.58	-	0.11	0$\overset{s}{.}$14	0$\overset{s}{.}$12	0.07	
17	0.01	0.02	Tr.	0.02	1.61	0.09	0.71	0.04	Tr.	-	0$\overset{s}{.}$12	0.01	
18	-	-	0.01	0.01	0.61	Tr.	0.49	0.01	0.20	-	0$\overset{s}{.}$11	0$\overset{s}{.}$02	
19	-	-	-	Tr.	1.31	0.50	Tr.	0.01	0.04	-	0$\overset{s}{.}$03	-	
20	-	0.09	0.07	-	0.67	0.24	0.01	0.04	0.09	Tr.	0$\overset{s}{.}$13	0$\overset{s}{.}$07	
21	-	0.38	Tr.	0.01	0.78	0.10	0.13	0.22	0.09	0.07	0$\overset{s}{.}$25	Tr.	
22	-	0.15	0.02	0.14	0.17	Tr.	0.04	0.45	0$\overset{s}{.}$50	0.01	0$\overset{s}{.}$24	0$\overset{s}{.}$24	
23	-	0.04	-	0.14	0.42	0.32	1.14	0.31	-	Tr.	0$\overset{s}{.}$08	0.59	
24	-	0.60	0.01	0.01	0.03	0.38	0.10	0.63	0.10	0.01	0$\overset{s}{.}$16	0.05	
25	Tr.	Tr.	0.17	-	Tr.	0.05	0.01	0.01	0.36	0.01	0$\overset{s}{.}$04	0.01	
26	-	0.01	0.12	0.32	-	0.05	0.78	0.63	0.02	0.02	-	0.03	
27	-	0.22	0.18	0.50	Tr.	0.04	0.27	1.31	0.13	0.12	-	Tr.	
28	-	0.83	Tr.	0.02	0.01	0.04	1.08	0.04	0.09	0.17	0.01	-	
29	-	Tr.	Tr.	0.01	0.05	0.30	0.08	0.40	0.01	0.15		-	
30	0.12	0.07	-	-	0.03	0.05	0.04	1.07	Tr.	0.04		Tr.	
31		Tr.		-	0.01		0.18		0.02	0.08		Tr.	YEAR
Totals	0.61	5.75	2.47	2.08	7.59	4.69	7.12	8.25	5.59	3.65	3.14	1.70	52.64

Middlehope Burn. Scarsike Head. Precipitation.

	1954								1954	1955		1955	
	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	
1	0.03	0.62	0.01	0.02	0.16	Tr.	0.24	Tr.	0.62	-	0.11	0.03	
2	0.22	0.60	-	0.05	-	0.08	Tr.	0.05	0.24	$0\overset{s}{.}09$	0.01	-	
3	0.12	0.18	-	0.31	-	0.04	0.48	0.03	0.30	$0\overset{s}{.}03$	0.12	-	
4	0.12	0.01	-	0.46	0.38	Tr.	0.07	0.03	0.31	$0\overset{s}{.}01$	$0\overset{s}{.}24$	$0\overset{s}{.}09$	
5	0.02	0.74	-	-	0.28	Tr.	0.16	0.55	0.03	-	-		
6	-	0.18	0.13	0.05	Tr.	0.13	-	0.12	-	-	$0\overset{s}{.}14$		
7	-	-	0.35	0.03	0.04	0.03	0.07	0.02	-	-	0.19	0.27	
8	-	-	0.19	-	0.03	0.06	Tr.	0.25	$0\overset{s}{.}21$	-	$0\overset{s}{.}10$		
9	-	-	0.42	0.01	0.21	0.21	0.01	0.02	0.04	0.89	$0\overset{s}{.}03$	0.04	
10.	-	-	0.03	-	0.29	0.66	0.09	0.39	-	0.56	-	0.02	
11	0.02	-	-	-	Tr.	0.11	0.01	0.50	$0\overset{s}{.}17$		$0\overset{s}{.}03$	-	
12	0.01	0.02	-	Tr.	0.17	0.13	0.05	0.11	0.14	-	$0\overset{s}{.}03$	-	
13	-	0.09	0.01	0.15	0.01	0.03	0.37	0.31	0.02	-	$0\overset{s}{.}01$	-	
14	-	0.24	0.01	0.02	-	0.06	0.17	Tr.	0.12	$0\overset{s}{.}02$	$0\overset{s}{.}03$	-	
15	-	0.03	0.47	-	0.73	0.65	0.23	0.01	Tr.	$0\overset{s}{.}14$	$0\overset{s}{.}03$	-	
16	0.02	0.01	0.01	0.01	0.01	0.17	0.50	-	0.11			0.05	
17	0.03	0.03	-	0.04	1.61	0.10	0.62	0.06	0.01			0.01	
18	-	-	0.02	0.01	0.58	Tr.	0.44	Tr.	0.37	-	$0\overset{s}{.}28$	Tr.	
19	Tr.	-	-	0.01	1.41	0.49	0.02	0.02	0.12	-		-	
20	-	0.14	0.05	0.01	0.75	0.27	0.01	0.04	0.13	Tr.		0.06	
21	-	$0\overset{s}{.}18$	0.02	0.02	1.72	0.09	0.08	0.12	0.12	0.07			
22	-	0.17	0.03	0.14	0.27	Tr.	0.03	0.36	0.72	0.04		0.58	
23	-	0.10	-	0.24	0.40	0.20	1.00	0.32	-	Tr.	-		
24	Tr.	0.42	0.07	0.01	0.04	0.36	0.10	0.55	0.14	0.01		0.05	
25	0.01	Tr.	0.22	-	-	0.06	Tr.	0.02	0.41	0.02		0.03	
26	-	0.01	0.16	0.25	-	0.07	0.60	0.55	0.07	0.03		0.01	
27	-	0.28	0.27	0.36	0.01	0.05	0.26	0.82	0.20	0.10		Tr.	
28	-	0.90	Tr.	0.09	0.01	0.04	0.87	0.01	0.33	0.16	-	-	
29	0.01	Tr.	Tr.	0.03	0.04	0.35	0.07	0.43	0.01	0.14		0.01	
30	0.14	0.06	-	0.01	0.04	0.04	0.06	0.54	0.01	0.04		-	
31		Tr.		-	0.03		0.24		0.02	0.04		-	YEAR
Totals	0.75	5.01	2.46	2.33	9.22	4.48	6.85	6.23	4.97	2.39	1.35	1.25	47.29

Middlehope Burn. Middlehope Lodge. Precipitation.

	1954								1954	1955		1955	
	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	
1	Tr.	0.83	-	0.02	0.17	-	0.22	Tr.	0.99	-	0.15	0.01	
2	0.22	0.87	-	0.05	-	0.07	Tr.	0.05	0.46	$0\overset{s}{.}07$	Tr.	-	
3	0.11	0.21	-	0.23	-	0.05	0.29	0.03	0.44	$0\overset{s}{.}06$	0.15	-	
4	0.17	0.04	-	0.39	0.38	-	0.09	0.03	0.38	$0\overset{s}{.}02$	0.34	0.23	
5	0.03	1.43	-	-	0.25	Tr.	0.15	1.00	0.02	$0\overset{s}{.}01$	Tr.		
6	-	0.23	0.13	0.03	Tr.	0.13	Tr.	0.14	-	0.01	$0\overset{s}{.}20$		
7	-	-	0.31	0.03	0.06	0.04	0.05	0.04	-	-	0.27	0.05	
8	-	-	0.15	-	0.03	0.07	-	0.37	$0\overset{s}{.}58$	-	$0\overset{s}{.}18$	0.05	
9	-	-	0.44	Tr.	0.23	0.29	0.01	0.03	0.13	1.49	$0\overset{s}{.}09$	0.04	
10	-	-	0.05	-	0.27	0.66	0.07	0.45	Tr.	$0\overset{s}{.}60$	$0\overset{s}{.}01$	Tr.	
11	0.02	-	-	-	Tr.	0.08	0.01	0.72	$0\overset{s}{.}08$	$0\overset{s}{.}01$	$0\overset{s}{.}19$	-	
12	0.02	0.03	-	0.01	0.11	0.14	0.05	0.22	0.24	-	$0\overset{s}{.}07$	-	
13	-	0.10	0.01	0.16	-	0.05	0.36	0.21	0.04	-	0.02	-	
14	-	0.21	0.01	0.02	-	0.09	0.19	Tr.	0.14	-	$0\overset{s}{.}06$	-	
15	-	0.02	0.64	-	0.57	0.80	0.29	0.01	Tr.	0.15	$0\overset{s}{.}01$	-	
16	0.01	Tr.	0.01	0.01	Tr.	0.21	0.49	-	0.13		$0\overset{s}{.}03$	0.08	
17	Tr.	0.02	-	0.04	1.55	0.14	0.74	0.04	0.01	-		0.01	
18	-	-	0.01	0.01	0.66	Tr.	0.63	Tr.	0.42	-	$0\overset{s}{.}26$	0.01	
19	-	-	-	0.01	1.68	0.43	0.04	0.01	0.13	-		-	
20	-	0.08	0.06	0.01	0.81	0.28	0.01	0.03	0.15	Tr.		0.06	
21	-	0.49	0.02	0.01	1.58	0.08	0.08	0.15	0.21	0.06			
22	-	0.14	0.04	0.16	0.25	Tr.	0.05	0.35	1.00	0.03	$0\overset{s}{.}33$	0.13	
23	-	0.01	Tr.	0.19	0.49	0.20	1.16	0.31	-	Tr.	$0\overset{s}{.}28$	0.57	
24	-	0.44	0.07	0.01	0.03	0.43	0.16	0.59	0.15	-			
25	0.01	0.01	0.28	-	-	0.07	0.01	0.02	0.50	0.01	-	0.02	
26	-	0.01	0.21	0.28	-	0.08	0.60	0.52	0.10	0.02	-	0.02	
27	-	0.20	0.25	0.44	Tr.	0.08	0.33	1.23	0.26	0.08	-	Tr.	
28	-	0.88	-	0.07	0.01	0.06	1.15	0.02	0.42	0.18	-	-	
29	0.01	Tr.	0.01	0.04	0.05	0.30	0.08	0.32	0.01	0.19		0.01	
30	0.13	0.04	-	0.01	0.03	0.06	0.04	1.03	0.01	0.07		-	
31		-		-	0.03		0.20		0.02	0.05		-	YEAR
TOTALS	0.73	6.29	2.70	2.23	9.24	4.89	7.55	7.92	7.02	3.11	2.64	1.29	55.61

