A study of stream bedload - its origin, characteristics and movement with particular reference to two catchments in the Northern Pennines

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"A STUDY OF STREAM BEDLOAD - ITS ORIGIN, CHARACTERISTICS AND MOVEMENT WITH PARTICULAR REFERENCE TO TWO CATCHMENTS IN THE NORTHERN PENNINES"

Thesis for the degree
of M.A.

by

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ABSTRACT

This thesis outlines work undertaken on the bed-load and sediment movement in two small catchments in Northern England, the Lanehead Catchment (Weardale) and the Netherhearth Catchment (Teesdale), which are situated in the Alston Block, the part of the Northern Pennines most widely described by research workers.

In section one a general description of the physical features of Northern England is given, with particular attention paid to Weardale and Teesdale within this general context. In this section also, a history of previous research into the problems of sediment movement in Great Britain, Northern America and Western Europe is outlined.

Section two contains a description of the methods of field investigation, and the various techniques used in the analysis of the sediments. Attention is focussed on the results obtained from the bed, the bank and the trays. Using stone count analysis and the long axis measurement of material larger than 2 inches, attempt is made to discover the lithologies of the sediment, and the capability of these streams to move the coarse as well as the fine sediment. This section also includes a brief study of some water samples and an assessment of the material in solution passing a certain point at a certain time.

Section three is a discussion of the findings of the whole study in a form of conclusion.

ACKNOWLEDGMENTS

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My deep gratitude to Dr. Peter Beaumont, for his patience, keen interest and supervision throughout this research.

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SECTION ONE

INTRODUCTION

In many ways the studies of sediment movement in streams is governed by the economic importance of such streams. Where streams are vital for agriculture or provide water for dams and irrigation schemes, studies of the volumes of sediments carried by such streams are often of crucial importance. In the northern Pennines, with ~~its~~ the high rainfall a great many streams are, as yet, not utilized by man. Possibly the lack of such utilisation accounts for the very few studies which have been made of sediment transport in the streams of Northern England. In order to provide some quantitative information on the nature of bed load and sediment movement two small catchments were chosen for detailed studies. One catchment, (the Lanehead catchment) is located in Upper Weardale, and the other, (the Netherhearth Catchment) is situated in Upper Teesdale within the Moor House National Nature Reserve.

This study is presented in three major sections:-

Section I

In this first section the nature of the physical environment of the Northern Pennines is described and more detailed descriptions are given of the Weardale and Teesdale Catchments within this general context. This section also includes a brief review of the previous work on the study of sediment movement in Great Britain, North America and West European Countries.

Also included in this section is a description of the Lanehead and the Netherhearth catchments including such topics as geology, slopes, vegetation cover, and the characteristics of the bed and banks of the streams during the study period.

Section II :-

This section describes the methods of field investigation and the various techniques used in the analysis of the sediments. Several problems which arose during the field and laboratory investigations are described. The final part of this section is concerned with a statistical analysis of the data which were obtained following laboratory analysis of material collected from the stream bed, stream banks, and from trays placed in the stream bed.

Section III :-

Section three includes a comparison between the results obtained from the Lanehead and the Netherheart Catchments and showing of interrelationships between different types of analysis.

Chapter One

The Physical Background of Northern England with Particular Reference to Weardale and Teesdale

Introduction:-

This study was carried out in two areas, both of which are situated in the Alston Block area of the Northern Pennines (Fig. 1.1.).

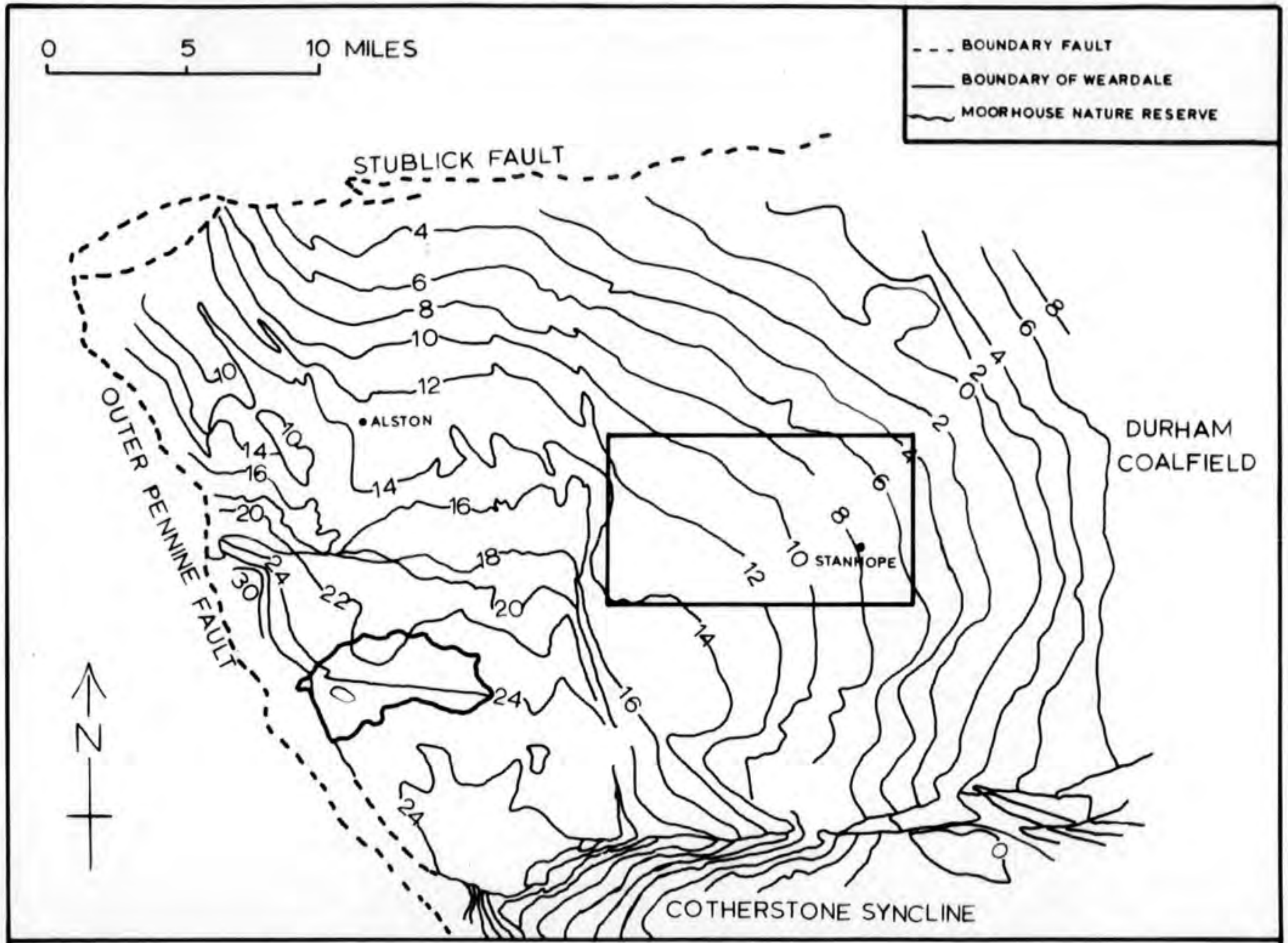
The first area is a small catchment in Weardale and consists of two small peaty tributaries. The other area which was chosen for comparative purposes is the Netherhearth Catchment in Teesdale, situated within the Moorhouse Nature Reserve.

a) Position of Weardale in Northern England

The River Wear rises on high land at 2300 feet lying to the east of the main Cross-Fell range, and is separated there from the valley of the South Tyne.

At its upper end the Wear Valley is divided into three main valleys. The northernmost is the Killhope Burn, with the other two being occupied respectively by the Welhope Burn and the Burnhope Burn. The Wear itself is formed by the union of these three streams.

The River Wear receives numerous small tributaries from the watershed areas to the north and south, with the majority of these meeting the main channel almost at right



STRUCTURE OF THE ALSTON BLOCK ILLUSTRATED BY STRUCTURE CONTOURS ON THE BASE OF THE GREAT LIMESTONE, HEIGHTS IN HUNDREDS OF FEET ABOVE ORDNANCE DATUM

After Johnson

Fig. 1.1

angles.

The area is bounded on the north by the catchments of the River Derwent and the River East Allen; on the south by Teesdale, and on the west by the uplands of Killhope Law and Burnhope Seat.

In general the River Wear follows an easterly course through a narrow valley with its floor all above 500 feet O.D., and with the highest parts of the dale being found on the south-west margin where Burnhope and Harthope Fells rise to 2000 and 2452 feet respectively.

b) <u>Position of Teesdale in Northern England</u>:-

The River Tees rises on the southern shoulder of Cross Fell and drains from the Alston Block in a south-easterly direction. The river valley is one of the most distinctive of the Pennine dales. It is characterised by the widespread outcrops of the intrusive Whin Sill which give the landscape a pattern considerably different from the limestone dales which surround the area. The river head is situated amongst the wildest of the Pennine moors and draws its water from the slopes of the highest summits.

Teesdale, as it is generally referred to, covers, together with its tributary valley, an area of some 300 square miles. It is little more than 30 miles long and some 15 miles in width at its widest point.

The Moor House Field Station is situated at the head of Teesdale. The Nature reserve of the station covers 10,000 acres of high moorland and fell country in Upper Teesdale and the Westmorland Pennines to the south of Cross-Fell. The Nature Reserve is situated in the north-east corner of Westmorland and the northern boundary, along Crowdundale Beck and the river Tees, is also the County boundary between Cumberland and Westmorland. At Crook Burn foot on the Tees the County boundaries of Cumberland, Westmorland and Durham meet. On the west of the Nature Reserve lies the Pennine Escarpment, which rises steeply in a series of benches from the low-lying ground of the Vale of Eden and forms the western boundary of the reserve.

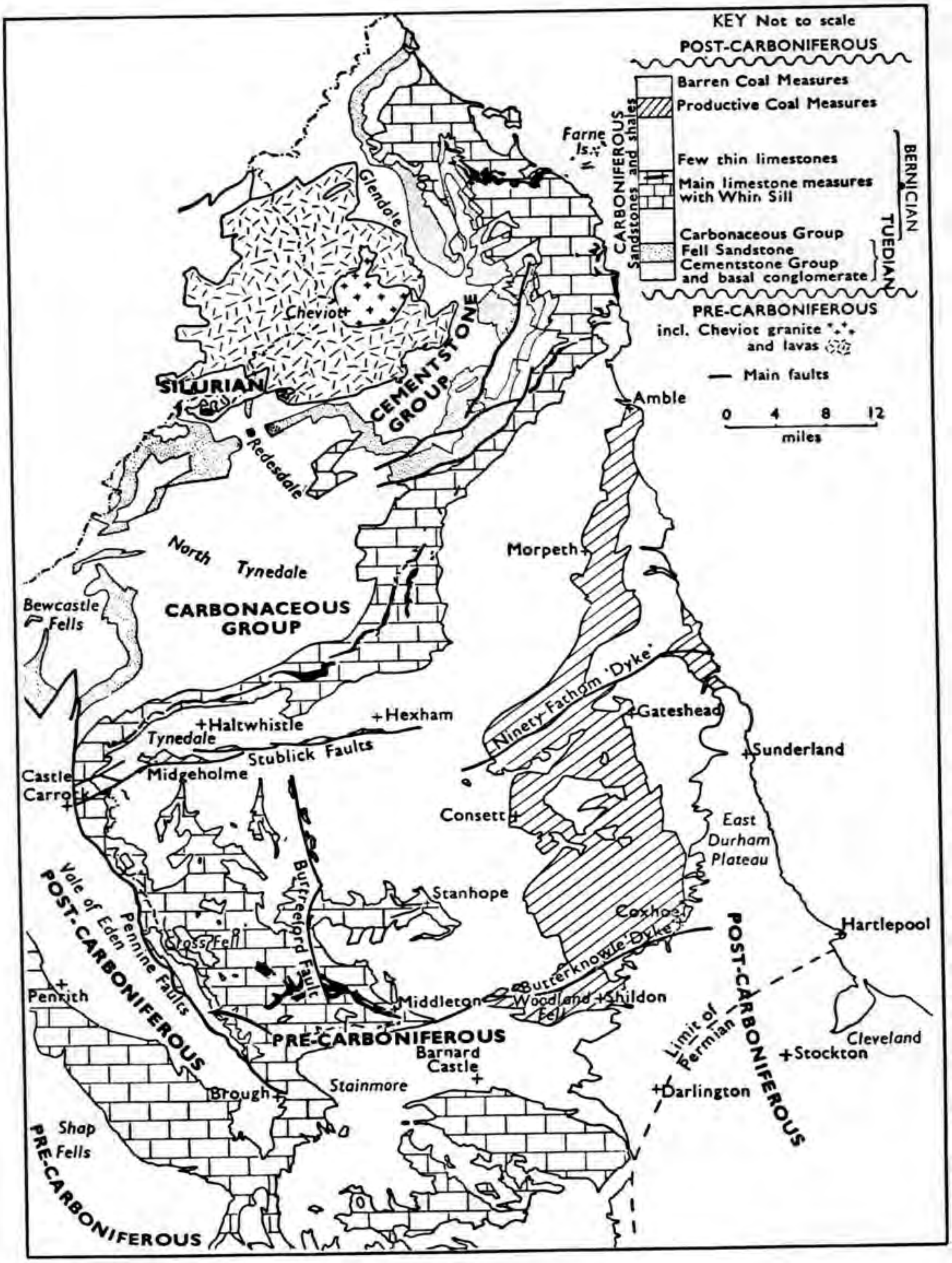
The Tees Valley is very wide in the region of the Nature Reserve and forms a wide amphitheatre near its head between Hard Hill and Little Dun Fell. A similar, but wider, amphitheatre occurs in the Trout Beck drainage area between Knock Ridge, Knock Fell, Great Dun Fell and Hard Hill. The low rounded hills in the Tees Valley at the eastern and northern margin of the Nature Reserve are formed of glacial drift and appear to represent drumlin and moraine-like features.

A. Geology of Northern England :-

The geology of Northern England consists of a gently warped mass of Carboniferous rocks overlain by Permian and Triassic sediments in the extreme south-east. The lower Palaeozoic floor emerges in the Cross-Fell inlier on the western margin of the area. To the north the Carboniferous sediments pass down into a considerable mass at Upper Old Red Sandstones, except in the eastern Cheviot region, where the Carboniferous base laps over thick layers of lower Old Red lavas.

Younger rocks are now restricted to three areas with the most extensive of these outcrops being in the south-east, where beyond an irregular line running from the mouth of the River Tyne to the River Tees below Barnard Castle the Magnesian Limestone is found. Triassic strata also outcrop in the lowlands at the head of the Salway round Carlisle, and extend south-eastwards up the Vale of Eden between the Pennine and Lake District highlands to Kirkby Stephen(Fig. 1.2.). Finally, a narrow fringe of Triassic rocks flanks the western margin of the Lake District highlands along the Coast south of Whitehaven. The Alston Block is the most important structural feature of the geology of Northern Pennines, and is the most northerly of the Pennine domes. It reaches its highest elevation of 2930 feet at Cross Fell. In common with all Pennines blocks the western edge is more abrupt and is broken by the great-Pennine Fault Scarp.

Fig. 1.2



The Geology of Northern England

After Smailes 1960

Its northern edge is defined at its western end by the east-west Stublick Fault system, while to the south it is separated from the Yorkshire Askrigg Block by the Stainmore depression.

The whole of North England presumably once had a complete cover of Carboniferous rocks although Carboniferous sedimentation did not apparently begin at the same time throughout the area. Quite apart from the great differences in the amount of Carboniferous sediments, there were also considerable differences in thicknesses of Carboniferous rocks as originally laid down. Daysh and Symonds, 1953, estimated the general stratigraphy of the West Durham Carboniferous Series as follows:-

		Approx. average thickness in feet
Upper Coal Measures	Shales-Sandstones and Coals	over 1000
Middle Coal Measures		about 800
Lower Coal Measures		200 to 240
Millstone Grit (Sandstone, Grits and Shales)		350 to 5000
Limestone Group (Limestones, Sandstones and Shales)		2000 to 3000

The northern Pennine hills are formed of rocks of Carboniferous age. The region is structurally a tilted double fault-block lying between the Tyne Valley and the Craven Country of West Yorkshire. The rocks exposed in the Pennine dales are chiefly of lower Carboniferous age and the successions are thin as compared with regions north and south of the bounding faults of the block. Upper Carboniferous deposits occur as outliers on the high watersheds in the western and central part of the region and these coalesce eastwards to form a continuous outcrop brought in by the easterly regional dip. The faults bounding the Northern Pennine Block were active during the deposition of the Carboniferous succession and the block was not submerged by the carboniferous seas until thick sequences of strata had been laid down in the surrounding basins. Even so, between 2000 feet and 3000 feet of Carboniferous deposits are present in the Northern Pennines.

Several subdivisions of Carboniferous succession have been attempted, although that suggested by Dunham, (1948) for the Alston Block is probably the most widely accepted.

<u>Table: 1.1</u>

Local Millstone Grit

Carboniferous Limestone Series	Upper Limestone Group
	Middle Limestone Group
	Lower Limestone Group
	Basement Group

In this succession Dunham stressed that the lithological variations were largly governed by the sedimentary units. He also summerized the geological sequences as follows:-

Table 1.2

Group	Main Strata	approx. thicknes
(Local Millstone Grit	Coarse grits, Sandstone and Shales with ganisters between the groups	275 - 375 feet
Upper Limestone Group	Coarse grits, Sandstone ganisters, thin Coals, Limestone and Shales	580 - 780 "
Middle Limestone Group	Rhythmic alternation of Limestones, Shales Sandstone and thin Coal	725-850 "
Lower Limestone Group	Massive Limestone over lain by alternating Limestones, Shales, Sandstones	300 - 550 "

I. The Geology of Upper Weardale :-

The dale ranges in altitude from 2452 feet at Burnhope Seat in the west to 600 feet at Stanhope in the east. Within this altitudinal range slope form is largely governed by the characteristics of lithology, geological dip, and superficial deposits. The flat areas to the east and west of Killhope Law just over 2100 feet are similarly developed on the Middle and Upper Carboniferous Limestone Stratum whilst Killhope Law itself (2208 feet) consists on outlier of the lowest (Millstone Grit) Sandstone.

The geological structure and lithology of Upper Weardale can always be related to the regional geology of the Alston Block which has long been the site of detailed investigations by structural geologists and mineralogists such as Woolacott, (1907) Raistrick, (1931) Dunham, (1948) and Johnson, (1963).

In Upper Weardale, the correspondence of detailed topography to lithology is so precise that sometimes, where a resistant geological horizon has been shifted by faulting, there is a change in the position of the topographical feature associated with it. This is well illustrated in the extreme western part of the dale. Maling (1955) noticed that there is, however, a series of extensive platforms on the valley sides. Although these, too, appear to be related to resistant beds, it is possible that they are all erosional, for it can be shown that these shelves transgress the various geological horizon on which they are developed and it is believed that this may be related to definite stages in the morphological evolution of the Wear Valley.

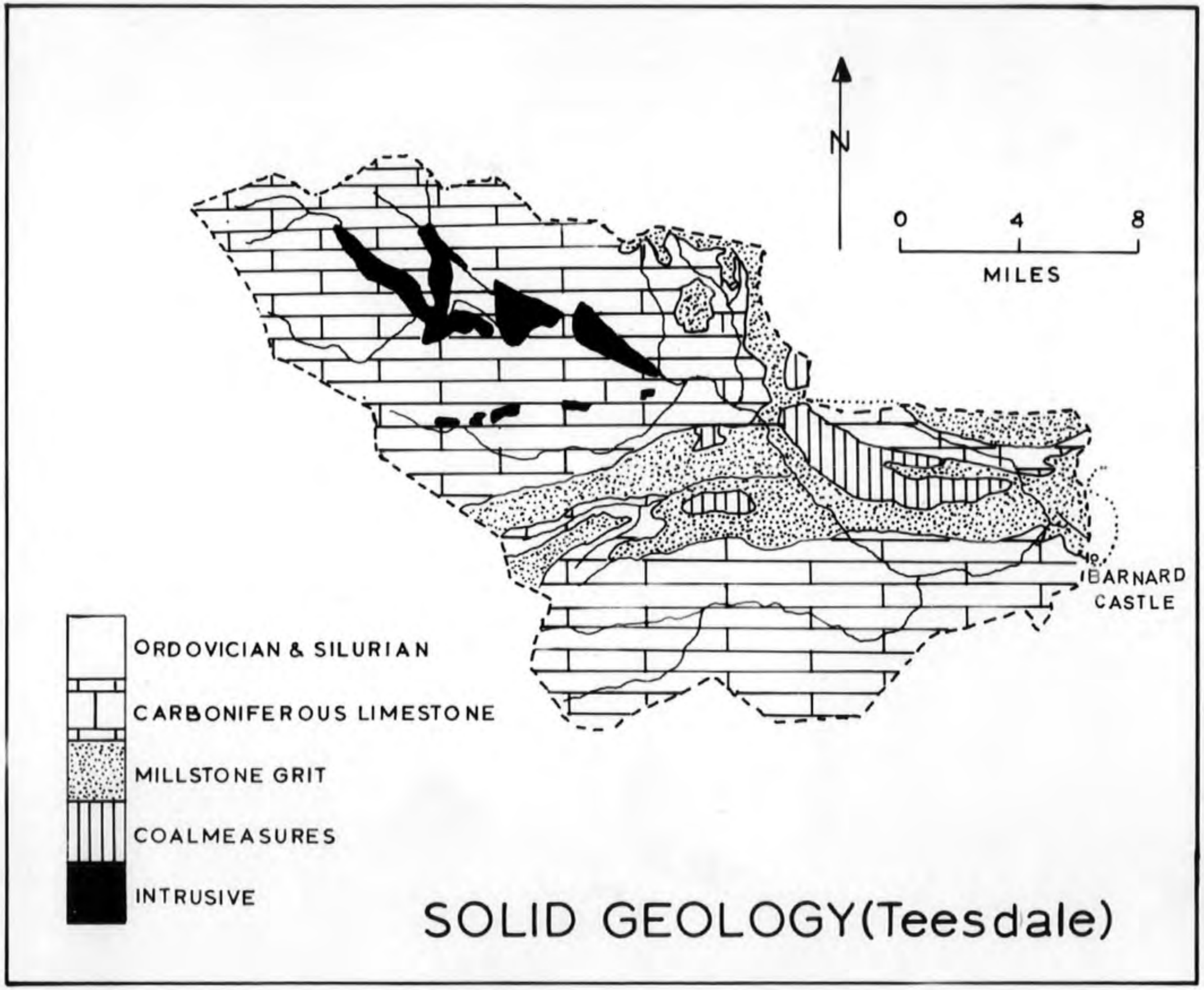
The most well known beds of the Carboniferous Limestone Series in Weardale are those of the Middle Limestone group which corresponds with the Yordale Series. The top member of this group is the Great Limestone which is found outcroping in the dale at 2,000 feet in the Killhope and Burnhope Valleys, at 900 feet in the quarries above Stanhope and disappears under the river bed at 530 feet near Frosterley.

The Middle Limestone group consists of an alternating sequence of Shales, Sandstones and Limestones; a complete cycle presenting the following beds in upward succession : Limestone calcereous shale, ferruginous shale, sandy shale or shaly sandstone, sandstone, ganister or under clay and coal.

The uppermost limestone outcrop in Weardale is the Fell Top limestone which is found about 400 feet above the Great Limestone. Above this, is a massive coarse sandstone, the grindstone sill, and this, in turn, is overlain by the Millstone grit which in Weardale Caps only the uppermost ridges. On the northern watershed of Weardale two areas of erosion can be observed (Atkinson 1968). One site is on the north of Stanhope, where unconsolidated quartz sands appear to be residual from the underlying local "Millstone Grit". Also at Killhope Law a heavy soliflucted debris deposit beneath blanket peat appears to be derived from the underlying shales.

2. The Geology of Moor House Area :- (Teesdale)

The Pennines in this region rise to a maximum of 2930 ft. at Cross-Fell. The basement complex of the Northern Pennine area consists of intensely folded Ordovician and Silurian Shales and Sandstones, which had been extensively eroded before the deposition of younger sediments occurred (Fig. 1.3).



SOLID GEOLOGY(Teesdale)

Fig. 1.3

An outcrop of this basement complex exists as an inlier below Couldron Snout. The Carboniferous succession, chiefly the Yardale series, consists of Limestone interspersed with shales and sandstones and an occasional coal seam. The limestones increase in importance southwards towards the West Riding where they become the dominant features of the topography. Overlying the limestones are the Millstone Grits, remnants of which may be seen forming resistant caps on the divides throughout the Nature Reserve.

The Teesdale inlier is a small inlier of Lower Palaeozoic rocks in Upper Teesdale, and lies below Cronkley Scar near the Hamlet of Langdon Beck. Geographically the inlier is on the western margin of an east-facing monacline called the Burtreeford Disturbance. It is poorly exposed and consists of a belt of soft greenish and light coloured highly cleaved slates. It was discovered in the latter part of the last Century by Dakyns, 1877.

Overlying these Basal strata is the Carboniferous basement group. Eastwards from the Pennine Escarpment the Basement Group thins to only 140 feet. This group is not well exposed in the Reserve but can be seen at Falcon Clints and below Cronkly Scar(Fig. 1.4 A.). The unconformable junction between the Lower Palaeozoic

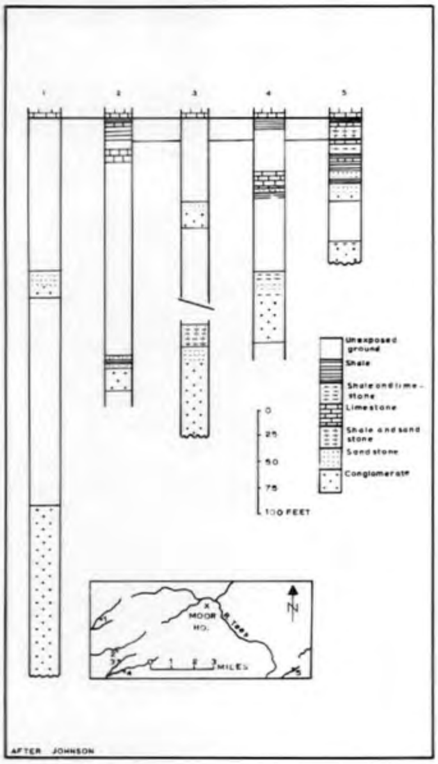


Fig. 1.4 A

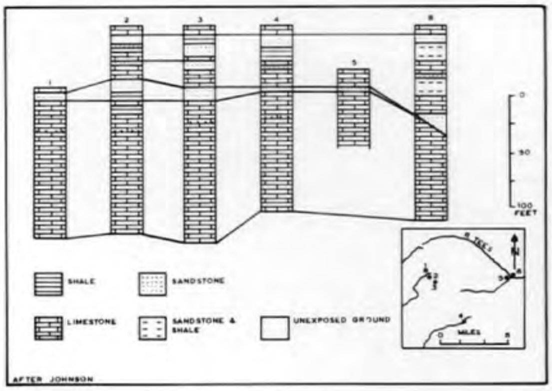


Fig. 1.4 B

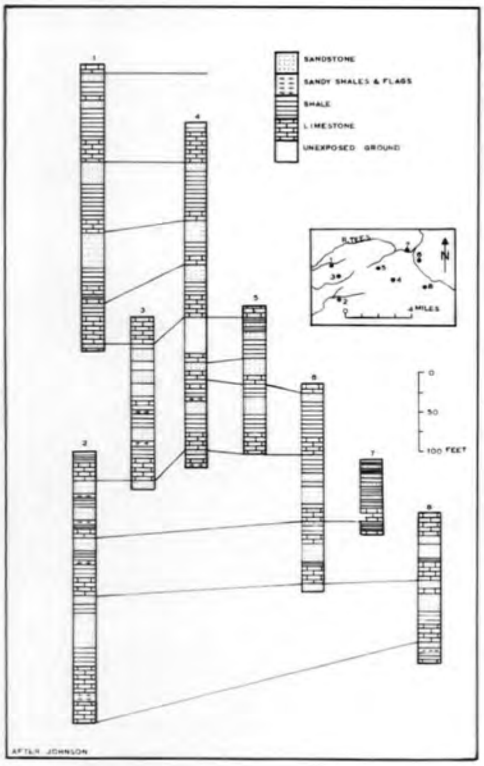


Fig. 1.4 C

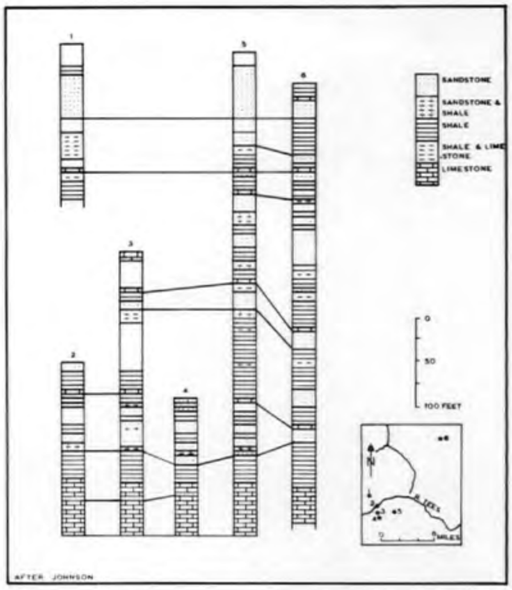


Fig. 1.4 D

After Johnson 1963

Skiddaw slates and the carboniferous basement has been seen in excavations below Cronkley Scar near the Pencil Mill by Gunn and Clough,(1878) and by Harry,(1950).

The most important member of the carboniferous lower limestone group is the Melmerly Scar limestone which is the thickest limestone stratum in the local carboniferous succession and averages about 125 feet in thickness on the Reserve area. The top of the Melmerly Scar Limestone and the overlying beds belonging to the lower limestone group outcrop in the River Tees at the foot of Mattergill Sike(Fig. 1.4.B.). The Carboniferous Middle Limestone Group is exposed in a broad band along the Pennine Escarpment and also to the east of the summit ridge where it forms the surface outcrop over most of the area of the Reserve(Fig. 1.4.C.). The Middle Limestone Group can be divided into five main categories:

The first is the Jew Limestone Cyclothem, this is about 28 feet in thickness on the Reserve and is composed of dark grey finely fragmented limestone in thick wavy-bedded posts with shaly partings. The shale and sandstone succession above the Jew Limestone averages about 35 feet in thickness.

The Scar Limestone cyclothem is one of the thicker limestones of the Middle Limestone Group, and is over 37 feet in thickness on the Reserve. It is composed of light coloured wavey - bedded finely, fragmental limestone in rather thin beds and a few small dark chert nodules are present. Above the Scar Limestone the shale and sandstone succession is variable in thickness, there are only 18 feet of beds in this position on the western escarpment and as much as 40 feet on the eastern end of the Kneck Ridge. (Johnson 1963)

On the Escarpment the Five Yard Limestone is 22 feet in thickness and divided into two bands by a bed of Calcareous Shale. It is 20 feet thick on Knock Fell where the calcareous shale bed is missing. The limestone is dark coloured with even bedded shaly partings and is fossiliferous.

The three yard limestone is rarely seen outcropping on the Reserve. It is about 11 feet in thickness and composed of grey compact Crinoidal Limestone in thick slightly wavy-bedded bands. A shale succession about 40 feet in thickness is developed above the three yard limestone. The overlying sandstone is above 40 feet in thickness and formed of well bedded medium-grained sand. The Four-Fathom Limestone, about 21 feet in thickness on the Reserve is composed of medium grey coloured fine grained limestone in thick beds with conspicuous wavy bedding. The top of the Four Fathom Limestone is shaly and then trends upwards into a fossiliferous calcareous shale.

The summit of the Pennine Escarpment at Cross Fell together with the neighbouring peaks of Little Dun Fell, Great Dun Fell and Knock Fell form an elongated outlier of the carboniferous upper limestone group. This group is divided into two parts by Johnson (1963):-

The Great Limestone cyclothem forms the main part. The name Great Limestone is due to Forster (1809) and was given to the thick limestone which outcrops as a thick and characteristic band throughout the Northern Pennines. The Limestone is similar to those of the Middle Limestone Group in being blue grey in colour, fine grained and tending to occur in beds varying from a few inches to a few feet in thickness (Fig. 1.4D). The second is the Little Limestone Group which is thin and seldom exposed in the Cross-Fell outlier. On the Reserve it is best seen in Croundundle Beck where some 2 feet of dark brown impure Crinoidal Limestone outcrop.

B. <u>The Glaciation of Northern England</u>:-

Rocks of Carboniferous age outcrop over the greater part of Northern England, but are extensively concealed by an irregular cover of glacial and other superficial deposits.

The detailed pattern of ice movement within this area is uncertain, although the maximum elevation attained by the ice plateau in the northeast of England may be estimated by the evidence of isolated erratics and signs of glacial erosion at about 2000 feet around the Cheviots and the Cross Fell mass. These highland masses therefore, divided the ice flow over the region with the ice coming principally from the southern uplands and the Lake District. Further control of the movement of the main ice sheets was provided south of Stainmore by the high Pennine mass of north-west Yorkshire, and by the Cleveland Hills in the South-east.

The final controlling factor was the impact of the North Sea ice, deflecting all movement along the Coastal belt in a southerly direction.

The Cheviots were an important snowfield in the earlier and later stage gave rise to local glaciers. Throughout the main period of glaciation much of Central Northumberland was covered solely by Cheviot ice. The Cross-Fell massif was a smaller center of distribution. It furnished small glaciers in the Upper Valley of the South Tyne, in Teesdale and in Weardale and at least one small corrie glacier on the west in the High Cup Nick Valley. The glaciation history of Northern England has been tabulated by

(Trotter and Hollingworth 1932) as follows:-

Table 1.3

	WEST		EAST	
	Southern Part of the Irish Sea Basin	Lake District and the Solway Firth	Northumberland and Durham	Yorkshire
FIFTH GLACIAL EPISODE		Retreat Phenomena: lakes, channels, sands and gravels, and laminated clays Scottish Readvance Boulder Clay	Not represented	Not represented
FOURTH GLACIAL EPISODE		Retreat Phenomena: lakes, channels, sands and gravels, and laminated clays, (=Middle Sands of Carlisle).	Retreat Phenomena: lakes, channels, sands and gravels	Retreat, Phenomena: lakes, channels, sands and gravels
	?Upper Boulder-Clay of Liverpool District	Boulder-clay of Lake District-Edenside Maximum and N. Pennines	Prismatic Boulder-Clay Cheviot and Scottish Ice with Western Ice in the west	Hessle Clay and its inland equivalents
THIRD GLACIAL EPISODE	Middle Sands and Gravels	Gravels and laminated clays	Gravels and laminated clays	Gravels etc.
	?Lower Boulder-Clay of Liverpool district	Boulder-clay of "Early Scottish Glaciation" (including Lake District Ice).	Boulder-clay of Western Ice.	Upper Purple Clay
SECOND GLACIAL EPISODE			Gravels	Gravels
			Boulder-clay of Scottish and Western Ice	Lower Purple Clay
FIRST GLACIAL EPISODE	Represented farther south	?Weathered Boulder clay of Upper Caldew Valley	Loess	
			Scandinavian Clay	Basement (Scandinavian) Clay

I The Glaciation of Weardale:-

The glacial periods have undoubtedly had a marked influence on the character and deposition of superficial deposits in Upper Weardale. Dwerryhouse (1902) believed that the Alston Block, was only thinly covered with ice, even during the glacial maxima. He showed from the distribution of erratics in Northern England, that the great part of the Upland of the Alston Block including Weardale nourished only local glaciers.

Raistrick (1931-33) recognised in Weardale that much weathered drift occurred at greater altitudes than the boulder clay of the dale floors. He suggested that only the higher summit of the Cross-Fell massif and the hills of Upper Weardale had remained exposed during the maximum glaciation. On the higher hills of Weardale, stony clays may be recognised at considerable altitudes, and some of them may exist below the peat right to the summits of the moors. Maling's examinations of these clays in (1955) has shown that they are sandy in texture and they are therefore coarser and less cohesive than the sticky boulder clay of the valley floor.

On the Upland of the West Durham plateau and in Weardale in particular drift exposures do not suggest the presence of ice on more than one occasion during the Pleistocene. In Weardale exposures of glacial sands are not common. A few sand-hills are situated about one mile north-west of Wolsingham, but apart from these, there is no superficial sand or gravel which cannot be related to terrace development during the late or post glacial period.

2. The Glaciation of Teesdale:-

There were five main ice masses in Northern England but only one was of importance in Teesdale area. This was the ice, which originating in the Lake District, was forced up the Vale of Eden by the south-flowing Scottish ice mass, and being unable to cross Cross Fell, was turned east across Stainmore and came by that route to the lower Tees Valley. Blocked by the Cleveland Hills and the North Sea ice, these streams mainly passed from the region through the Northallerton Gap to the Vale of York.

In Teesdale itself ice formed on the high divides, feeding a Teesdale glacier which flowed eastwards joining with Stainmore ice and was then deflected South by ice from the Cheviots and from Scandinavia.

During the glaciation, glacial lakes were thought to have been impounded in the valley of the Maize Beck and in the Valleys of the Lune and Balder against walls of ice - (R.Dwerryhouse 1902)

The extensive studies of Trotter (1929) on the glaciation of Eastern Edenside covered ground at the

Western extremity of the Nature Reserve(Fig. 1.5.). He found evidence of two major glaciations in this region followed by a less extensive readvance periods.

Much of the drift of the Upper Tees and Tyne Valleys, in particular, occurs in the form of large mounds elongated in the general line of the valley. Many might be described as drumlin like in form, but their more gravelly composition suggests that they may be more correctly regarded as masses of morains.

C. <u>Peat Growth and Erosion</u>:-

Peat is partially decayed plant material that has accumulated over a considerable period of time. It forms under cool and wet climatic conditions and the rate and degree of composition becomes progressively poorer as conditions become more waterlogged. (Rawes 1967).

After the ice of the last glacial period had retreated from northern England the vegetation was dominated by birch, but 7,000 years ago, Peat formation started and extended over large areas eventually submerging them with a blanket of peat. The most dominant peat deposits covering the Upland area of the Reserve are bog peats and flush peats(Fig. 1.6.).