Correlation of Rainfall of Westgate & Scarsike Head

Year April 1954 - March 1955 (After Reitz)

Days with mean 0.1 ins. and over.

Correlation coefficient 0.826 ± 0.029.

WESTGATE

SY	S	Y^2fY	YfY	Y	fY	under 0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	
752	-188	800	-200	-4	50	38	12								under 0.2
327	-109	333	-111	-3	37	10	18	8			1				0.4
60	-30	80	-40	-2	20		3	8	6	2	1				0.6
8	-8	9	-9	-1	9			2	5	1	1				0.8
0	5	0	0	0	5					1	3	1			1.0
0	0	0	0	1	0										1.2
0	0	0	0	2	0										1.4
6	2	9	3	3	1							1			1.6
12	3	32	8	4	2				1					1	1.8
1165		1263	-349		124	48	33	18	12	4	6	2	0	1	fx
						-4	-3	-2	-1	0	1	2	3	4	X
					-325	-192	-99	-36	-12	0	6	4	0	4	Xfx
					1179	768	297	72	12	0	6	8	0	16	X^2fx
						-182	-108	-42	-13	-5	-6	3	0	4	T
					1165	728	324	84	13	0	-6	6	0	16	TX

Scarsike Head

$$\bar{X} = \frac{\Sigma Xfx}{\Sigma fx} = \frac{-325}{124} = -2.621 \qquad \bar{Y} = \frac{\Sigma Yfy}{\Sigma fy} = \frac{-349}{124} = -2.815$$

$$\sigma_x^2 = \frac{\Sigma X^2fx}{\Sigma fx} - \bar{X}^2 = \frac{1179}{124} - (-2.621)^2 = 2.638 \qquad \sigma_y^2 = \frac{\Sigma Y^2fy}{\Sigma fy} - \bar{Y}^2 = \frac{1263}{124} - (-2.815)^2 = 2.261$$

$$\therefore \sigma_x = 1.624 \qquad \therefore \sigma_y = 1.504$$

$$\frac{1}{n}\Sigma XY = \frac{1165}{124} = 9.395$$

Coefficient of correlation $= r = \dfrac{\frac{1}{n}\Sigma XY - \bar{X}\bar{Y}}{\sigma_x \sigma_y} = \dfrac{9.395 - (-2.621)(-2.815)}{(1.624)(1.504)}$

$$\therefore \underline{\underline{r = 0.826}}$$

Standard error $\sigma_r = \dfrac{1-r^2}{\sqrt{n}} = \dfrac{1-(0.826)^2}{\sqrt{124}} = \underline{\underline{\pm 0.029}}$

Middlehope Burn. Stream gauge record. (The stage in feet.)

	1954								1954	1955		1955
	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.
1	0.43	0.35	0.39	0.35	0.34	0.38	0.49	0.68	0.78	0.46	0.50	0.36
2	0.41	0.75	0.38	0.35	0.34	0.37	0.53	0.50	1.60	0.44	0.62	0.36
3	0.44	1.18	0.37	0.35	0.33	0.37	0.47	0.49	0.69	0.44	0.48	0.38
4	0.49	0.56	0.37	0.37	0.33	0.37	0.62	0.46	0.96	0.43	0.54	0.38
5	0.43	0.45	0.36	0.56	0.35	0.36	0.51	0.45	0.62	0.44	0.57	0.42
6	0.44	1.40	0.36	0.39	0.47	0.36	0.57	1.15	0.53	0.43	0.47	0.39
7	0.41	0.56	0.36	0.36	0.36	0.37	0.46	0.64	0.47	0.42	0.42	0.38
8	0.40	0.45	0.39	0.35	0.37	0.36	0.46	0.51	0.45	0.42	1.00	0.38
9	0.39	0.40	0.40	0.35	0.35	0.37	0.43	0.62	0.50	0.40	0.57	0.38
10	0.38	0.39	0.52	0.35	0.42	0.42	0.42	0.53	0.62	2.30	0.47	0.38
11	0.38	0.38	0.42	0.34	0.46	0.60	0.42	0.68	0.55	0.58	0.42	0.41
12	0.38	0.37	0.38	0.34	0.36	0.45	0.41	0.68	0.45	0.47	0.43	0.45
13	0.37	0.37	0.37	0.34	0.37	0.47	0.41	0.56	0.62	(0.45)	0.43	0.42
14	0.36	0.37	0.36	0.35	0.35	0.43	0.72	0.58	0.49	(0.43)	0.41	0.45
15	0.36	0.40	0.36	0.34	0.34	0.43	0.65	0.49	0.86	0.42	0.41	0.54
16	0.36	0.37	0.55	0.33	0.44	1.07	0.65	0.48	0.54	0.41	0.40	0.75
17	0.36	0.37	0.40	0.33	0.42	0.53	1.18	0.45	0.60	(0.41)	0.40	0.51
18	0.36	0.36	0.38	0.34	1.80	0.48	1.25	0.45	0.50	0.40	0.40	0.43
19	0.36	0.36	0.37	0.33	0.66	0.43	1.15	0.45	0.83	0.39	0.39	0.42
20	0.35	0.35	0.36	0.33	1.43	0.72	0.57	0.44	0.56	0.39	0.39	0.41
21	0.35	0.35	0.37	0.33	0.93	0.57	0.50	0.44	0.52	0.39	0.39	0.43
22	0.35	0.40	0.37	0.33	1.23	0.50	0.50	0.50	0.51	0.55	0.38	0.39
23	0.35	0.45	0.36	0.34	0.80	0.44	0.47	0.56	0.72	0.57	0.38	0.39
24	0.35	0.40	0.35	0.35	1.00	0.54	1.40	0.72	0.46	0.52	0.38	0.58
25	0.35	0.60	0.36	0.34	0.58	0.74	0.64	1.10	0.65	0.92	0.38	0.92
26	0.35	0.44	0.38	0.33	0.50	0.50	0.51	0.54	0.74	0.60	0.38	0.62
27	0.34	0.40	0.42	0.35	0.45	0.48	0.96	0.85	0.54	0.50	0.37	0.50
28	0.34	0.47	0.42	0.51	0.42	0.46	0.81	1.00	0.57	0.57	0.37	0.46
29	0.34	0.82	0.37	0.39	0.40	0.44	1.63	0.54	0.69	0.78		0.45
30	0.34	0.49	0.36	0.36	0.40	0.67	0.64	0.74	0.52	0.74		0.39
31		0.42		0.35	0.39		0.56		0.48	0.56		0.40

( ) estimated values

Discharge Measurements. (0.6 depth Method)

Oct. 4th 1954

1. GAUGE 0.55 Time 1422 hrs. 2. GAUGE 0.54 Time 1515 hrs. MEAN GAUGE 0.54.

Dist.fr. bank in ft.	Depth in ft.	Revs.	Time in secs.	Mean velocity in vertical	MEAN VEL. IN SECTION FT/SEC.	AREA SQ. FT.	MEAN DEPTH FT.	WIDTH FT.	DISCHARGE CUSECS.
0.5	Cups not covered.								
1	0.35	5	70	0.20	0.20	0.70	0.35	2	0.140
2	0.40	10	70	0.35					
					0.44	0.40	0.40	1	0.176
3	0.40	15	67	0.53					
					0.68	0.40	0.40	1	0.272
4	0.40	20	56	0.82					
					0.92	0.43	0.43	1	0.396
5	0.45	20	45	1.01					
					1.13	0.45	0.45	1	0.509
6	0.45	30	54	1.25					
					1.33	0.47	0.47	1	0.625
7	0.48	30	48	1.41					
					1.51	0.52	0.52	1	0.785
8	0.55	30	42	1.61					
					1.66	0.55	0.55	1	0.913
9	0.55	40	53	1.70					
					1.70	0.53	0.53	1	0.901
10	0.50	40	53	1.70					
					1.62	0.53	0.53	1	0.859
11	0.55	40	59	1.53					
					1.57	0.57	0.57	1	0.895
12	0.58	40	56	1.61					
					1.56	0.57	0.57	1	0.889
13	0.55	40	60	1.50					
					1.41	0.58	0.58	1	0.818
14	0.60	40	68	1.32					
					1.23	0.60	0.60	1	0.738
15	0.60	30	60	1.13					
					1.07	0.60	0.60	1	0.642
16	0.60	20	45	1.01					
					0.82	0.60	0.60	1	0.492
17	0.60	15	57	0.62					
					0.53	0.63	0.63	1	0.334
18	0.65	10	57	0.43					
					0.32	0.65	0.65	1	0.208
19	0.65	5	66	0.21					
19.5	0.67	3	70	0.13	0.13	0.67	0.67	1	0.087
20									