Bog peats are widespread in the Pennines as a whole

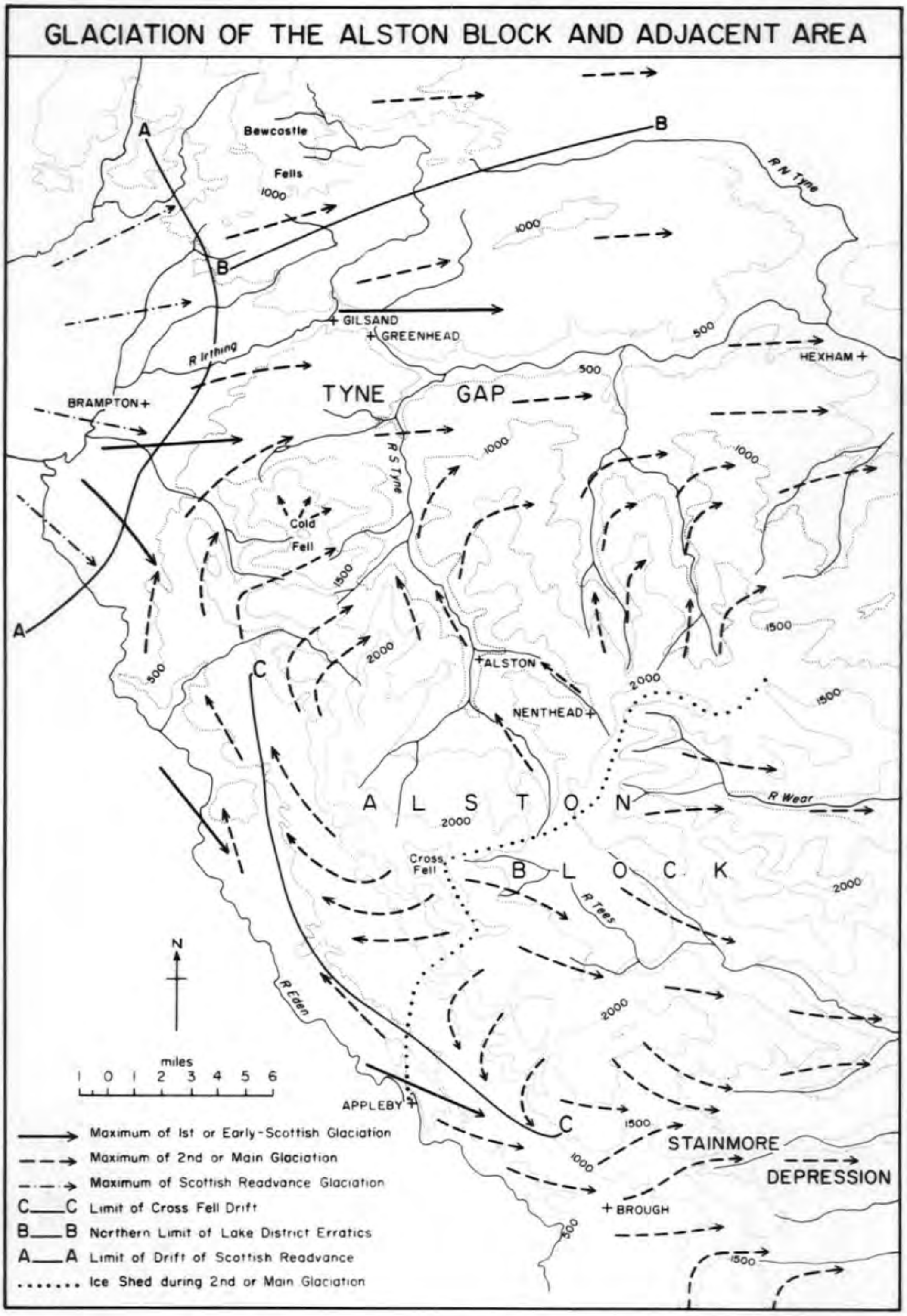


Fig. 1.5

After Trotter

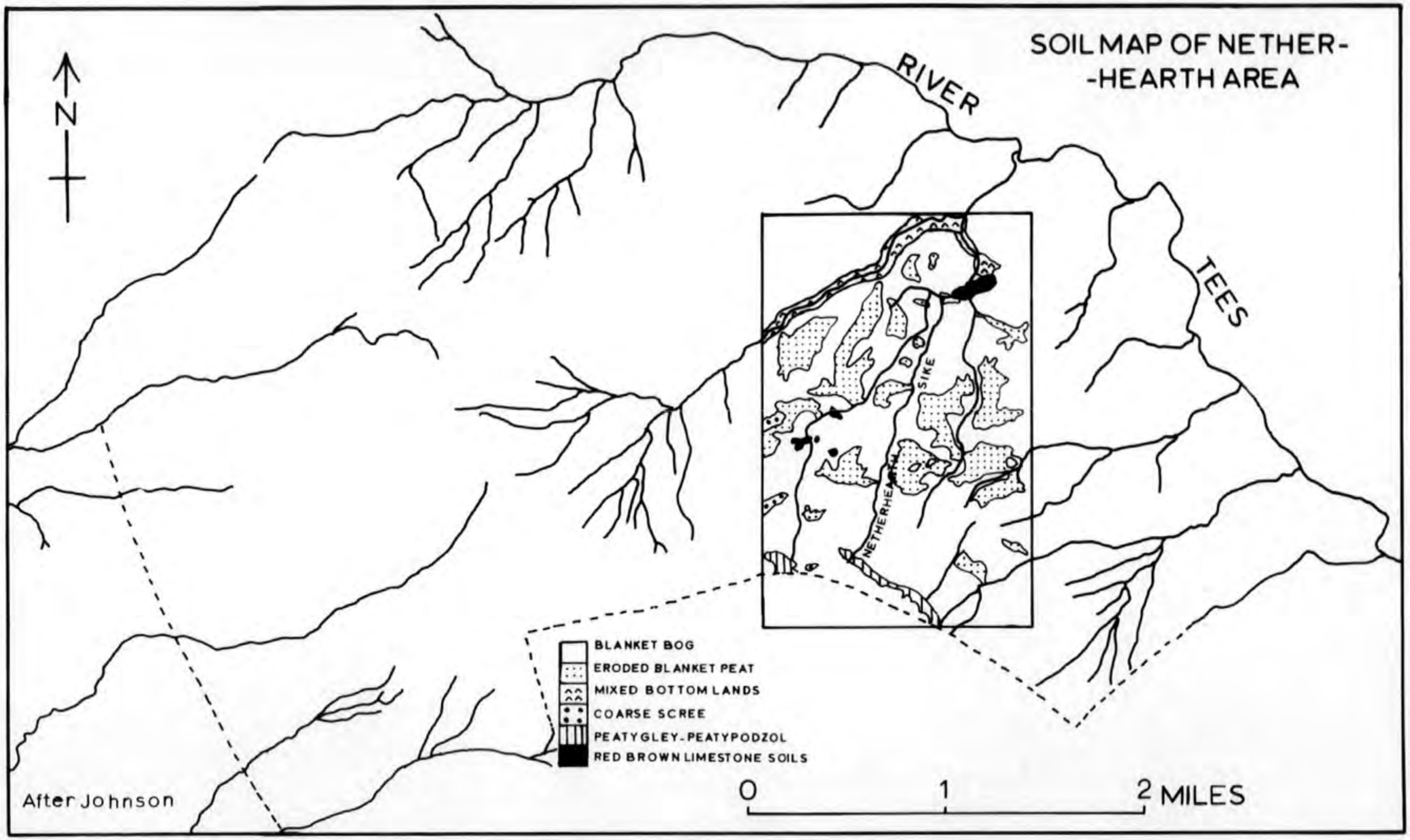

SOIL MAP OF NETHER-
-HEARTH AREA
N
RIVER
TEES
SIKE
NETHERHEARTH
BLANKET BOG
ERODED BLANKET PEAT
MIXED BOTTOM LANDS
COARSE SCREE
PEATYGLEY-PEATYPODZOL
RED BROWN LIMESTONE SOILS
0
1
2 MILES
After Johnson

Fig. 1.6

and can be divided into two topographic types. Those found in Concave hollows and old lake basins are called valley-bog deposits, while those which occur on convex slopes, ridges and flat benches are called blanket peat deposits.

Flush peats are also dependent on slope and occur where water from a higher level drains on to the bog surface and brings with it supply of minerals in solution. Erosion is primarily a natural phenomenon in which water and wind are the main agents.

In dry weather dusty peat is blown away from the eroding peat surface and in wet weather drainage streams carry away vast quantities of peat in suspension. An important factor also causing peat erosion to start is the collapse of the underground drainage channels. The rate of peat erosion depends mainly on climate and relative exposure of the site.

Both the detailed study catchments were extensively covered with blanket peat deposits.

D. General Climate of Northern England :-

Throughout much of Britain there is conflict between the influence of the climate generated by the continental landmass to the east, and that of the warm offshore currents which give a mild equable climate with heavy precipitation. The considerable range of altitude and marked contrasts in degree of exposure to the principal air streams that affect the climate of Britain are responsible for considerable differences of the climate within North England (Smailes, 1960)

In the case of North-east England, further considerations, mainly the influence of the North Sea, and the shelter from the westerly winds which the Pennines range provides, must be taken into account as well as those factors already mentioned.

The most striking differences are in precipitation. In the Lake District we find the wettest part in England, but round Tees mouth and in other places on the east Coast are found some of the lowest rainfall recordings in Britain. The average annual rainfall in these areas is 22 to 25 inches at altitude of less than 200 feet.

The rainfall generally increases to more than 50 inches in the higher parts of the Pennines and Cheviots; on Mickle Fell 2591 feet, in Lune Forest on the Crest of the Pennines it even exceeds 70 inches. Rainfalls on an average of about 170 days in the year in the dry areas, and on about 220 days in the higher hills, but there is much variation from year to year both in the annual rainfall and the number of days on which it falls.

Temperatures in the Coastal belt of the North-East generally range between-8°C and 25°C and inland between

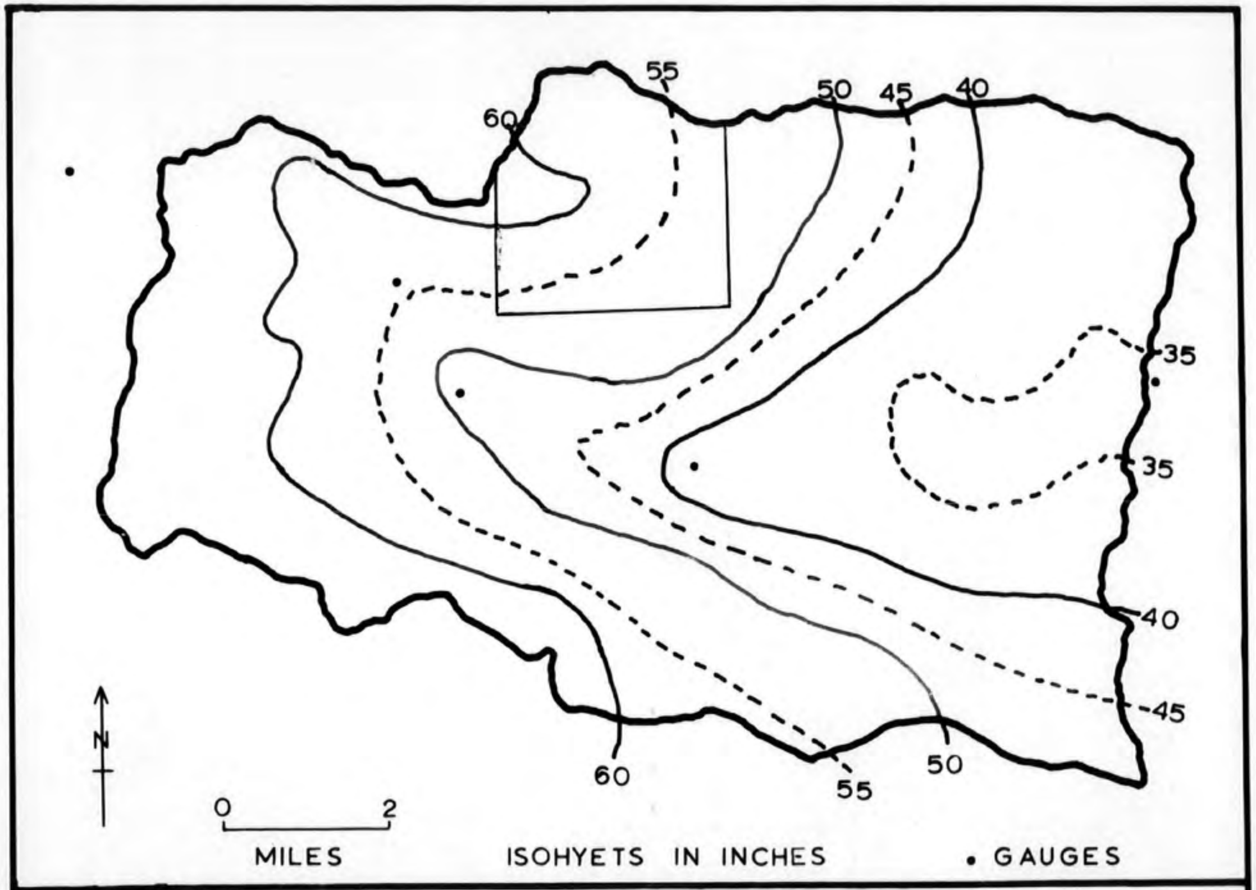
-12°C and 30°C (British Association, 1949) They occasionally rise to 35°C and fall below -8°C even at the Coast, and within the last twenty years temperatures of less than -18°C have been recorded at several inland places.

The occasional orographic precipitation on an easterly wind means that extremely heavy snowfalls are perhaps more liable to occur on the north-eastern slopes of the Pennines than any where else in Britain. Snow scarcely lies at all on the West Coast, however, and on the Northumberland Coast may be expected to cover the ground only on 7 or 8 days in the year. At Alston 1,000 feet above Sea level the average period is about 40 days, (Smailes 1960), and at Nenthead 500 feet higher, it is 55 days. Around the highest habitations in Upper Teesdale, above 1,800 feet, snow lies for about 120 days in the year, and Cross Fell summit is covered with snow on about 120 days in the year. What is more important is that the highest fells of the Lake District, Northern Pennines, and the Cheviots are all liable to be covered by snow in the aggregate for about four months of the year.

I The Climatological features of Upper Weardale:-

The striking variations in altitude, exposure and land configuration lead to a marked climatic contrast within Upper Weardale. The characteristics of the climate of the area west of Durham which includes Weardale are: a cool summer, a mild autumn, a rather prolonged winter and a cool cloudy spring. The mean temperature of July, the warmest month is about 11° - 12° C in the Pennines. (Daysh and Symonds 1953). January, the coldest month has a mean temperature of about 0 - 1° C. The average annual rainfall varies from about 30 inches in the West Durham area, and nearly 60 inches over the Pennine summits (Fig. 1.7.). Figures for precipitation on the higher fells are scanty, due principally to difficulties of studies. Nevertheless the wettness and humidity of the upland environment is emphasised, as is the steady diminution in rainfall eastwards.

The effect of altitude on precipitation is twofold within the Northern Pennines as a whole (Atkinson, 1968). The direct effect is for mean elevation to be lower as one moves eastwards. The indirect effect is for exposure to the predominant westerly air streams to be correspondingly reduced. The net result is to give a very close correlation between altitude and precipitation (Fig. 1.8.). Precipitation tends to be evenly distributed

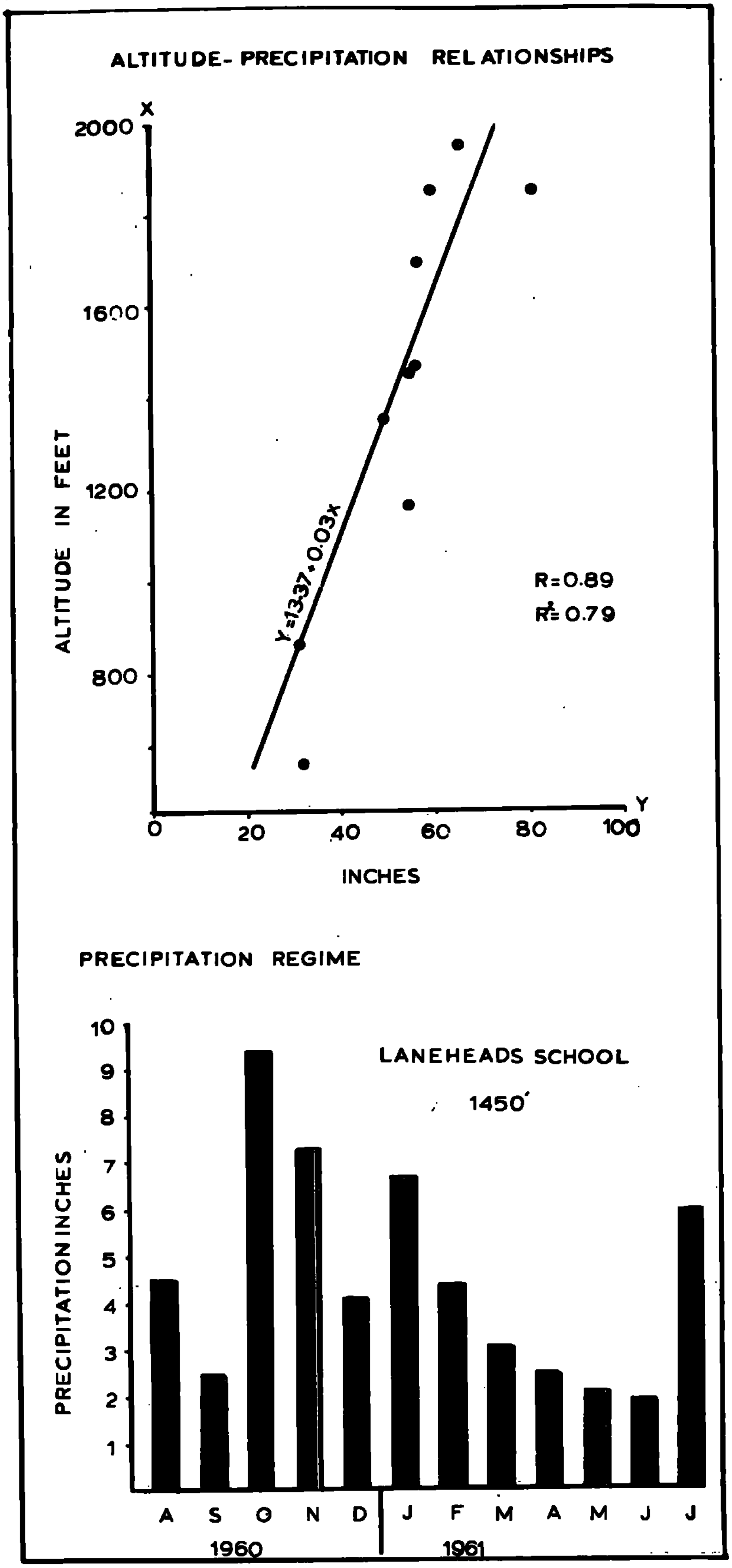


MEAN ANNUAL PRECIPITATION IN WEARDALE

After Atkinson

Fig. 1.7

Fig. 1.8



AFTER ATKINSON

through the year and rain can be expected on more than 17 days in August and more than 14 days in both July and September(the warmest and driest months of the year.)

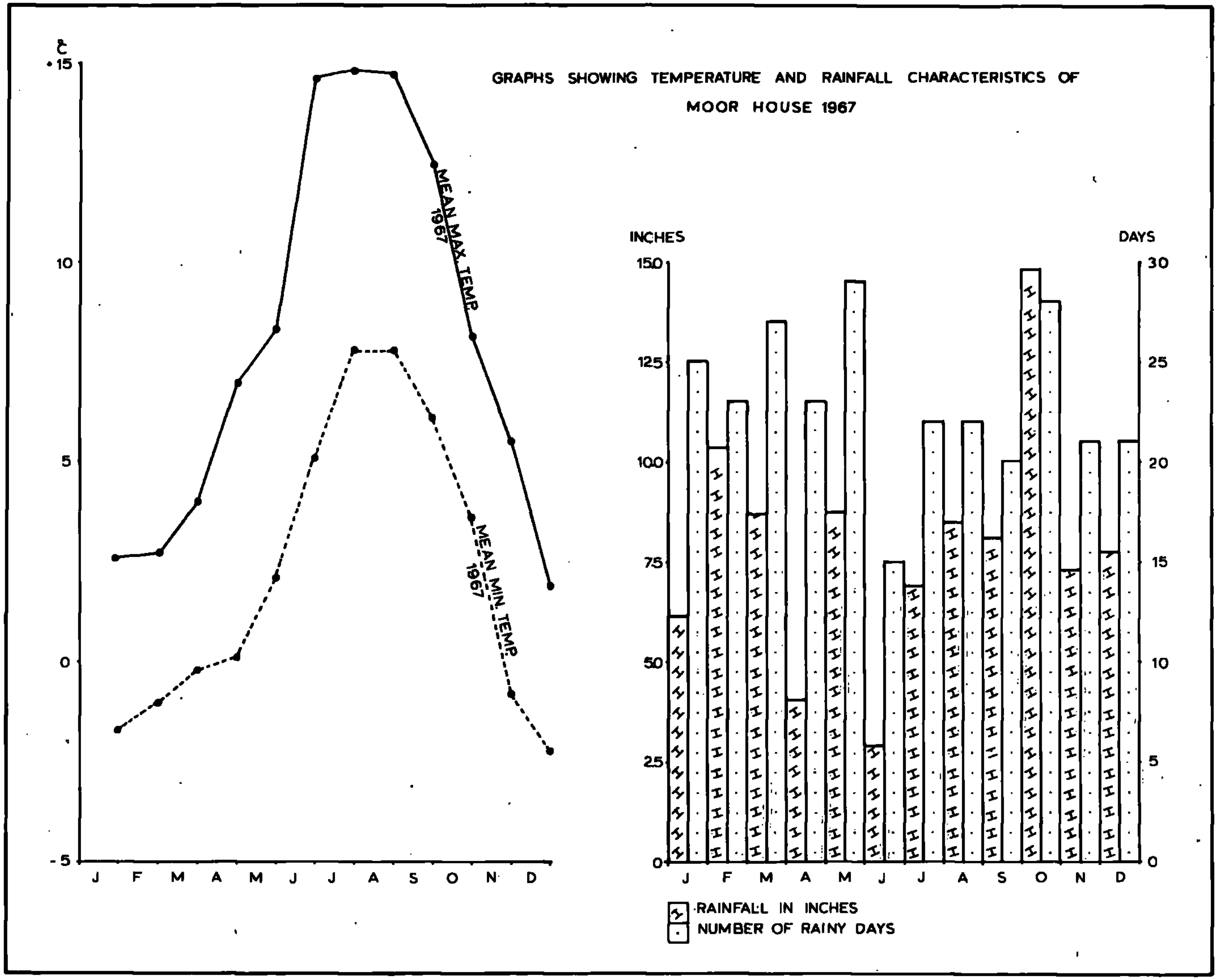
An appreciable amount of the precipitation occurs as snow, especially on the higher parts of the dale. Heavy snow rarely lies for more than two weeks below 800 feet. The area is liable to have severe frosts both on the hill ridges and the floors of the valleys. In the Pennines frost is likely to occur in any month of the year, though it is infrequent in July and August. The severest frosts generally occur in January, February and March.

2. The Climatological features of Moor House (Teesdale)

Moor House at 1840 feet is the highest station in the Upland of Britain, at which a continuous record of meteorological observations have been kept over a long period.

Mean annual temperature at the station is about 5.1°C which is some 3.7°C lower than at Penrith some 1330 feet below in the Vale of Eden. The mean maximum and mean minimum temperature for the year 1967 are 8.0° and 2.2°C respectively(Fig 1.9.).

In Teesdale total precipitation is considerably lower than on the extreme west of the Pennines, because of



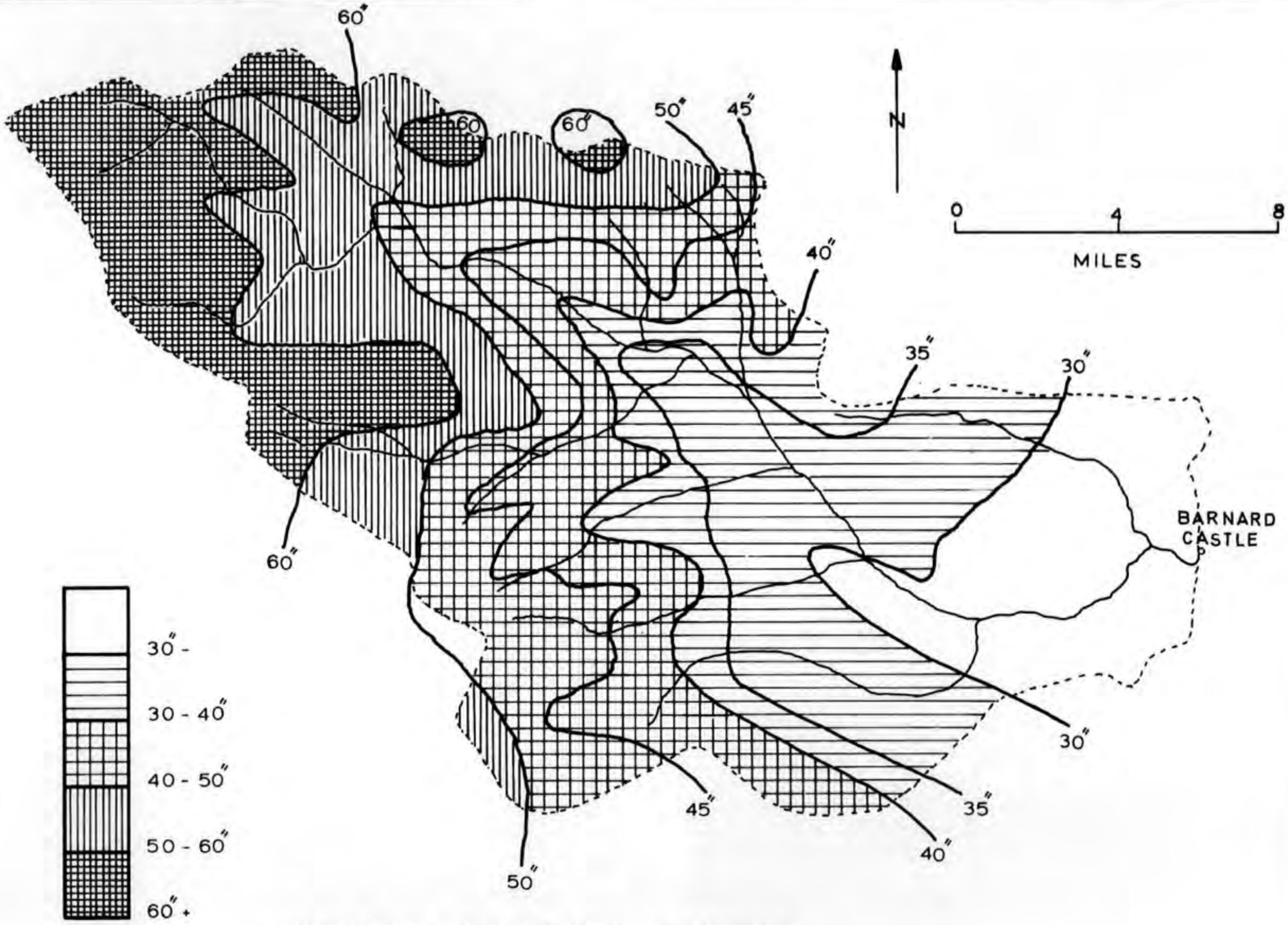
GRAPHS SHOWING TEMPERATURE AND RAINFALL CHARACTERISTICS OF MOOR HOUSE 1967

Fig. 1.9

the rain shadow effect, and it decreases significantly eastwards (Fig. 1.10) as the land decreases in altitude. The area recieves about 74 inches of rainfall annually. (Figure 1.9) shows that the highest amount of rainfall occurs in February and October and the lowest in June (Data for 1967) A distribution of the number of the rain days is also included in the same figure.

At Moor House, snow has been recorded in all months except June, July, August and September (Fig. 1.11) but the number of days with snow lying is highest in December, January, February and March.

Frost increases rapidly in frequency inland and katabatic flow makes valley bottoms colder than the slopes at night though warmer during the day. The histogram in (Fig. 1.11) shows that in November, December and January ground frost is more frequent, but in August it is rare. The same figure also shows that the months having a highest totals of sunny hours are June, July and August respedtively.



DISTRIBUTION OF THE RAINFALL IN TEESDALE

Fig. 1.10

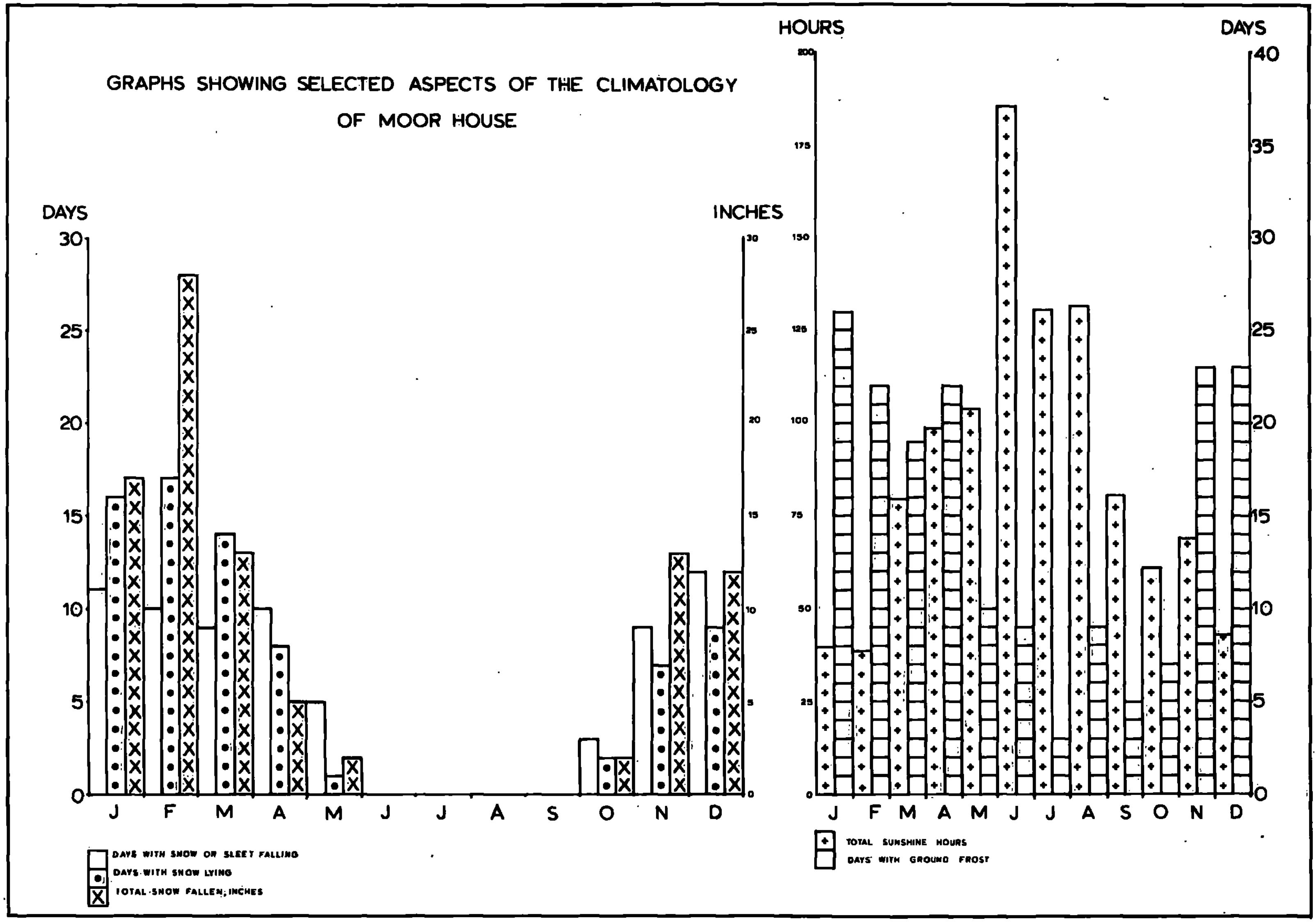

GRAPHS SHOWING SELECTED ASPECTS OF THE CLIMATOLOGY OF MOOR HOUSE
DAYS
0
5
10
15
20
25
30
INCHES
0
5
10
15
20
25
30
J F M A M J J A S O N D
DAYS WITH SNOW OR SLEET FALLING
DAYS WITH SNOW LYING
TOTAL SNOW FALLEN, INCHES
HOURS
0
25
50
75
100
125
150
175
200
DAYS
0
5
10
15
20
25
30
35
40
J F M A M J J A S O N D
TOTAL SUNSHINE HOURS
DAYS WITH GROUND FROST

Fig. 1.11

Chapter Two

History of Previous Research in Britain, North America and Western Europe

Introduction:-

The most important factors which determine the form of the land-surface, tectonic movements apart, are climate and geology. Climate determines the kind of the exogenous forces, and to a certain extent their intensity, while geology determines the power of the resistance of the land surface to such exogenous forces.

Within the humid temperate region the erosive work by running water is more important than that by other agencies. This mode of erosion may be briefly described in the following manner. The streams erode their bed and banks and remove the material eroded or supplied. By these processes the stream beds are lowered and form the lowest points within a catchment. Only a very small percent of this total area, however, consists of river bed. The areas between the different branches of a river are unaffected by river erosion and at such points there prevails instead interfluvial degradation by rainwash or sheet flood erosion, creep and solution.

The ability of flowing water to carve a channel, transport debris and thus ultimately to degrade the landscape, depends basically on the gravitational impelling force, and the resistances offered to it. The effects of lithology and topography on the ability of flowing water to carve and transport are exerted principally through their relation to the resisting forces. For these reasons a knowledge of some of these hydraulic relations is becoming increasingly important to the investigators of landscape evolution.

The fundamental aspect of river mechanics is the interrelationships between the flow of water, the movement of sediment and the mobile boundaries. These relationships are complex in detail and the mechanical principles governing their behaviour are not yet fully explained.

Sediment movement in rivers is of extreme practical importance. For example, when soil is eroded, land values are reduced and there is an increase in the amount of sediment transported and deposited by streams. High concentrations of suspended sediment interfere with the use of stream water for ~~by~~ industrial and domestic purposes ~~uses~~. Excessive concentration also harms fish and wildlife. Stream sediment is deposited in reservoirs and reduces their capacities. Irrigation canals, and navigable streams are often adversely affected by sediment deposition.

Because of the obvious economic interest in rivers, records of flow and sediment movement are far more extensive than they are for most other processes of interest to the geomorphologist.

Although in North America records are rarely longer than fifty years, and areal coverage is by no means complete, river discharge is relatively well documented in some areas. Because many research problems in river morphology require such measurement data, it is well to point out that there are available thousands of direct observations of velocity, width, depth and discharge at a variety of river stations. For example there are more than 7,300 gauging stations in the United States (Leopold, et al, 1964) and a total of 365 gauging stations in Britain, Wales and Scotland. (Fig. 2.1). (Water Yearbook 1963-1964). There are, however, relatively few in the under developed areas of the World.

It should be noted, however, that other parameters needed for geomorphological studies are in short supply. This applies particularly to measurements of water surface slope and the size and character of material comprising river bed load and banks, and other physiographic

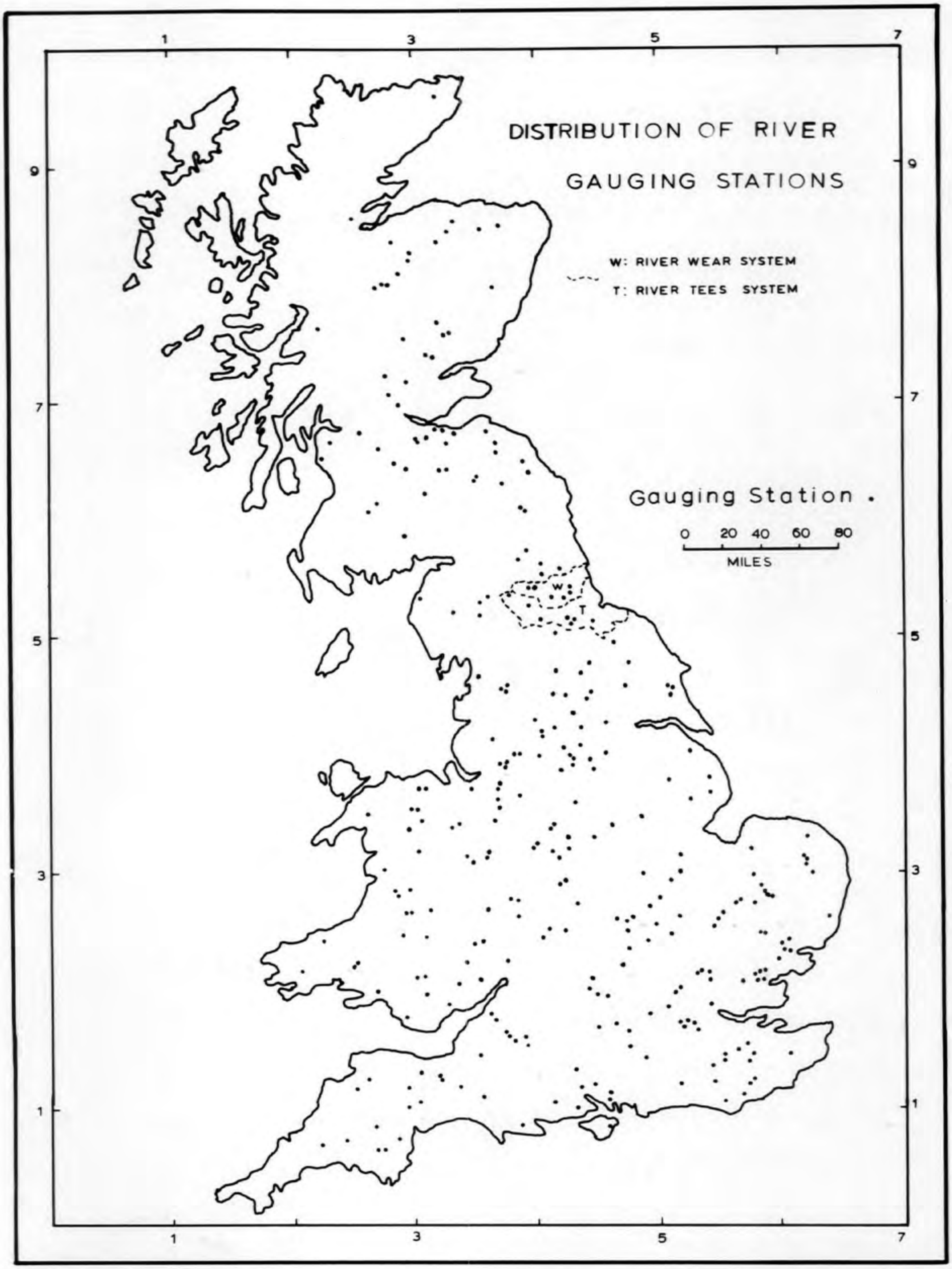


Fig. 2.1

G.B. Water Year Book 1962-64

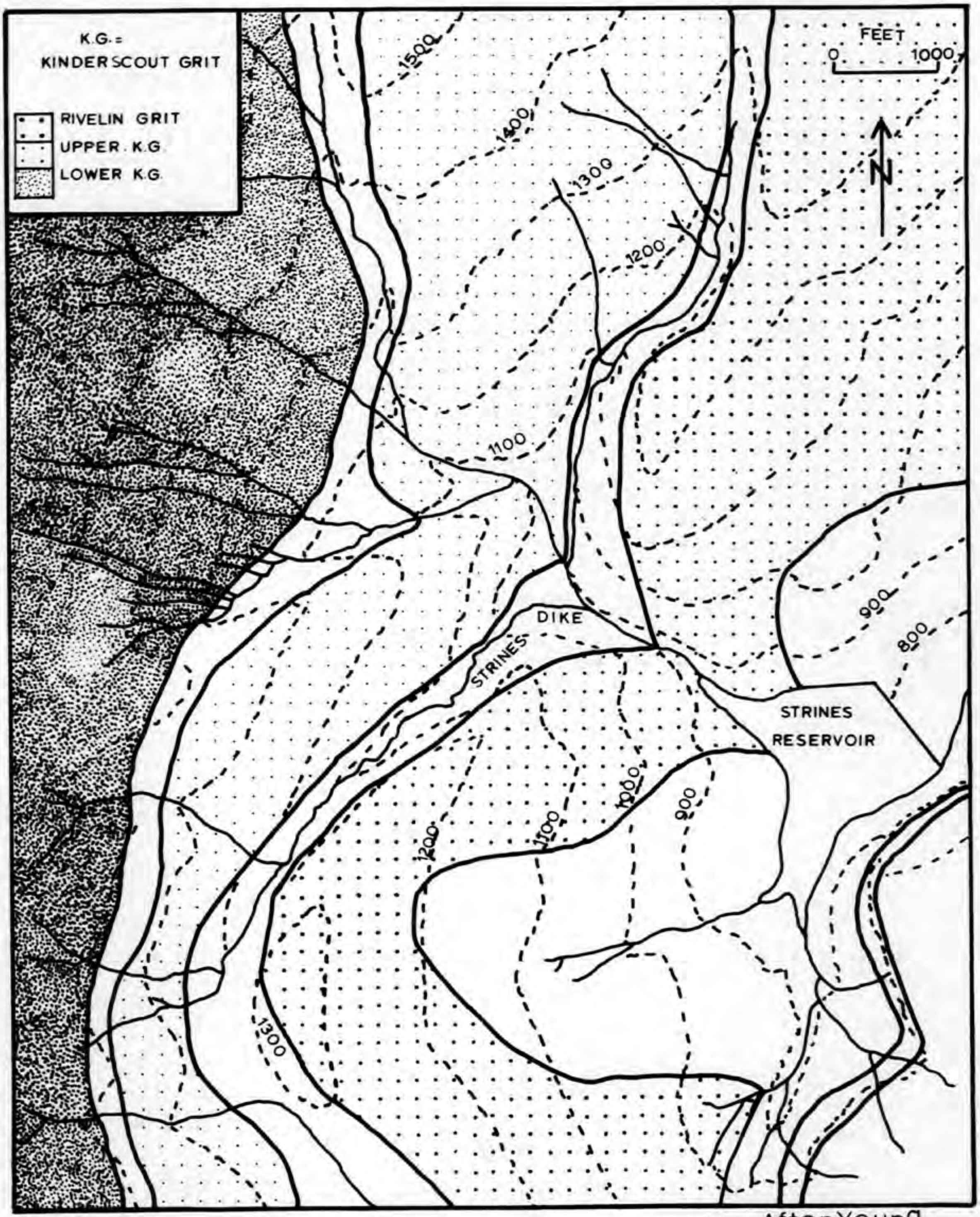
features.