TOTAL DISCHARGE 10.679

Oct. 14th 1954

1. GAUGE 0.58 Time 1355 hrs. 2. GAUGE 0.56 Time 1515 hrs. MEAN GAUGE 0.57

Dist.fr. bank in ft.	Depth in ft.	Revs.	Time in secs.	Mean vel. in vertical	MEAN VEL. IN SECTION FT/SEC.	AREA SQ. FT.	MEAN DEPTH FT.	WIDTH FT.	DISCHARGE CUSECS.
0.5	0.38	2	47	0.13	0.13	0.38	0.38	1	0.049
1	0.38	3	45	0.19					
					0.24	0.40	0.40	1	0.096
2	0.42	5	45	0.28					
					0.36	0.42	0.42	1	0.151
3	0.42	10	56	0.43					
					0.57	0.43	0.43	1	0.245
4	0.43	15	49	0.71					
					0.86	0.44	0.44	1	0.378
5	0.45	20	45	1.01					
					1.17	0.46	0.46	1	0.538
6	0.46	30	51	1.32					
					1.47	0.48	0.48	1	0.706
7	0.50	40	56	1.61					
					1.74	0.53	0.53	1	0.922
8	0.55	40	48	1.87					
					1.96	0.55	0.55	1	1.078
9	0.55	40	44	2.04					
					2.02	0.53	0.53	1	1.071
10	0.50	40	45	2.00					
					1.96	0.54	0.54	1	1.058
11	0.58	40	47	1.91					
					1.84	0.58	0.58	1	1.067
12	0.58	40	51	1.77					
					1.77	0.58	0.58	1	1.027
13	0.58	40	51	1.77					
					1.69	0.59	0.59	1	0.997
14	0.60	40	56	1.61					
					1.48	0.60	0.60	1	0.888
15	0.60	30	50	1.35					
					1.22	0.61	0.61	1	0.744
16	0.62	20	42	1.08					
					0.89	0.63	0.63	1	0.561
17	0.64	15	48	0.73					
					0.62	0.65	0.65	1	0.403
18	0.66	10	48	0.50					
					0.37	0.68	0.68	1	0.252
19	0.70	5	58	0.23					
19.5	0.68	2	53	0.12	0.12	0.68	0.68	1	0.082
20									
						TOTAL DISCHARGE			12.313

Nov. 25th 1954

1. GAUGE 0.75 Time 1403 hrs. 2. GAUGE 0.73 Time 1507 hrs. MEAN GAUGE 0.74

Dist.fr. bank in ft.	Depth in ft.	Revs.	Time in secs.	Mean vel. in vertical	MEAN VEL. IN SECTION FT/SEC.	AREA SQ. FT.	MEAN DEPTH FT.	WIDTH FT.	DISCHARGE CUSECS.
0.5	0.55	-	-	-		0.55	0.55	1	
1	0.55	-	-	-					
					-	0.58	0.58	1	
2	0.6	-	-	-					
					0.12	0.60	0.60	1	0.072
3	0.6	5	58	0.23					
					0.44	0.61	0.61	1	0.268
4	0.62	15	55	0.64					
					0.94	0.64	0.64	1	0.602
5	0.65	30	55	1.23					
					1.52	0.65	0.65	1	0.988
6	0.65	40	50	1.80					
					1.92	0.68	0.68	1	1.306
7	0.7	40	44	2.04					
					2.30	0.75	0.75	1	1.725
8	0.8	50	44	2.56					
					2.82	0.83	0.83	1	2.341
9	0.85	60	44	3.07					
					3.14	0.85	0.85	1	2.669
10	0.85	60	42	3.21					
					3.21	0.88	0.88	1	2.825
11	0.9	60	42	3.21					
					3.21	0.90	0.90	1	2.889
12	0.9	60	42	3.21					
					3.18	0.90	0.90	1	2.862
13	0.9	60	43	3.14					
					2.98	0.90	0.90	1	2.682
14	0.9	60	48	2.81					
					2.58	0.88	0.88	1	2.270
15	0.85	50	48	2.34					
					2.11	0.85	0.85	1	1.794
16	0.85	40	48	1.87					
					1.48	0.85	0.85	1	1.258
17	0.85	30	63	1.08					
					0.75	0.85	0.85	1	0.638
18	0.85	10	59	0.41					
					0.21	0.85	0.85	1	0.178
19	0.85	-	-						
19.5	0.85	-	-		-	0.85	0.85	1	
20									

TOTAL DISCHARGE 27.367

December 11th 1954.

1. GAUGE 0.52 Time 1418 hrs. 2. GAUGE 0.52 Time 1515 hrs. MEAN GAUGE 0.52

Dist.fr. bank in ft.	Depth in ft.	Revs.	Time in secs.	Mean vel. in vertical	MEAN VEL. IN SECTION FT/SEC.	AREA SQ. FT.	MEAN DEPTH FT.	WIDTH FT.	DISCHARGE CUSECS.
0.5	0.35	8	74	0.28	0.28	0.35	0.35	1	0.098
1	0.35	8	64	0.32					
					0.39	0.36	0.36	1	0.140
2	0.37	8	41	0.47					
					0.53	0.37	0.37	1	0.196
3	0.37	10	40	0.59					
					0.70	0.39	0.39	1	0.273
4	0.4	15	43	0.80					
					0.91	0.41	0.41	1	0.373
5	0.42	20	45	1.01					
					1.05	0.42	0.42	1	0.441
6	0.42	20	42	1.08					
					1.16	0.43	0.43	1	0.499
7	0.44	30	55	1.23					
					1.34	0.48	0.48	1	0.643
8	0.52	30	47	1.44					
					1.49	0.51	0.51	1	0.760
9	0.50	30	44	1.53					
					1.49	0.50	0.50	1	0.745
10	0.50	30	47	1.44					
					1.47	0.51	0.51	1	0.750
11	0.52	30	45	1.50					
					1.51	0.52	0.52	1	0.785
12	0.52	30	44	1.53					
					1.52	0.52	0.52	1	0.790
13	0.52	30	45	1.50					
					1.39	0.53	0.53	1	0.737
14	0.54	30	53	1.27					
					1.18	0.54	0.54	1	0.637
15	0.54	20	42	1.08					
					0.98	0.54	0.54	1	0.529
16	0.54	20	53	0.87					
					0.71	0.56	0.56	1	0.398
17	0.58	10	43	0.55					
					0.51	0.58	0.58	1	0.296
18	0.58	10	53	0.46					
					0.34	0.59	0.59	1	0.201
19	0.60	5	63	0.22					
19.5	0.64	-	-	-	-	0.64	0.64	1	
20									

TOTAL DISCHARGE 9.291

Dec. 30th 1954.

1. GAUGE 0.51 Time 1410 hrs. 2. GAUGE 0.51 Time 1510 hrs. MEAN GAUGE 0.51

Dist. fr. bank in ft.	Depth in ft.	Revs.	Time in secs.	Mean vel. in vertical	MEAN VEL. IN SECTION FT/SEC.	AREA SQ. FT.	MEAN DEPTH FT.	WIDTH FT.	DISCHARGE CUSECS.
0.5	0.32	3	46	0.18	0.18	0.32	0.32	1	0.058
1	0.32	5	50	0.26					
					0.36	0.34	0.34	1	0.122
2	0.35	10	53	0.46					
					0.56	0.35	0.35	1	0.196
3	0.35	15	52	0.67					
					0.72	0.37	0.37	1	0.266
4	0.40	15	45	0.77					
					0.88	0.41	0.41	1	0.361
5	0.42	20	46	0.99					
					1.03	0.42	0.42	1	0.433
6	0.42	20	42	1.08					
					1.11	0.43	0.43	1	0.477
7	0.44	30	60	1.13					
					1.20	0.47	0.47	1	0.564
8	0.50	30	53	1.27					
					1.32	0.50	0.50	1	0.660
9	0.50	30	49	1.38					
					1.41	0.51	0.51	1	0.719
10	0.52	30	47	1.44					
					1.46	0.51	0.51	1	0.745
11	0.50	30	46	1.47					
					1.45	0.50	0.50	1	0.725
12	0.50	30	47	1.44					
					1.40	0.51	0.51	1	0.714
13	0.52	30	50	1.35					
					1.30	0.54	0.54	1	0.702
14	0.56	30	54	1.25					
					1.16	0.55	0.55	1	0.638
15	0.54	20	42	1.08					
					0.94	0.54	0.54	1	0.508
16	0.54	20	59	0.79					
					0.67	0.55	0.55	1	0.369
17	0.56	15	65	0.55					
					0.42	0.57	0.57	1	0.239
18	0.58	5	42	0.30					
					0.15	0.59	0.59	1	0.089
19	0.60	-	-	-					
19.5	0.62	-	-	-	-	0.62	0.62	1	
20									
							TOTAL DISCHARGE		8.585

March 16th 1955.