I. Previous research in British Upland Catchments :-

Recently a number of British Catchments have been sites of various aspects of scientific research, such as studies of geology, climatology, hydrology and glaciation. Unfortunately, the study of sediment movement in many of these cases has been to a great extent neglected.

In spite of the relative paucity of information concerning sediment movement in Britain, a comprehensive study was made by Young,(1957)in the catchment area of River Strines Sike in Yorkshire(Fig. 2.2.). This catchment lies in the alternating shales and sandstones of the Millstone Grit series which have a south-easterly dip. The area is covered partly by moorland, and partly by mixed deciduous and coniferous plantations. The total catchment area of the river and its tributary branches covers 80 million square feet. The average annual rainfall of the catchment is about 42 inches. The valleys are directly related to the present streams and have slopes of over 20°. Much of the stream bed consists of bare rock, suggesting that bed material is largely supplied to the stream from the valley sides and by erosion of its banks.

The river has a very large delta at its mouth, and



After Young

THE CATCHMENT AREA OF STRINES DIKE YORKSHIRE

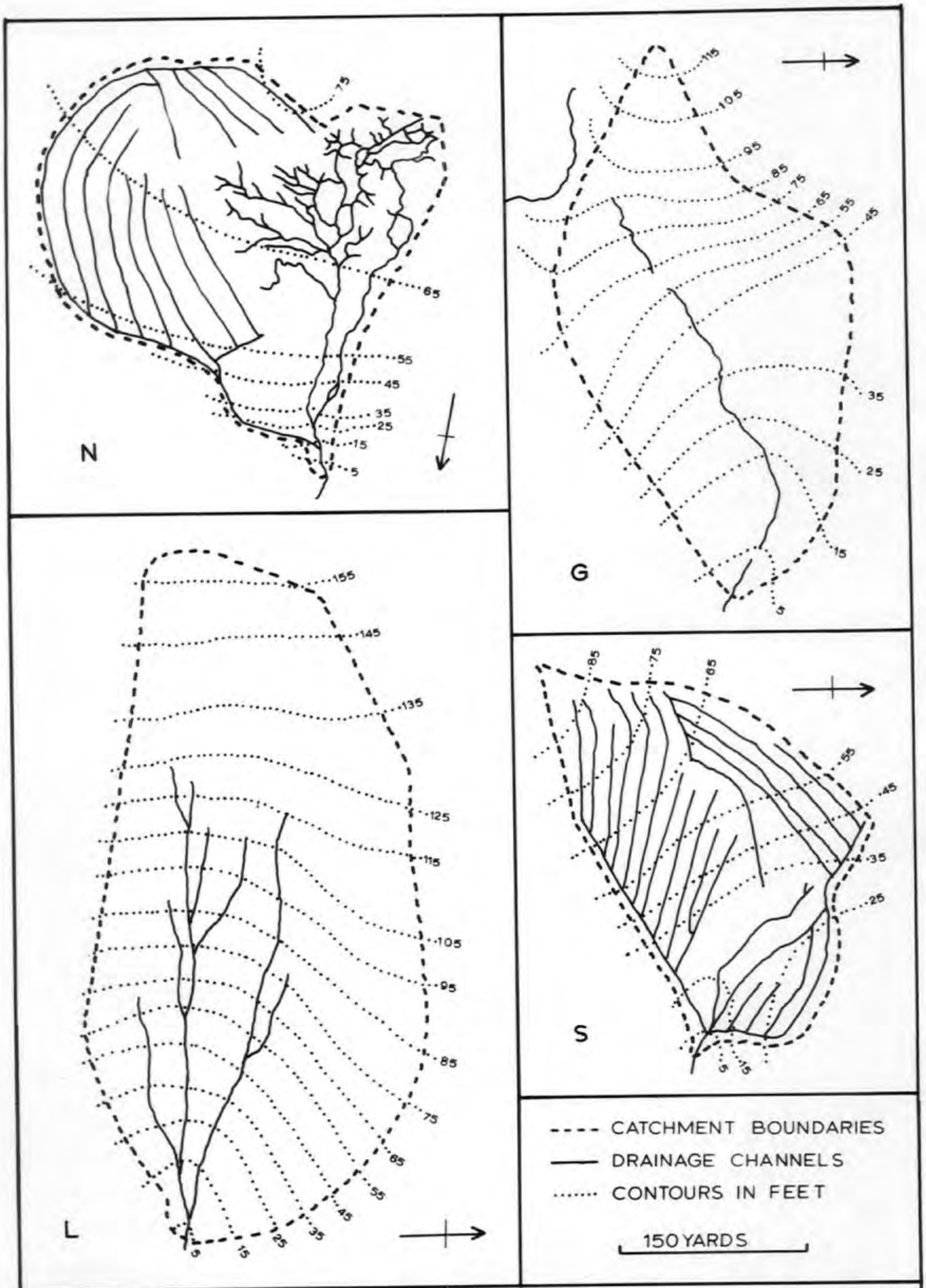
Fig. 2.2

the total volume of sediment which has been deposited in this delta was estimated as 2.5 million cubic feet. After considering the rate of erosion and sediment movement it was estimated that three million cubic feet of material had been eroded from the catchment to form this delta.

A study of four small catchments in Upper Tees drainage basin, varying from 10 to 20 acres in size and covered by thick blanket peat, has been made by Conway and Miller, (1962). These catchments range in altitude from 1700 feet to 2000 feet (Fig. 2.3.). The description and details of these catchments have been tabulated below :

Table 2.1

Catchment and Weir	Situation	Grid Ref. 100 Kg. square NY	Area in acres	Date records began	Nature of surface, etc.
N	Burnt Hill	752.332	11.9	1954	Severely burnt : drained partly b erosion channels partly by moor gripping
S	Syke Hill	772.333	9.4	1957	Drained by moor gripping, surfac heathery but wit fairly abundant sphagnum.
L	Long Hill	772.317	21.8	1957	Surface heathery but with fairly abundant sphagnu Burnt over in April 1958
G	Bog Hill	773.327	13.5	1954	Surface heathery but with abundant sphagnum



SKETCH MAPS OF THE FOUR CATCHMENTS STUDIED BY CONWAY & MILLAR

Fig. 2.3

In this region a large acreage of the hill land is covered by blanket peat. At the highest altitudes, the peat is up to 14 feet in thickness where it is still intact, but much of it is heavily eroded. During dry summers, the peat surfaces exposed in the erosion channels appear dusty and loose, and there may be little or no flow of water in the channels. Erosion in this region has been severe, and has left a type of land surface whose productivity or usefulness must be negligble from any point of view. This form of dereliction is even more severe and very widespread in the Southern Pennines. It is also common in Weardale in the area of the other experimental catchment.

Although the Moor House Reserve area is great, the choice of catchments for hydrological observations is restricted by the need to have a reasonably uniform type of ground cover if one is seeking to correlate run-off behaviour with ground cover. Most of the drainage channels in the area run far back into large erosion complexes. There are few small catchments not seriously affected by erosion, and most of those that can be found are not defined by clearly marked watersheds.

Estimations of sediment movement have been made for these catchments and are as follows. The amount of silt deposited in the N catchment stilling pool was estimated at about 400 cubic feet in four years. At G catchment nothing was taken out of the stilling pool while S catchment was intermediate in this respect with about 80 cubic feet of solid material being removed from it. This material accumulated during one year. The amount in L catchment was quite small.

The history of Some previous research in North America and Western Europe:-

The laws governing sediment transportation in rivers are receiving more and more attention from hydraulic laboratories and hydraulic engineers, as a knowledge of them is fundamental to both river models and river construction work. These require two distinct applications of the same principles. In river-models a sediment must be used which will respond to the flow in such manner that geometrical similarity is maintained, whereas in river work the cross-sections must be designed to suit the sediment from which they are composed. In both cases the same laws are applicable.

Recently both these problems have been attacked by the use of methods drawn from experience, but with varying success. It has now become evident that a knowledge of the principles of sediment transportation is necessary as observations of natural channels as well as theoretical considerations have failed to yield dependable conclusions.

The only way out is to take the problem into the laboratory and there to disect it under controlled conditions. Gilbert(1914) realized this many years ago, but in spite of a valiant effort the results of his work do not give more than a general conception of sediment laws. In his experiments the water-discharge and the rate of sand feed were kept constant until a state of equilibrium of the slope was reached. Then the bed slope, depth and sand discharge were measured. In most cases the surface slope was not recorded and the duration of the sand measurement was very short-frequently less than five minutes. This method allowed considerable error and it is not surprising that his experiments were inconclusive. Other experiments in Europe took up the work, but they have, for the most part, worked with sands and gravels of uniform size. As such only rarely occur in nature, this work is not immediately applicable, as it has been demonstrated that a mixture will behave quite differently from a sand of uniform grain size even though the mean grain size are the same. From the theoretical point of view the assessment of streams transportation power and competency was dealt with for a long time. Twenhofel,(1932) said that "The material transported and deposited range through wide dimensions, with every possible transition from the minimum to the maximum. Precision demands that their classification and the terms which express dimensions of particles should be on a mathematical basis." Several classifications have been proposed, but that of Wentworth 1922 given below, appears to be the most satisfactory one.

Table 2.2

Type of Sediment	mm.
Boulder	256 or above
Cobble	64 - 256
Pebble	4 - 64
Granule	2 - 4
Very Coarse Sandgrain	1 - 2
Coarse Sand grain	$\frac{1}{2}$ - 1
Medium sand grain	$\frac{1}{4}$ - $\frac{1}{2}$
Fine sand grain	$\frac{1}{8}$ - $\frac{1}{4}$
Very fine sand grain	$\frac{1}{16}$ - $\frac{1}{8}$
Silt particle	$\frac{1}{256}$ - $\frac{1}{16}$
Clay particle	smaller than $\frac{1}{256}$

Quirke,(1945) mentioned that "A stream or current transporting sedimentary materials has, for a given condition, a certain capacity, a definite load, and a maximum size of debris". The capacity is represented by the maximum quantity of debris that can be transported under the given conditions. The load is the actual quantity of debris that is being carried. The load may equal the capacity but usually is smaller. The maximum size of the debris is a reflection of the velocity or transporting power of the current. The maximum size may be less than the current could carry, under given conditions, because larger particles may not be available. If, however, the largest particle is the maximum size the current can transport under the given conditions, it is then a measure of the competency of the current.

Blackwell's experiments in(1857)showed a velocity of 2.25 to 2.50 feet per second to be competent for the movement by traction of pebble having a diameter of 12.56 mm. Also in this respect Thiel,(1932)in his study of a small stream connecting two lakes in Minnesota discovered that the approximate current velocities necessary to move debris of different sizes as shown below in Table : 2.3.

No single procedure, whether theoretical or empirical, has been universally accepted as completely adequate for the determination of bed load discharge over the wide range of sediment and hydraulic conditions in nature.

Table 2.3

Description	Mean diam. in mm.	Depth in M.	Velocity M/sec.
Coarse Sand	1.7	0.006	0.34
Fine Gravel	3.2	0.026	0.46
Rounded pebbles size of peas		shallow	0.61
Fine gravel	4.9	0.033	0.65
Fine gravel	7.0	0.066	0.86
Gravel	27.0	shallow	0.97
Gravel	54.0	"	1.62
Boulders	171.0	"	2.27
Boulders	323.0	"	3.25
Boulders	409.0	"	4.87
Boulders	700 - 800	"	11.68

In spite of the difficulty of measuring bed load in rivers many attempts have been made in North America and some of the European Countries to solve the problem in the laboratories and also in the field.

Generally speaking, two approaches were used in the field to determine the bedload discharge.

1. The trapping of bedload which passes a certain point during a given period of time.
2. The forcing of all of the bedload into suspension by increased turbulence so that it could be measured with the

usual sampling devices (Lelievsky 1966). As a rule the first method is simpler more efficient and feasible in the field.

Recently the radioactive tracer technique was selected by Sayre and Hubbell,(1965)as the most suitable method for studying the transport and dispersion of sediment particles along the North Loup River(Nebraska U.S.A.) because, with suitable instrumentation, the distribution of the particles at any time could be measured in place.

A site near Purdum in Blaine County was selected because it was particularly suitable for the experiment from both a hydraulic and radiological-health standpoint. Specifically the river maintained a relatively constant water discharge for weeks and the bed form was normally one of large dunes with the bed material being sand with a medium diameter of about 0.29 mm. The test reach was fairly straight and had stable banks, while the channel was narrow and the depth small.

The post-experimental analysis showed that if the number of particles that were actually used in the experiment were uniformly distributed throughout the test reach to a depth of 1.5 feet, the particle population density would be 1.98 particles per cubic inch. To insure that the tracer particles would not be in suspension for any significant part of time but that the most dominant particle size would be represented, a narrow particle size range slightly coarser than the dominant size range of the bed material was selected(Fig. 2.4.). The figure shows the size distribution of the measured bed material.

The median size of the tracer particles is 0.305 mm. and the assumption that the tracer particles were spherical and had a specific gravity of 2.65 were used to calculate the weight of the required number of tracer particles. The results of this study are summarized in Table 2.4.

This study concluded that when the streambed was composed of dunes and contaminated bed material particles were transported by the flow, the vertical distribution of contaminated particles in the streambed varied considerably from place to place and followed no regular discernible pattern. The discharge of the bed material that is simulated by tracer particles can be computed by a continuity-type equation, which states that the discharge is proportional to the product of the cross-sectional area of the bed through which the particles move and the mean velocity of the particles. The cross-

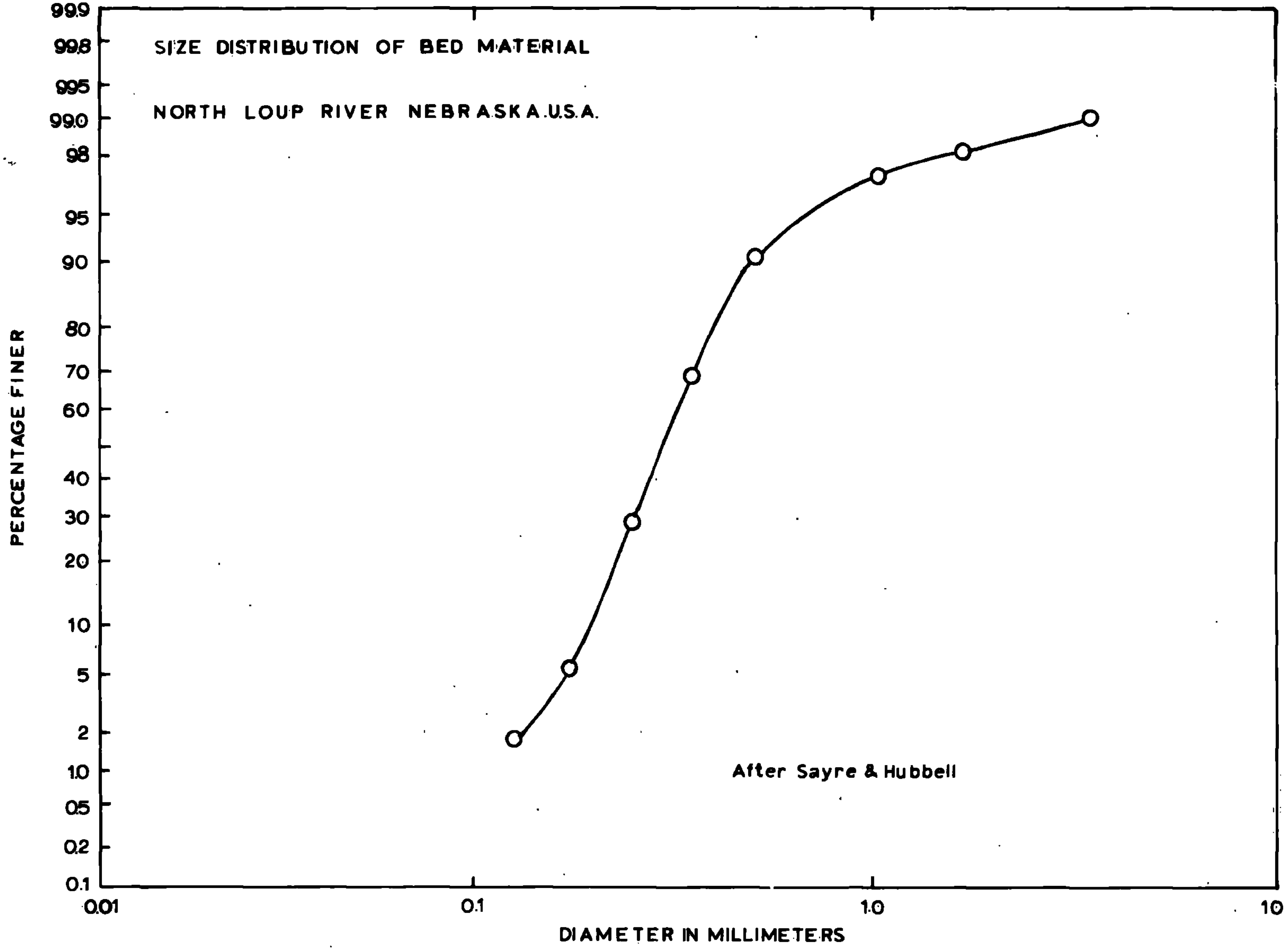

SIZE DISTRIBUTION OF BED MATERIAL
NORTH LOUP RIVER NEBRASKA U.S.A.
After Sayre & Hubbell
PERCENTAGE FINER
99.9
99.8
99.5
99.0
98
95
90
80
70
60
40
30
20
10
5
2
1.0
0.5
0.2
0.1
0.01
0.1
1.0
10
DIAMETER IN MILLIMETERS

Fig. 2.4

Table 2.4

Bed Material

Depth below trough surface in inches	Percent finer than indicated size in millimeters										
	0.088	0.125	0.175	0.250	0.350	0.500	0.700	1000	1.651	3.327	9.424
1.	0	2	6	29	68	91	96	97	98	99	100
0 - 12	0	1	6	27	65	87	92	94	97	99	100
12 - 24	0	1	8	32	66	91	97	-	98	100	-
24 - 36	-	0	3	18	55	86	98	99	100	-	-
0 - 12	-	0	4	25	69	93	99	-	100	-	-
12 - 24	0	1	5	21	45	87	97	-	99	100	-
24 - 36	0	1	4	15	41	70	84	90	93	99	100

1. Composite of 3 feet cores collected throughout test reach.

sectional area can be determined either from longtitudinal profiles of the bed surface, the area under the concentration - distribution curve, or core-sampling measurements, which define the depth of penetration of the tracer particles.

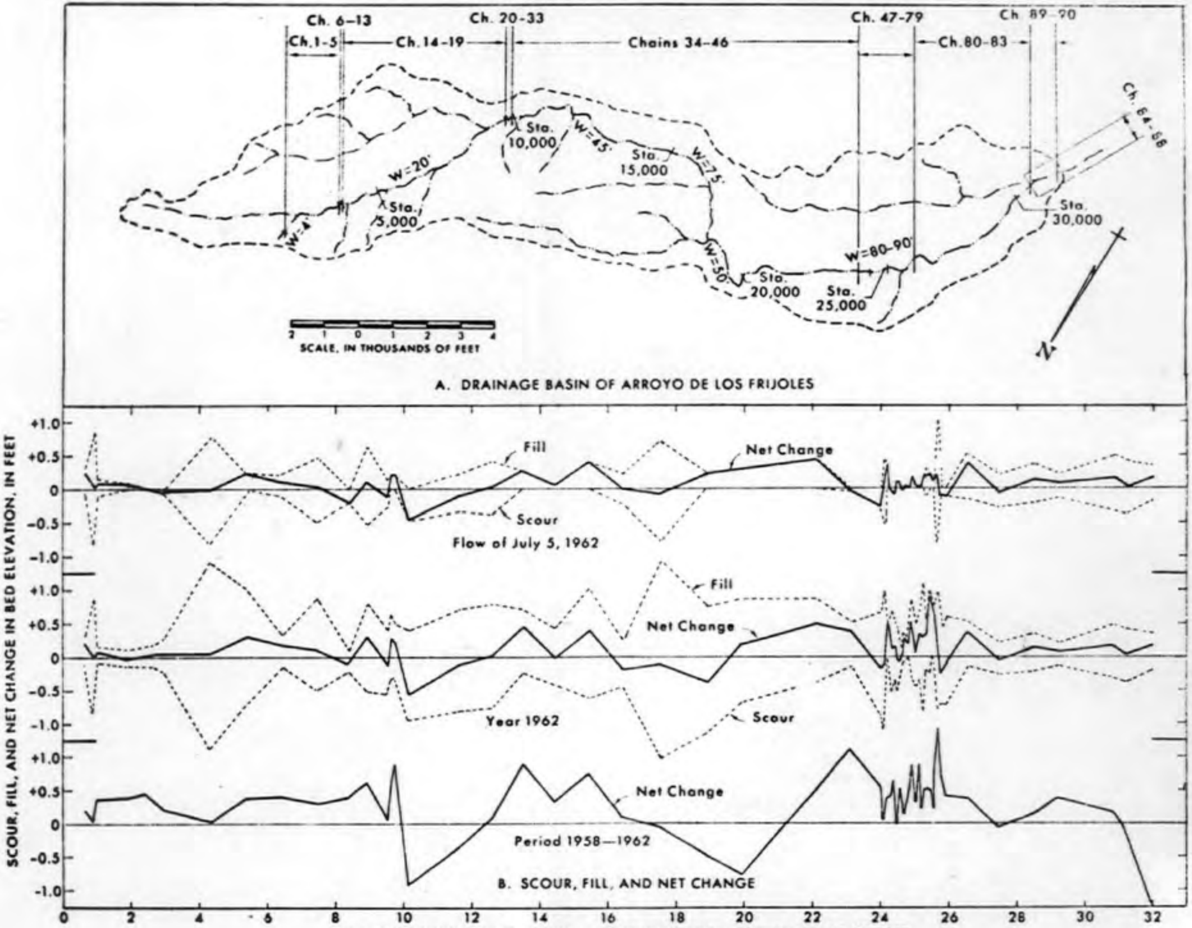
Progress has also been made in describing river bed characteristics at a given stream section. Recent observations of channel scour and fill over relatively long reaches of three streams in the Western United States has been achieved by Emmett and Leopold(1965).

The Arroyo de los Frijoles is a sandy ephemeral channel located about 4 miles north-west of Santa Fe New Mexico. Normally, flows are the result of runoff from local thunderstorms during summer months. Peak flow occurs within several minutes after the initial flood wave. Throughout the study reach, the channel increases in size from a rill near the watershed divide to a width of about 100 feet downstream. The bed is composed of medium sand and a moderate amount of gravel. The medium sand grain diameter is about 0.5 mm.

Determination of the amount of scour and fill using the chain method is a simple procedure. The chains are buried vertically in the stream bed with the top link at, or slightly above the bed surface. After a flood, the elevation of the stream bed ~~was~~ is resurveyed and the bed is ~~was~~ dug until the chain is exposed. If scour has occurred, a part of the chain will be lying horizontally. The difference between the previous streambed elevation and the elevation of the horizontal chain is the depth of scour. The difference between the existing bed elevation and the horizontal chain is the depth of fill. If no scour has occurred, the depth of fill is the increase in bed elevation.

By 1959 the majority of the chains had been installed a long the Arroyo. Scour and fill data for a sample flow, for the year 1962 and for the period 1958-62 are shown on Fig. 2.5. For each flow on this figure, the lower dashed line represents the depth of scour and is plotted against distance along the channel. The upper dashed line represents the depth of fill. The heavy solid line represents the net change in bed elevation after scour and fill, the upper part of the figure shows the drainage area studied and the general location of the chains by chain number. The findings of this experiment are summarized on Fig. 2.6 despite considerable scatter among the data, the mean scour depth appears to be proportional to the square root of discharge per unit width of the channel.

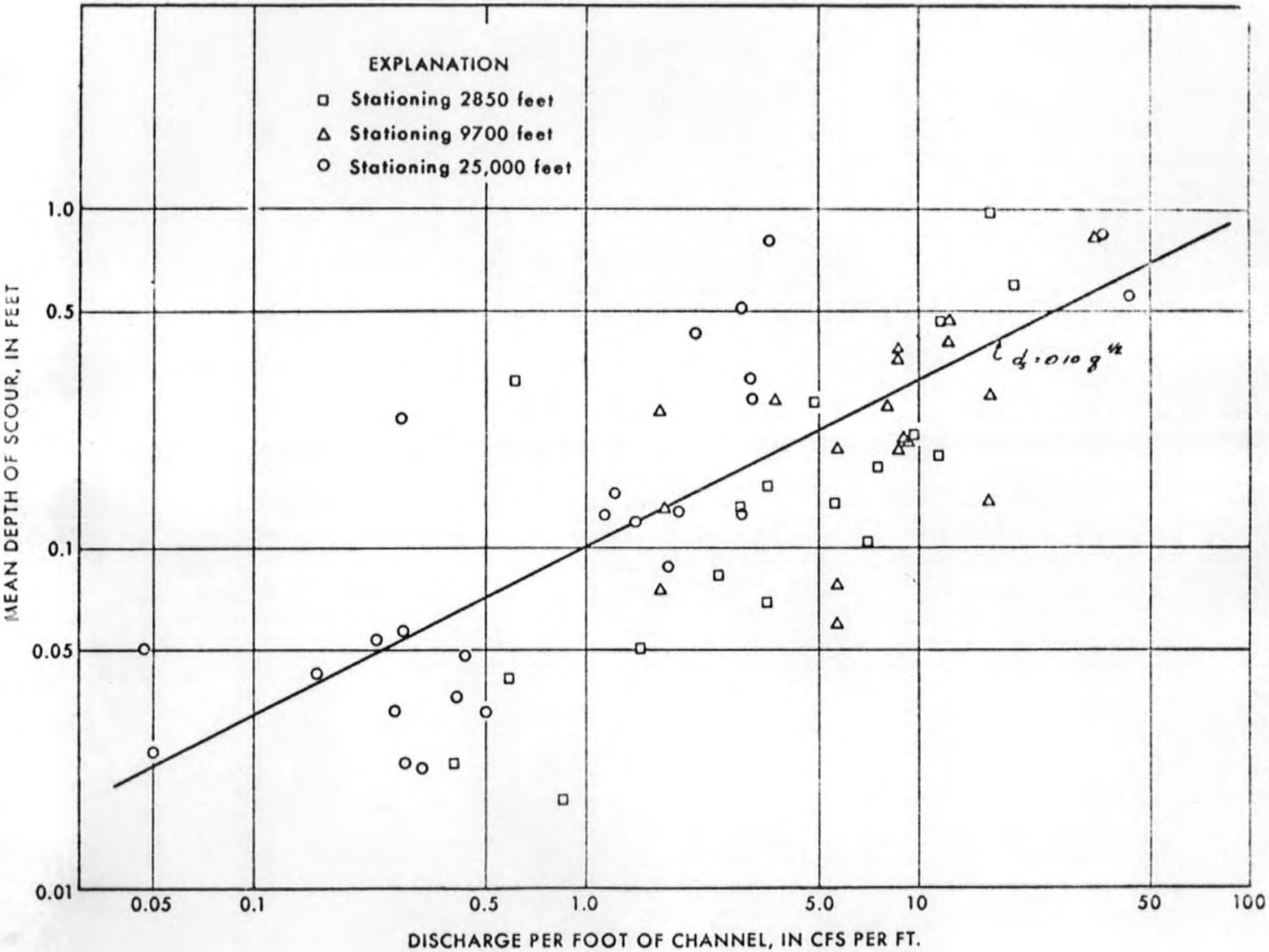
The Rio Grande del Ranchos is a small perennial stream on the west slopes of the Sangre de Cristo Range, about 7 miles south of Taos, New Mexico. Peak discharges occur



Arroyo de los Frijoles near Santa Fe, N. Mex.

Fig. 2.5

After Emmett and Leopold 1965



Depth of scour as a function of unit discharge.

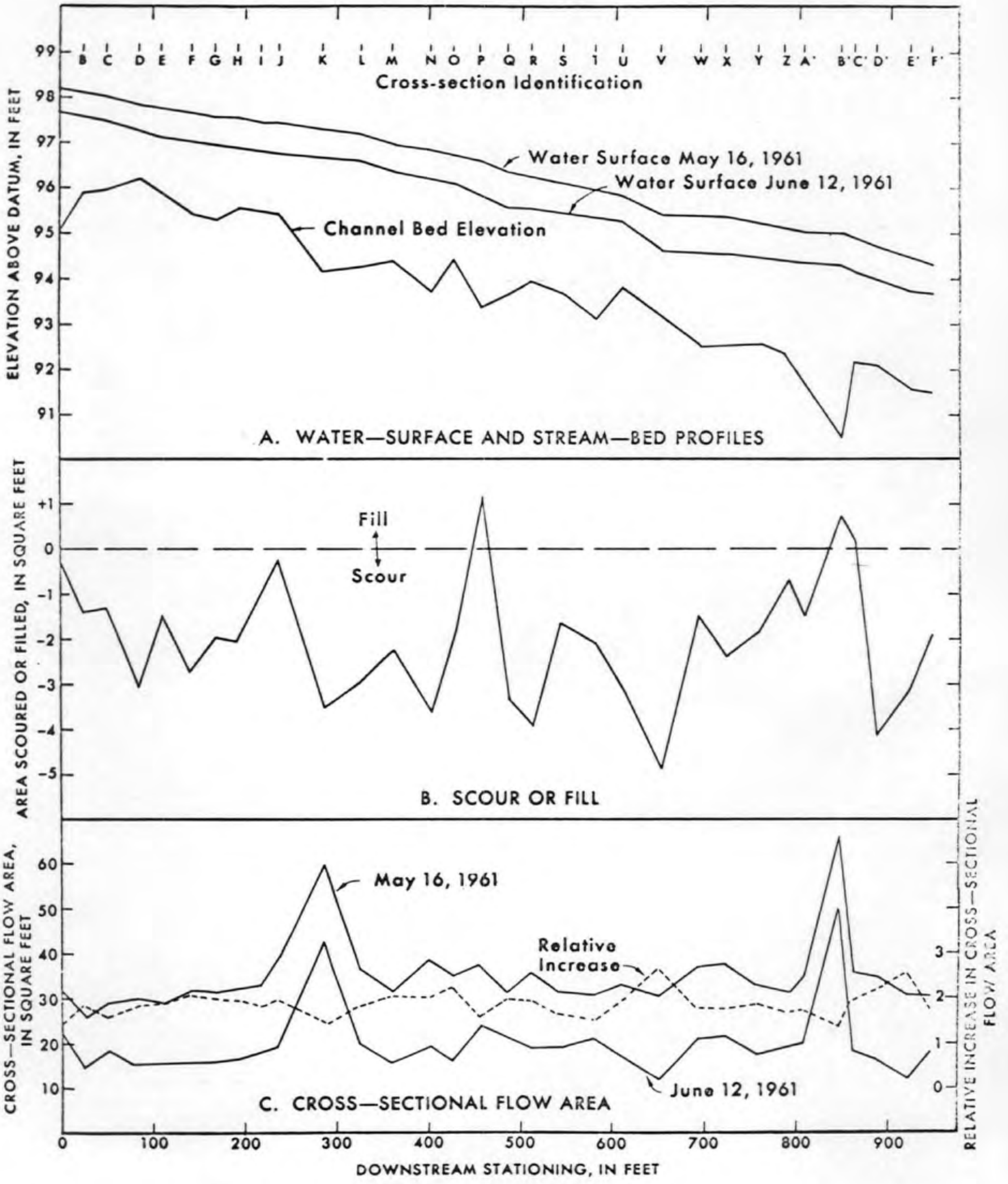
Fig. 2.6

After Emmett and Leopold 1965

in the spring and are normally produced by snowmelt. The study reach consisted of a straight reach of 250 feet. The streambed was predominantly gravel and quite uniform in size, median particle size ranged from 21 to 33 m.m. High flow discharge was 130 C.F.S. and low flow discharge was 25 C.F.S. The data consisted of 32 cross sections surveyed during spring high flow and again at low flow in the succeeding summer.

The Papo Agie River is a larger perennial stream in Western Wyoming. The study reach is located one mile northeast of Hudson, it consists of a curved reach of 2,000 feet, followed by a straight reach 2,100 feet. The Peak flow was associated with spring snowmelt. The stream bed was gravel ranging in size from fine gravel to large cobbles. The data for the two streams represent high stage measurements obtained during peak flow and low flow.

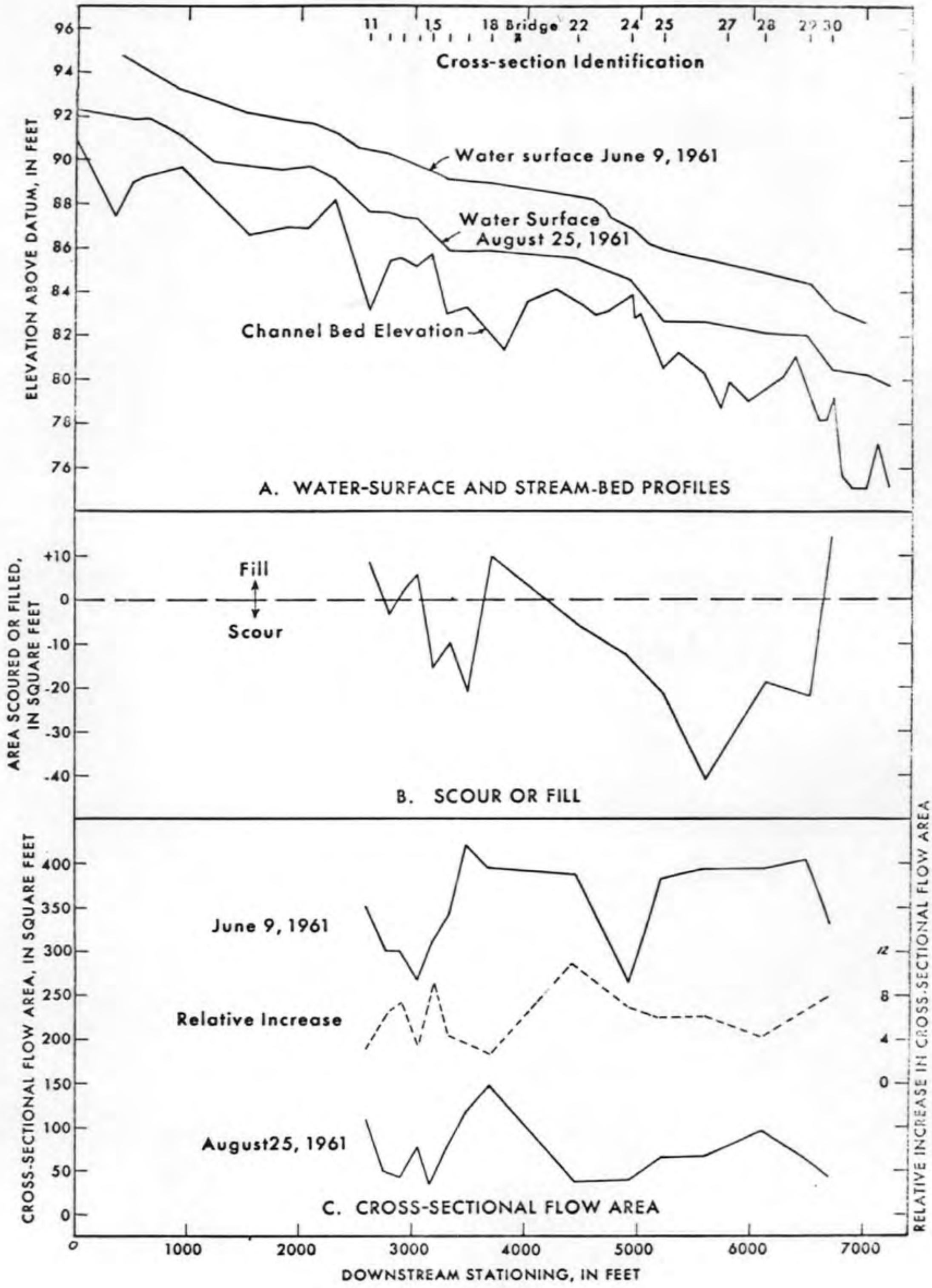
Profiles of the streambed and water surfaces were plotted against distance along the channel on (Fig. 2.7) and (Fig. 2.8.). Below these profiles is a plot of the net changes in cross sectional areas of the bed and, separately, the cross-sectional areas of flow. Values are considered scour if the bed elevations at high flow are lower than those at low flow. Thus, a negative area



Rio Grande del Ranchos near Taos, N. Mex.

Fig. 2.7

After Emmett and Leopold 1965



Popo Agie River near Hudson, Wyo.

Fig. 2.8

After Emmett and Leopold 1965

within this curve represents the total volume of material per foot of length scoured from the streambed. Positige area represents the total volume of material brought in from upstream and temporarily deposited as a fill.

In (1932) a comprehensive survey of the sediment in the Mississippi River Channel, by the U.S. Waterways Experiment Station, furnished sufficient data to prove that there is a progressive downstream decrease in the size of the detritus composing the bed. Over 600 samples were taken from the channel bed at fairly uniform distances apart between Cairo and the Gulf of Mexico. To relate the grain diameter of a sample to the local currents that transported it, a choice must be made between the average diameter, the median diameter, and the maximum diameter. If the sample is well sorted the choice is usually not difficult. This is illustrated in Table 2.5 by a sample from the bed of the river on the Head of Racetrack Town Head, 606 miles below Cairo. The sample was coarse sand containing some gravel. The average grain diameter is 0.94 mm. the median is 0.54 mm. and 2 percent of the sample is coarser than about 8 mm. For some 500 miles downriver from Cairo abundant gravel indicated that velocities greater than 2 miles per hour

Table 2.5.

MM. Opening	Percent on	Cumulative Percent through
1.65	0.0	100.0
1.17	0.1	99.9
0.83	0.0	99.9
0.59	0.1	99.8
0.42	0.1	99.7
0.30	2.2	97.5
0.21	68.9	28.6
0.10	28.4	0.2
0.07	0.1	0.1

(Sample 606 miles downriver from Cairo)

are common in the channel during high flow. Table 2.6 has been prepared from the U.S. Waterways diagramatic chart which shows that the character of the bed materials averaged by 25 mile reaches.

Another investigation of fluvial sediment of the Mississippi River at St. Louis, Missouri, was begun by Jordan in 1948. The flow of the Mississippi River at St. Louis is a composite of the flows from many tributaries in a drainage area of about 701,000 square miles. An average of about 45% of the flow at St. Louis is from the

Table 2.6

Miles below Cairo	100	300	500	700	900	1000
Large gravel	8.0	3.0	6.0	2.0	tr	--
Medium gravel	10.0	2.0	6.0	2.0	tr	--
Fine gravel	11.0	3.0	2.0	1.0	tr	--
Coarse sand	30.0	22.0	9.0	8.0	1.0	--
Medium sand	32.0	50.0	46.0	44.0	26.0	9.0
Fine sand	8.0	18.0	26.0	40.0	68.0	65.0
Very fine sand	tr	1.0	2.0	1.0	2.0	4.0
Silt	tr	tr	2.0	1.0	2.0	10.0
Clay	tr	tr	1.0	tr	1.0	10.0

(Mississippi River Sediments - 100 to 1000 miles below Cairo)

Missouri River, which is confluent with the Mississippi River about 15 miles upstream from St. Louis.