1. GAUGE 0.86 Time 1115 hrs. 2. GAUGE 0.94 Time 1155 hrs. MEAN GAUGE 0.90

Dist. fr. bank in ft.	Depth in ft.	Revs.	Time in secs.	Mean vel. in vertical	MEAN VEL. IN SECTION FT/SEC.	AREA SQ. FT.	MEAN DEPTH FT.	WIDTH FT.	DISCHARGE CUSECS.
0.5	0.68	15	56	0.63	0.63	0.68	0.68	1	0.428
1	0.65	20	52	0.88					
					1.08	0.68	0.68	1	0.734
2	0.70	30	53	1.27					
					1.31	0.73	0.73	1	0.956
3	0.75	30	50	1.35					
					1.46	0.75	0.75	1	1.095
4	0.75	30	43	1.57					
					2.25	0.78	0.78	1	1.755
5	0.80	60	46	2.93					
					3.18	0.85	0.85	1	2.703
6	0.90	70	46	3.43					
					3.39	0.95	0.95	1	3.221
7	1.00	70	47	3.35					
					3.51	1.00	1.00	1	3.510
8	1.00	70	43	3.67					
9					3.84	2.10	1.05	2	8.064
10	1.10	80	45	4.00					
11					3.13	2.10	1.05	2	6.573
12	1.00	50	50	2.25					
13					2.50	2.00	1.00	2	5.000
14	1.00	50	41	2.74					
15					2.78	2.00	1.00	2	5.560
16	1.00	50	40	2.81					
					2.51	1.00	1.00	1	2.510
17	1.00	40	41	2.20					
					1.97	1.00	1.00	1	1.970
18	1.00	40	52	1.73					
					1.32	1.00	1.00	1	1.320
19	1.00	20	51	0.90					
19.5	1.00	10	41	0.58	0.58	1.00	1.00	1	0.580
20									

TOTAL DISCHARGE 45.979

April 4th 1955

1. GAUGE 0.50 Time 1435 hrs. 2. GAUGE 0.50 Time 1550 hrs. MEAN GAUGE 0.50

Dist.fr. bank in ft.	Depth in ft.	Revs.	Time in secs.	Mean vel. in vertical	MEAN VEL. IN SECTION FT/SEC.	AREA SQ. FT.	MEAN DEPTH FT.	WIDTH FT.	DISCHARGE CUSECS.
0.5	0.25	-	-						
1		-	-		0.19	0.54	0.27	2	0.103
2	0.30	8	53	0.37					
					0.42	0.33	0.33	1	0.139
3	0.35	10	51	0.47					
					0.61	0.36	0.36	1	0.220
4	0.37	15	47	0.74					
					0.87	0.39	0.39	1	0.339
5	0.40	20	46	0.99					
					1.05	0.40	0.40	1	0.420
6	0.40	30	62	1.10					
					1.11	0.41	0.41	1	0.455
7	0.42	30	61	1.12					
					1.15	0.45	0.45	1	0.518
8	0.48	30	58	1.17					
					1.21	0.48	0.48	1	0.581
9	0.48	30	54	1.25					
					1.22	0.46	0.46	1	0.561
10	0.44	30	57	1.19					
					1.16	0.47	0.47	1	0.545
11	0.50	30	60	1.13					
					1.01	0.50	0.50	1	0.505
12	0.50	20	52	0.88					
					0.85	0.50	0.50	1	0.425
13	0.50	20	57	0.81					
					0.84	0.50	0.50	1	0.420
14	0.50	20	53	0.87					
					0.90	0.50	0.50	1	0.450
15	0.50	20	49	0.93					
					0.89	0.51	0.51	1	0.454
16	0.52	15	41	0.84					
					0.77	0.55	0.55	1	0.424
17	0.57	15	50	0.70					
					0.62	0.57	0.57	1	0.353
18	0.57	15	66	0.54					
					0.42	0.59	0.59	1	0.248
19	0.60	8	70	0.29					
19.5	0.62	-	-		0.15	0.61	0.61	1	0.092
20									

TOTAL DISCHARGE 7.252

Current meter measurement higher upstream

April 14th 1955

1: GAUGE 0:35 Time 1410 hrs: 2: GAUGE 0:35 Time 1510 hrs: MEAN GAUGE 0:35

Dist.fr. bank in ft.	Depth in ft.	Revs.	Time in secs.	Mean vel. in vertical	MEAN VEL. IN SECTION FT/SEC.	AREA SQ: FT.	MEAN DEPTH FT.	WIDTH FT.	DISCHARGE CUSECS.
0.5	0.82	-	-	-	0.09	0.82	0.82	1	0.074
1	0.82	3	49	0.18					
					0.18	0.47	0.93	0.5	0.085
1.5	1.03	3	51	0.17					
					0.22	0.52	1.03	0.5	0.114
2	1.02	5	50	0.26					
					0.24	0.52	1.04	0.5	0.125
2.5	1.05	5	65	0.21					
					0.24	0.53	1.05	0.5	0.127
3	1.05	5	50	0.26					
					0.31	0.52	1.04	0.5	0.161
3.5	1.03	10	68	0.36					
					0.44	0.52	1.03	0.5	0.229
4	1.03	10	46	0.52					
					0.34	0.51	1.02	0.5	0.173
4.5	1.00	3	53	0.16					
					0.08	0.50	1.00	0.5	0.040
5	1.00	-	-	-					
					-	0.50	1.00	0.5	-
5.5	1.00	-	-	-					
					-	0.50	0.99	0.5	-
6	0.98	-	-	-					
6.5	0.87	-	-	-	-	0.87	0.87	1	-
7									
					TOTAL DISCHARGE				1.128

May 5th 1955

1. GAUGE 0.70 Time 1450 hrs. 2. GAUGE 0.66 Time 1550 hrs. MEAN GAUGE 0.68

Dist.fr. bank in ft.	Depth in ft.	Revs.	Time in secs.	Mean vel. in vertical	MEAN VEL. IN SECTION FT/SEC.	AREA SQ. FT.	MEAN DEPTH FT.	WIDTH FT.	DISCHARGE CUSECS.
0.5	0.50	10	56	0.43	0.43	0.50	0.50	1	0.215
1	0.50	10	43	0.55					
					0.68	0.51	0.51	1	0.347
2	0.52	20	57	0.81					
					1.07	0.52	0.52	1	0.556
3	0.52	30	51	1.32					
					1.56	0.56	0.56	1	0.874
4	0.60	40	50	1.80					
					2.10	0.63	0.63	1	1.323
5	0.65	50	47	2.39					
					2.57	0.65	0.65	1	1.671
6	0.65	50	41	2.74					
					2.71	0.68	0.68	1	1.843
7	0.70	50	42	2.68					
					2.75	0.75	0.75	1	2.063
8	0.80	50	40	2.81					
					2.74	0.80	0.80	1	2.192
9	0.80	50	42	2.68					
					2.57	0.75	0.75	1	1.928
10	0.70	50	46	2.45					
					2.23	0.70	0.70	1	1.561
11	0.70	40	45	2.00					
					1.78	0.70	0.70	1	1.246
12	0.70	40	58	1.55					
					1.51	0.73	0.73	1	1.102
13	0.75	30	46	1.47					
					1.64	0.75	0.75	1	1.230
14	0.75	40	50	1.80					
					1.90	0.78	0.78	1	1.482
15	0.80	40	45	2.00					
					1.98	0.80	0.80	1	1.584
16	0.80	40	46	1.96					
					1.90	0.80	0.80	1	1.520
17	0.80	40	49	1.84					
					1.58	0.80	0.80	1	1.264
18	0.80	30	51	1.32					
					0.96	0.80	0.80	1	0.768
19	0.80	15	60	0.59					
19.5	0.80	5	54	0.24	0.24	0.80	0.80	1	0.192
20									
						TOTAL DISCHARGE			24.961

Measurement c. 2' upstream from gauge post

June 4th 1955

1. GAUGE 0.33 Time 1425 hrs. 2. GAUGE 0.33 Time 1450 hrs. MEAN GAUGE 0.33

Dist.fr. bank in ft.	Depth in ft.	Revs.	Time in secs.	Mean vel. in vertical	MEAN VEL. IN SECTION FT/SEC.	AREA SQ. FT.	MEAN DEPTH FT.	WIDTH FT.	DISCHARGE CUSECS.
1	0.40	-	-	-	-	0.40	0.40	1	-
					-	0.42	0.42	1	-
2	0.44	-	-	-					
					-	0.45	0.45	1	-
3	0.45	-	-	-					
					0.06	0.48	0.48	1	0.029
4	0.50	2	62	0.11					
					0.12	0.50	0.50	1	0.060
5	0.50	2	50	0.13					
					0.16	0.51	0.51	1	0.082
6	0.52	3	43	0.19					
					0.19	0.54	0.54	1	0.103
7	0.55	3	46	0.18					
					0.22	0.58	0.58	1	0.128
8	0.60	5	51	0.26					
					0.25	0.60	0.60	1	0.150
9	0.60	5	54	0.24					
					0.16	0.60	0.60	1	0.096
10	0.60	2	70	0.10					
					0.05	0.60	0.60	1	0.030
11	0.60	-	-	-					
					-	0.60	0.60	1	-
12	0.60	-	-	-					
					0.09	0.60	0.60	1	0.054
13	0.60	3	48	0.18					
					0.09	0.61	0.61	1	0.055
14	0.62	-	-	-					
					-	0.66	0.66	1	-
15	0.70	-	-	-					
					-	0.68	0.68	1	-
16	0.66	-	-	-					
					-	0.68	0.68	1	-
17	0.70	-	-	-					
					-	0.70	0.70	1	-
18									
					TOTAL DISCHARGE				0.787

Measurement 2' upstream of gauge post

June 11th 1955

1. GAUGE 0.36 Time 1450 hrs. 2. GAUGE 0.36 Time 1520 hrs. MEAN GAUGE 0.36

Dist.fr. bank in ft.	Depth in ft.	Revs.	Time in secs.	Mean vel. in vertical	MEAN VEL. IN SECTION FT/SEC.	AREA SQ. FT.	MEAN DEPTH FT.	WIDTH FT.	DISCHARGE CUSECS.
1	0.45	-	-	-					
2	0.52	-	-	-					
3	0.52	-	-	-					
4	0.57	-	-	-					
					-	-	-	-	-
5	0.54	-	-	-					
					0.15	0.57	0.57	1	0.086
6	0.60	5	42	0.30					
					0.26	0.58	0.58	1	0.151
7	0.56	3	40	0.21					
					0.24	0.59	0.59	1	0.142
8	0.62	5	48	0.27					
					0.14	0.62	0.62	1	0.087
9	0.62	-	-	-					
					-				
10	0.67	-	-	-					
					-				
11	0.67	-	-	-					
					-				
12	0.65	-	-	-					
					-				
13	0.70	-	-	-					
					-				
14	0.65	-	-	-					
					-				
15	0.72	-	-	-					
					-				
16	0.68	-	-	-					
					-				
17	0.64	-	-	-					
					-				
18									
						TOTAL DISCHARGE			0.466

Measurement higher upstream

June 11th 1955

GAUGE 0.36

Dist. fr. bank in ft.	Depth in ft.	Revs.	Time in secs.	Mean vel. in vertical	MEAN VEL. IN SECTION FT/SEC.	AREA SQ. FT.	MEAN DEPTH FT.	WIDTH FT.	DISCHARGE CUSECS.
0.5	0.88	-	-	-	-				
1	0.94	-	-	-					
					-				
1.5	0.97	-	-	-					
					-				
2	0.97	-	-	-					
					-				
2.5	0.97	-	-	-					
					0.15	0.49	0.97	0.5	0.074
3	0.97	5	44	0.29					
					0.35	0.5	1.00	0.5	0.175
3.5	1.02	8	48	0.41					
					0.39	0.51	1.02	0.5	0.199
4	1.02	8	52	0.37					
					0.19	0.52	1.04	0.5	0.099
4.5	1.05	-	-	-					
					-				
5	1.02	-	-	-					
					-				
5.5	1.02	-	-	-					
					-				
6	1.04	-	-	-					
					-				
6.5	1.00	-	-	-					
					-				
7	0.65	-	-	-					
					-				
7.5									
						TOTAL DISCHARGE			0.547

July 3rd 1955

1. GAUGE 0.75 Time 1315 hrs. 2. GAUGE 0.69 Time 1410 hrs. MEAN GAUGE 0.72

Dist.fr. bank in ft.	Depth in ft.	Revs.	Time in secs.	Mean vel. in vertical	MEAN VEL. IN SECTION FT/SEC.	AREA SQ. FT.	MEAN DEPTH FT.	WIDTH FT.	DISCHARGE CUSECS.
0.5	0.54	8	49	0.40	0.40	0.54	0.54	1	0.216
1	0.52	15	52	0.67					
					0.83	0.54	0.54	1	0.448
2	0.56	20	46	0.99					
					1.26	0.58	0.58	1	0.731
3	0.60	30	44	1.53					
					1.77	0.63	0.63	1	1.115
4	0.66	40	45	2.00					
					2.23	0.68	0.68	1	1.516
5	0.70	50	46	2.45					
					2.54	0.72	0.72	1	1.829
6	0.74	50	43	2.62					
					2.59	0.75	0.75	1	1.943
7	0.76	50	44	2.56					
					2.62	0.78	0.78	1	2.044
8	0.80	50	42	2.68					
					2.75	0.80	0.80	1	2.200
9	0.80	60	48	2.81					
					2.66	0.80	0.80	1	2.128
10	0.80	50	45	2.50					
					2.23	0.80	0.80	1	1.784
11	0.80	40	46	1.96					
					1.67	0.78	0.78	1	1.303
12	0.76	30	49	1.38					
					1.30	0.76	0.76	1	0.988
13	0.76	30	56	1.21					
					1.61	0.78	0.78	1	1.256
14	0.80	40	45	2.00					
					2.00	0.80	0.80	1	1.600
15	0.80	40	45	2.00					
					1.90	0.80	0.80	1	1.520
16	0.80	40	50	1.80					
					1.64	0.82	0.82	1	1.345
17	0.84	30	46	1.47					
					1.22	0.82	0.82	1	1.000
18	0.80	20	47	0.97					
					0.61	0.80	0.80	1	0.488
19	0.80	5	54	0.24	0.12	0.40	0.80	0.5	0.048
19.5	0.80	-	-	-	-				
20									
							TOTAL DISCHARGE		25.502

July 4th 1955

1. GAUGE 0.68 Time 0920 hrs. 2. GAUGE 0.66 Time 1010 hrs. MEAN GAUGE 0.67

Dist. fr. bank in ft.	Depth in ft.	Revs.	Time in secs.	Mean vel. in vertical	MEAN VEL. IN SECTION FT/SEC.	AREA SQ. FT.	MEAN DEPTH FT.	WIDTH FT.	DISCHARGE CUSECS.
0.5	0.47	8	51	0.39	0.39	0.47	0.47	1	0.183
1	0.44	15	54	0.65					
					0.81	0.46	0.46	1	0.373
2	0.48	20	47	0.97					
					1.18	0.49	0.49	1	0.578
3	0.50	30	49	1.38					
					1.54	0.52	0.52	1	0.801
4	0.54	30	40	1.69					
					1.87	0.54	0.54	1	1.010
5	0.54	40	44	2.04					
					2.15	0.56	0.56	1	1.204
6	0.58	50	50	2.25					
					2.25	0.59	0.59	1	1.328
7	0.60	40	40	2.25					
					2.28	0.63	0.63	1	1.436
8	0.66	50	49	2.30					
					2.32	0.68	0.68	1	1.578
9	0.70	50	48	2.34					
					2.27	0.68	0.68	1	1.544
10	0.66	40	41	2.20					
					2.02	0.66	0.66	1	1.333
11	0.66	40	49	1.84					
					1.49	0.66	0.66	1	0.983
12	0.66	30	60	1.13					
					1.19	0.68	0.68	1	0.809
13	0.70	30	54	1.25					
					1.35	0.70	0.70	1	0.945
14	0.70	30	47	1.44					
					1.59	0.70	0.70	1	1.113
15	0.70	40	52	1.73					
					1.69	0.70	0.70	1	1.183
16	0.70	30	41	1.65					
					1.59	0.72	0.72	1	1.145
17	0.74	30	44	1.53					
					1.25	0.74	0.74	1	0.925
18	0.74	20	47	0.97					
					0.62	0.75	0.75	1	0.465
19	0.76	5	47	0.27					
					0.14	0.38	0.76	0.5	0.053
19.5	0.76	-	-	-					
20									
					TOTAL DISCHARGE				18.989