The sediment was sampled and streamflow was measured at the MacArthur Bridge, 178.9 miles upstream from the mouth of the Ohio River and 1.1 miles downstream from the water-stage recorder.

Samples of bed material were obtained with a U.S. BM - 48 sampler from May 1951 to 1958 and with a U.S. BM. - 54 sampler from April 1958 to July 1959. Both samplers obtain material from the upper 1 to 1.5 inches of the bed.

Because of improved design, the B.M. 54 sampler was less likely than the BM - 48 to permit fine material to be washed out as the sample was taken and raised to the bridge. The sieve method was used to analyse all bed material, samples were analysed individually, and the results were averaged to give the particle size distribution for the entire cross-section.

The size distribution of bed material was highly variable with location in the cross-section and was highly variable with time also. The data for four sampling points are shown for 1955-59 in (Fig. 2.9) to indicate the probable reliability of the (1951-55) data. A general relation between median diameter and discharge was suggested by the fact that the discharge was higher in (1951-52) than in (1953-56) and was intermediate in (1957-59).

A test was made to determine whether or not the particle size was related to the discharge for short periods. Average median diameters were plotted against mean discharge for one day to 2 years period, and one year was the shortest period for which a good relation was found. The relation for two years was slightly better than the relation for one year as shown in (Fig. 2.10). It was found also that the mean bed elevation was not significantly related to the instantaneous discharge mean velocity, shear velocity, mean depth nor suspended

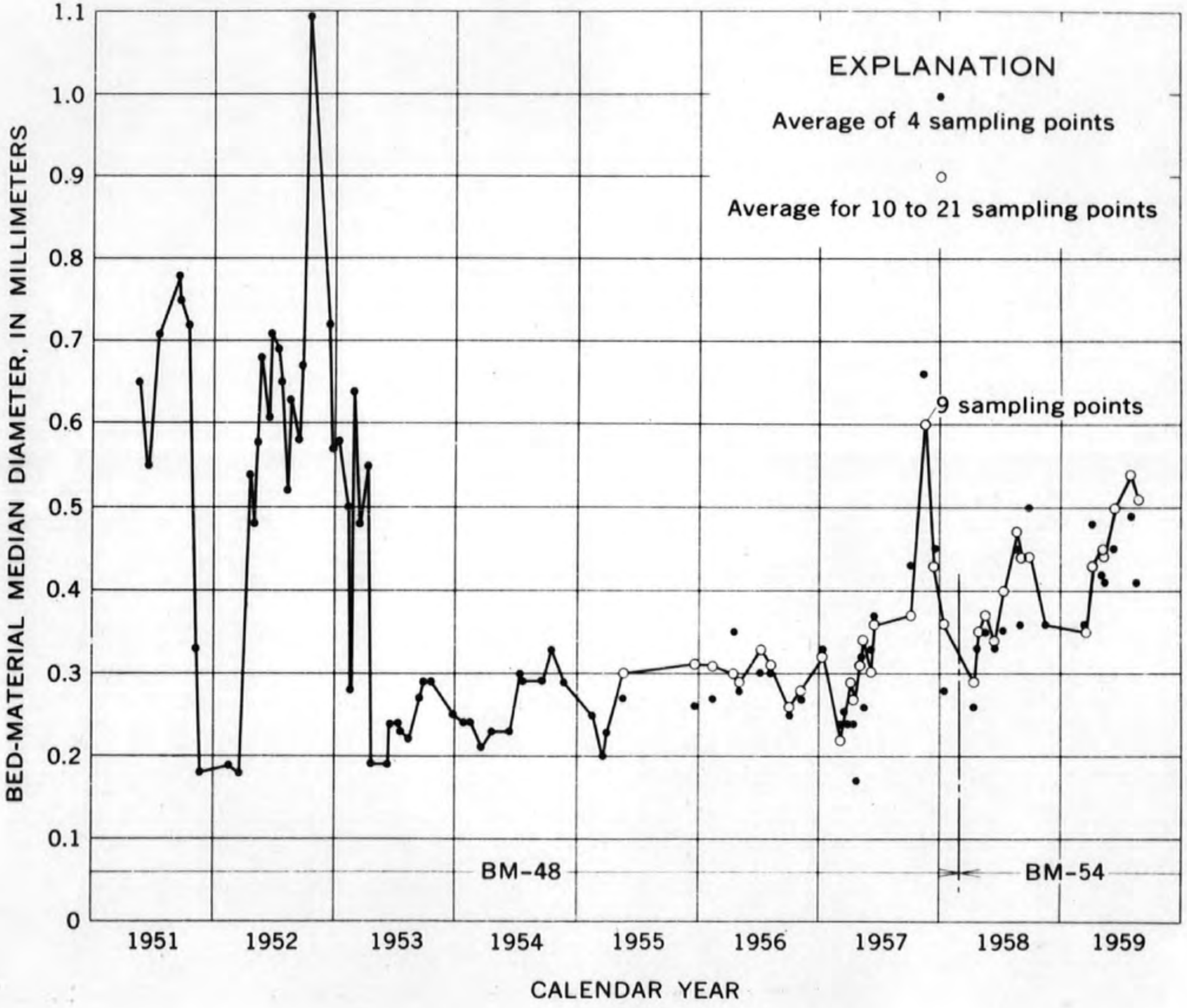


Fig. 2.9 **Variation of bed-material size with time.** (AFTER JORDAN)

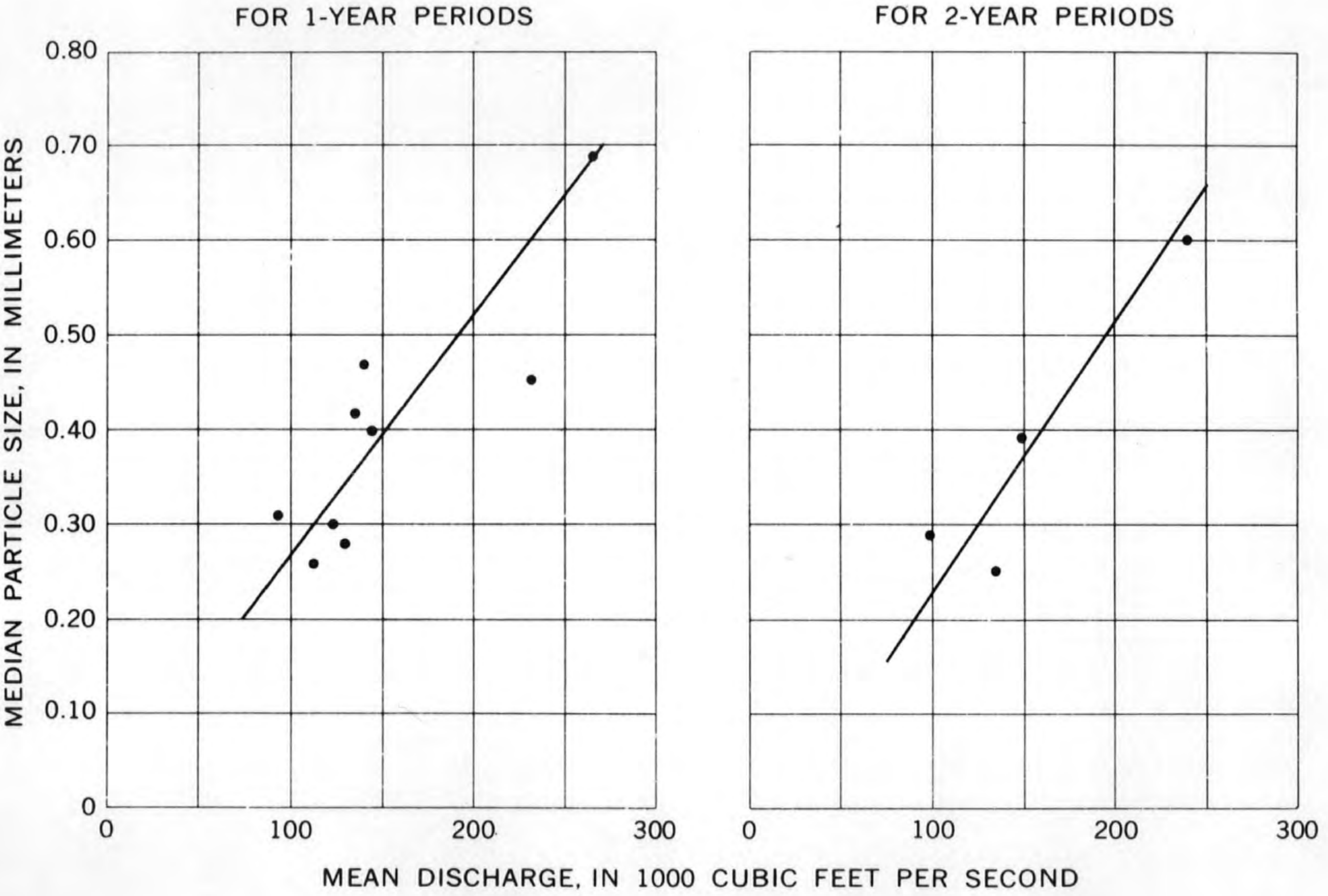


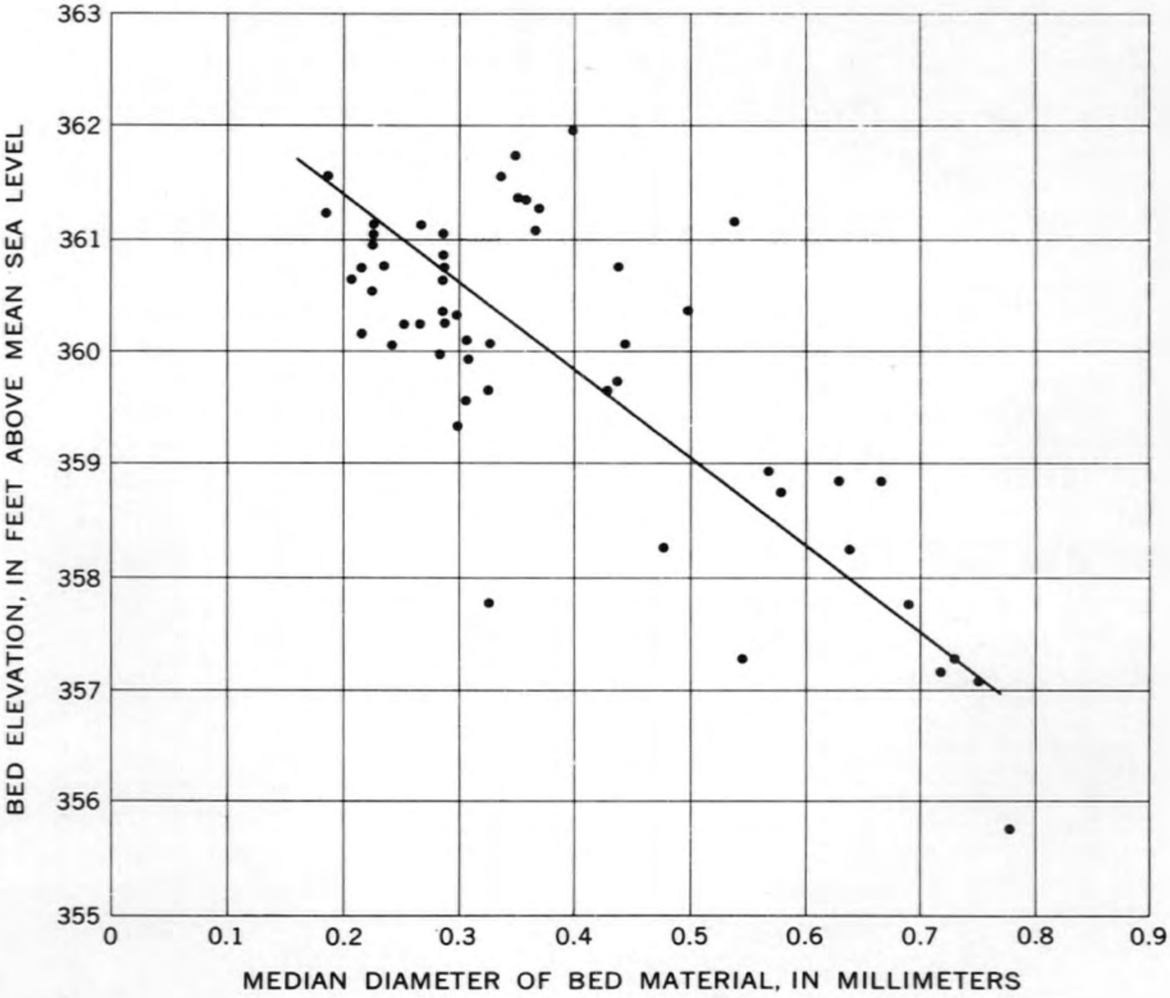
Fig. 2.10 **Relation of bed-material size to discharge.** (AFTER JORDAN)

sand concentration. The bed elevation and the median diameter of the bed material were fairly closely related, this was indicated clearly in (Fig. 2.11). The relation shows that the particle size was partly dependent on the depth of scour or that the depth of scour and the particle size are mutually dependent on the same causes.

The Rio Grande in New Mexico has been the site of several investigations in sediment transport. The observed and computed sediment concentrations and size distributions of bed material were measured by, Nordin and Beverage (1965) at six sediment stations in down stream order :-

1. Rio Grande at Otowi Bridge, near San Ildefonso
2. Rio Grande at Cochiti
3. Rio Grande at San Felipe
4. Rio Grande near Bernalillo
5. Rio Grande at Alluquerque
6. Rio Grande near Belen

From Otowi Bridge to Cochiti the river is composed of coarse gravel, cobble, and boulders and appear to be fairly stable and permanent features of the channel. Between Cochiti and San Felipe, the channel is braided and composed of coarse gravel and cobbles. At San Felipe,



Relation between bed elevation and particle size.

Fig. 2.11

AFTER JORDAN

the channel is confined by a volcanic talus on the right bank and stable clay banks on the left, the maximum width at the measuring section was about 210 feet. The Bernalillo station has a confined measuring section, and for all discharges more than about 2000 C.F.S. the flow width was approximately constant at 270 feet.

During high flows, the discharge measurements and samples were taken from highway bridges for the river at Albuquerque and near Belen.

The characteristics of bed material in the river change systematically with distance downstream from Otowi. This systematic variation is indicated by the average size distribution curves plotted in (fig. 2.12). For most sand bed channels, the characteristics of the bed material change slightly with discharge or with time, and the bed material characteristics to be used in transport parameters may often be expressed in terms of the median diameter or of some representative grain size. The changes with time of the transport rates must be directly related to the systematic changes with time of the characteristics of the bed material this was clearly shown in (Fig. 2.13) in the Rio Grande at Otowi Bridge.

This study concluded that the bed material discharge,

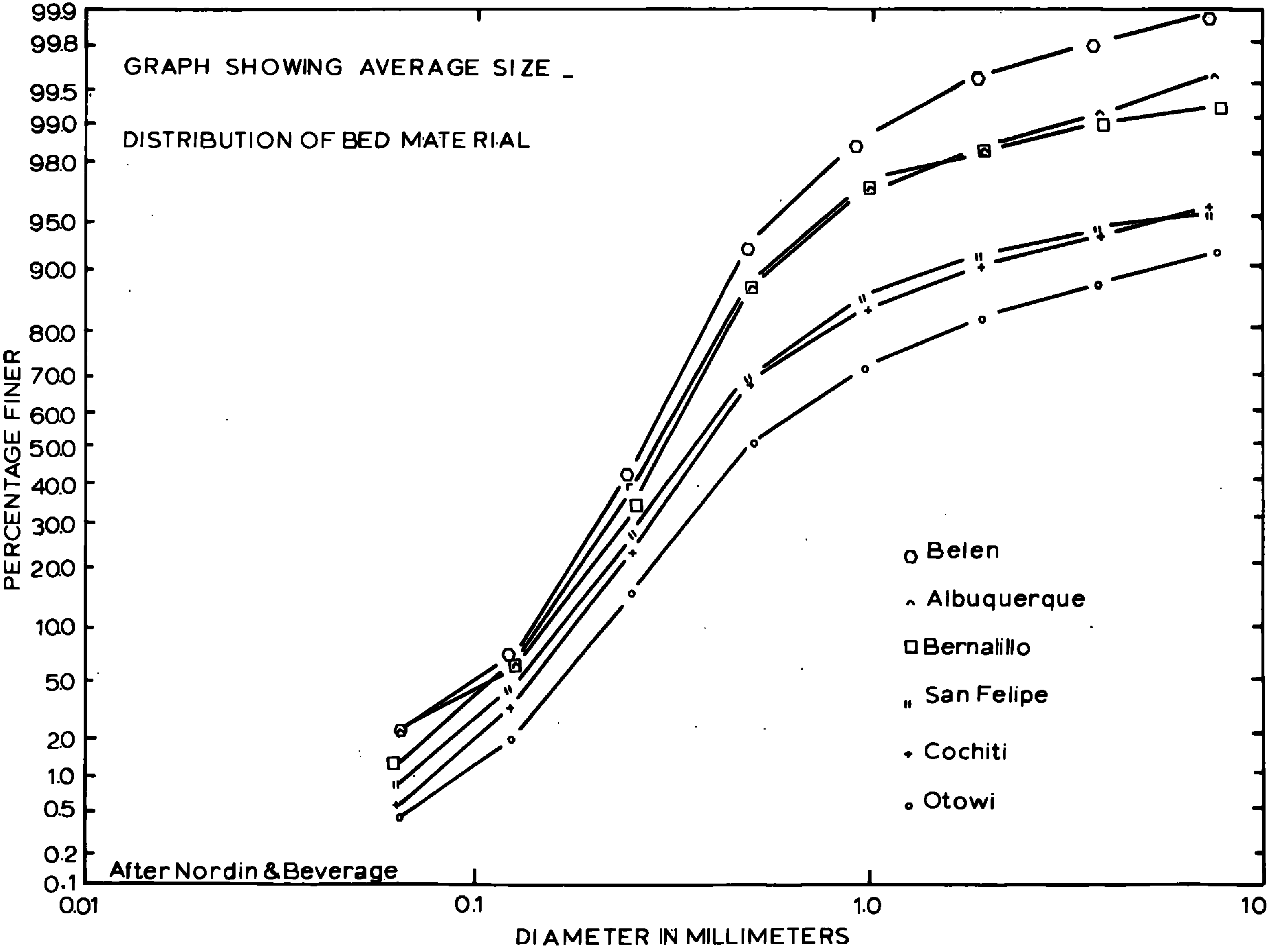

GRAPH SHOWING AVERAGE SIZE _
DISTRIBUTION OF BED MATE RI.AL
After Nordin & Beverage
PERCENTAGE FINER
99.9
99.8
99.5
99.0
98.0
95.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
5.0
2.0
1.0
0.5
0.2
0.1
0.01
0.1
1.0
10
DIAMETER IN MILLIMETERS
○ Belen
^ Albuquerque
□ Bernalillo
" San Felipe
+ Cochiti
∘ Otowi

Fig. 2.12

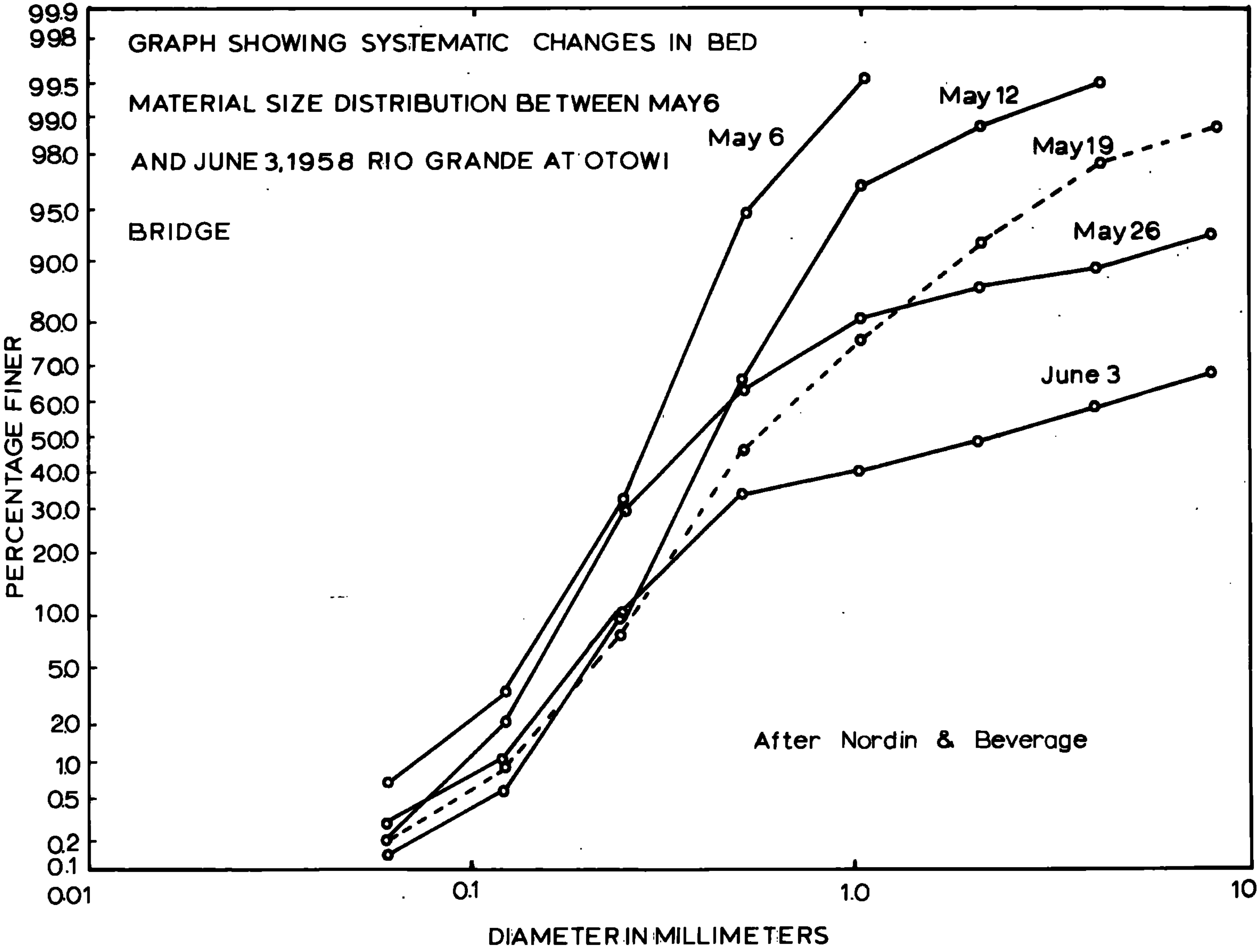

GRAPH SHOWING SYSTEMATIC CHANGES IN BED
MATERIAL SIZE DISTRIBUTION BETWEEN MAY6
AND JUNE 3,1958 RIO GRANDE AT OTOWI
BRIDGE
May 6
May 12
May19
May 26
June 3
After Nordin & Beverage
PERCENTAGE FINER
99.9
99.8
99.5
99.0
98.0
95.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
5.0
2.0
1.0
0.5
0.2
0.1
0.01
0.1
1.0
10
DIAMETER IN MILLIMETERS

Fig. 2.13

computed by the modified Einstein method(1942) was related to simple hydraulic variables for observations at six sediment stations through a 110 mile reach of the Rio Grande in New Mexico. Transport relations vary in downstream direction, or with decreasing particle size, and fall into two distinct groups, one group representing the confined sections and the other representing sections without lateral restrictions. At low flows, greater sediment loads are carried at a wide sections. This difference reflects the tendency for the wide sections to aggrade and channelized at low flows.

Sediment Studies in the Western Europe Countries:-

Most of the work done in France and Germany ~~have~~ has been devoted to specific purposes. For example, in France the work ~~have~~ has been of a practical nature, particularly that concerned with the improvement of navigable streams.

The German experiments were, and still are, addressed to the broader subject of river engineering and include within their scope the scientific study of river shape and channel morphology.

For instance Suchier experiments(1883) in the Rhine River at Brisbach which showed the competency of the river to move a certain size at a certain velocity as follow:-

A.	Stream bed covered by fine sediment	M. Per Sec.
1.	Under action of current alone, no movement found with bottom velocity at	0.694
2.	After being stirred up, the movement of the sediment began for fragments of the size of bean, when bottom velocity reached	0.897
3.	Fragments of the size of hazelnuts, when bottom velocity reached	0.923
4.	Fragments of the size of walnuts, when bottom velocity reached	1.062
5.	Fragments of the size of pigeon egg, when bottom velocity reached	1.123
B.	River bottom free from sediment	M. Per.Sec.
1.	The smallest particles are moved when the current velocity reaches at the bottom	1.180
2.	Pebbles of pea and hazelnut size move freely with velocity of	1.247
3.	With noticeable noise at	1.300
4.	Pebbles of walnut size are moved without stirring, and such of 250 grams weight after stirring up, with current at	1.476
5.	Pebbles of 1,000 grams weight rolled at	1.589
C.	General movements of Pebbles:-	
1.	Upto the size of pigeons eggs at	1.800
2.	Upto the size of hens eggs at (including such of 1500 grams)	1.717
3.	Pebbles of less than 2500 grams weight are moved at	1.800
4.	All pebbles moved at	2.063

Also the following Table 2.7 shows that a much greater velocity is required to start motion than to continue it after once started:-

Table 2.7

Size of Pebbles	Velocity required to move after stirring up	Velocity required to start motion
	M. Per.Sec.	M. Per.Sec.
Hazelnut size	0.923	1.35
Walnut size	1.062	1.39
Pigeon egg size	1.123	1.45

The following study was carried out by Hjulström(1935) to give a determination of the degradation of the Fyris river basin in central Sweden.

The methods which he used implied a calculation of the matter carried by a stream through a selected profile. The calculation extended to three ways of transportation : The amount of material carried in suspension and in solution as well as of the bed load.

The plot method: that is to say, a calculation of the amount of material carried away by rainwash from selected plots. The run-off must be desilted and the amount of silt determined. The plots should be chosen so that the loss of soil is obtained from representative types of soil, slope and vegetation.

Here, only the bed load measurement will be dealt with. The writer said that "the bed load offers greater difficulties than the suspended material when attempting to determine the total mass of transported sedimentary material". Up to now no accurate and reliable method has been fully worked out for such investigations. However, in recent years the matter has been given much attention.

At the beginning of the investigation into the site transportation of the Fyris river, it seemed to Hjulstrôm that it is necessary to obtain a method for direct measurements of the amount of bed load transported.

In the Fyris River Hjulstrôm used only a catch basket consisting of an iron frame into which a kind of catch basket or box of brass wire-netting may be placed. It was found that there was no transportation at all of bed load. Hjulstrôm ~~have~~ has made examinations at all high waters since September(1932) but without ever being able to determine any such transportation.

Hjulstrôm concluded his investigation that the River Fyris transported on suspension 5.540 tons of sedimentary material during one year past Uppsala. This material was eroded from a drainage area of about 1200 square km. He also calculated that from each 159 km. 4.6 tons was eroded per year.

Conclusion

Sediment movement in rivers is a very important phenomenon which affects man's life in many different ways. For this reason it has been studied for a long time ago but unfortunately no single procedure, whether theoretical or empirical, has been universally accepted as completely adequate for the determination of bed load discharge over the wide range of sediment and hydraulic conditions in nature.

In England this type of study was to a great extent neglected because, as yet, many streams are not utilized by man in any kind of economic life. On the contrary in North America and Western Europe a great attention was devoted to the sediment movement and some of the great rivers of the world have been investigated and studied.

Chapter 3

The Physical environment of the Lanehead Catchment:-

Section 1

Introduction:-

This chapter is a description of the Lanehead Catchment (Fig. 3.1)[1]. For convenience it is divided into four sections:- A - Relief, B - Geology, C - Exposure to climatic elements, D - Vegetation Cover.

A - Relief:-

The Lanehead Catchment is composed of two north bank tributaries of the River Wear, and is separated from the East Allendale drainage to the north by a watershed which although variable in height is for the most part above 1800 feet O.D.

Within the Catchment the absolute range of altitude is from 1500 feet O.D. to 1940 O.D. Relative relief is therefore only 440 feet. The catchment is characterised by gentle slopes falling away southwards from the high watershed area, steep slopes are limited to the banks of incised stream channels, and to the outcrops of some of the more resistant rocks, especially the massive limestones.

The evolution of the topography in this region is complex. It does seem likely, however, that the high

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[1] This Catchment was recently resurveyed by the Newcastle Surveying Department, especially for Dr. K. Smith of the Geography Department. The contour intervals were in metres and the present author converted them approximately to feet intervals to be comparable with the six inch map of the area.

THE TOPOGRAPHY OF LANEHEAD CATCHMENT AREA

Fig. 3.1

interfluve which forms the northern boundary of the catchment is part of an old erosion surface. Undoubtedly the most of the catchment below this highest watershed forms part of a sequence of erosional levels which have been defined in other parts of the Alston Block. (Maling 1955).

Examination of the superficial deposits indicates the widespread activity of solifluction. In some streams exposures of at least ten feet of soliflucted material occur. These deposits mask the bed rock relief and blanket the whole catchment area with particularly thick cover in the west.

Much of the subdued nature of the local relief is, therefore, due to the cover of these deposits. Typical scenery of this catchment are shown in (Plates 1 and 2).

B:- Geology:-

The solid geology of the catchment is shown in (Fig. 3.2.). The strata which outcrop within the catchment are, without exception of Carboniferous age. A simple division of the geology of the catchment is possible both in terms of geological age of the strata and also of the lithology.

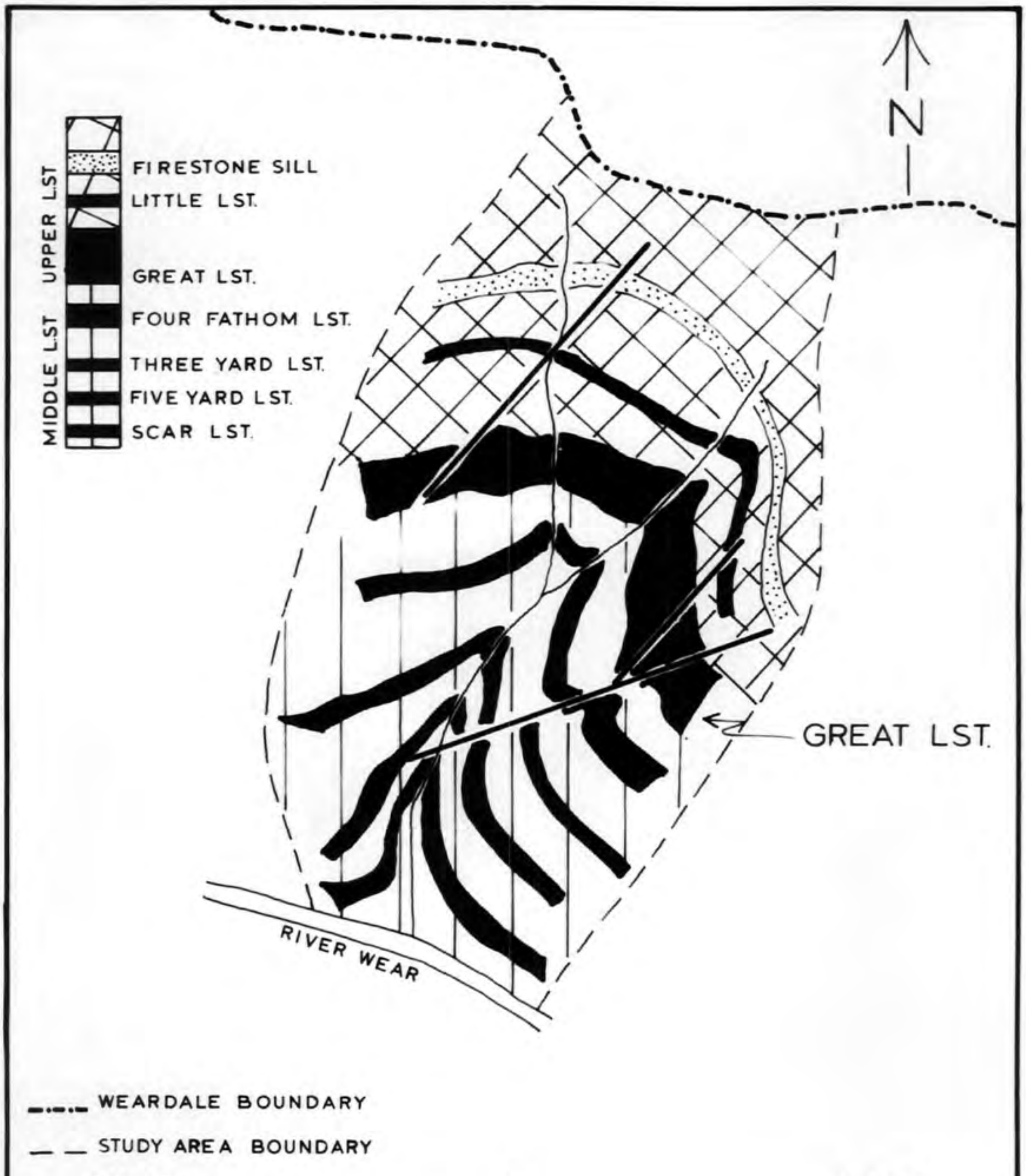
The southern half of the catchment is characterised by strata of the Middle Limestone Group. These strata are amongst the most characteristic Carboniferous rocks

PLATE 1

The Lanehead Catchment during late summer - looking south-west

PLATE 2

The western watershed of the Lanehead Catchment with some snow patches lying on the higher gullies - looking north-west



SOLID GEOLOGY OF LANEHEAD CATCHMENT

Fig. 3.2

of Northern England. They exhibit a marked rhythmic pattern of sedimentation with the alternation of beds of different lithology.

Each rhythmic unit is composed of the following sequence of beds; Limestone, Shale, Sandstone, Coal, and is known as the Yoredale cyclothem. The base of the Limestone member is taken as the base of the rhythmic unit or cyclothem as this indicates the position of a major marine transgression. The limestone are characteristically blue-grey in colour, compact, fine grained and often thinly bedded.

Overlying each limestone is a series of dark coloured calcareous and richly fossiliferous shales. The shales become coarser towards the top of the succession and give way to massive and current bedded medium-grained sandstones which represent shallow water deltaic deposits.

At the end of this phase a land surface is thought to have developed, and vegetation to have colonised the newly exposed sand. This is, today, represented by the presence of a thin coal seam and its accompanying seat earth overlying the sandstones.

Four such cyclothems are found in the catchment and their basal limestone members are recorded in (Fig. 3.2.).

The northern half of the catchment consists of rocks of the Upper Limestone Group, with the basal member of this series being the Great Limestone. The Great Limestone is the youngest of the Carboniferous rocks to exhibit a cyclothemic succession.

The Great Limestone is, on average, 60 feet thick and is blue-grey in colour and fine grained. It is the most important limestone horizon within the catchment. Above the Great Limestone there is a succession of thick shales and sandstones with only rare thin limestone bands.

The geological structure of the Catchment is relatively simple, three small faults are found in the area, while the important Burtreeford Disturbance severely dislocates the strata a mile or so to the east.

C: Exposure to Climatic Elements:-

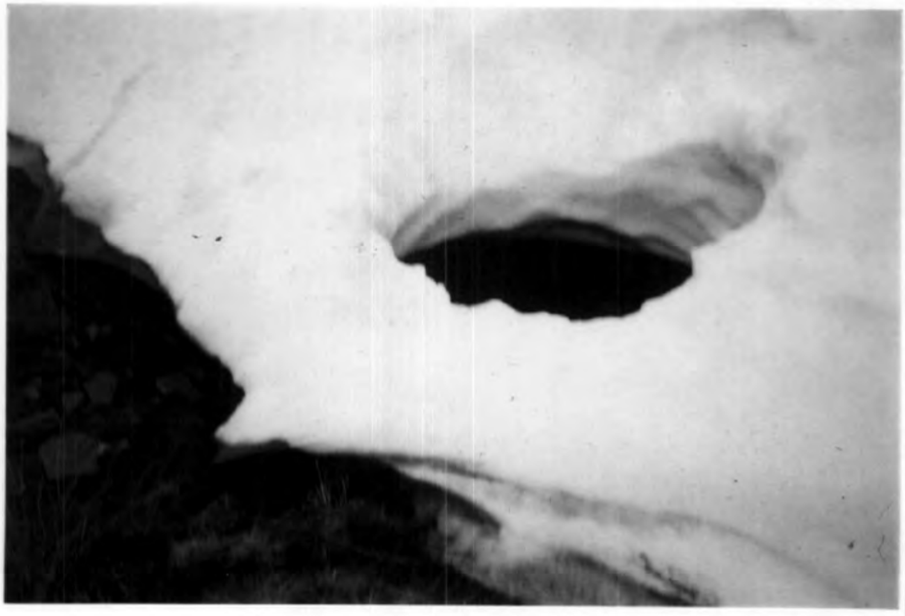
Exposure is as much a climatological phenomena as a topographical one. In every respect one may regard the Catchment as well exposed. The interfluve to the north offers little protection from the elements and the Catchment is totally exposed to climatological phenomena, particularly weather approaching from the south-west.

Traversing and moving along the western watershed, some indication of the degree of exposure is given by the snow cover in the winter of 1968. (Plates 3 and 4.). The whole area was blanketed by a thick cover of snow; so much so that the

PLATE 3

Severe winter conditions in the Lanehead Catchment

PLATE 4



The thickness of the snow cover within the Catchment in February 1969 stream courses and stone walls were completely obscured. The duration of this snow cover was more than thirty-five days and snow has been observed in the higher gullies at 1,000 feet O.D. as late as May.

D: - Vegetation Cover:-

The vegetation of the Lanehead Catchment may be regarded as a product of two important factors. Firstly the environmental factor obviously plays an important role. The bleak moors with their open exposure, high rainfall and relatively inhibitive temperatures to plant growth are necessarily dominated by certain types of vegetation. Secondly, in this marginal environment it is not possible to discuss anthropogenic factors which influence the present pattern of vegetation. In simple terms it is possible to differentiate the western half of the catchment from the eastern half. The western part of the area is dominated by a cover of Erica tetralix, Calluna Vulgaris heath, (Plate 5.). This ericaceous cover with its associated acid soils and more humus becomes more dominant as the watershed is approached. Where drainage is impeded thick deposits of peat occur. Such peaty deposits are frequently exposed in the banks of the western tributary. Small pools of Sphagnum also occur in wet areas. It is interesting to note here that the banks of the western tributary are relatively unstable, this may be in part due to the lack of effective cover by this

PLATE 5

The Calluna Vulgaris heath which cover the western part of the Lanehead Catchment acid moorland heath.

The eastern and southern halves of the catchment represent improved moorland. Pastures of Molinia species and Nardus species, are typical of the better drained areas, while wetter areas are often infested with Sedges.

The stream banks are better covered than their western counterparts, with the efficiency of coverage being reflected in the stability of the stream banks. No trees occur within the catchment owing to the very exposed conditions.

Section 2

Introduction:-

This section attempts to describe various aspects of the fluvial geomorphology of the two streams occupying the Lanehead Catchment. Broadly speaking the descriptions fall into two parts. Firstly, the longitudinal aspects of the two streams are considered. Secondly, reference is made to the cross sectional nature of the streams and the various phenomena affecting the channel shapes.

For the sake of convenience each stream will be dealt with separately.

I The Eastern Tributary:

The source of this stream lies in the peaty accumulations of the northern influves at 1764 feet O.D. The stream flows in a general north-east to south-west direction for some 2700 feet until its confluence with the western tributary.

The valley of this stream has a smooth V shaped form, with a moderate degree of incision. The side slopes in most places rise immediately away from the water's edge.

The upper and lower slopes are covered with blanket peat which varies in thickness along the stream. The massive limestones appear in different places forming resistant exposures which give rise to small waterfalls along the stream bed(Plate. 6.).