Jan. 5th 1956

1. GAUGE 0.45 Time 1040 hrs. 2. GAUGE 0.45 Time 1135 hrs. MEAN GAUGE 0.45

Dist.fr. bank in ft.	Depth in ft.	Revs.	Time in secs.	Mean vel. in vertical	MEAN VEL. IN SECTION FT/SEC.	AREA SQ. FT.	MEAN DEPTH FT.	WIDTH FT.	DISCHARGE CUSECS.
0.5	0.28	–	–	–					
1	0.28	–	–	–					
					0.20	0.58	0.29	2	0.116
2	0.30	8	50	0.39					
					0.43	0.30	0.30	1	0.129
3	0.30	8	42	0.46					
					0.52	0.32	0.32	1	0.166
4	0.34	15	62	0.57					
					0.60	0.34	0.34	1	0.204
5	0.34	15	57	0.62					
					0.66	0.37	0.37	1	0.244
6	0.40	15	51	0.69					
					0.73	0.41	0.41	1	0.299
7	0.42	15	46	0.76					
					0.78	0.42	0.42	1	0.328
8	0.42	15	43	0.80					
					0.80	0.41	0.41	1	0.328
9	0.40	15	44	0.79					
					0.77	0.42	0.42	1	0.323
10	0.44	15	46	0.76					
					0.70	0.44	0.44	1	0.308
11	0.44	15	55	0.64					
					0.63	0.44	0.44	1	0.277
12	0.44	15	58	0.61					
					0.60	0.43	0.43	1	0.258
13	0.42	15	61	0.58					
					0.60	0.43	0.43	1	0.258
14	0.44	15	56	0.63					
					0.60	0.44	0.44	1	0.264
15	0.44	10	42	0.56					
					0.53	0.45	0.45	1	0.238
16	0.46	10	49	0.49					
					0.46	0.46	0.46	1	0.212
17	0.46	8	46	0.42					
					0.39	0.48	0.48	1	0.187
18	0.50	8	55	0.36					
					0.28	0.51	0.51	1	0.143
19	0.52	5	69	0.20					
19.5	0.50	5	67	0.20	0.20	0.50	0.50	1	0.100
20									
							TOTAL DISCHARGE		4.382

Middlehope Burn. Rating Table

From the curve log Q = 1.458 log (G - 0.33) + log 99.3

G	G-a	log (G-a)	log Q	Q	G	G-a	log (G-a)	log Q	Q
0.33	0	0	0	0	0.65	0.32	1.505	1.273	18.750
0.34	0.01	2.000	1.078	0.120	0.66	0.33	1.519	1.295	19.724
0.35	0.02	2.301	1.518	0.330	0.67	0.34	1.531	1.312	20.512
0.36	0.03	2.477	1.773	0.593	0.68	0.35	1.544	1.331	21.429
0.37	0.04	2.602	1.957	0.906	0.69	0.36	1.556	1.349	22.336
0.38	0.05	2.699	0.100	1.259	0.70	0.37	1.568	1.367	23.28
0.39	0.06	2.778	0.215	1.641	0.71	0.38	1.580	1.383	24.155
0.40	0.07	2.845	0.310	2.042	0.72	0.39	1.591	1.400	25.119
0.41	0.08	2.903	0.397	2.495	0.73	0.40	1.602	1.417	26.112
0.42	0.09	2.954	0.470	2.951	0.74	0.41	1.613	1.433	27.102
0.43	0.10	1.000	0.537	3.443	0.75	0.42	1.623	1.445	27.861
0.44	0.11	1.041	0.598	3.963	0.76	0.43	1.633	1.461	28.907
0.45	0.12	1.079	0.652	4.487	0.77	0.44	1.645	1.488	30.761
0.46	0.13	1.114	0.703	5.047	0.78	0.45	1.653	1.491	30.974
0.47	0.14	1.146	0.751	5.636	0.79	0.46	1.663	1.506	32.063
0.48	0.15	1.176	0.795	6.237	0.80	0.47	1.672	1.517	32.885
0.49	0.16	1.204	0.835	6.839	0.81	0.48	1.681	1.532	34.041
0.50	0.17	1.230	0.875	7.497	0.82	0.49	1.690	1.544	34.995
0.51	0.18	1.255	0.910	8.128	0.83	0.50	1.699	1.558	36.141
0.52	0.19	1.279	0.945	8.811	0.84	0.51	1.708	1.571	37.239
0.53	0.20	1.301	0.976	9.462	0.85	0.52	1.716	1.583	38.282
0.54	0.21	1.322	1.005	10.116	0.86	0.53	1.724	1.593	39.174
0.55	0.22	1.342	1.035	10.839	0.87	0.54	1.732	1.604	40.179
0.56	0.23	1.362	1.065	11.614	0.88	0.55	1.740	1.617	41.400
0.57	0.24	1.380	1.091	12.331	0.89	0.56	1.748	1.630	42.658
0.58	0.25	1.398	1.120	13.183	0.90	0.57	1.756	1.641	43.750
0.59	0.26	1.415	1.143	13.900	0.91	0.58	1.763	1.652	44.875
0.60	0.27	1.431	1.166	14.655	0.92	0.59	1.771	1.663	46.026
0.61	0.28	1.447	1.190	15.488	0.93	0.60	1.778	1.673	47.098
0.62	0.29	1.462	1.212	16.293	0.94	0.61	1.785	1.682	48.084
0.63	0.30	1.477	1.233	17.100	0.95	0.62	1.792	1.693	49.317
0.64	0.31	1.491	1.253	17.906	0.96	0.63	1.799	1.703	50.466

Table continued overleaf

Middlehope Burn. Rating Table cont.

G	G-a	log (G-a)	log Q	Q	G	G-a	log (G-a)	log Q	Q
0.97	0.64	1.806	1.714	51.761	1.19	0.86	1.934	1.901	79.62
0.98	0.65	1.813	1.725	53.088	1.20	0.87	1.940	1.910	81.28
0.99	0.66	1.820	1.734	54.200	1.21	0.88	1.944	1.916	82.41
1.00	0.67	1.826	1.743	55.34	1.22	0.89	1.949	1.922	83.56
1.01	0.68	1.833	1.753	56.62	1.23	0.90	1.954	1.930	85.11
1.02	0.69	1.839	1.762	57.81	.	.	.	.	.
1.03	0.70	1.845	1.771	59.02	1.25	0.92	1.964	1.945	88.11
1.04	0.71	1.851	1.780	60.26		.	.	.	.
1.05	0.72	1.857	1.788	61.38	1.35	1.02	0.009	2.011	102.57
1.06	0.73	1.863	1.797	62.66	.	.	.	.	.
1.07	0.74	1.869	1.806	63.97	1.40	1.07	0.029	2.040	109.65
1.08	0.75	1.875	1.814	65.16	1.43	1.10	0.041	2.057	114.02
1.09	0.76	1.881	1.823	66.53		.	.	.	.
1.10	0.77	1.886	1.832	67.92	1.60	1.27	0.104	2.148	140.60
1.11	0.78	1.892	1.839	69.02	.	.	.	.	.
1.12	0.79	1.898	1.849	70.63	1.63	1.30	0.114	2.163	145.55
1.13	0.80	1.903	1.857	71.95	.	.	.	.	.
1.14	0.81	1.908	1.863	72.95	1.80	1.47	0.167	2.240	173.78
1.15	0.82	1.914	1.872	74.47		.	.	.	.
.	.	.	.	.	2.30	1.97	0.294	2.423	264.85
1.18	0.85	1.929	1.893	78.16	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.

The Runoff Calculations

APRIL 1954				MAY 1954			
DAY	STAGE FEET	DISCHARGE CUSECS	MEAN DIS-CHARGE CUSEC.DAYS	DAY	STAGE FEET	DISCHARGE CUSECS	MEAN DIS-CHARGE CUSEC.DAYS
1	0.43	3.44	2.97	1	0.35	0.33	14.09
2	0.41	2.49	3.23	2	0.75	27.86	53.01
3	0.44	3.96	5.40	3	1.18	78.16	44.89
4	0.49	6.84	5.14	4	0.56	11.61	8.05
5	0.43	3.44	3.70	5	0.45	4.49	57.07
6	0.44	3.96	3.23	6	1.40	109.65	60.63
7	0.41	2.49	2.27	7	0.56	11.61	8.05
8	0.40	2.04	1.84	8	0.45	4.49	3.27
9	0.39	1.64	1.45	9	0.40	2.04	1.84
10	0.38	1.26	1.26	10	0.39	1.64	1.45
11	0.38	1.26	1.26	11	0.38	1.26	1.09
12	0.38	1.26	1.09	12	0.37	0.91	0.91
13	0.37	0.91	0.75	13	0.37	0.91	0.91
14	0.36	0.59	0.59	14	0.37	0.91	1.47
15	0.36	0.59	0.59	15	0.40	2.04	1.47
16	0.36	0.59	0.59	16	0.37	0.91	0.91
17	0.36	0.59	0.59	17	0.37	0.91	0.75
18	0.36	0.59	0.59	18	0.36	0.59	0.59
19	0.36	0.59	0.46	19	0.36	0.59	0.46
20	0.35	0.33	0.33	20	0.35	0.33	0.33
21	0.35	0.33	0.33	21	0.35	0.33	1.19
22	0.35	0.33	0.33	22	0.40	2.04	3.27
23	0.35	0.33	0.33	23	0.45	4.49	3.27
24	0.35	0.33	0.33	24	0.40	2.04	8.35
25	0.35	0.33	0.33	25	0.60	14.65	9.30
26	0.35	0.33	0.23	26	0.44	3.96	3.00
27	0.34	0.12	0.12	27	0.40	2.04	3.84
28	0.34	0.12	0.12	28	0.47	5.64	20.31
29	0.34	0.12	0.12	29	0.82	34.99	20.91
30	0.34	0.12	0.23	30	0.49	6.84	4.89
				31	0.42	2.95	2.29
May 1st	0.35	0.33		June 1st	0.39	1.64	
TOTAL			39.80				341.86