The improved vegetation cover in the eastern part of the catchment has a great effect in strengthening the upper slopes.

The Longitudinal Profile:-

The long profile of this stream was accurately levelled for a distance of 2,700 feet, the levelled profile is shown in(Fig. 3.3.).

Gradients

The profile shows a uniform slope. The average angle of slope of the profile calculated from the field measurement is 4.5°. The steepest portion of this profile

PLATE 6

The resistant Limestone strata which forms the small waterfalls along the stream course

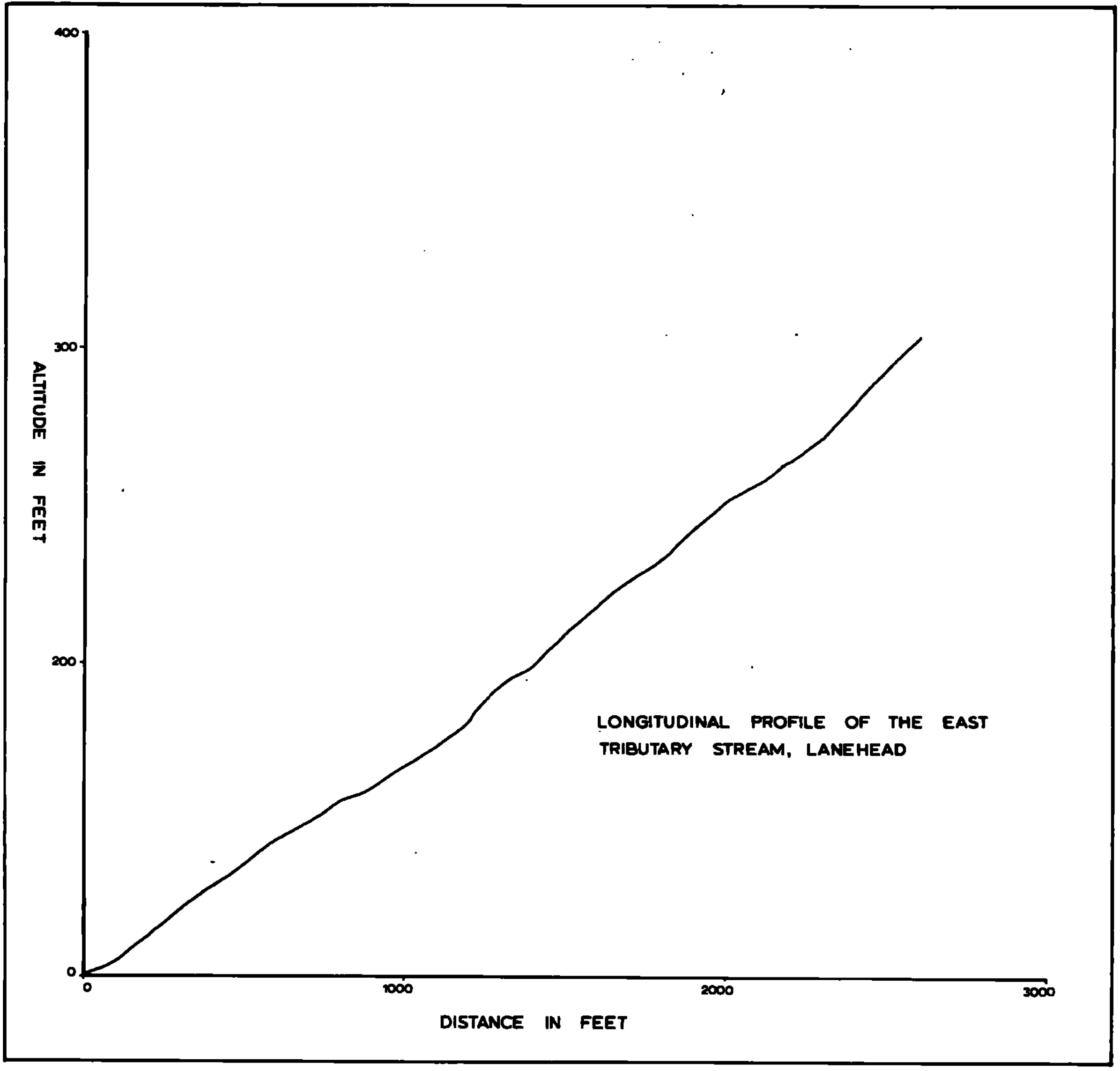

400
300
200
0
ALTITUDE IN FEET
0
1000
2000
3000
DISTANCE IN FEET
LONGITUDINAL PROFILE OF THE EAST TRIBUTARY STREAM, LANEHEAD

Fig. 3.3

is found at the uppermost part of the stream and has a slope of 6°.

No major breaks of slope were found throughout the profile but small waterfalls due to the resistant strata and up to five feet in height were observed during the field study.(see Plate 6).

The Channel Cross-Sections:-

Complementary to a description of the longitudinal profile is a description of the cross-profiles of the stream. In this study ten cross-profiles were accurately levelled to give some indication of the different types of cross-sections which are to be found along this stream.

Preliminary assessment of the cross-sections indicated that two major forms were present.

Type a:

This type consists of cross-sections number 1,2,3,4 and 8 in (Fig. 3.4.). The common factor between these cross profiles is the manner in which the stream is bounded by its banks with steep slopes rising almost immediately away from the water edge without any perceptible "flood plain" development. It is useful also to note here that these cross-sections are cut into solid rocks, mainly limestone, and only have a thin cover of solifluction material.

The cross-profiles of the eastern tributary
Lanehead

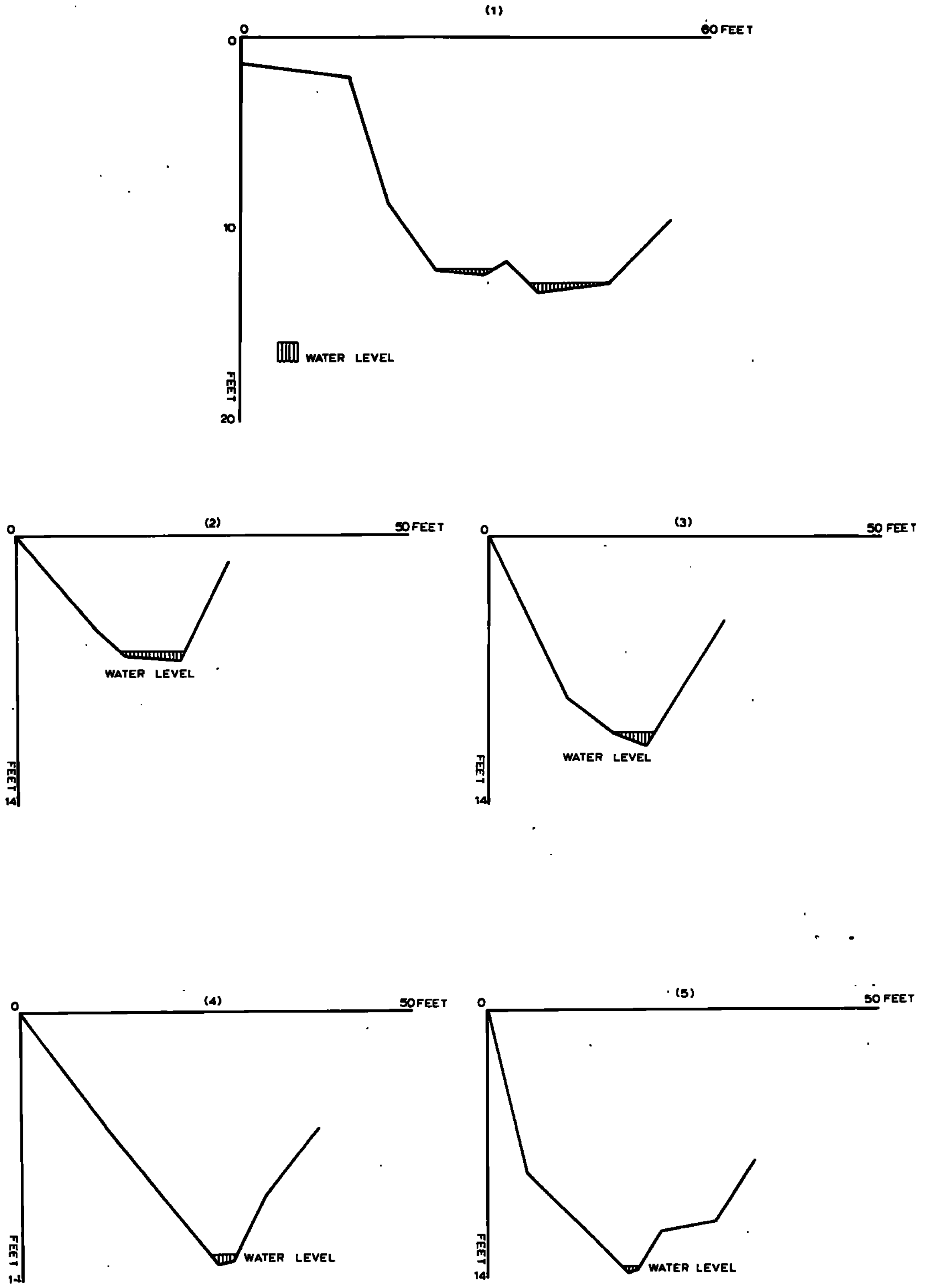


Fig. 3.4

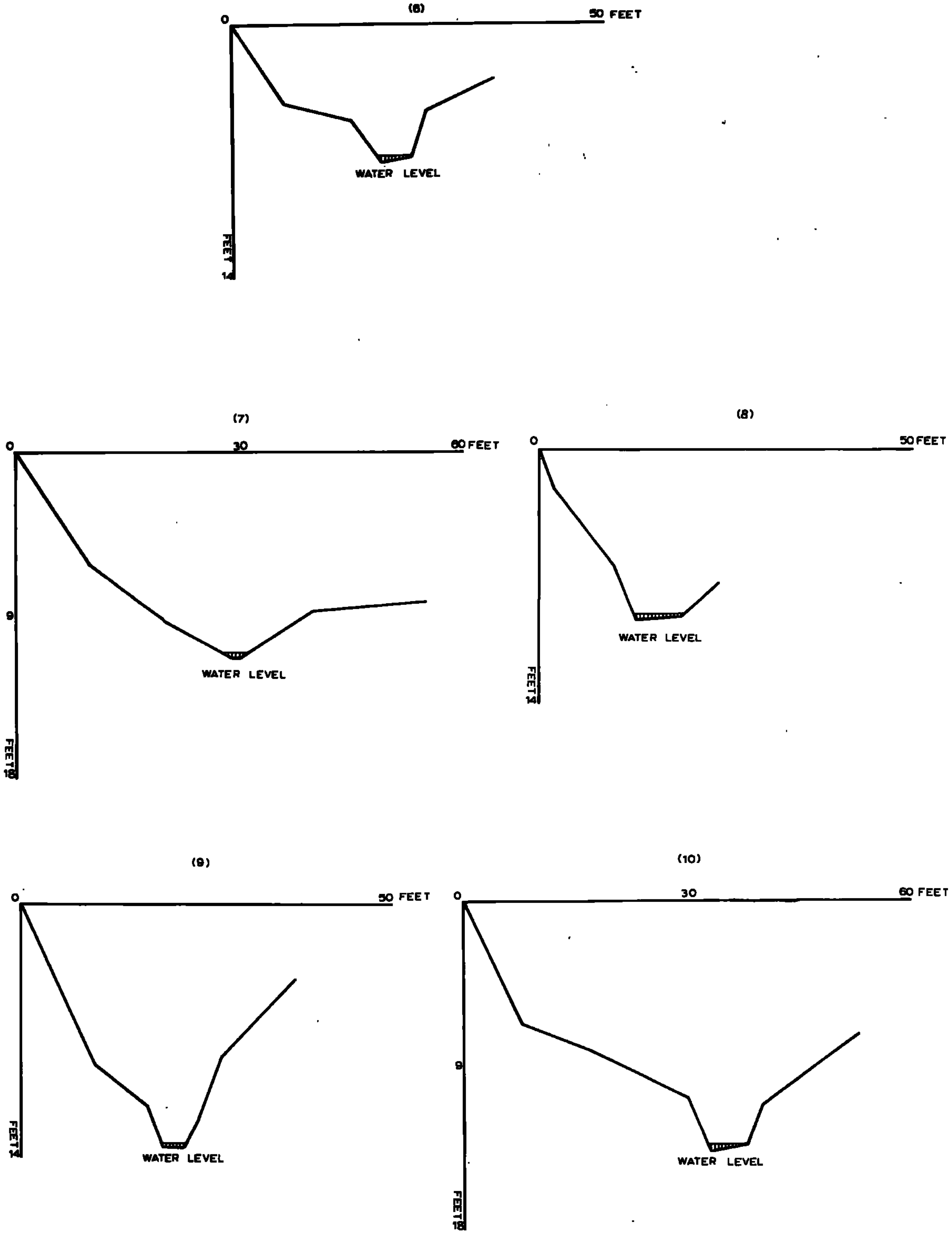

(6)
0
50 FEET
WATER LEVEL
FEET
14
(7)
0
30
60 FEET
9
WATER LEVEL
FEET
18
(8)
0
50 FEET
WATER LEVEL
FEET
14
(9)
0
50 FEET
WATER LEVEL
FEET
14
(10)
0
30
60 FEET
9
WATER LEVEL
FEET
18

Fig. 3.4

Type b

This group includes cross-sections numbers 5,6,7, 9 and 10, which are mostly found in the upper reaches of the stream. These five cross-sections are characterised by the development of small "flood plains". Great thicknesses of soliflucted material are found in the upper sections of the stream and it is likely that this unconsolidated drift facilitated terracing to some extent.

The vegetation cover protects the upper slopes of this stream from landsliding. On the lower slopes, however, landsliding occurs specially in spring following snow melt when the ground is saturated and the swollen stream undercuts the peaty and soliflucted material found on the outside of the bends. (Plate 7).

The major effect of man started in this particular area more than hundred years ago when stone walls were built and mining took place throughout Weardale. One of the noticable effects of man which still remains in the area is the large hush joining the stream on its left bank 1500 feet above its confluence with the western tributary (see Plate 8).

II The Western Tributary:-

The origin of the western stream lies on one of the thickest peat accumulations of Weardale at 1880 feet O.D.

PLATE 7

The landsliding, and the stream undercutting the peat and soliflucted material

PLATE 8

A large hush joining the eastern stream on its left bank 1,500 feet above the confluence

The stream runs in a general north-west to south-east direction for over 3,000 feet down to the junction with the eastern tributary.

The valley of this stream does not possess a well formed valley in most places owing to the unstable peaty banks which are completely saturated and easily undercut during the high periods of flow.

The valley is in general deep and the degree of slope is greater than in the other tributary. The vegetation cover which is mostly Calluna Vulgaris heath has not any marked effect on the banks of this stream. In many places exposures of weathered shales and sandstone were noted.

The longitudinal Profile:-

Accurate levelling over a distance of more than 2670 feet was carried out. The levelled part of the stream is shown in (Fig. 3.5.).

Gradients:-

A first glance at this profile makes it clear that the degree of slope is greater than on the eastern counterpart. The calculated figure for the average slope is approximately 6°. The chief interest in this profile is the fact that the steepest part has a slope of 19° and is found in the lower part of the stream's course. This

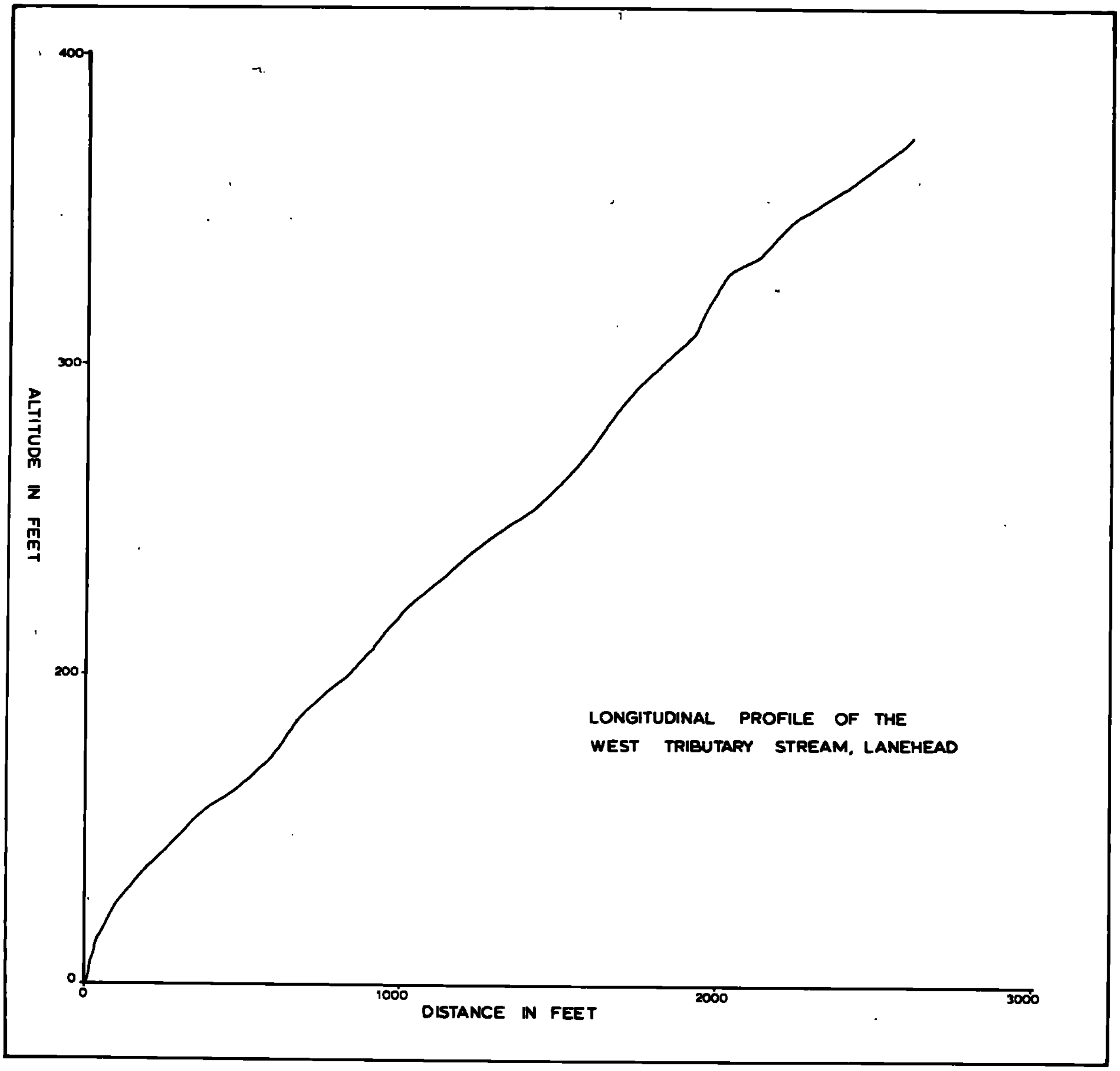

400
300
200
0
ALTITUDE IN FEET
0
1000
2000
3000
DISTANCE IN FEET
LONGITUDINAL PROFILE OF THE
WEST TRIBUTARY STREAM, LANEHEAD

Fig. 3.5

is in complete in contrast to the eastern tributary.

Even in this long profile there is no major break of slope although the upper part of the profile shows abrupt but small changes in slopes.

The Channel Cross-Sections:-

The ten cross sections (Fig 3.6) which were levelled to represent this stream are classified into three major types:-

Type 1:- This group includes the cross sections numbers 1,3,4,5 and 8 in(Figure 3.6.). The common feature which characterised these cross-sections is the presence of terrace features with steep side slopes on either side. The average width of the channels in this group is about 5 feet.

Type 2:- This group contains cross-sections numbers 2 and 7 which are very different from the other two groups, and shows the widest parts of the channels to be found along the stream with an average width of 8 feet. The side slopes fall as a vertical wall towards the channel.

Type 3:- This type is made up of cross-sections numbers 6,9 and 10. The main factor distinguishing this type is the straight lined walls without the development of any sort of flat terrace or "flood plain".

Without doubt the two most important factors

The Cross-Profile of the western tributary Lanehead

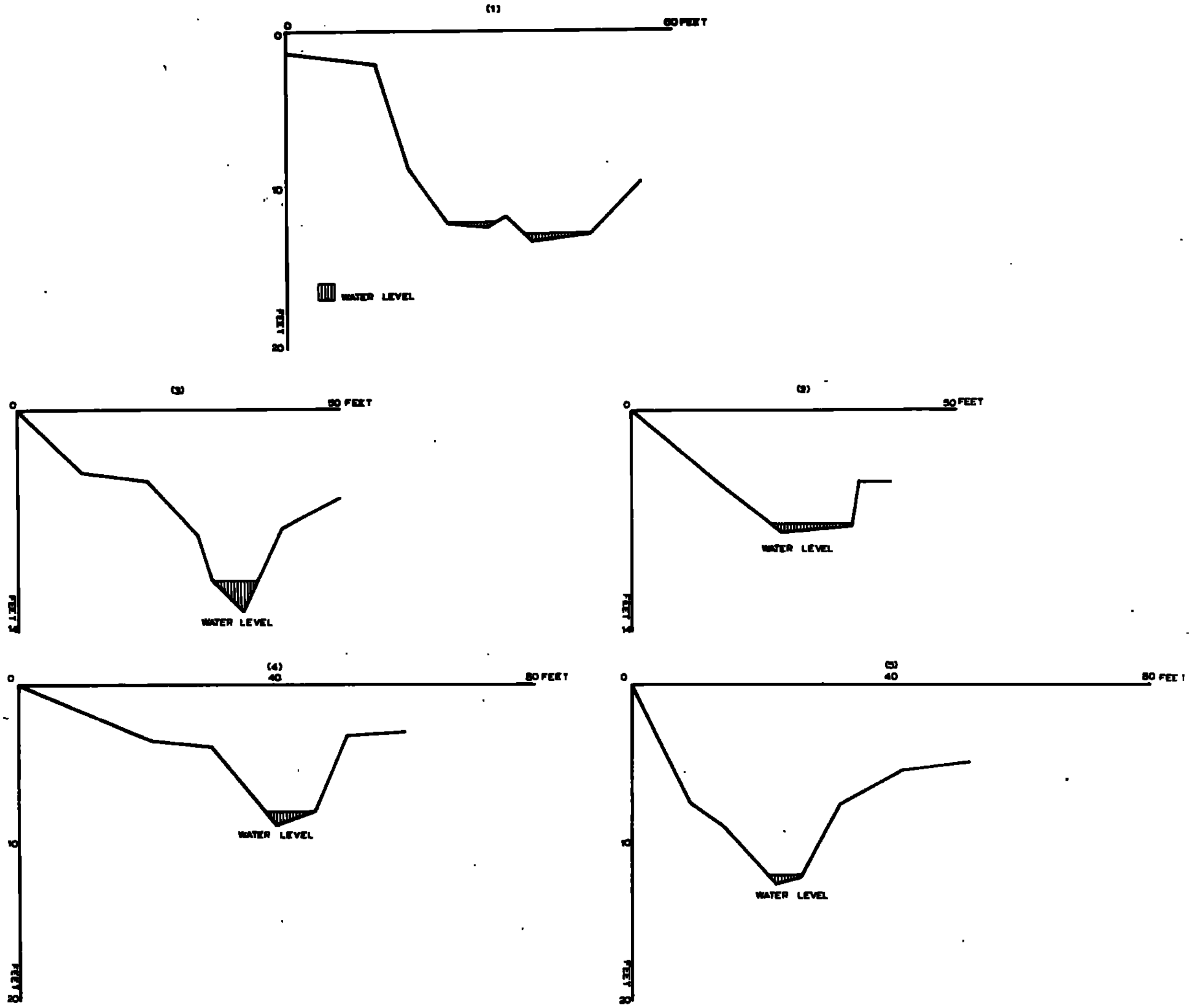


Fig. 3.6

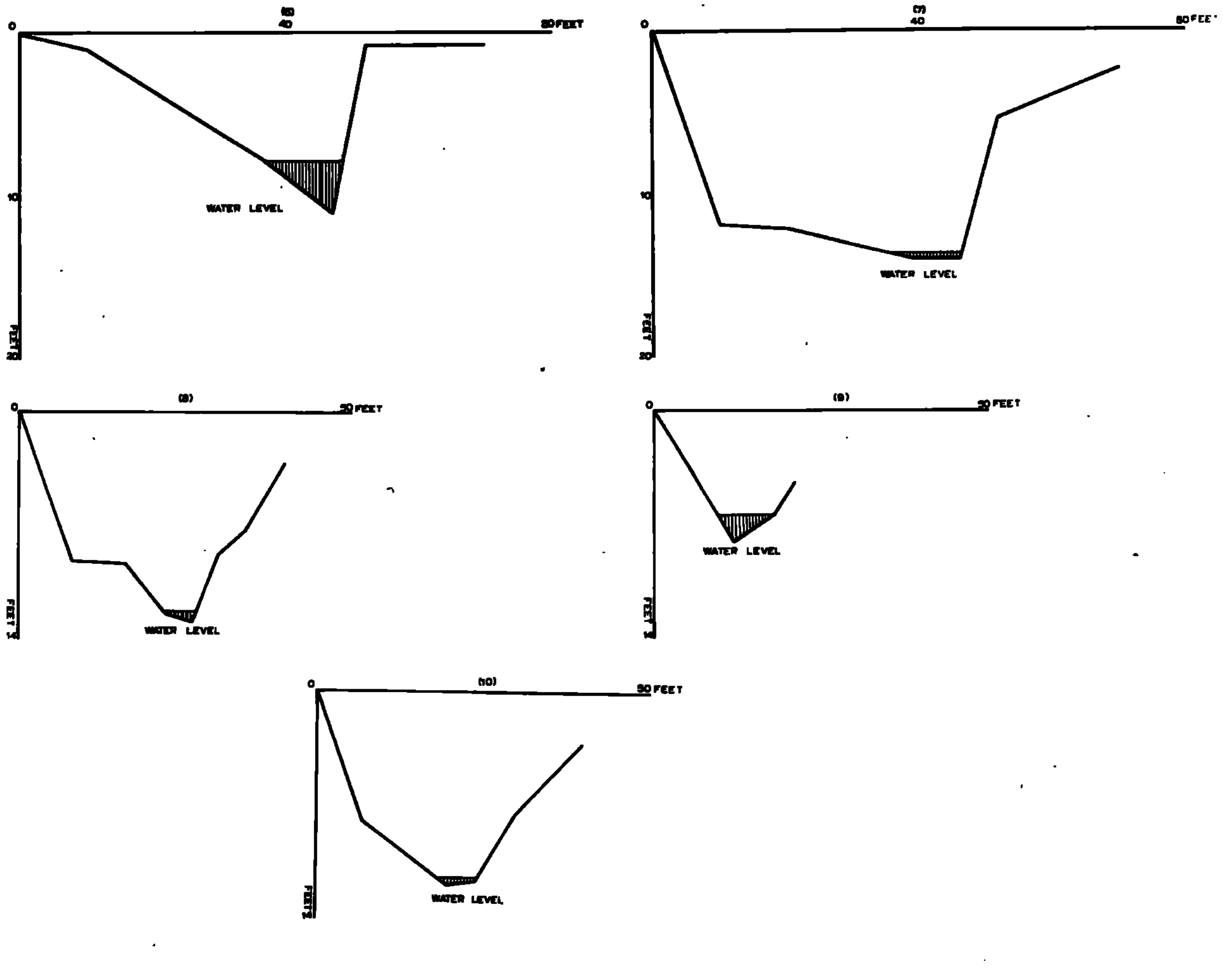

(6)
0
40
80 FEET
10
20 FEET
WATER LEVEL
(7)
0
40
80 FEET
10
20 FEET
WATER LEVEL
(8)
0
50 FEET
14 FEET
WATER LEVEL
(9)
0
50 FEET
14 FEET
WATER LEVEL
(10)
0
50 FEET
14 FEET
WATER LEVEL

Fig. 3.6

influencing the above mentioned types of cross-sectional profiles are the thick deposits of peat which are up to 12 feet in thickness in the northern cross profiles and the extensive deposits of soliflucted bed-rock.

The influence of the peat cover is particularly marked in the western and northern parts of the catchment. Here the easily eroded peat forms a very high percentage of the stream banks, and after periods of torrential rain and the subsequent rise of the stream erosion of the saturated peat is considerable. The writer's has observed many such eroded hags of peat in these streams. (See Plates 9 and 10). Characteristically the eroded hags are elongated in shape and often were found to be temporarily partially blocking the channel thus causing further severe erosion.

As previously mentioned much of the catchment is covered by a veneer of solifluction deposits which probably were formed during the intense period of cryoturbation which followed the last glaciation. The unconsolidated nature of these deposits which are for the most part lacking substantial quantities of clay sized material makes them ripe for erosion when they occupy stream bank positions.

Apart from being continuously and easily eroded where they are in contact with the stream these deposits are also

PLATE 9

Eroded and falling hags of peat which sometimes block the channel and causes more severe erosion

PLATE 10

The saturated peat and the severe frost effect on the vegetation cover subject to continuous erosion and removal of the fine material by percolating water. This is especially common in Spring when great quantities of water are released by the melting snow.

From the above description of the two streams occupying the Lanehead Catchment, it is obvious that there exists a number of interesting differences in terms of geomorphological phenomena exhibited by the two streams. Several of the more pronounced differences will now be described and discussed.

An examination in the field of the solid geology of the area, indicated that the streams varied considerably in terms of the area of the outcrop of various lithologies. In particular it was observed that the eastern tributary crossed a considerably larger area of limestone strata than did the western tributary in which the dominant lithology was Shale often in a highly weathered state.

This fundamental difference can be shown to influence a variety of phenomena. For instance as will be shown later the lithology of the bed load carried by the two streams can be highly correlated with the rock types outcropping in the stream bed. The differences in lithology must also affect the rates of erosion and solution by the two streams.

4

It has been shown that the peat is particularly confined in the western and northern parts of the catchments. This fact affects the streams in three ways. Firstly, where peat is exposed in the banks it is easily eroded. Secondly, water running off peat is likely to be more acid and therefore more capable of solution than water running off grass land. Thirdly, a cover of peat forms an effective sponge soaking up excess precipitation and releasing it more slowly at some later time.

From the field observations it was found that the western stream runs in the thickest peat area which ranges from 2 to 12 feet in depth. On the other hand in the eastern stream the peat cover ranges only from 2 to 5 feet in thickness. This difference has encouraged man to improve the type of vegetation in the eastern part of the catchment which has to some extent stabilised the banks of the stream.

Referring to the differences between the two longitudinal profiles and the cross-section number 1 which includes the two streams close to their confluence, it is seen that the mouth of the western stream is higher in elevation than the eastern one. It is also found that the steepest part of the eastern stream profile occurs in the upper portion near to the watershed, where as the steepest part of the western stream lies close to its confluence with the eastern stream.

A comparison of the two longitudinal profiles shows that the western stream is steeper than the eastern counterpart.

Owing to the fact that the western stream is the steeper of the two it is found that this is potentially, therefore, the more active one in terms of its erosive ability and transporting power.

Chapter 4

Introduction:-

This chapter may be divided into two sections. Firstly, the relief, geology and vegetation cover of the Netherhearth Catchment are described with reference to their affects on the stream behaviour during the study period. Secondly, the description of the longitudinal profile and the fifteen cross-sections of the Netherhearth stream are illustrated and described.

Section I

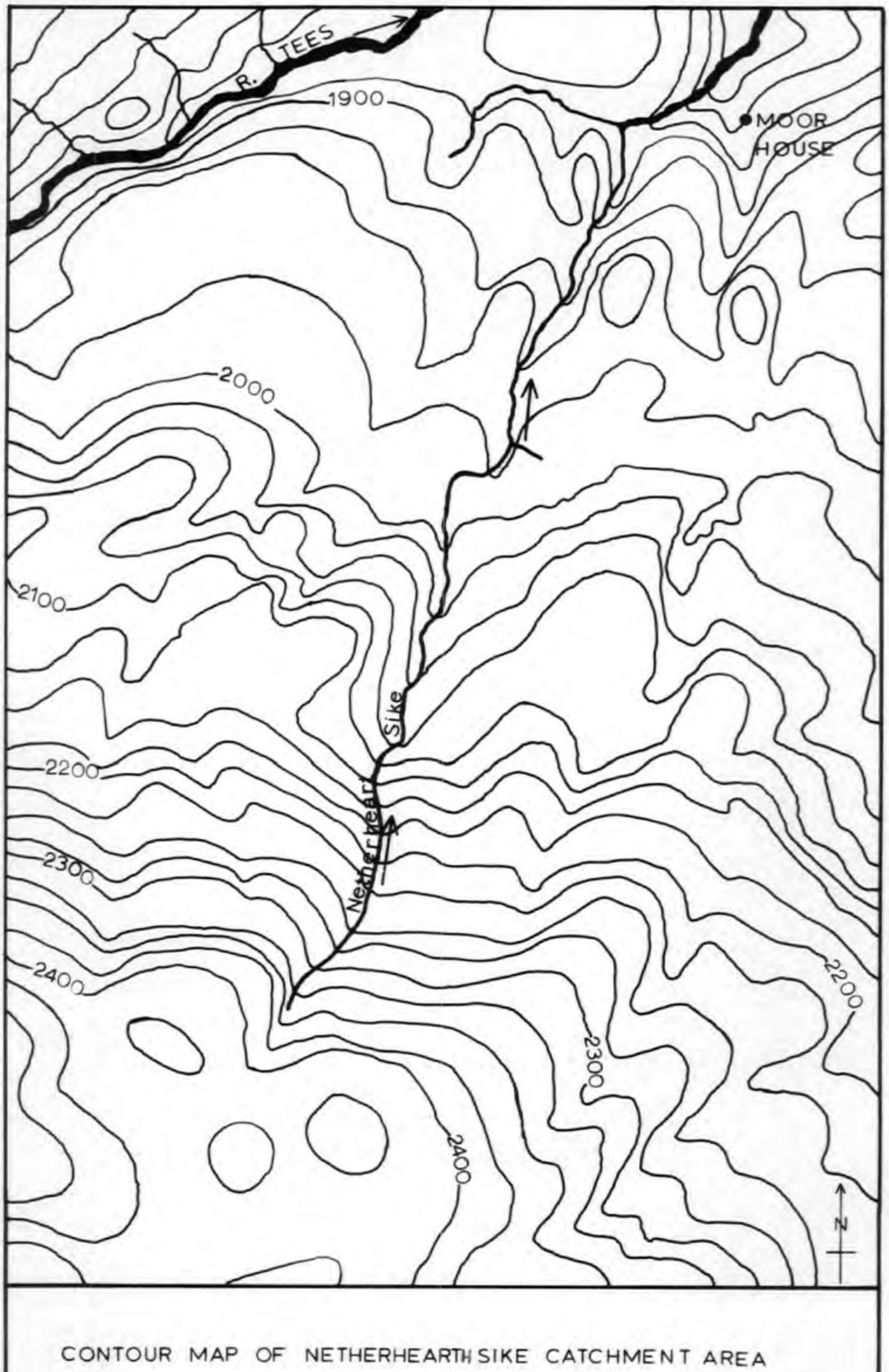
A - Relief:-

The Netherhearth Catchment area is covering about 15 acres. The stream is a west bank tributary of the River Tees and runs from the south to the north until its confluence with the Trout Beck, the largest tributary of the River Tees. Within the Catchment the range of altitude is from 1900 to 2400 feet O.D. with relative relief of 500 feet O.D. (Fig. 4.1).

The Catchment is surrounded by Hearth Hill in the North, Bog Hill and House Hill in the east, Netherhearth flats in the South and Burnt Hill in the West. The Catchment has little relative relief and is covered with a thick peat cover particularly in the south.

B. Geology:-

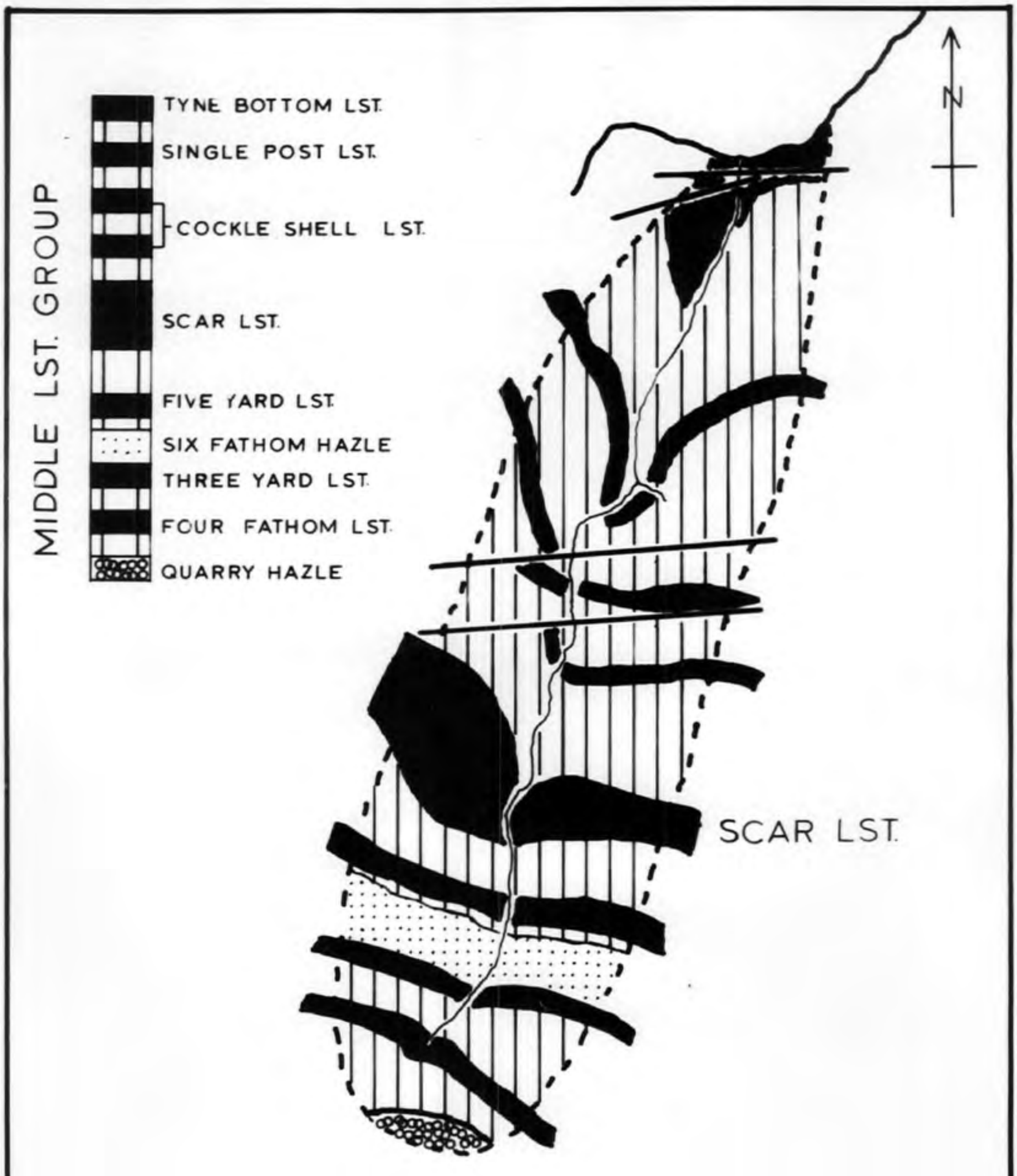
The solid geology of the Catchment is shown in(Fig. 4.2.).



CONTOUR MAP OF NETHERHEARTH SIKE CATCHMENT AREA

912 YARDS

Fig. 4.1



SOLID GEOLOGY OF NETHERHEARTH CATCHMENT

Fig. 4.2

The area is mostly situated within outcrop of the Middle Limestone Group which, in the Alston Block, extends from the base of the Lower Smiddy Limestone to the base of the Great Limestone. A simple division of the outcropping strata within this Catchment is discussed below:-

1. The Tyne Bottom Limestone is exposed in the vicinity of Moor House on the northernmost part of the Catchment and shows the full thickness of the Tyne Bottom Limestone which is here about 26 feet in thickness. The band is composed of even and wavy-bedded posts of dark fossiliferous Limestone and has a band at the top which is characteristically argillaceous and slaggy.

2. The Single Post Limestone is a light grey mottled pseudo-brecciated Limestone in three thick bands making 11 feet of Limestone strata. This was followed by the Cockle Shell Limestone which is fossiliferous dark argillaceous limestone in thick bands with shaly partings, within the Catchment this strata is about 8 feet in thickness.

3. The Scar Limestone is the most important strata in the catchment. It is one of the thicker limestone of the Middle Limestone Group and is over 37 feet in thickness in the Catchment. It is composed of light grey wavy-bedded finely fragmental limestone in rather thin beds and a few

small dark chart nodules are present.

On the escarpment the Five Yard Limestone is 22 feet in thickness and divided into two bands by a bed of calcareous shale. In the catchment it is about 20 feet thick. The limestone is dark coloured with even bedded shaly partings and is fossiliferous. A bed of dark shales about 15 feet thick overlies the Five Yard Limestone and on this rests an important series of thick sandstone called the Six Fathom Hazle, this sandstone is 55 feet thick on the escarpment but thins eastwards to about 30 feet. The sandstone is medium grained, and light coloured.

4. The Three Yard Limestone is rarely seen at outcrop on the catchment, and it is about 11 feet in thickness and composed of grey compact Crinoidal Limestone in thick slightly wavy-bedded bands. Fairly fine Crinoidal debris is abandant in this Limestone.

5. The Four Fathom Limestone is about 21 feet thick and it is composed of medium grey coloured fine grained limestone in thick beds with conspicuous many bedding bands. Many dark chart nodules are developed in the Limestone.

6. The Quarry Hazle is here an important aquifer and many springs occur along its outcrop. It consists of about 15 feet of sandstone and of rather friable and ill-cemented well-bedded strata.

4

C. Vegetation Cover :-

Within this Catchment as a whole most of the vegetation cover has been modifed by sheep grazing and to some extent by burning and erosion. The dominant vegetation, which occurs on the blanket peat, is a community containing heather (Calluna Sp.) * Cotton grass (Eriosphorum Sp.) and (Sphagna Sp.) whose composition varied according to the degree of peat moisture, the altitude and the time since it was last burnt. Naturally occurring trees are not present within the Catchment.

Section 2

The description of the Netherhearth Longitudinal profile:-

The Netherhearth was levelled to a distance of nearly 3,900 feet upstream from the Weir which was established by the Department of Geography close to the Confluence of the Netherhearth with the Trout Beck. The profile shows a very gentle slope all through the stream course which indicate the flat nature of this peaty Catchment, (Fig. 4.3).

To compare this with the Lanehead streams one can easily find out the great similarity between the Netherheath and the eastern tributary.

No observable breaks are found throughout the profile,

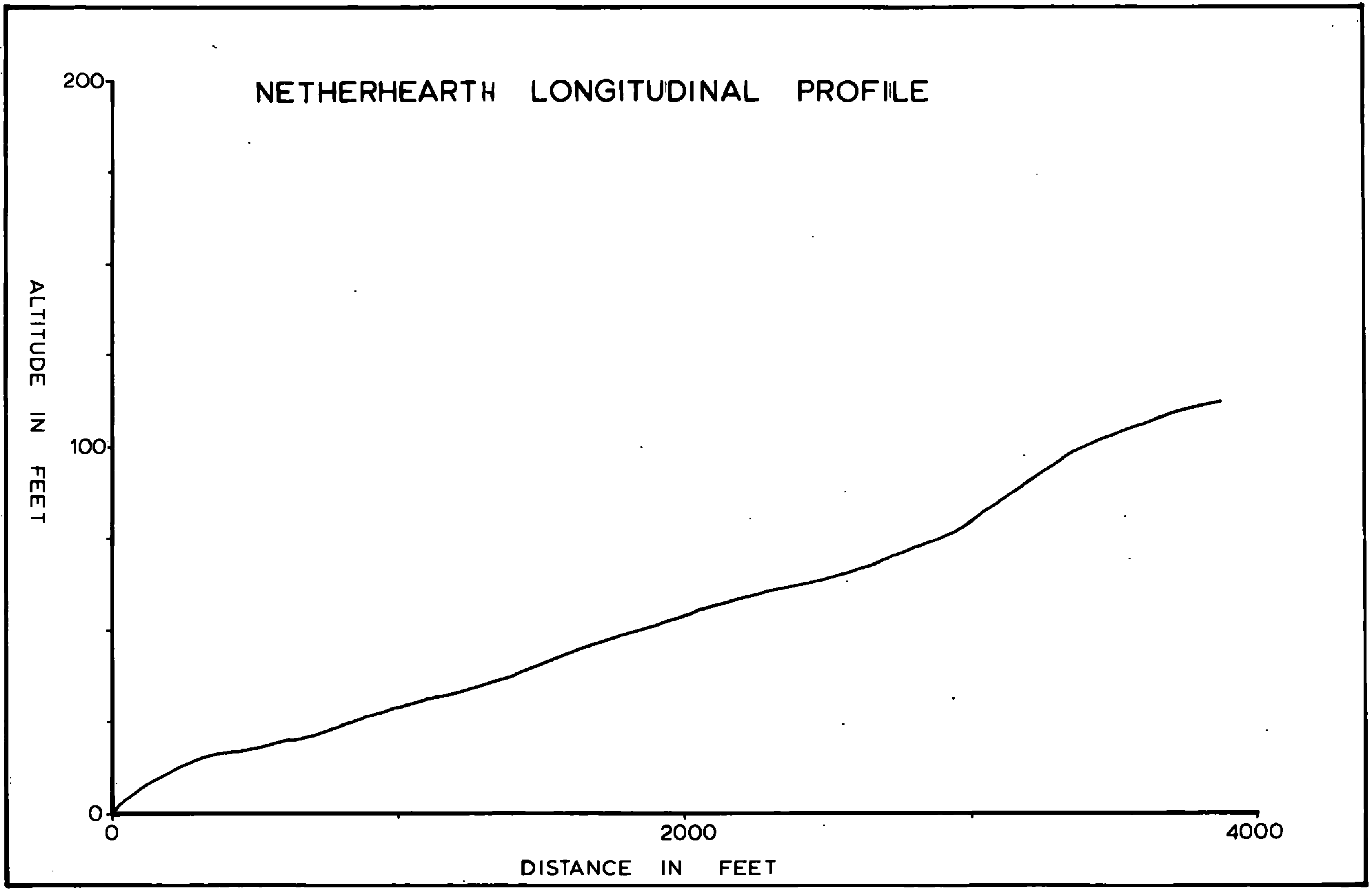

NETHERHEARTH LONGITUDINAL PROFILE
200
100
0
ALTITUDE IN FEET
0
2000
4000
DISTANCE IN FEET

Fig. 4.3

even the small waterfalls which were noticed in Lanehead Catchment are completely absent within the Netherhearth.

The Channel Cross-Sections:-

The physical nature of this area has a great influence on the fifteen cross-sections covered the longitudinal profile of this stream(Fig. 4.4.).

Preliminary evaluation of the cross-sections showed that two major types were present:-

Type I

This type includes the cross-sections numbers 1,2,6,7,9,12,13,14 and 15 in(Fig. 4.4.). The common factor between these cross-sections is the narrow channels with an average width of 3 feet and with steep slopes rising almost immediately away from the water edge.

Type 2

This type consists of the cross-sections numbers 3,4,5,8,10 and 11 in(Fig 4.4) These cross-sections are characterised by the development of small "flood plains" and with an average width of 5 feet.

The final conclusion drawn from these 15 cross-sections is that the valley of this stream in most places is not

The cross-profiles of the Netherhearth stream

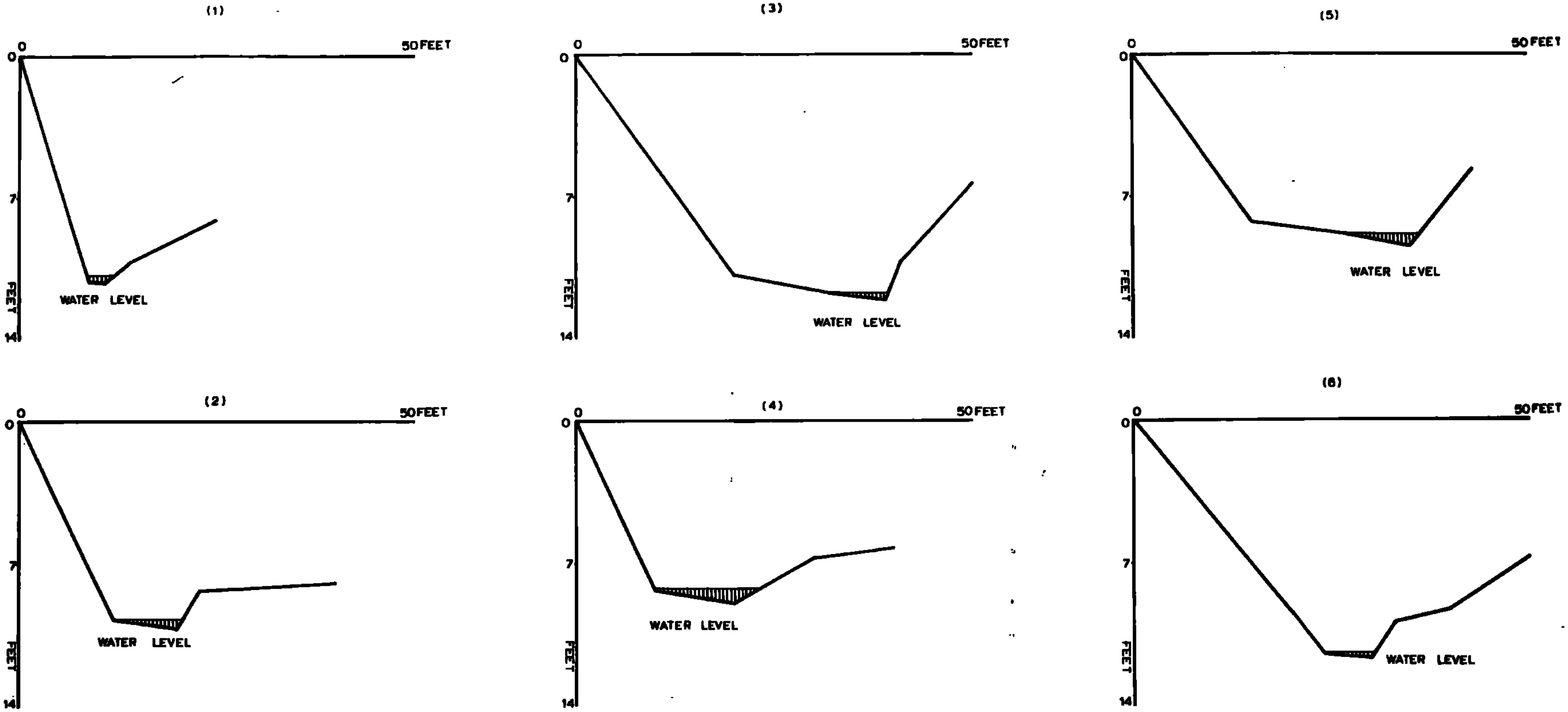


Fig. 4.4

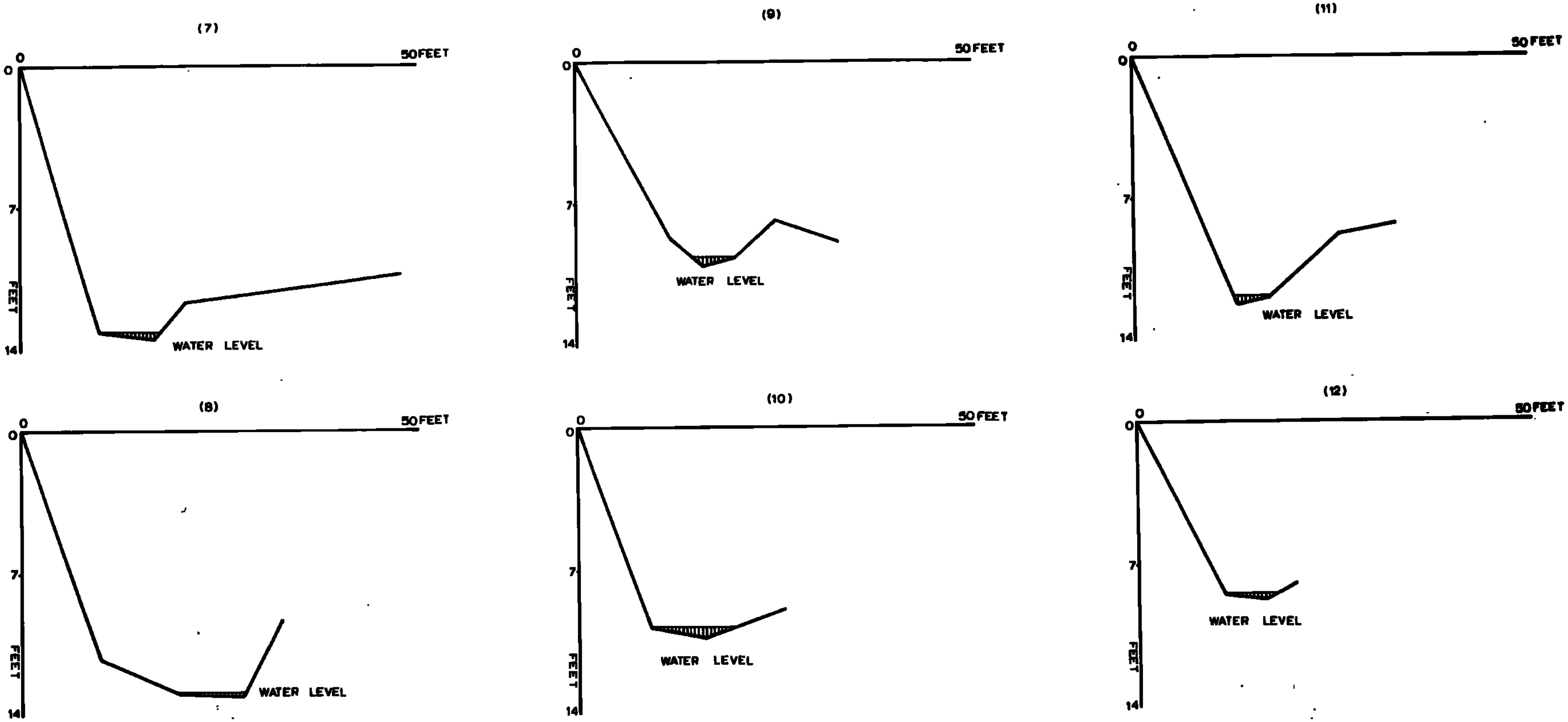
(7)
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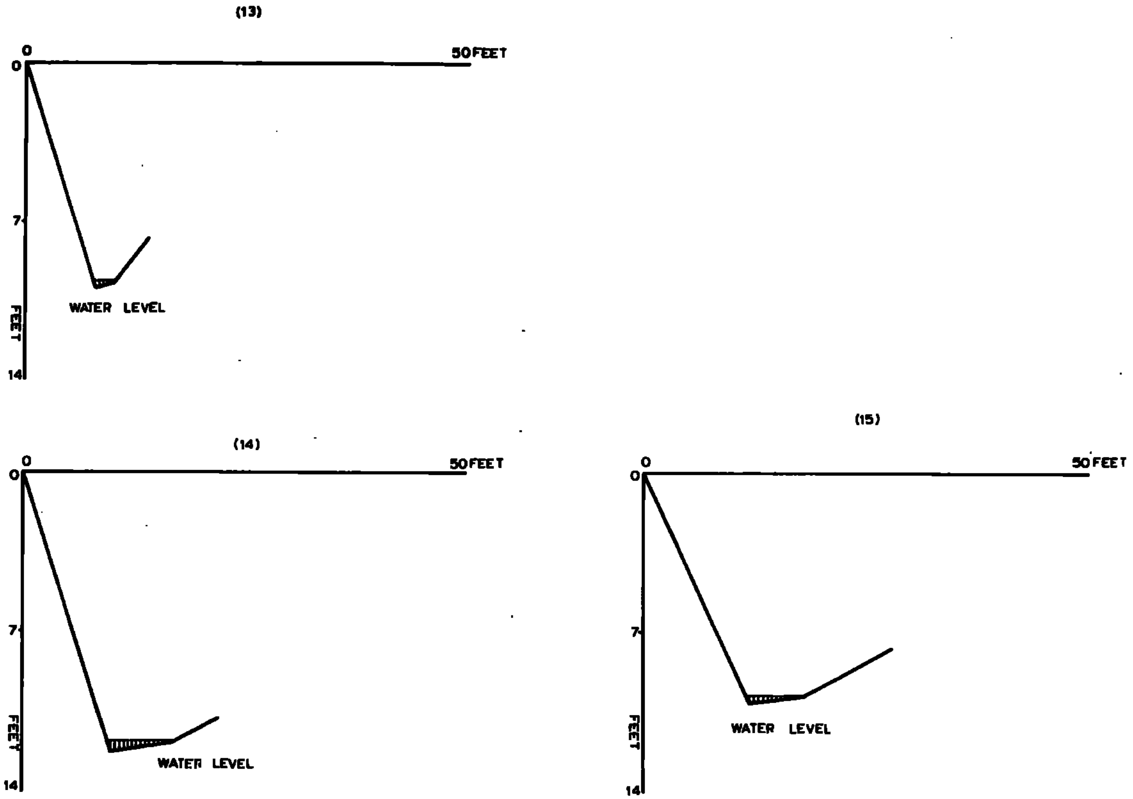
Fig. 4.4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7
FEET
14
WATER LEVEL

Fig. 4.4

clearly defined and the cross-sections are to some extent similar. Terraces are poorly developed and partly obscured.

SECTION TWO

Chapter 5

Field work methods, and techniques of laboratory analysis:-

Introduction:-

The first part of this chapter deals with the fieldwork methods and techniques which were used in the study of the research catchments, while the second part describes the laboratory analysis of the sediment samples which were collected in the field.

I: Field methods:-

The aim of the project was to study the bed load of certain small stream beds in the higher parts of the Northern Pennines. The first part of the study was an attempt to discover the size range of material which composed the bed load and to discover how this varied in character along a given stream length. The second part was to examine and analyse the material making up the banks of the stream, which was the parent material from which the bed load was derived, in order to discover the effects of water sorting on the formation of the bed-load. The final part was to obtain some quantitative estimation of the amount of bed load movement which occurred over a given time period and under varying discharges.

a. Surveying:-

As the slope of the stream determines to a large extent the erosive and carrying capacity of the stream and therefore in turn the nature of the bed load, the initial fieldwork consisted of accurately levelling the stream profiles. The base point for the levelling of the two streams, which made up the Lanehead Catchment, was selected at a distance of 25 feet downstream from their confluence. For the levelling a self-setting level was employed. On the eastern tributary, which was the more gently sloping, the average distance between the surveyed points was 100 feet. On the western tributary owing to the very rugged terrain and steep ground slopes, the distance between stations was much lower and averaged only 15 feet.

The starting point for the survey of the Netherhearth Stream, which is the longest of the three streams studied in detail and almost 3900 feet in length, was a weir newly established by the Department of Geography close to the confluence of this stream with the Trout Beck. The Netherhearth stream flows through a flat peaty area with gentle slopes. This made the task of surveying relatively easy and the average distance between stations was 100 feet.

In all cases the tripod and level was set up in the center of the stream bed and foresight and backsight readings were taken of surveying staffs also situated along the stream bed.

In order to gain information concerning the shape and slopes of the banks of the streams a series of cross profiles were also surveyed. Only a limited number of profiles were surveyed and these were chosen as representative of typical conditions along the various stream sections. In the Lanehead Catchment ten cross profiles were measured on each of the two main streams, while in the Netherhearth Catchment a total of fifteen cross-section measurements were made. For these measurements the tripod and level was set up on one of the banks of the stream while the staff was placed at different points across the channel and up the valley sides. Distances between the staff and the tripod were measured with a chain. At each of the cross-section points the width of the stream water surface was measured, and also the deepest part of the stream channel. Such figures are, of course, only of limited value as both stream width and depth alter markedly with variations in discharge. They do, however, provide a quantitative parameter which is useful for simple comparitive purposes.

b. <u>Sampling of bed load</u>:-

To determine the particle size distribution of the bedload, sediment samples were collected, from the bed of the stream, and then taken back to the laboratory for detailed analysis. The choice of sampling points is always difficult and in this case it was decided that in order to obtain a representative sampling "random sampling" techniques would have to be employed. It was decided that 100 samples of bed load material should be obtained from each of the Lanehead and Netherhearth Catchments. In the case of the Lanehead Catchment 50 samples would be taken from each of the two streams which made up the catchment in order that a comparitive study could be made of the results.

For the sampling, random numbers were selected and used to represent distances in feet along the streams from the base points of the levelling surveys. These sampling points were then determined and marked using a 100 feet long chain.

At each of the sampling points sediment samples weighing between 1,000 - 3,000 grams were collected to represent the finer portion of the bedload below ¾" in average diameter. The sediment was collected from the bed of the stream, usually in a plastic beaker with the minimum disturbance of the sediment that was possible. This material was then ~~transformed~~ transferred to polythene bags and labelled before being transported to the laboratory for analysis.

5

To gain some idea of the size distribution of particles of more than ¾" in average diameter, measurements of the larger stones, comprising the bed load, were measured at each of the sampling points.

This was achieved by placing a surveying ranging rod across the stream channel at the sampling point and then measuring the long axis of every individual stone beneath the pole from one stream bank to the other. With this method the number of stones measured at each of the sampling points varied from less than 2 inches to about 6 feet in some places.

C. <u>Sampling of material composing the banks of the stream channel</u>:-

In order to assess the relationships between bank material and bedload a number of sediment samples were taken from the banks of the streams.

These sampling points, as with those of bed load, were chosen by means of random sampling techniques. 15 samples were chosen along each of the streams in the Lanehead Catchment, and 26 samples from the Netherhearth Catchment in Teesdale. The decision as to which bank of the stream should be sampled at the sampling point was made arbitrarily on the basis of which was easiest to sample. The collection of the bank samples proved considerably easier than those of the bed load and the majority weighed from 800 to 2,000 grams. A number of the samples included considerable amounts of peat which were later separated from the samples during analysis. Other samples consisted of large rock fragments as solid rock outcrops of sandstone, shale or limestone.

d. Collection of bedload in movement along the course of the stream:-

The aim of this study was to find out how much sediment was moving downstream, within the Catchments, in a given period of time and to discover what was the size range of material that these streams were capable of moving under present day conditions. At the same time it was hoped to be able to determine to what extent the natural factors, such as the geology, the amount of precipitation, the snow melt and the vegetation cover of these catchments, affected the characteristics of the bed load in these streams.

The sediment moving along the stream channel was collected by means of traps set into the floor of the channel.

In the Lanehead Catchment the bed load trap was constructed at a point 15 feet below the confluence of the two small streams. The stream channel was here 4 feet across. With digging, the channel was widened to six feet across to accomodate two metal trays, placed side by side, which were sunk into the bed of the stream. The trays were 5 feet long, 3 feet wide and 6 inches deep. In order to obtain more efficient deposition of sediment into the trays a stilling pool was constructed over the trays by placing an 8 feet long railway sleeper across the stream and then covering this with large boulders to form a dam. (See Plate 11).

In the Netherhearth Catchment the stream was 6 feet across, and here a single tray was sunk into the stream bed (5' x 3' x 0.5'), and a stilling pool constructed behind a dam made of boulders.

Unfortunately, however, this installation proved unstable in times of increased discharge and was, on a number of occasions, swept downstream. As a result no information on the amount of sediment movement was able to be obtained from the Netherhearth Catchment.

At the Lanehead Catchment bed material, which had moved downstream, was collected from the trays between the period 25th of June (1968) to 8th of May (1969). This was achieved by removing the trays from the stream bed, draining them of water, and then weighing the material in a bucket using a Salter spring balance which weighed up to

PLATE 11

The metal trays which were sunk into the bed of the stream in front of them the boulder dam covered with snow

50 kgs. Portions of this collected bed load were taken back to the laboratory for further detailed analysis.

2. Laboratory analysis:-

The laboratory analysis carried out in this study consisted of three main types. The first, and by far the most important, was the particle size analysis of the sediment samples. This was achieved by using standard methods of dry sieving for the bed load, and wet sieving for the banks material. The second type of analysis was a stone count analysis into main lithological groups of the larger rock particles making up the bed load and banks of the stream. Finally, the third part consisted of the analysis of water samples taken from the stream.

Particle size analysis:-

A preliminary survey of both the Lanehead and Netherheath Catchment revealed that the vast majority of the material comprising the bed load of the streams was made up of particles with diameters greater than 0.06 mms. As this was the case it was decided that sieve analysis alone would give an accurate measure of the particle size distribution. In all cases the samples which had been collected in the field were initially, when they arrived in the laboratory, placed in metal or cardboard trays and then

½", ⅜", ¼", 3/16", ⅛", No. 8, No. 14, No. 25, No. 36, No. 52, No. 72, No. 100, No. 150, No. 200, No. 240 sieves. This nest of sieves was placed on a mechanical sieve shaker and vibrated for five minutes. The weight of the material retained on each of the sieves was weighed and recorded.

The samples of material obtained from the banks of the streams often contained relatively high proportions of silt and clay-sized particles which meant that dry sieving

Graphs showing particle size distribution curves of the eastern tributary bed material

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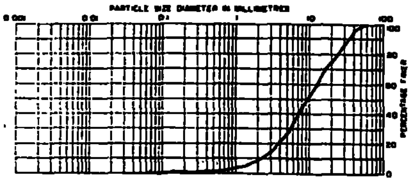

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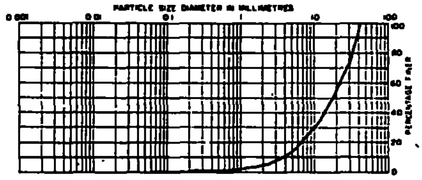

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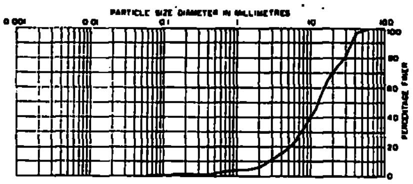

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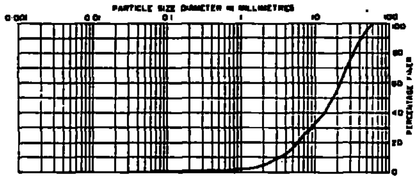

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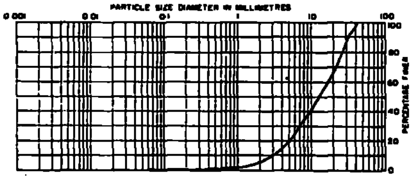

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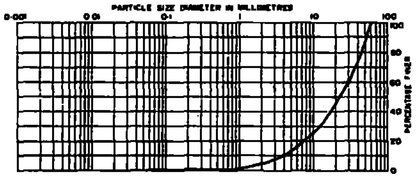

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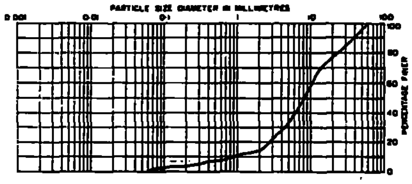

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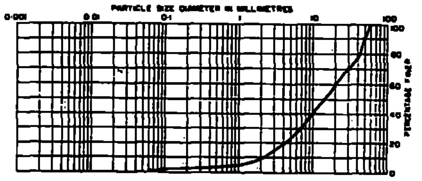

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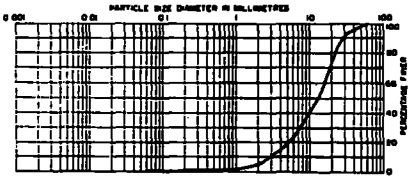

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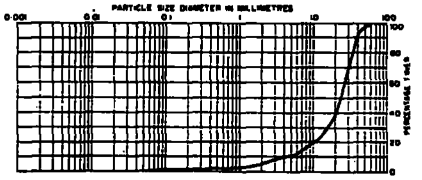

Fig. 6.1 A

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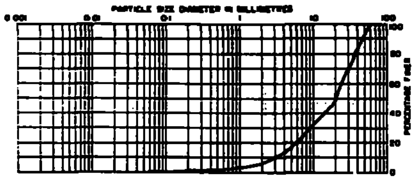

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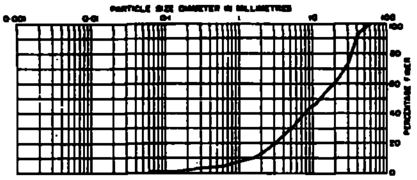

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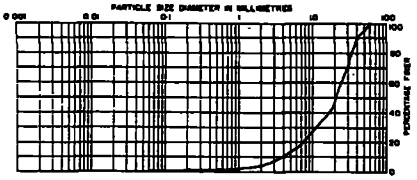

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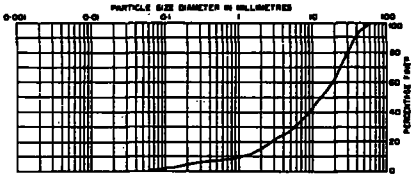

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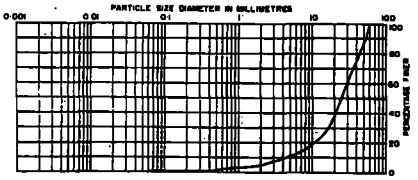

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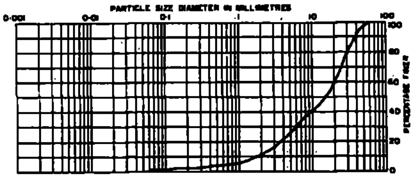

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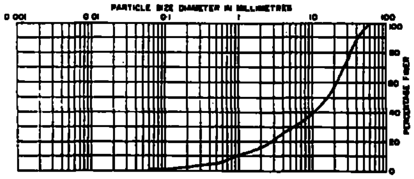

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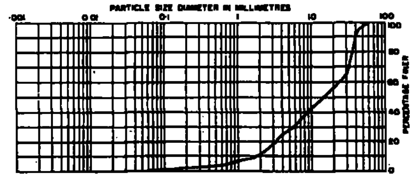

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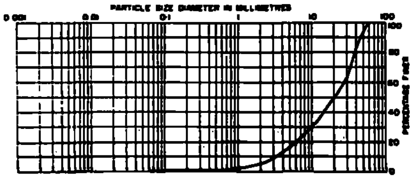

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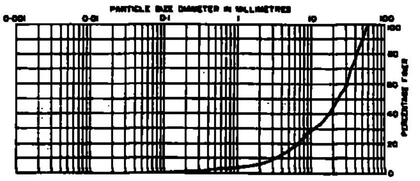

Fig. 6.1 A

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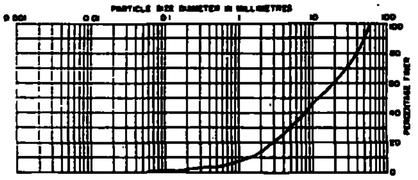

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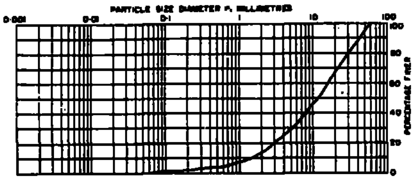

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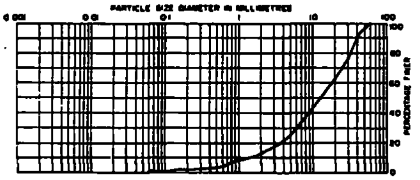

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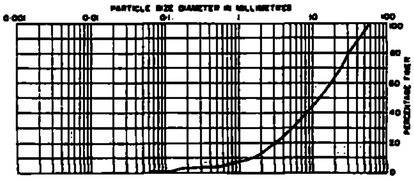

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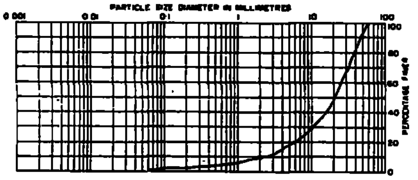

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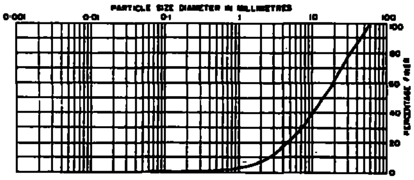

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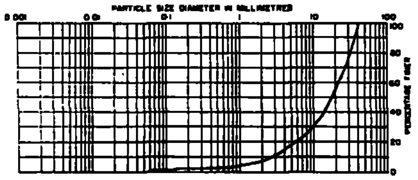

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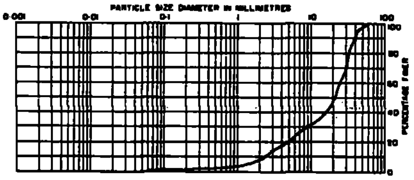

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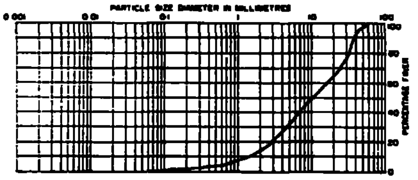

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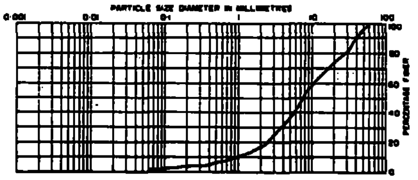

Fig. 6.1 A

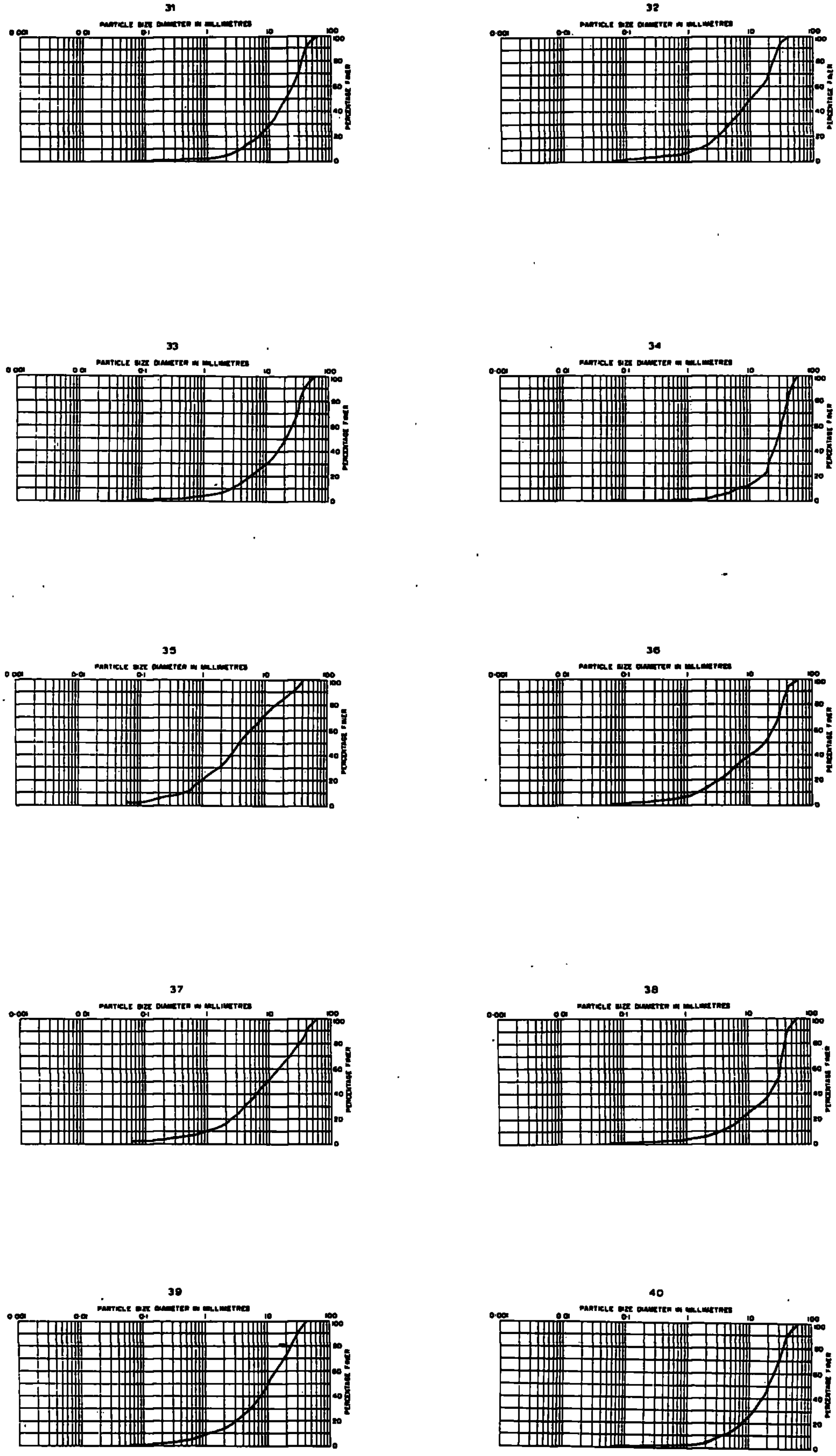
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Fig. 6.1 A

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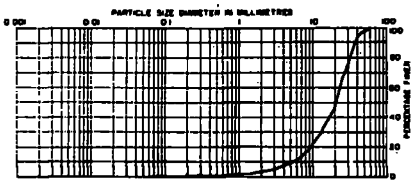

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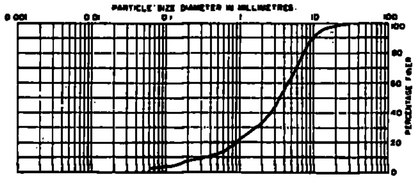

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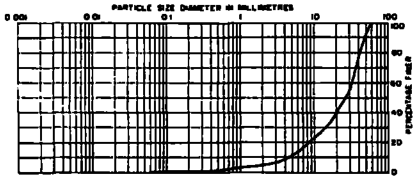

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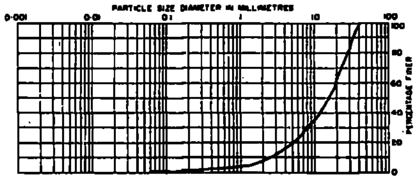

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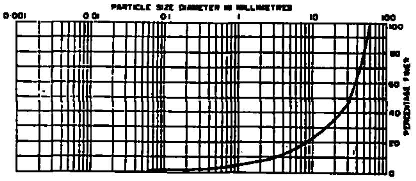

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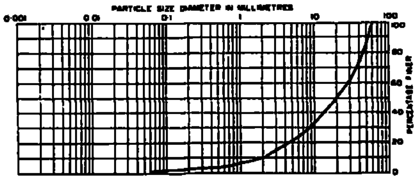

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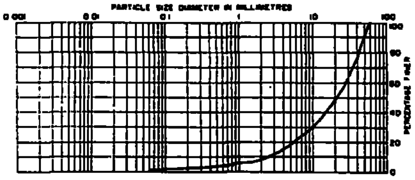

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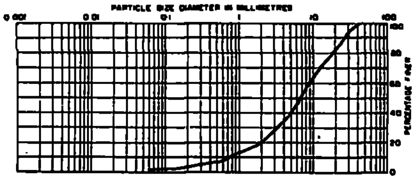

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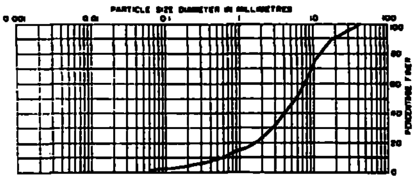

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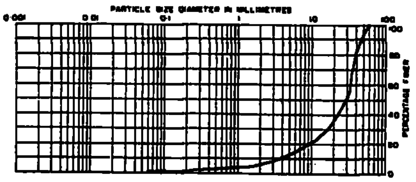

Fig. 6.1 A

Graphs showing particle size distribution curves of the western tributary bed material