The Runoff Calculations

JUNE 1954				JULY 1954			
DAY	STAGE FEET	DISCHARGE CUSECS	MEAN DISCHARGE CUSEC.DAYS	DAY	STAGE FEET	DISCHARGE CUSECS	MEAN DISCHARGE CUSEC.DAYS
1	0.39	1.64	1.45	1	0.35	0.33	0.33
2	0.38	1.26	1.09	2	0.35	0.33	0.33
3	0.37	0.91	0.91	3	0.35	0.33	0.62
4	0.37	0.91	0.75	4	0.37	0.91	6.26
5	0.36	0.59	0.59	5	0.56	11.61	6.63
6	0.36	0.59	0.59	6	0.39	1.64	1.11
7	0.36	0.59	1.11	7	0.36	0.59	0.46
8	0.39	1.64	1.84	8	0.35	0.33	0.33
9	0.40	2.04	5.43	9	0.35	0.33	0.33
10	0.52	8.81	5.88	10	0.35	0.33	0.23
11	0.42	2.95	2.10	11	0.34	0.12	0.12
12	0.38	1.26	1.09	12	0.34	0.12	0.12
13	0.37	0.91	0.75	13	0.34	0.12	0.23
14	0.36	0.59	0.59	14	0.35	0.33	0.23
15	0.36	0.59	5.71	15	0.34	0.12	0.06
16	0.55	10.84	6.44	16	0.33	-	-
17	0.40	2.04	1.65	17	0.33	-	0.06
18	0.38	1.26	1.09	18	0.34	0.12	0.06
19	0.37	0.91	0.75	19	0.33	-	-
20	0.36	0.59	0.75	20	0.33	-	-
21	0.37	0.91	0.91	21	0.33	-	-
22	0.37	0.91	0.75	22	0.33	-	0.06
23	0.36	0.59	0.46	23	0.34	0.12	0.23
24	0.35	0.33	0.46	24	0.35	0.33	0.23
25	0.36	0.59	0.93	25	0.34	0.12	0.06
26	0.38	1.26	2.10	26	0.33	-	0.17
27	0.42	2.95	2.95	27	0.35	0.33	4.23
28	0.42	2.95	1.93	28	0.51	8.13	4.89
29	0.37	0.91	0.75	29	0.39	1.64	1.11
30	0.36	0.59	0.46	30	0.36	0.59	0.46
				31	0.35	0.33	0.23
July 1st	0.35	0.33		August 1st	0.34	0.12	
TOTAL			52.26				29.18

The Runoff Calculations

AUGUST 1954				SEPTEMBER 1954			
DAY	STAGE FEET	DISCHARGE CUSECS	MEAN DIS-CHARGE CUSEC.DAYS	DAY	STAGE FEET	DISCHARGE CUSECS	MEAN DIS-CHARGE CUSEC.DAYS
1	0.34	0.12	0.12	1	0.38	1.26	1.09
2	0.34	0.12	0.06	2	0.37	0.91	0.91
3	0.33	-	-	3	0.37	0.91	0.91
4	0.33	-	0.17	4	0.37	0.91	0.75
5	0.35	0.33	2.99	5	0.36	0.59	0.59
6	0.47	5.64	3.11	6	0.36	0.59	0.75
7	0.36	0.59	0.75	7	0.37	0.91	0.75
8	0.37	0.91	0.62	8	0.36	0.59	0.75
9	0.35	0.33	1.64	9	0.37	0.91	1.93
10	0.42	2.95	4.00	10	0.42	2.95	8.80
11	0.46	5.05	2.82	11	0.60	14.65	9.57
12	0.36	0.59	0.75	12	0.45	4.49	5.07
13	0.37	0.91	0.62	13	0.47	5.64	4.54
14	0.35	0.33	0.23	14	0.43	3.44	3.44
15	0.34	0.12	2.04	15	0.43	3.44	33.70
16	0.44	3.96	3.45	16	1.07	63.97	36.71
17	0.42	2.95	88.37	17	0.53	9.46	7.85
18	1.80	173.78	96.75	18	0.48	6.24	4.84
19	0.66	19.72	66.87	19	0.43	3.44	14.28
20	1.43	114.02	80.56	20	0.72	25.12	18.73
21	0.93	47.10	66.10	21	0.57	12.33	9.91
22	1.23	85.11	59.10	22	0.50	7.50	5.73
23	0.80	32.89	44.11	23	0.44	3.96	7.04
24	1.00	55.34	34.26	24	0.54	10.12	18.61
25	0.58	13.18	10.34	25	0.74	27.10	17.30
26	0.50	7.50	5.99	26	0.50	7.50	6.87
27	0.45	4.49	3.72	27	0.48	6.24	5.65
28	0.42	2.95	2.49	28	0.46	5.05	4.50
29	0.40	2.04	2.04	29	0.44	3.96	12.23
30	0.40	2.04	1.84	30	0.67	20.51	13.67
31	0.39	1.64	1.45				
Sept. 1st	0.38	1.26		Oct. 1st	0.49	6.84	
TOTAL			587.26				257.47

The Runoff Calculations

OCTOBER 1954				NOVEMBER 1954			
DAY	STAGE FEET	DISCHARGE CUSECS	MEAN DISCHARGE CUSEC.DAYS	DAY	STAGE FEET	DISCHARGE CUSECS	MEAN DISCHARGE CUSEC.DAYS
1	0.49	6.84	8.15	1	0.68	21.43	14.47
2	0.53	9.46	7.55	2	0.50	7.50	7.17
3	0.47	5.64	10.97	3	0.49	6.84	5.95
4	0.62	16.29	12.21	4	0.46	5.05	4.77
5	0.51	8.13	10.23	5	0.45	4.49	39.48
6	0.57	12.33	8.69	6	1.15	74.47	46.19
7	0.46	5.05	5.05	7	0.64	17.91	13.02
8	0.46	5.05	4.25	8	0.51	8.13	12.21
9	0.43	3.44	3.19	9	0.62	16.29	12.87
10	0.42	2.95	2.95	10	0.53	9.46	15.45
11	0.42	2.95	2.72	11	0.68	21.43	21.43
12	0.41	2.49	2.49	12	0.68	21.43	16.52
13	0.41	2.49	13.81	13	0.56	11.61	12.39
14	0.72	25.12	21.93	14	0.58	13.18	10.01
15	0.65	18.75	18.75	15	0.49	6.84	6.54
16	0.65	18.75	48.45	16	0.48	6.24	5.37
17	1.18	78.16	83.13	17	0.45	4.49	4.49
18	1.25	88.11	81.29	18	0.45	4.49	4.49
19	1.15	74.47	43.40	19	0.45	4.49	4.23
20	0.57	12.33	9.91	20	0.44	3.96	3.96
21	0.50	7.50	7.50	21	0.44	3.96	5.73
22	0.50	7.50	6.57	22	0.50	7.50	9.55
23	0.47	5.64	57.65	23	0.56	11.61	18.37
24	1.40	109.65	63.78	24	0.72	25.12	46.52
25	0.64	17.91	13.02	25	1.10	67.92	39.02
26	0.51	8.13	29.30	26	0.54	10.12	24.20
27	0.96	50.47	42.25	27	0.85	38.28	46.81
28	0.81	34.04	89.79	28	1.00	55.34	32.73
29	1.63	145.55	81.73	29	0.54	10.12	18.61
30	0.64	17.91	14.76	30	0.74	27.10	29.03
31	0.56	11.61	16.52				
Nov. 1st	0.68	21.43		Dec. 1st	0.78	30.97	
TOTAL			821.99				531.58

The Runoff Calculations

DECEMBER 1954				JANUARY 1955			
DAY	STAGE FEET	DISCHARGE CUSECS	MEAN DISCHARGE CUSEC.DAYS	DAY	STAGE FEET	DISCHARGE CUSECS	MEAN DISCHARGE CUSEC.DAYS
1	0.78	30.97	85.79	1	0.46	5.05	4.51
2	1.60	140.60	81.47	2	0.44	3.96	3.96
3	0.69	22.34	36.40	3	0.44	3.96	3.70
4	0.96	50.47	33.38	4	0.43	3.44	3.70
5	0.62	16.29	12.87	5	0.44	3.96	3.70
6	0.53	9.46	7.55	6	0.43	3.44	3.19
7	0.47	5.64	5.07	7	0.42	2.95	2.95
8	0.45	4.49	5.99	8	0.42	2.95	2.49
9	0.50	7.50	11.89	9	0.40	2.04	133.45
10	0.62	16.29	13.57	10	2.30	264.85	139.01
11	0.55	10.84	7.67	11	0.58	13.18	9.41
12	0.45	4.49	10.39	12	0.47	5.64	5.07
13	0.62	16.29	11.57	13	0.45	4.49	3.97
14	0.49	6.84	23.01	14	0.43	3.44	3.19
15	0.86	39.17	24.65	15	0.42	2.95	2.72
16	0.54	10.12	12.39	16	0.41	2.49	2.49
17	0.60	14.65	11.07	17	0.41	2.49	2.27
18	0.50	7.50	21.82	18	0.40	2.04	1.84
19	0.83	36.14	23.87	19	0.39	1.64	1.64
20	0.56	11.61	10.21	20	0.39	1.64	1.64
21	0.52	8.81	8.47	21	0.39	1.64	6.24
22	0.51	8.13	16.63	22	0.55	10.84	11.59
23	0.72	25.12	15.09	23	0.57	12.33	10.57
24	0.46	5.05	11.90	24	0.52	8.81	27.42
25	0.65	18.75	22.93	25	0.92	46.03	30.34
26	0.74	27.10	18.61	26	0.60	14.65	11.07
27	0.54	10.12	11.23	27	0.50	7.50	9.91
28	0.57	12.33	17.33	28	0.57	12.33	21.65
29	0.69	22.34	15.57	29	0.78	30.97	29.03
30	0.52	8.81	7.53	30	0.74	27.10	19.35
31	0.48	6.24	5.65	31	0.56	11.61	9.55
Jan. 1st	0.46	5.05		Feb.1st	0.50	7.50	
			601.57				521.62