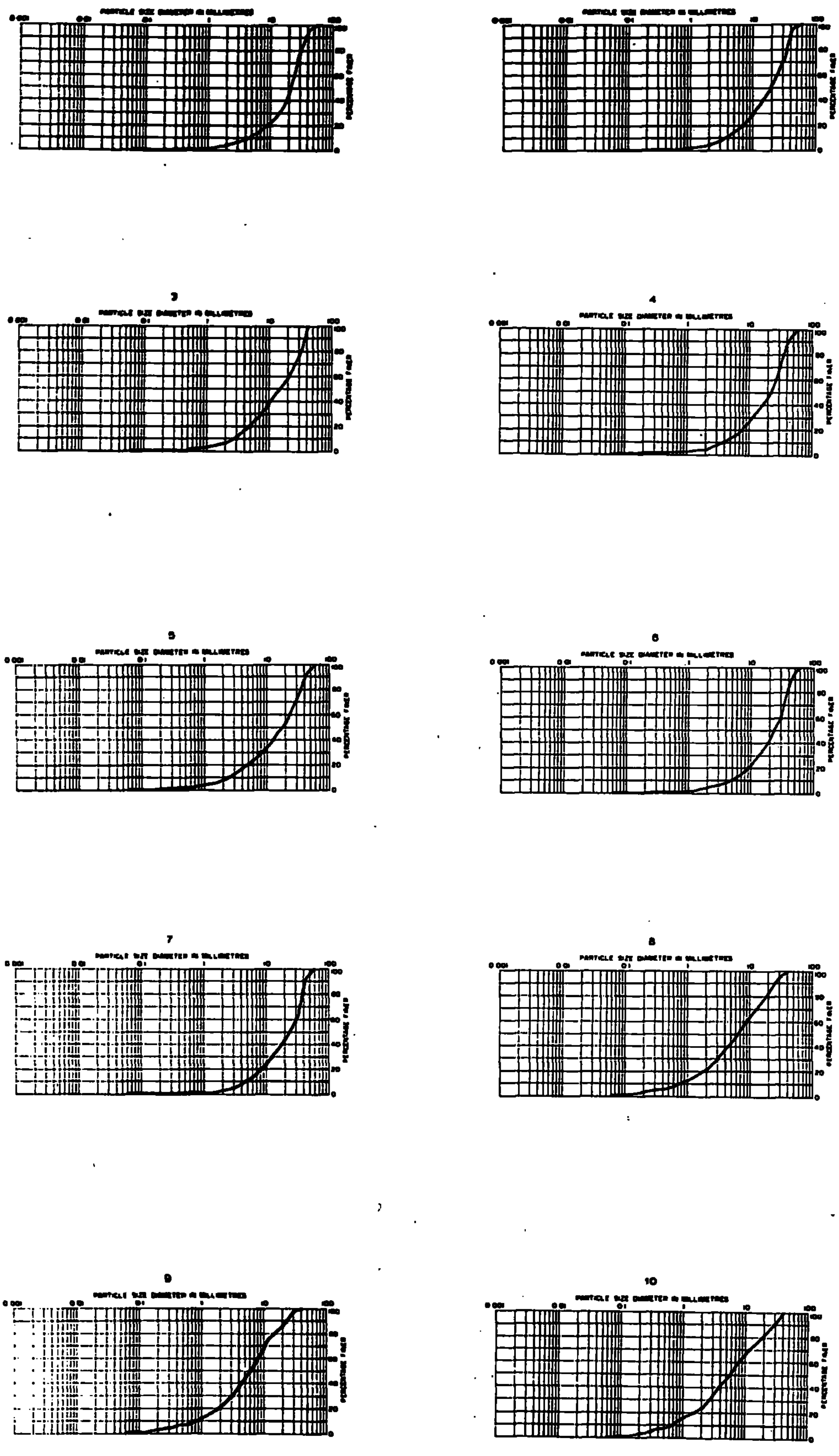

Fig. 6.1 B

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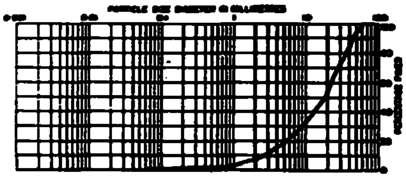

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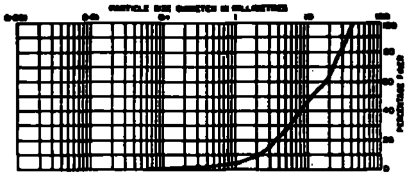

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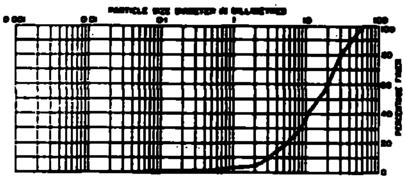

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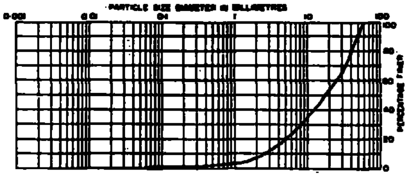

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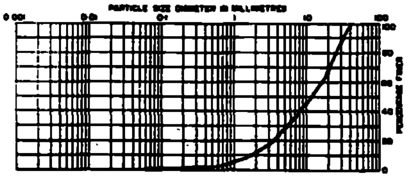

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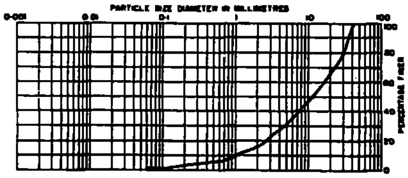

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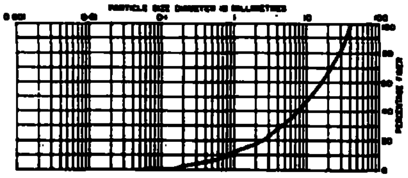

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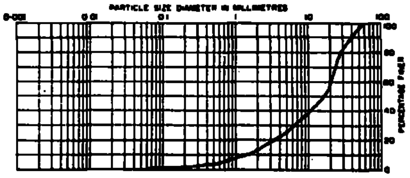

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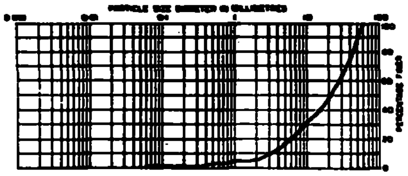

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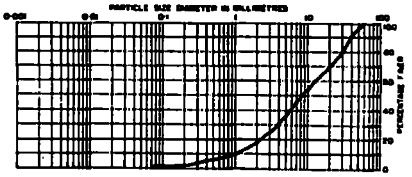

Fig. 6.1 B

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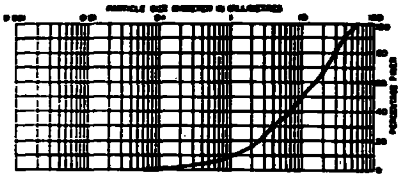

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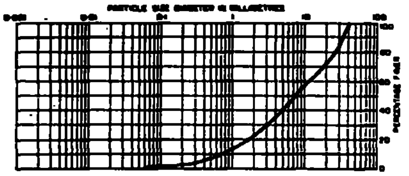

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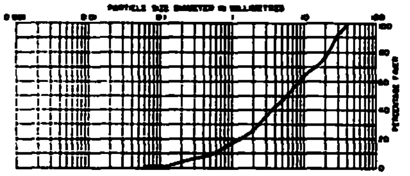

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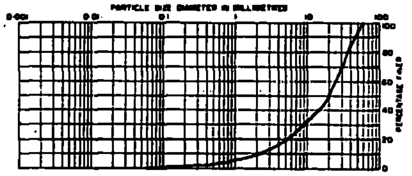

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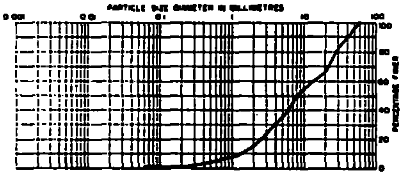

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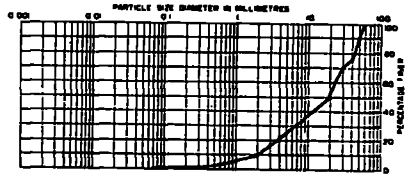

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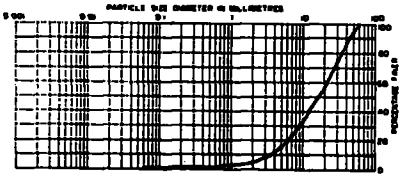

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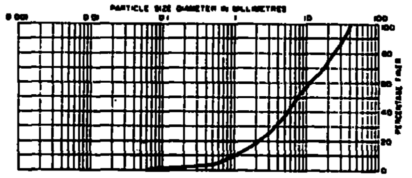

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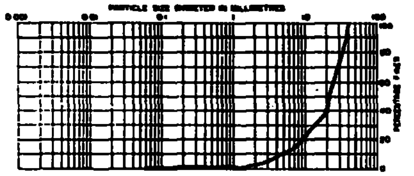

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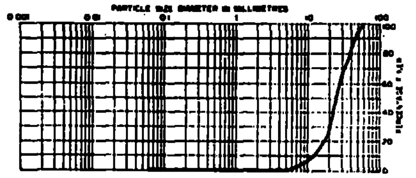

Fig. 6.1 B

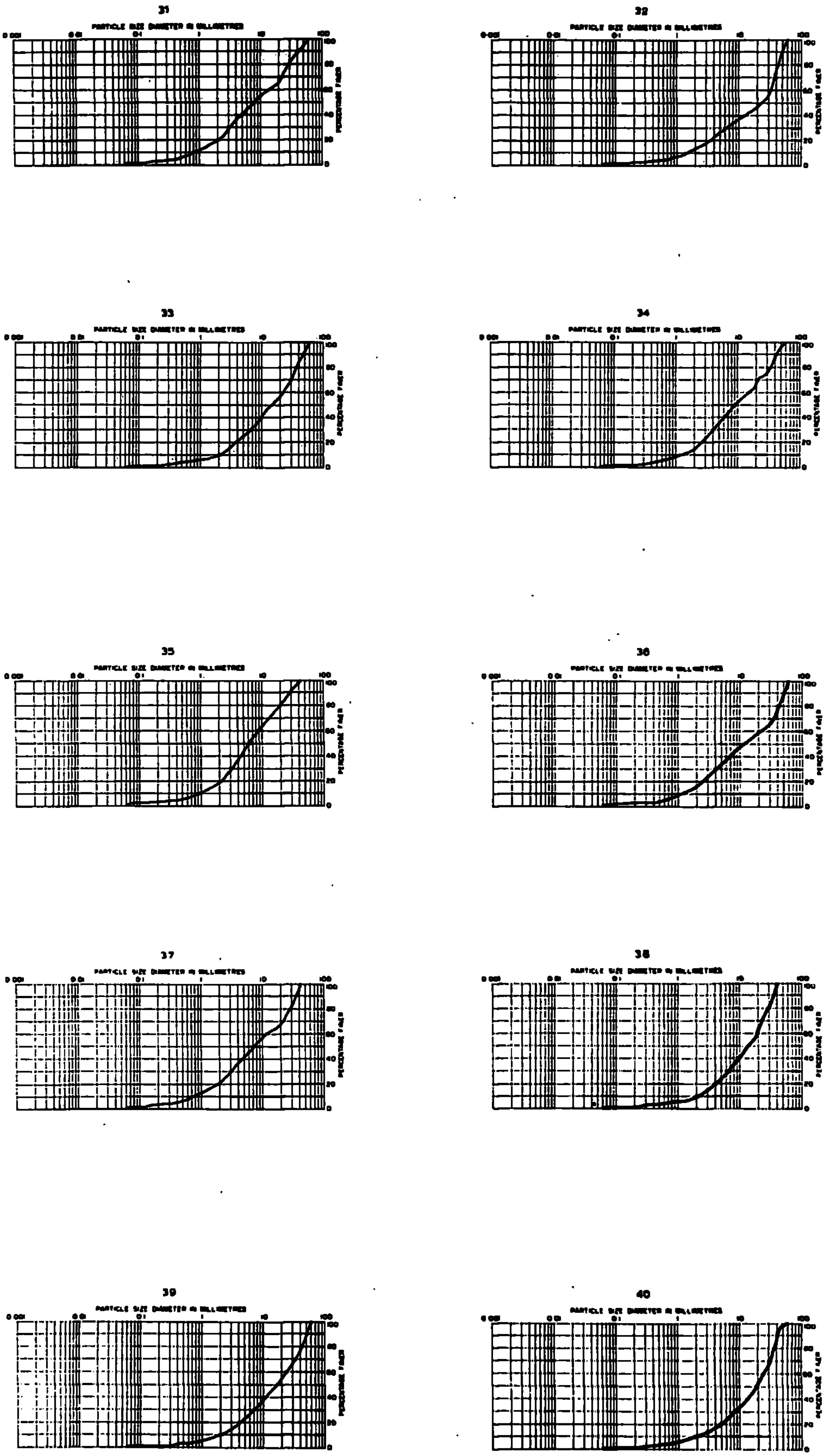
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Fig. 6.1 B

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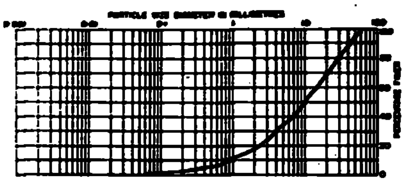

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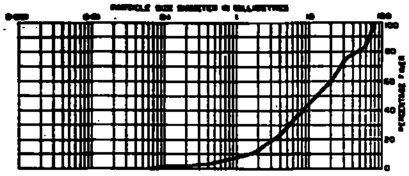

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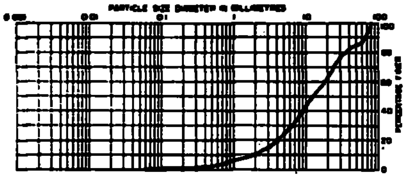

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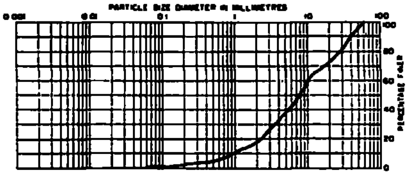

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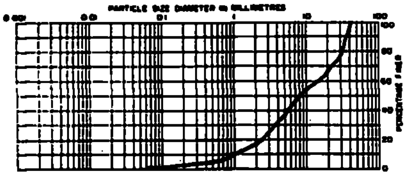

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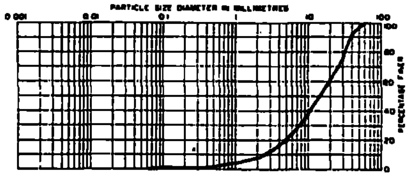

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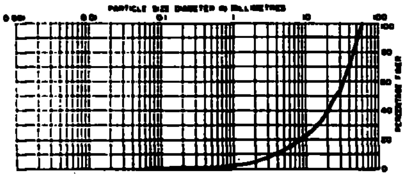

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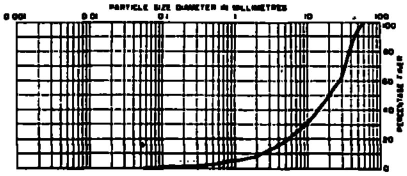

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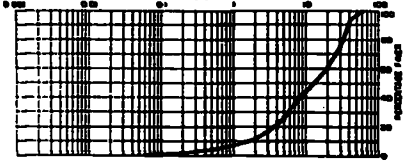

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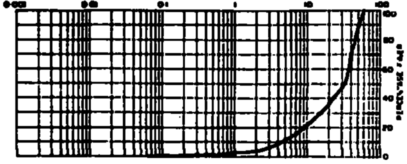

Fig. 6.1 B

Graphs showing particle size distribution curves of the Nethetherhearth bed material

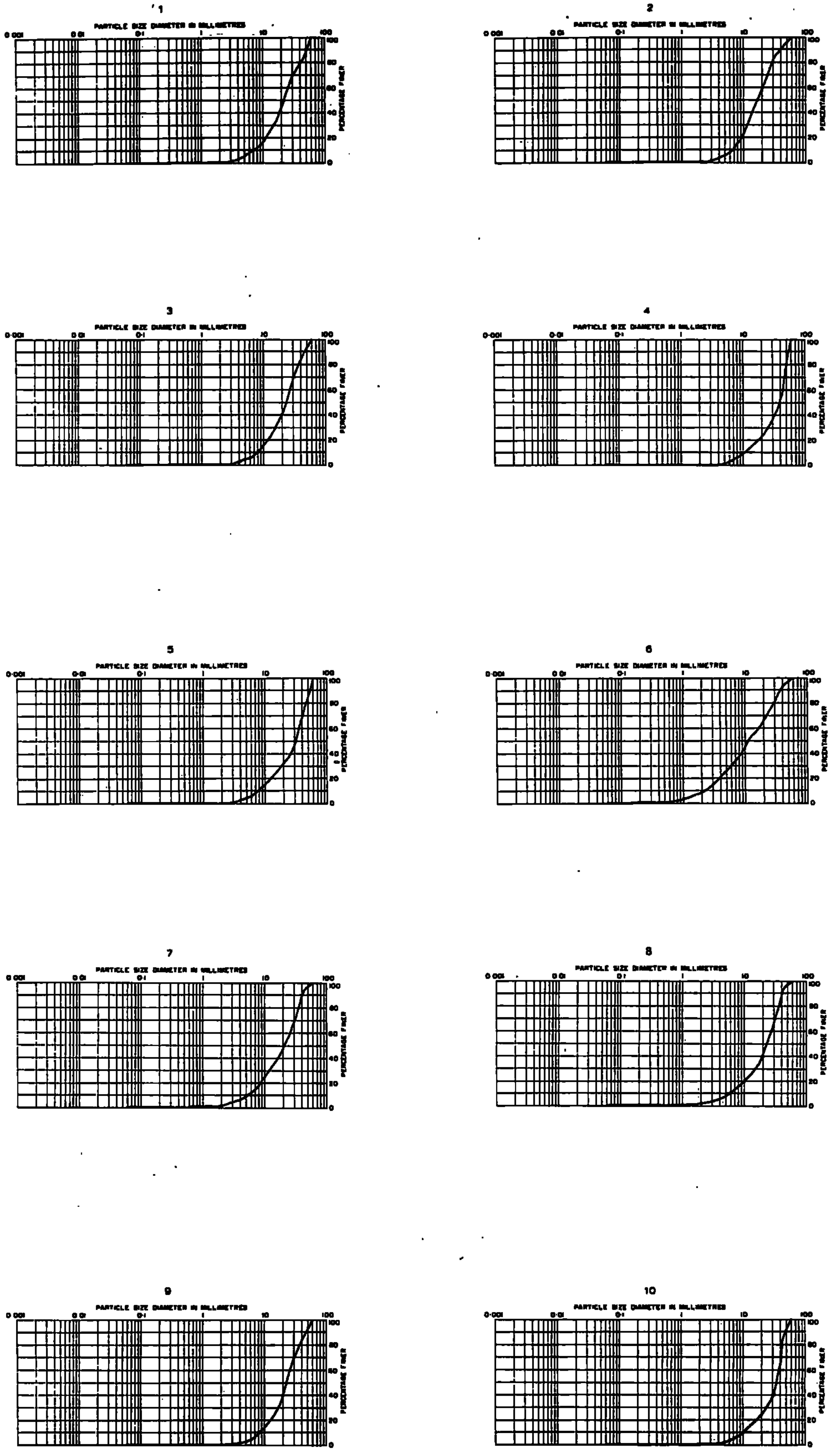

Fig. 6.1 C

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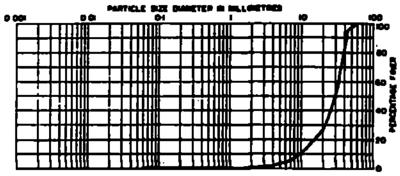

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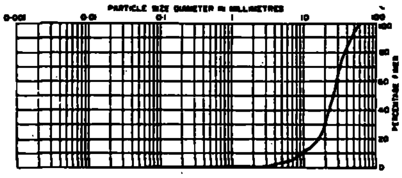

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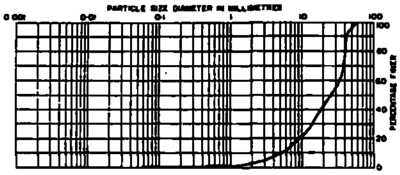

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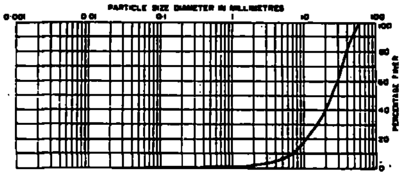

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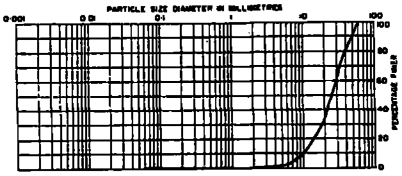

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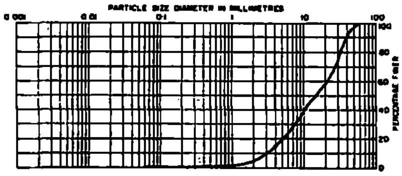

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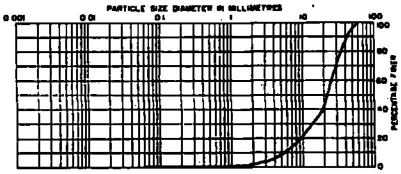

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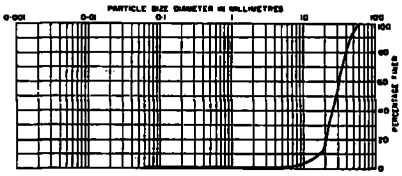

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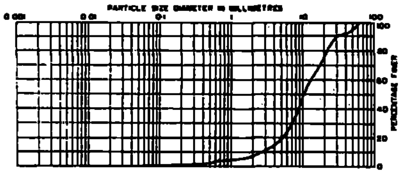

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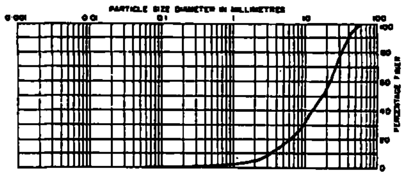

Fig. 6.1 C

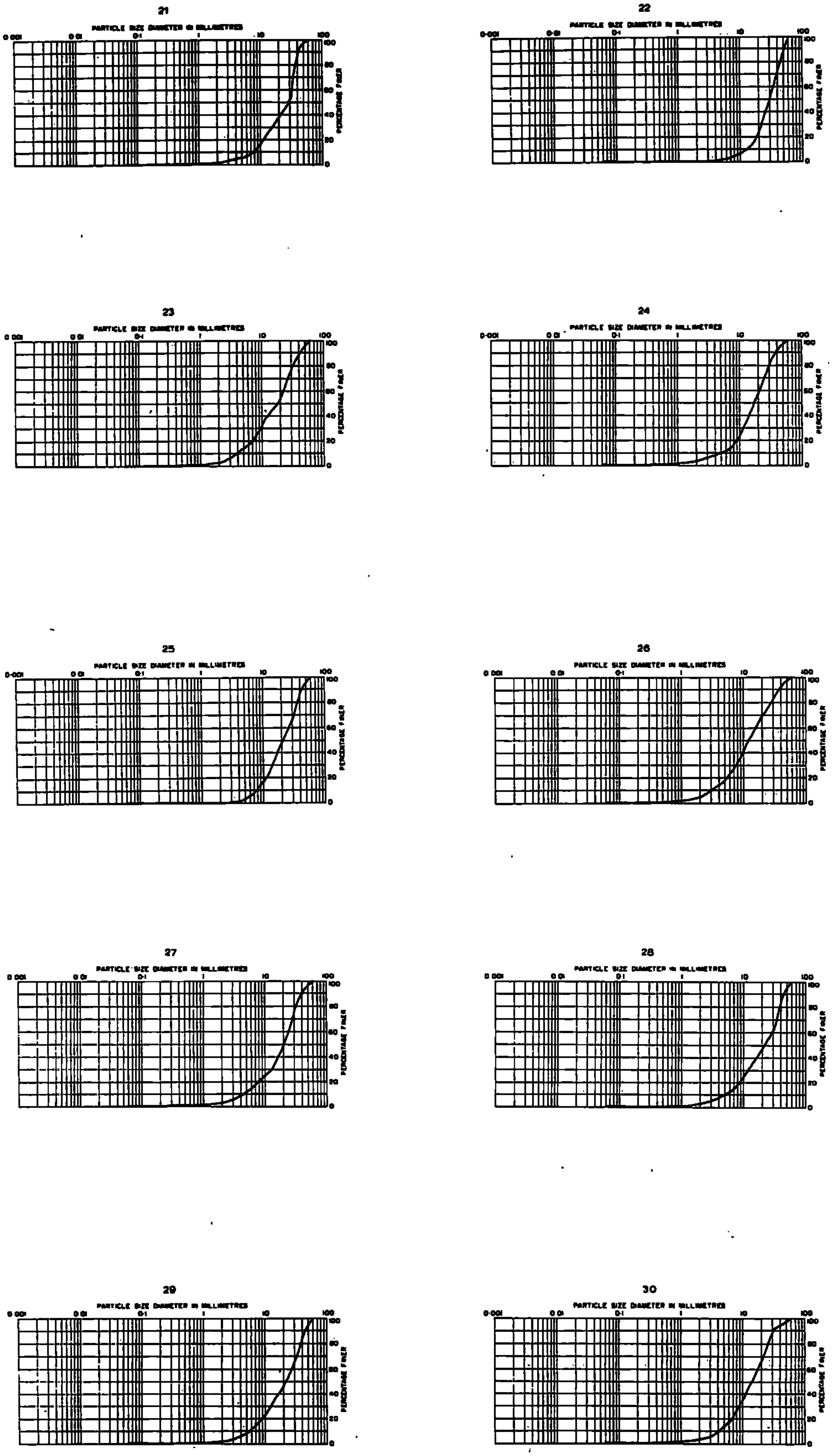
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Fig. 6.1 c

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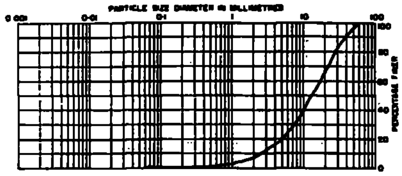

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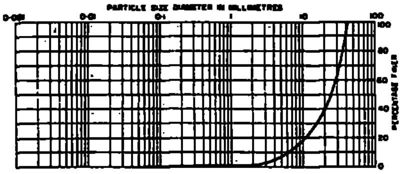

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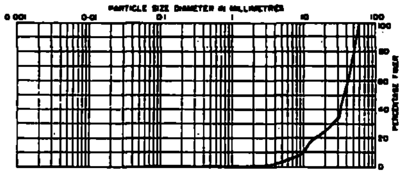

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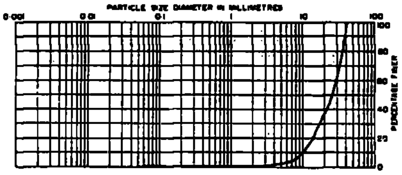

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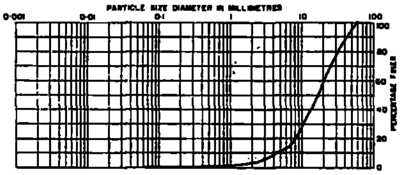

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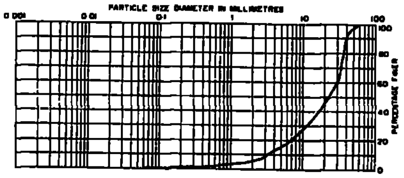

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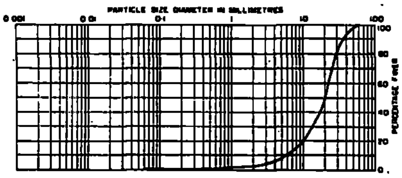

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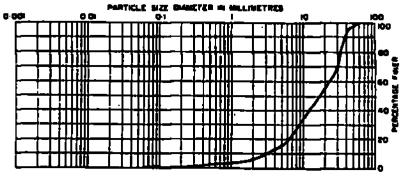

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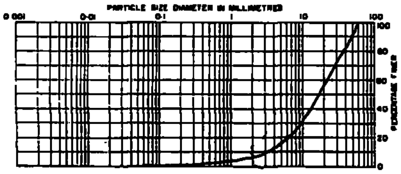

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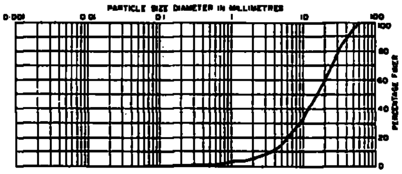

Fig. 6.1 C

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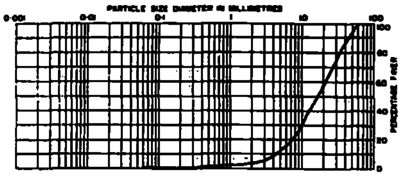

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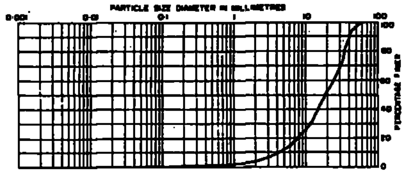

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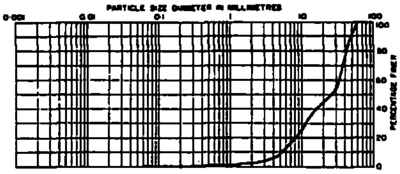

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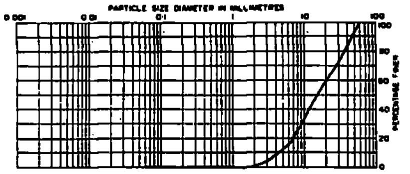

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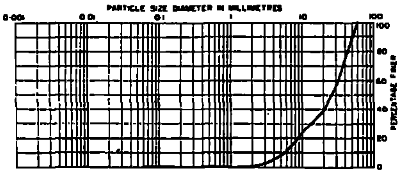

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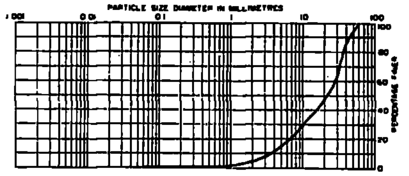

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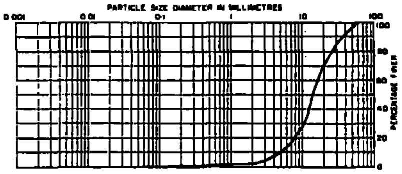

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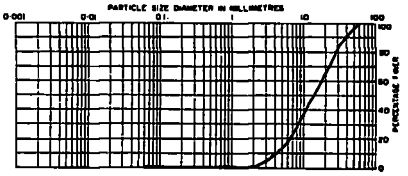

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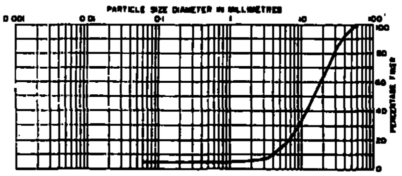

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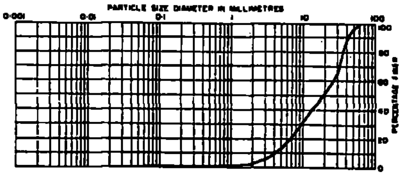

Fig. 6.1 C

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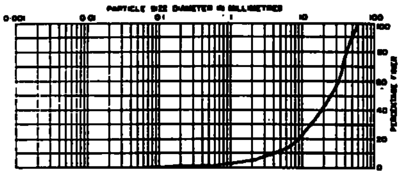

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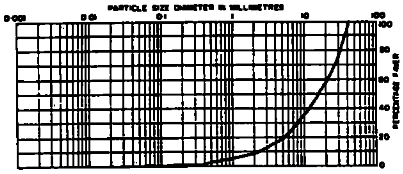

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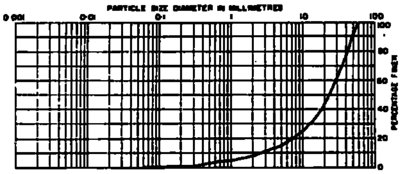

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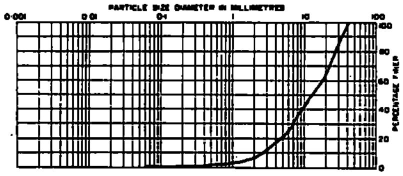

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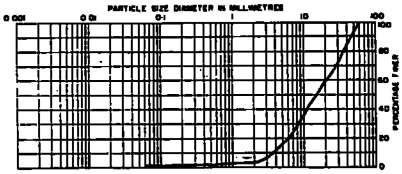

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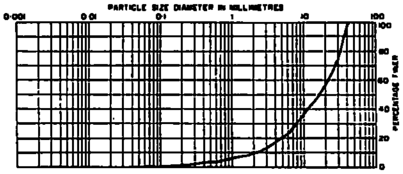

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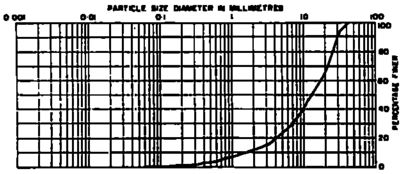

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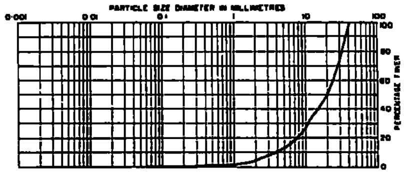

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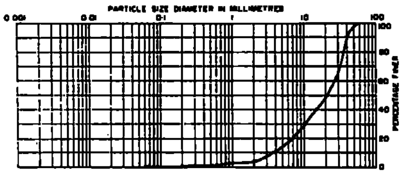

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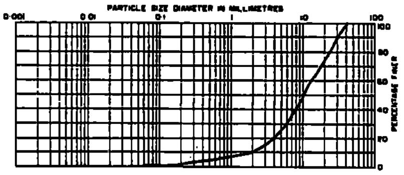

Fig. 6.1 C

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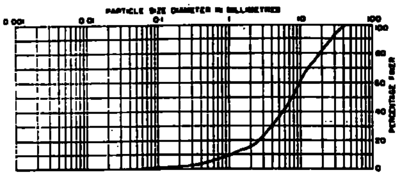

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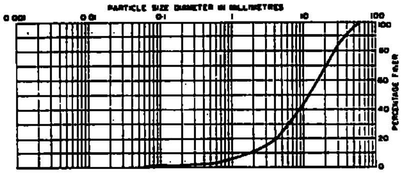

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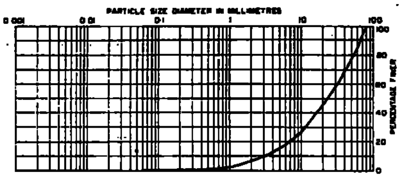

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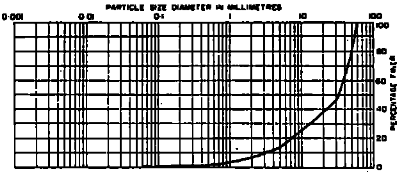

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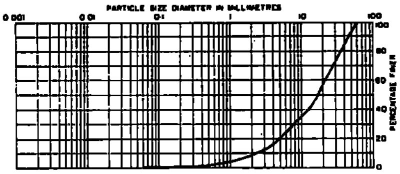

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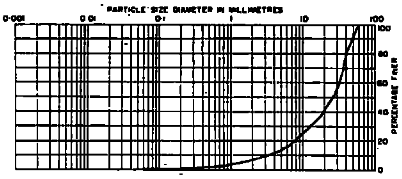

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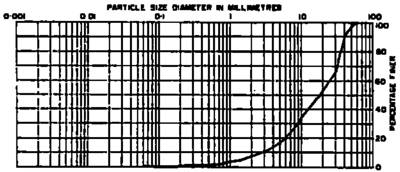

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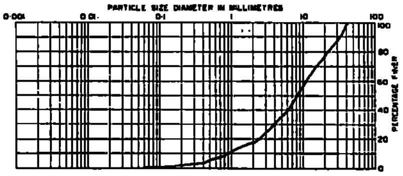

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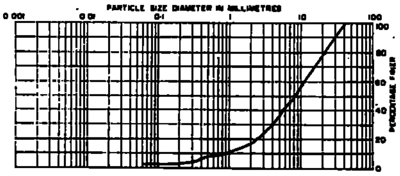

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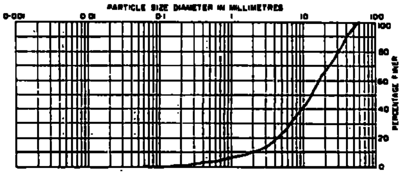

Fig. 6.1 C

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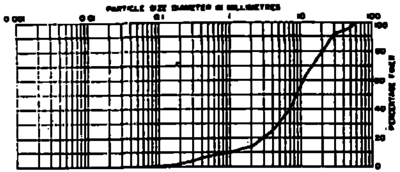

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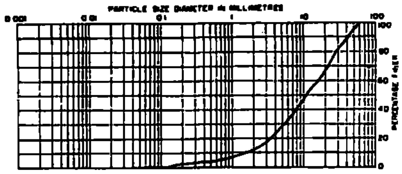

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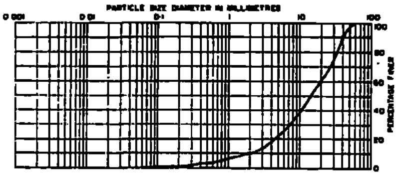

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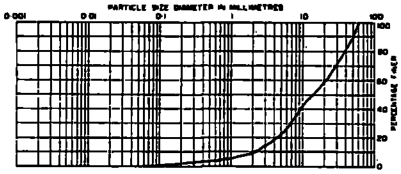

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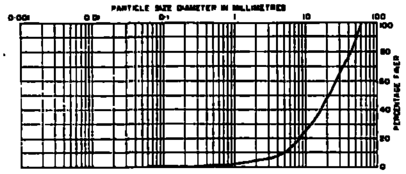

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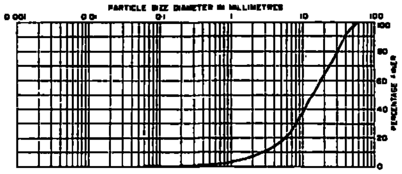

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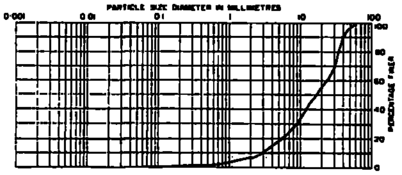

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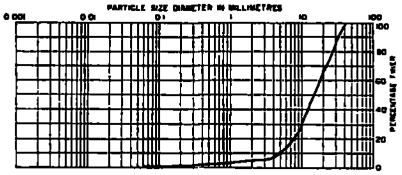

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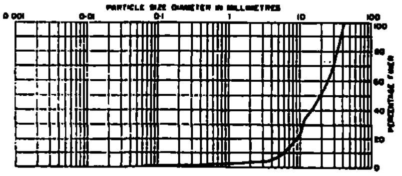

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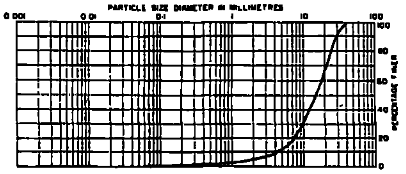

Fig. 6.1 C

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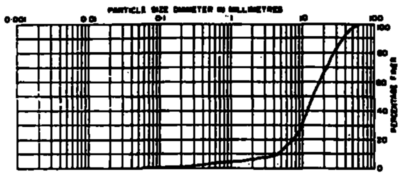

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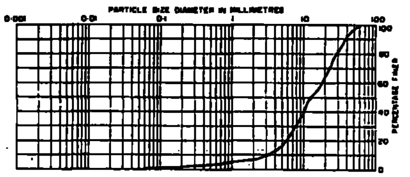

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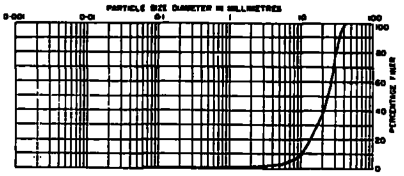