The Runoff Calculations

FEBRUARY 1955				MARCH 1955			
DAY	STAGE FEET	DISCHARGE CUSECS	MEAN DIS-CHARGE CUSEC.DAYS	DAY	STAGE FEET	DISCHARGE CUSECS	MEAN DIS-CHARGE CUSEC.DAYS
1	0.50	7.50	11.89	1	0.36	0.59	0.59
2	0.62	16.29	11.27	2	0.36	0.59	0.93
3	0.48	6.24	8.18	3	0.38	1.26	1.26
4	0.54	10.12	11.23	4	0.38	1.26	2.11
5	0.57	12.33	8.99	5	0.42	2.95	2.29
6	0.47	5.64	4.29	6	0.39	1.64	1.45
7	0.42	2.95	29.15	7	0.38	1.26	1.26
8	1.00	55.34	33.83	8	0.38	1.26	1.26
9	0.57	12.33	8.99	9	0.38	1.26	1.26
10	0.47	5.64	4.29	10	0.38	1.26	1.87
11	0.42	2.95	3.19	11	0.41	2.49	3.49
12	0.43	3.44	3.44	12	0.45	4.49	3.72
13	0.43	3.44	2.97	13	0.42	2.95	3.72
14	0.41	2.49	2.49	14	0.45	4.49	7.31
15	0.41	2.49	2.27	15	0.54	10.12	18.99
16	0.40	2.04	2.04	16	0.75	27.86	17.99
17	0.40	2.04	2.04	17	0.51	8.13	5.79
18	0.40	2.04	1.84	18	0.43	3.44	3.19
19	0.39	1.64	1.64	19	0.42	2.95	2.72
20	0.39	1.64	1.64	20	0.41	2.49	2.97
21	0.39	1.64	1.45	21	0.43	3.44	2.54
22	0.38	1.26	1.26	22	0.39	1.64	1.64
23	0.38	1.26	1.26	23	0.39	1.64	7.41
24	0.38	1.26	1.26	24	0.58	13.18	29.61
25	0.38	1.26	1.26	25	0.92	46.03	31.16
26	0.38	1.26	1.09	26	0.62	16.29	11.89
27	0.37	0.91	0.91	27	0.50	7.50	6.27
28	0.37	0.91	0.75	28	0.46	5.05	4.77
				29	0.45	4.49	3.07
				30	0.39	1.64	1.84
				31	0.40	2.04	2.49
Mar. 1st	0.36	0.59		Apr.1st	0.42	2.95	
TOTAL			164.91				186.86

Computation of the Trend of Burnhope Precipitation by the Method of Least Squares

YEAR	PRECIP. INS. P.	ORDER T	TP.	T^2	YEAR	PRECIP. INS. P.	ORDER T	T.P.	T^2
1903	78.26	0	0	0	1928	64.96	25	1624.00	625
1904	44.28	1	44.28	1	1929	43.95	26	1142.70	676
1905	41.35	2	82.70	4	1930	60.20	27	1625.40	729
1906	50.91	3	152.73	9	1931	51.19	28	1433.32	784
1907	52.79	4	211.16	16	1932	54.44	29	1578.76	841
1908	47.66	5	238.30	25	1933	40.75	30	1222.50	900
1909	54.83	6	328.98	36	1934	56.80	31	1760.80	961
1910	53.56	7	374.92	49	1935	56.91	32	1821.12	1024
1911	53.99	8	431.92	64	1936	59.35	33	1958.55	1089
1912	53.04	9	477.36	81	1937	45.43	34	1544.62	1156
1913	52.08	10	520.80	100	1938	60.65	35	2122.75	1225
1914	59.85	11	658.35	121	1939	55.65	36	2003.40	1296
1915	41.31	12	495.72	144	1940	46.33	37	1714.21	1369
1916	71.94	13	935.22	169	1941	41.79	38	1588.02	1444
1917	55.66	14	779.24	196	1942	45.41	39	1770.99	1521
1918	54.47	15	817.05	225	1943	52.68	40	2107.20	1600
1919	48.34	16	773.44	256	1944	54.28	41	2225.48	1681
1920	54.96	17	934.32	289	1945	46.13	42	1937.46	1764
1921	47.88	18	861.84	324	1946	54.41	43	2339.63	1849
1922	45.52	19	864.88	361	1947	55.75	44	2453.00	1936
1923	53.48	20	1069.60	400	1948	60.97	45	2743.65	2025
1924	49.28	21	1034.88	441	1949	50.87	46	2340.02	2116
1925	56.33	22	1239.26	484	1950	58.85	47	2765.95	2209
1926	51.49	23	1184.27	529	1951	59.29	48	2845.92	2304
1927	59.16	24	1419.84	576	1952	51.32	49	2514.68	2401
						2660.78	1225	65,115.19	40,425

Eq.1. $\Sigma P = Na + b\Sigma T$

Eq.2. $\Sigma TP = a\Sigma T + b\Sigma T^2$

i.e. (1) $2660{\cdot}78 = 50a + 1225b$

(2) $65115{\cdot}19 = 1225a + 40425b$

Multiply (1) by 24·5

Then $65189{\cdot}11 = 1225a + 30012{\cdot}5b$

Eq(1) − Eq(2) $73{\cdot}92 = -10412{\cdot}5b$

$\therefore \underline{b = -0{\cdot}007099}$

$\therefore a = \dfrac{2660{\cdot}78 - (1225)(-0{\cdot}007099)}{50}$

$= \underline{53{\cdot}3895}$

$\therefore P = 53{\cdot}39 - 0{\cdot}007T$

For $T = 0$, $P = 53{\cdot}39$

For $T = 50$, $P = 53{\cdot}04$.

Monthly Precipitation. Burnhope 1903-1952

Month	Max. year	Min. year	Mean	Standard deviation
Jan.	13.72 1948	1.57 1929	6.18	2.61
Feb.	12.18 1903	0.29 1921	4.85	2.52
Mar.	11.67 1909	0.44 1929	4.33	2.49
April	10.95 1947	0.97 1912	3.64	1.81
May	7.12 1920	0.72 1922	3.04	1.40
June	6.87 1948	0.19 1925	2.78	1.64
July	6.23 1930	0.57 1911	3.48	1.40
August	9.55 1930	0.21 1947	4.32	2.10
Sept.	11.25 1918	0.36 1910	3.92	2.19
Oct.	13.28 1903	0.98 1915	5.52	2.78
Nov.	12.02 1951	1.04 1945	5.58	2.58
Dec.	13.34 1914	1.32 1933	5.57	2.72
Absolute	13.72 Jan.1948	0.19 June 1925		
MEAN	10.68	0.72	4.43	

Examples of runoff data from the Burnhope Reservoir Records

I 1937

Week ending	RESERVOIR HEIGHT	MILL. GALLS.	DIFFERENCE + or -	CONSUMED MILL. GALLS.	COMPENSATION MILL. GALLS.	CATCHWATERS N.	S.	TOTAL RUN OFF
Dec. 4	-12'9"	1036	6.0	49.111	17.387	-	-	72.498
" 11	-14'3"	1002	-34.0	49.105	15.7125	-	-	30.818
" 18	-15'10½"	965	-37.0	49.070	14.875	-	-	26.945
" 25	-2'7½"	1275	310.0	49.454	55.875	-	-	415.329

II 1951

Week ending	RESERVOIR HEIGHT	MILL. GALLS.	DIFFERENCE + or -	CONSUMED MILL. GALLS.	COMPENSATION MILL. GALLS.	CATCHWATERS N.	S.	TOTAL RUN OFF
May 5	1"	1359.3732	8.3732	44.697	98.980	35.050	28.290	88.710
" 12	½"	1358.1866	-1.1866	30.141	123.035	47.600	28.690	75.499
" 19	Full	1357.0	-1.1866	10.499	26.547	13.665	0.995	21.199
" 26	-4"	1347.0	-10.0	32.479	25.968	16.130	5.235	27.082
June 2	-5"	1344.0	-3.0	42.905	65.585	35.650	17.785	52.055