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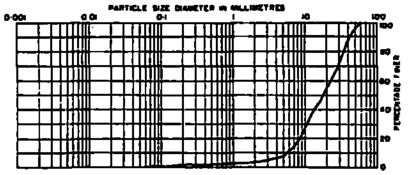

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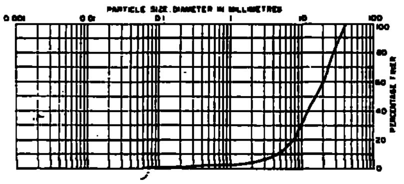

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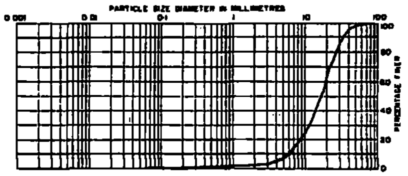

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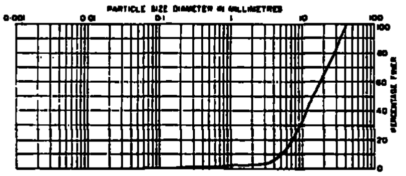

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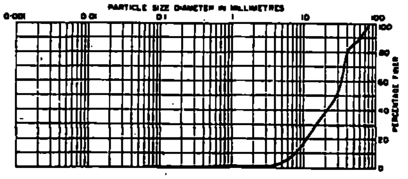

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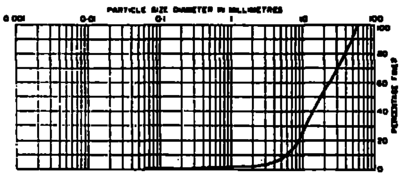

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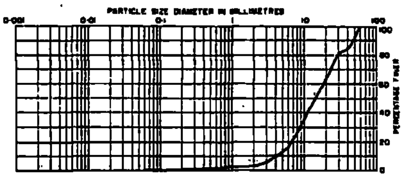

Fig. 6.1 C

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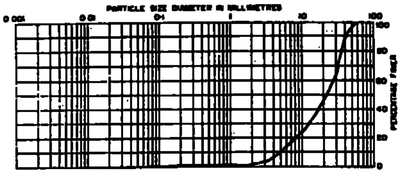

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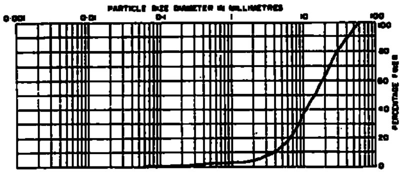

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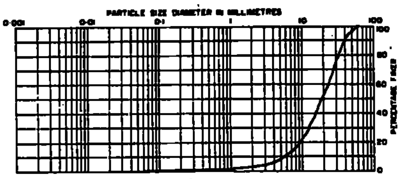

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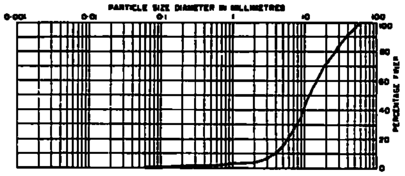

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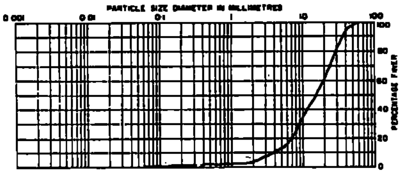

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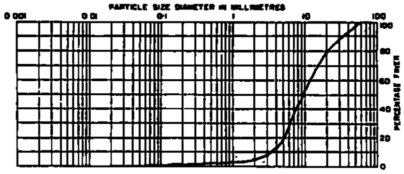

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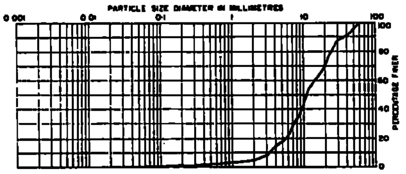

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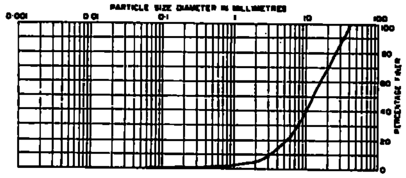

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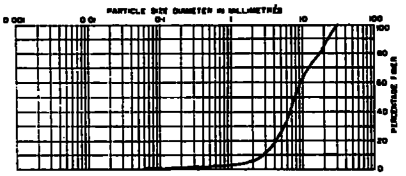

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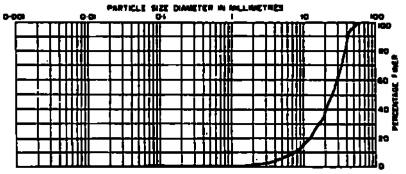

Fig. 6.1 C

Graphs showing particle size distribution curves of the eastern tributary bank material

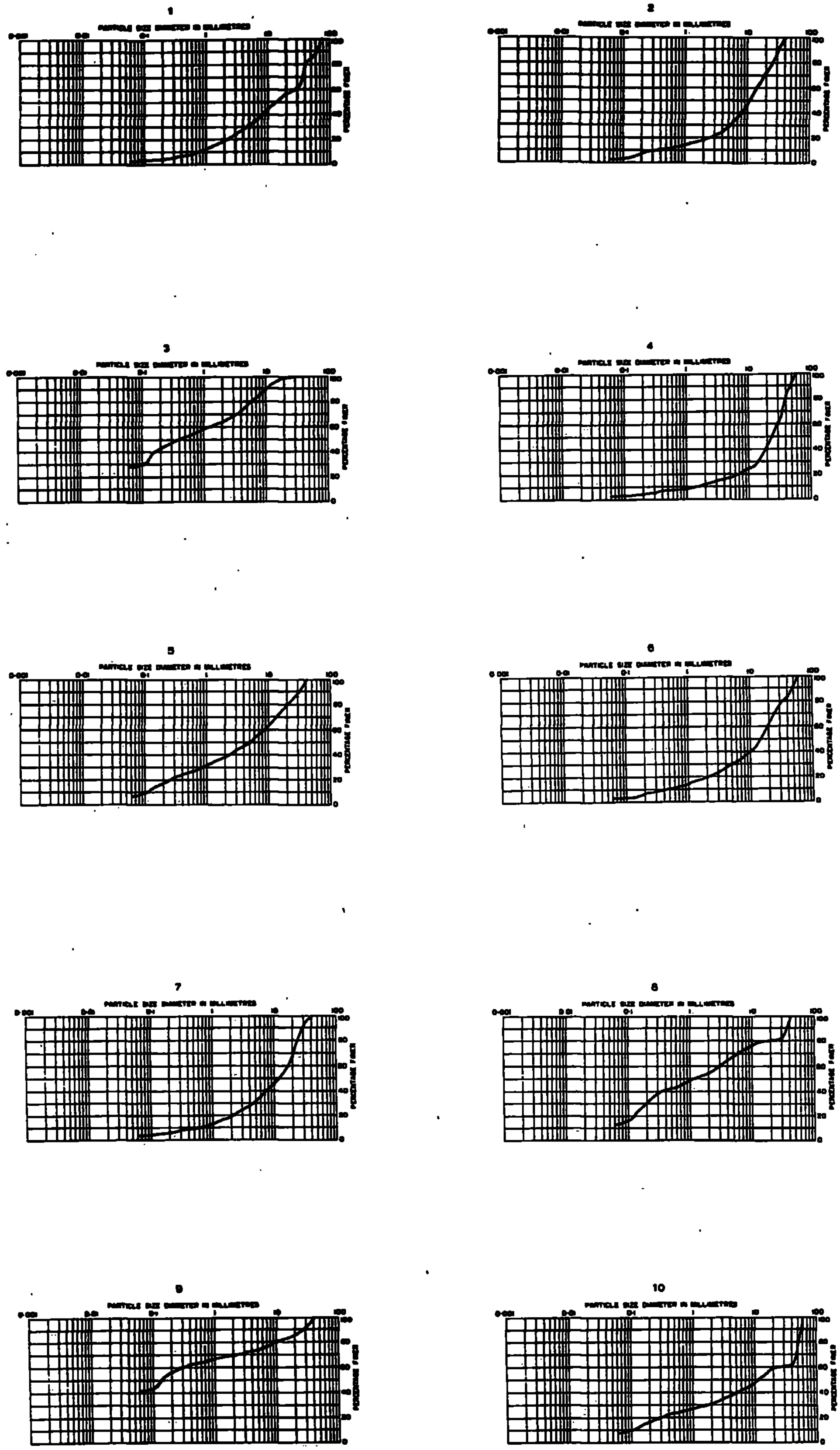

Fig. 6.1 D

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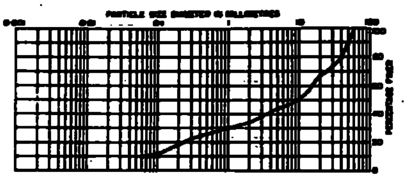

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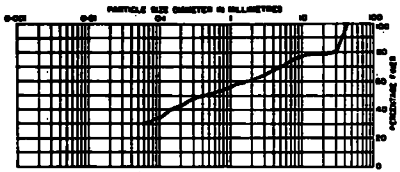

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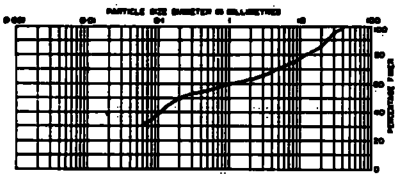

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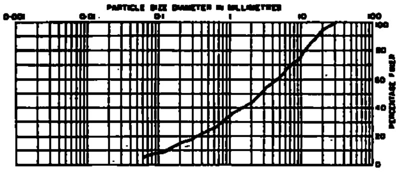

Fig. 6.1 D

Graphs showing particle size distribution curves of the western tributary bank material

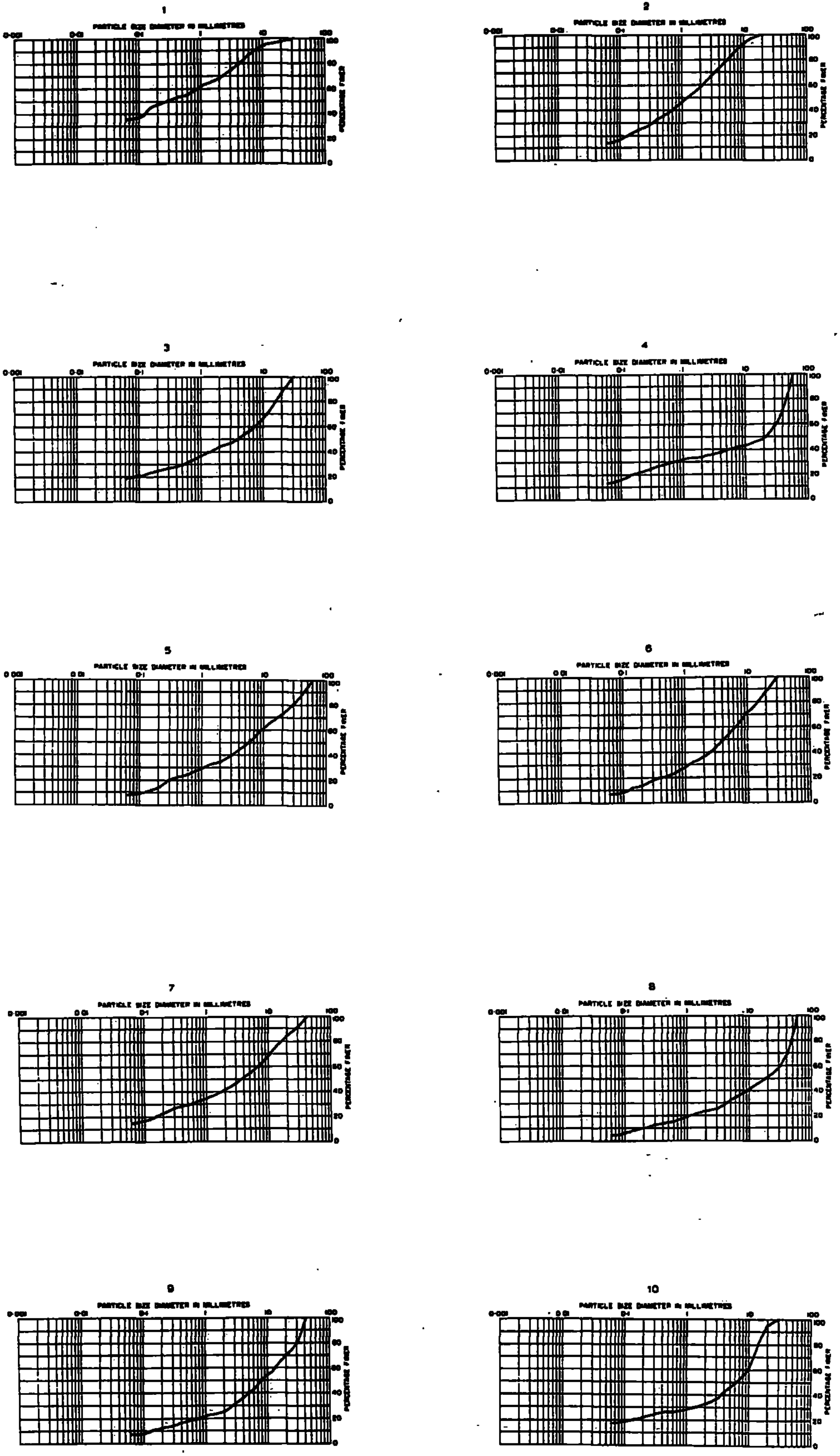

Fig. 6.1 E

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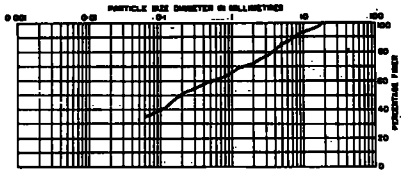

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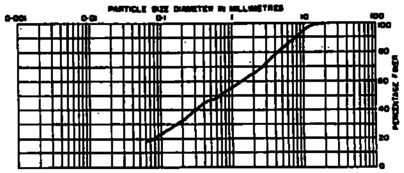

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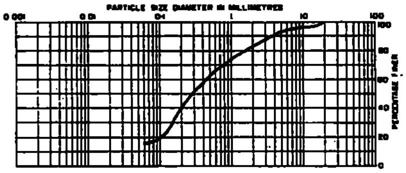

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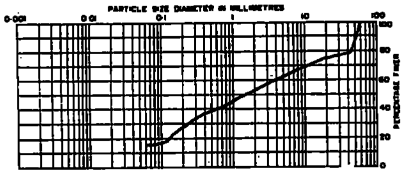

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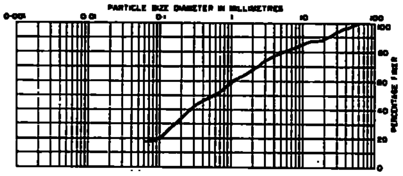

Fig. 6.1 E

Graphs showing particle size distribution curves of the Netherhearth bank material

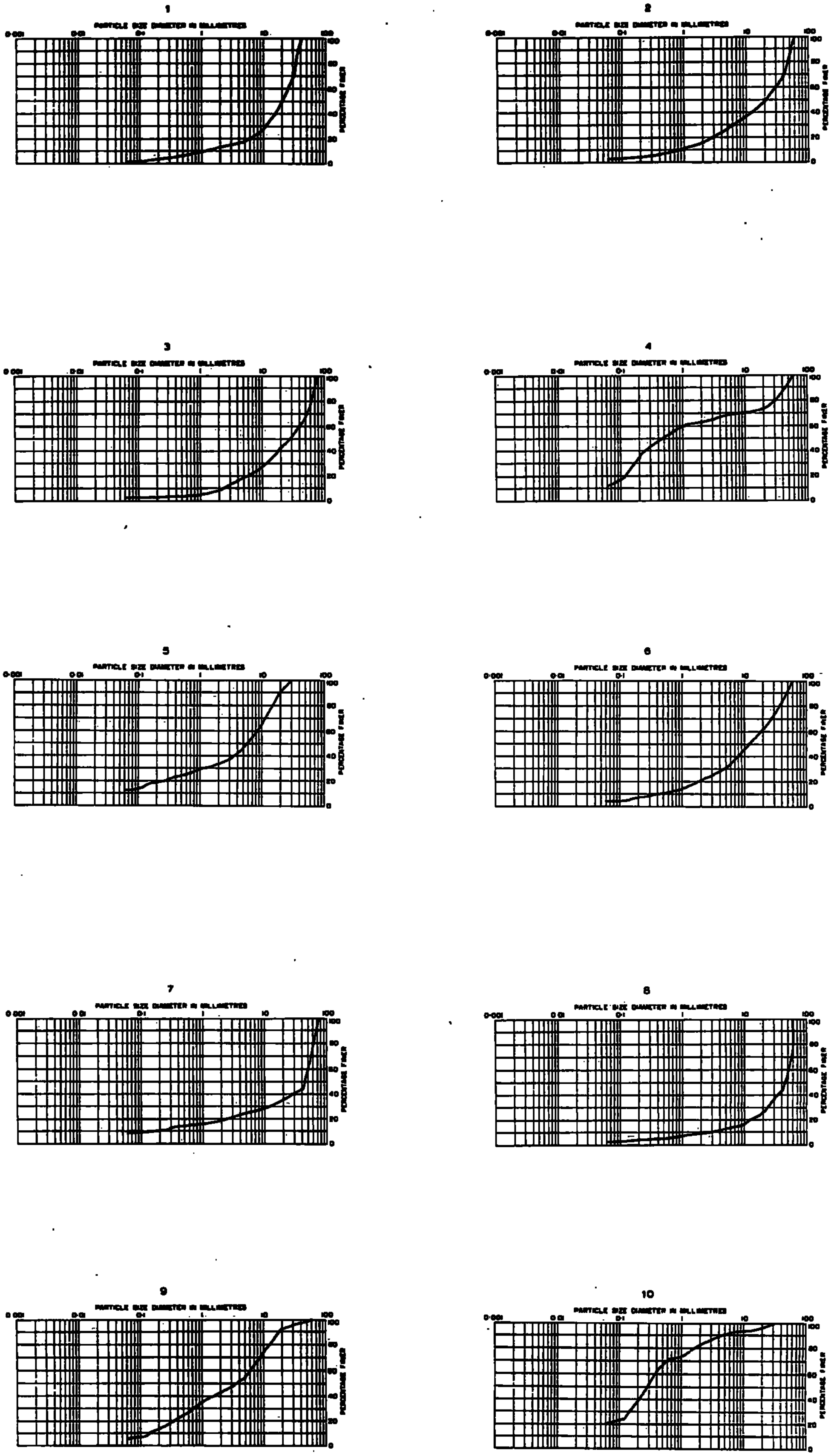

Fig. 6.1 F

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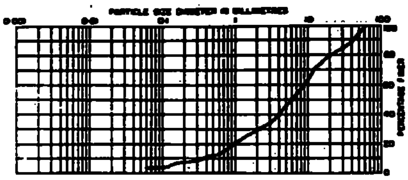

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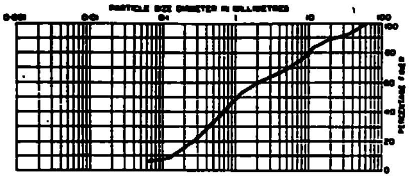

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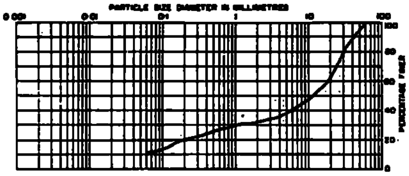

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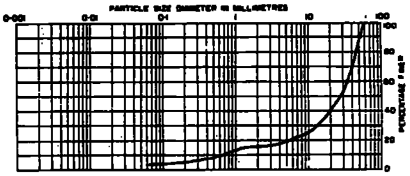

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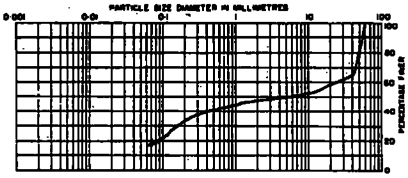

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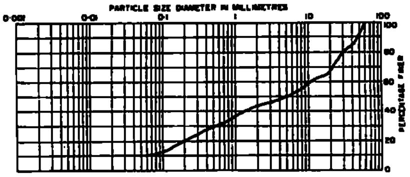

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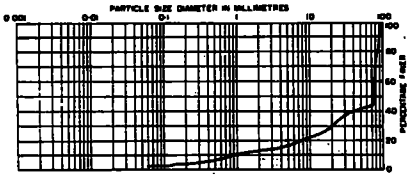

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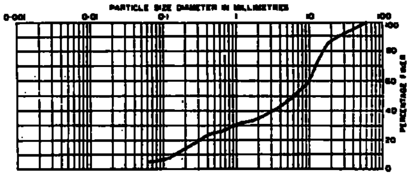

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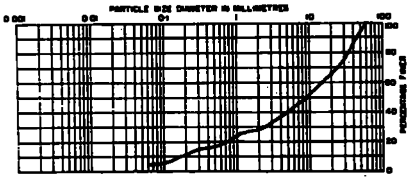

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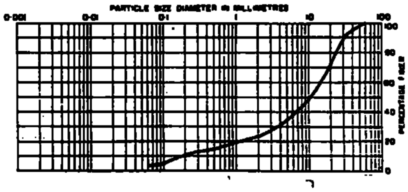


Fig. 6.1 F

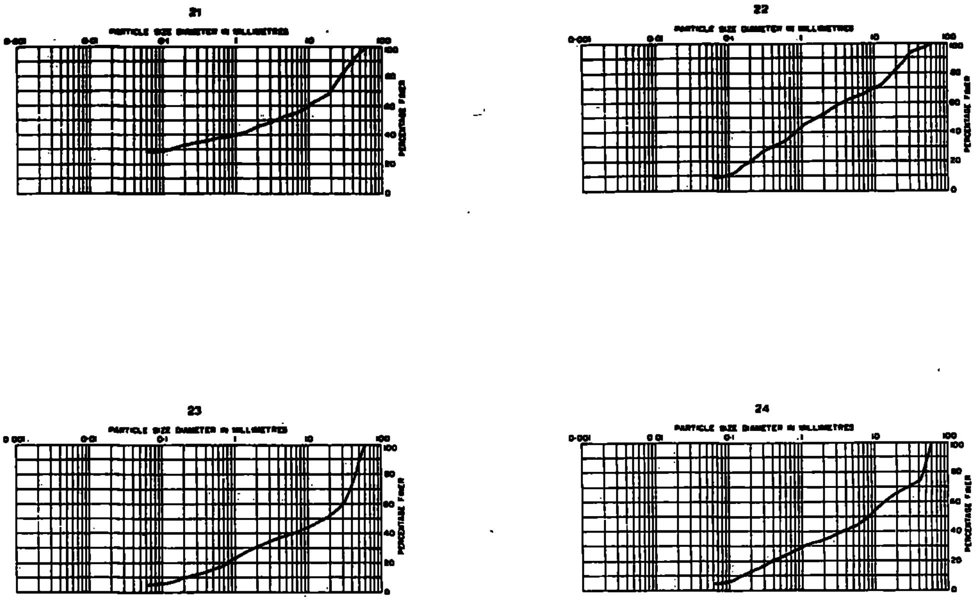

21
PARTICLE SIZE DIAMETER IN MILLIMETRES
0·001
0·01
0·1
1
10
100
PERCENTAGE FINER
0
20
40
60
80
100
22
PARTICLE SIZE DIAMETER IN MILLIMETRES
23
PARTICLE SIZE DIAMETER IN MILLIMETRES
24
PARTICLE SIZE DIAMETER IN MILLIMETRES

Fig. 6.1 F

as the mean, sorting, and skewness which summarize the characteristics of the cumulative frequency curves. The mean was calculated using the following formula of Falk and Ward (1957)

$$\text{Mean} = \frac{\phi 16\% + \phi 50\% + \phi 84\%}{3} \qquad (\phi = \text{phi})$$

Sorting values were calculated by the following formula.

$$\text{Sorting} = \tfrac{1}{2}\,(\phi 84\% - \phi 16\%)$$

This method has the disadvantage of paying little attention to the tails of the distribution and, therefore tending to estimate the sorting as better than it really is. It does, however, possess the advantage of relatively easy and simple calculation.

Skewness is a measure of deviation from the normal distribution, and was calculated using the formula of Inman (1952)

$$\text{Skewness} = \frac{\text{Mean phi} - \text{Median phi}}{\text{Sorting phi}}$$

Results:-

In this section the analytical data obtained from samples from the stream bed, and stream banks will be dealt with separately.

A. Bed material:-

At the Lanehead Catchment 50 samples were taken from each of the two streams, and at the Netherhearth Catchment 100 samples.

Preliminary analysis revealed that in the eastern tributary at Lanehead no sample contained particles with diameters of more than 65 mms. or less than 0.06mms. In the western tributary at Lanehead particles ranged from 0.06 mms to 60 mms., and at the Netherhearth Catchment from 0.06 mms to 65 mms. Therefore in all three streams it was noticeable that very little material was present along the stream bed with a grain size finer than 0.06 mms. This was thought to be due to the fact that any finer material which was present would be carried away in suspension by the water movement of the stream.

1. Lanehead Catchment:-

a. Eastern tributary:-

In order to show the range of values associated with the mean, sorting and skewness parameters a series of histograms were constructed (Fig. 6.2) (see Appendix 2A)

Mean particle size: The histogram showing mean particle size records a range varying from - 1.0 Ø to 5.0 Ø with more than 32% of the values falling between - 3.5 Ø and

Histograms and graphs showing the distribution of the mean particle size, sorting and skewness values along the eastern tributary

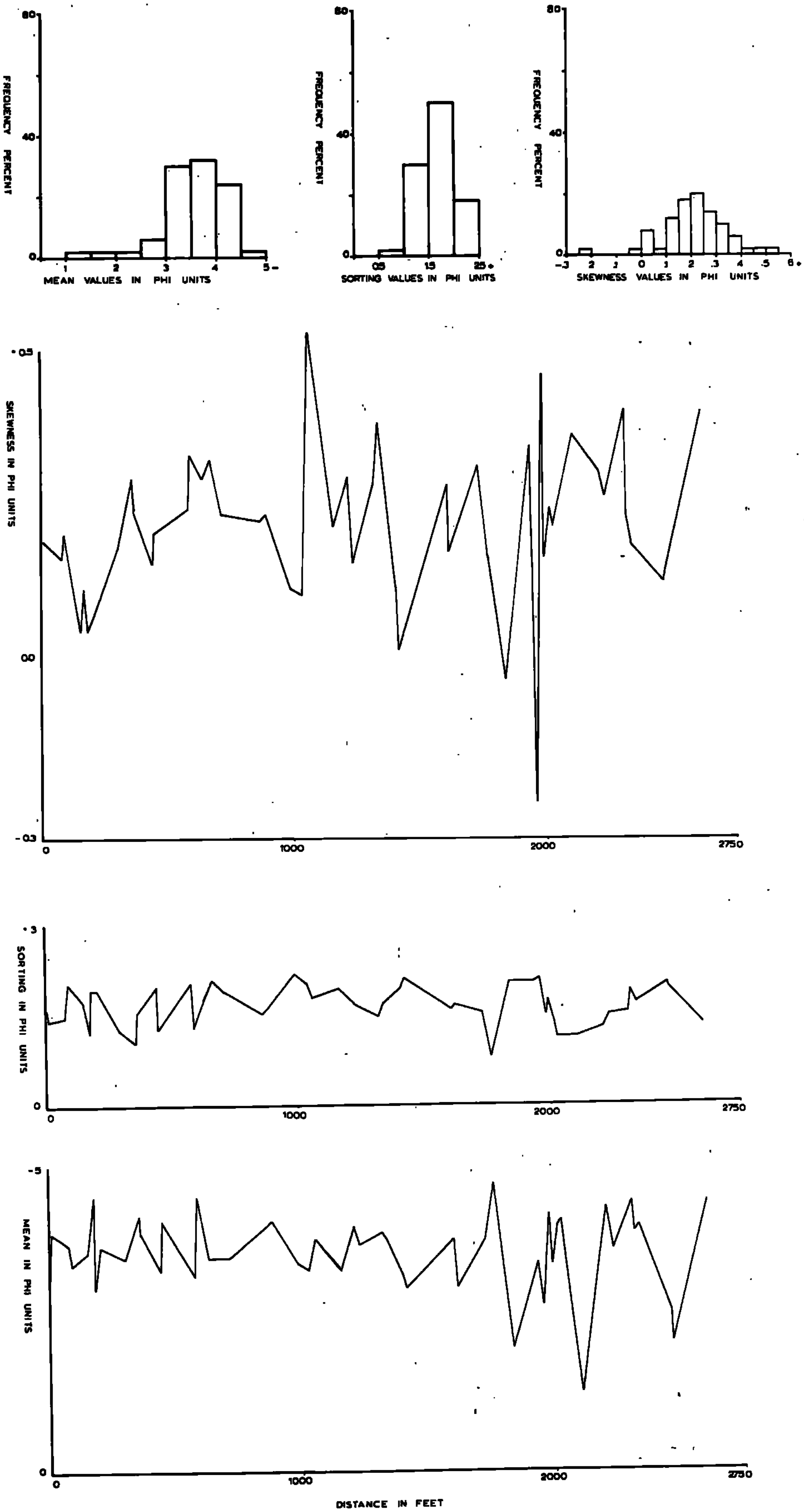


Fig. 6.2

- 4.0 Ø, which represents the modal class of the distribution, and with more than 92% of the total observations falling between - 2.5 Ø to - 4.5 Ø.

These data were also plotted graphically to show the changes in mean particle size along the stream course (Fig. 6.2). On this graph fairly rapid changes in mean particle size were to be noted especially in the upper reaches, but no overall or well marked increase or decrease in mean particle size was observed in a downstream direction. It was concluded, therefore, that mean particle size along this stream course was relatively uniform apart from random variations near the source caused by the influence of sedimentary material from the banks of the streams.

<u>Sorting</u>:-

The histogram showing sorting values records a range varying from + 0.5 Ø to + 2.5 Ø with 50% of the observations falling between +1.5 Ø and + 2.0 Ø which forms the modal class of the distribution, and with almost 99% of the observations falling between + 1.0 Ø and + 2.5 Ø.

In the graph showing changes in sorting values along the stream course it will be seen that no pronounced trend is found although between 1,000 feet and the starting point the average sorting values seem to be decreasing. In other words in this stretch the bed load is becoming better sorted.

Skewness:-

The histogram showing skewness values records a range varying from - 0.03 Ø to + 0.60 Ø, with 88% of the observations falling between 0.0 Ø/ and + 0.55 Ø. The distribution appears to be normal in character with the modal class lying between +0.20 Ø and + 0.25 Ø. In the graph showing changes along the stream it was seen that rapid changes in skewness took place, without any marked trend, although there was a tendency for the magnitude of the changes to decrease in a downstream direction.

An attempt was also made to discover if any marked relationships existed between mean particle size, sorting and skewness. To achieve this the following graphs were plotted:-

1. Mean particle size against sorting values
2. Mean particle size against skewness values
3. Sorting values against skewness values

Correlation and regression analysis of these values was carried out using a computer programme. (Fig. 6.3). In all three cases it was seen that linear relationships appeared to exist between the variables. The correlation coefficients were then tested to determine their

Correlation and regression analysis of the statistical parameters, eastern tributary

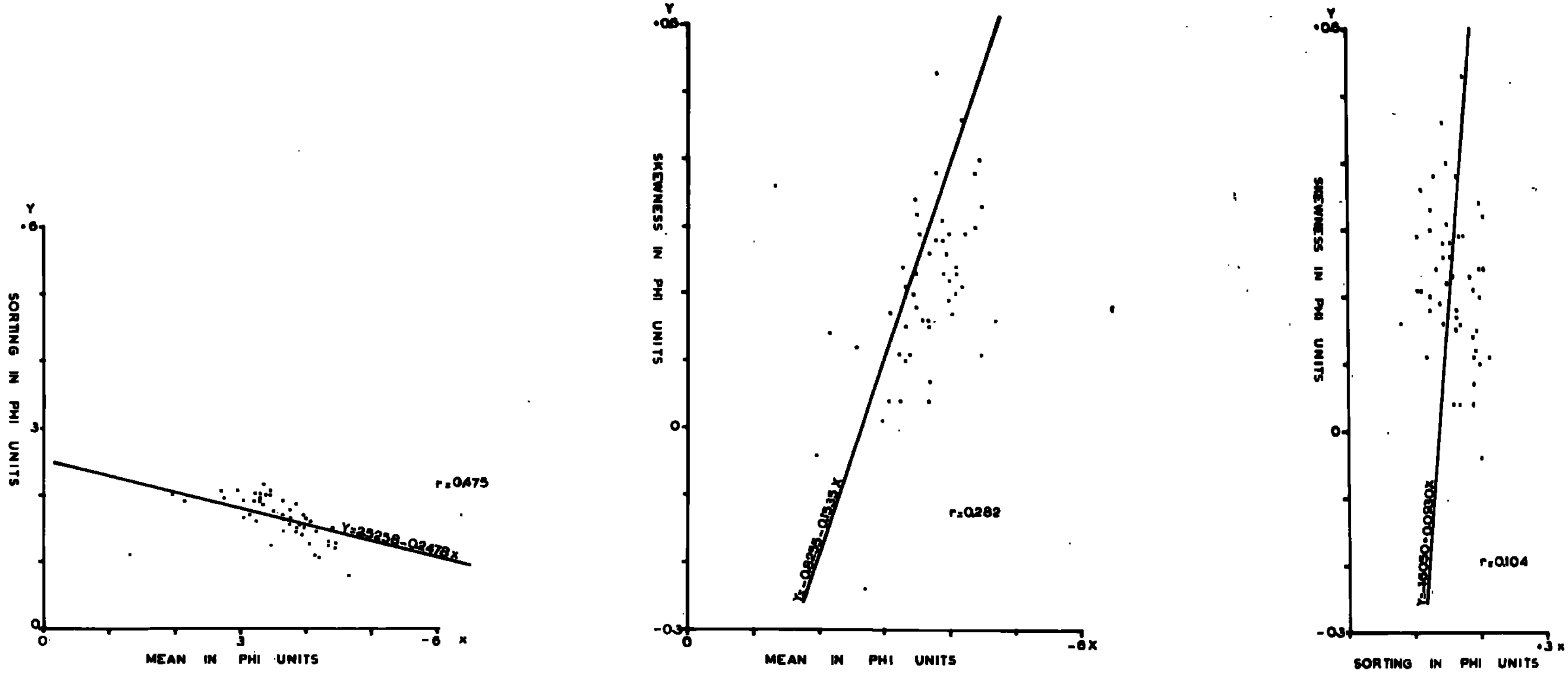


Fig. 6.3

6

significance using a student's t test (Huntsberger, D.V. 1964)

$$t = \frac{rx\sqrt{n - 2}}{\sqrt{1 - r2}}$$

r = the number of pairs of data studied, and where the degrees of freedom are n - 2.

The following results were obtained:-

1. Mean values against sorting values

   t = 3.74 - significant at 0.05% level.

2. Mean values against Skewness values

   t = 2.04 - significant at 0.05 % level.

3. Sorting values against skewness values

   t = 0.72 - not significant at 0.05% level.

It was therefore concluded that there was a significant relationship between mean size and sorting values, and between mean size and skewness values, but that no such relationship could be proved between the sorting and skewness values.

b. <u>Western tributary</u>:-

<u>Mean particle size</u>: (See Fig 6.4 and Appendix 2.B)

The histogram showing mean particle size records a range varying from - 2.0 Ø to - 5.0 Ø, with more than 36% of the observations falling between - 3.5 Ø and - 4.0 Ø and with more than 95% between - 2.5 Ø and - 4.5 Ø.

Histograms and graphs showing the distribution of the mean particle size, sorting and skewness values along the western tributary

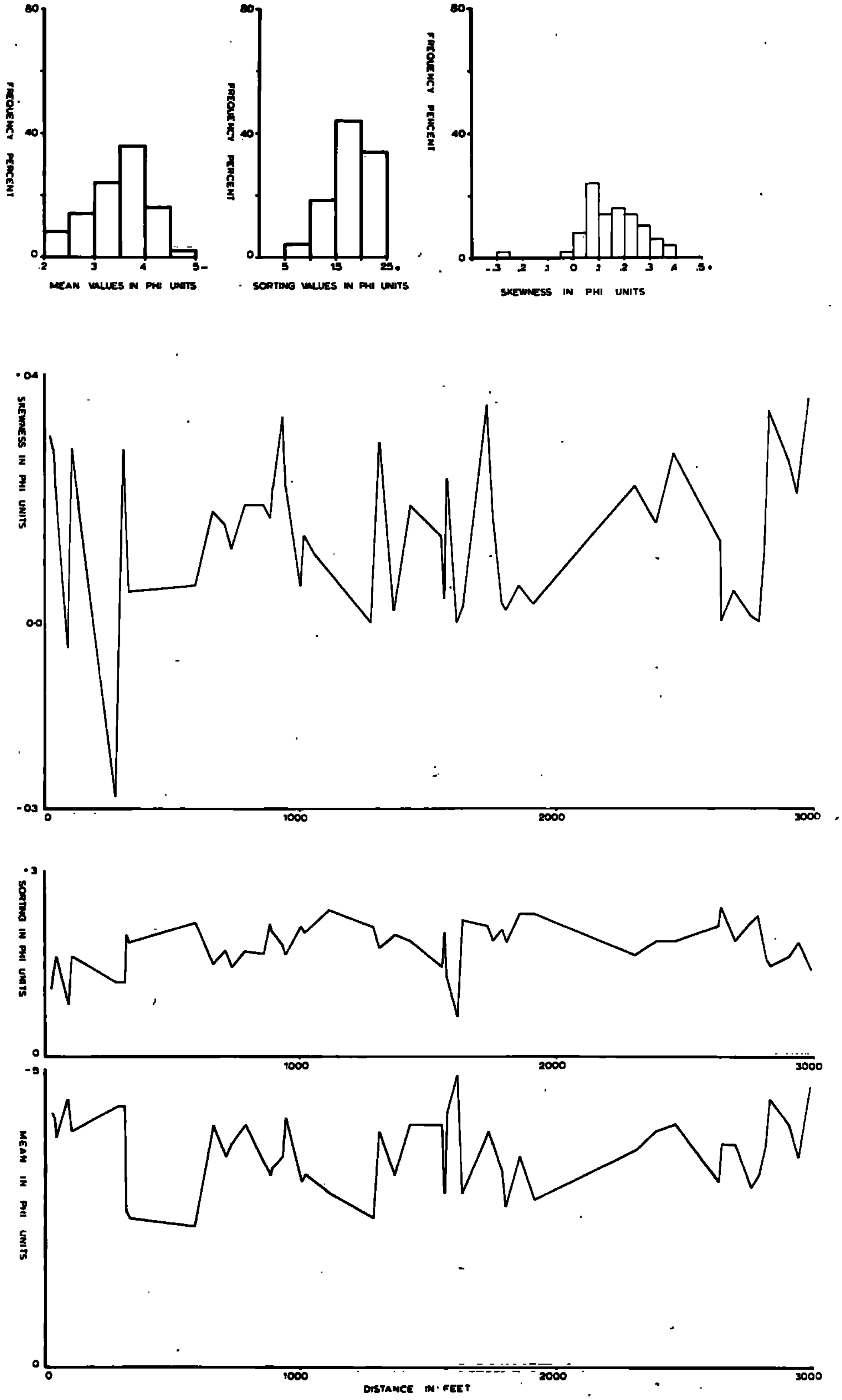


Fig. 6.4

In the graph showing changes in mean particle size along the stream course it can be seen that no marked trend is to be noted with the individual values apparently revealing random fluctions around an overall mean value, of somewhere between -3.0 to - 4.0 Ø. No obvious changes in the magnitude of the fluctuations in mean particle size were observed in this stream.

Sorting:-

The histogram showing sorting values records a range varying from + 0.5 Ø to+2.5 Ø, with more than 44% of the observations falling between +1.5 Ø and+2.0 Ø, and with 66% falling between + 0.5 Ø and + 2.0 Ø. In this distribution a marked skewness towards the higher values is to be seen.

In the graph showing changes in sorting along the stream it is seen that the sorting values increase over a short distance near the source, then remain at a relatively uniform level until just above 1,000 feet, and finally below this point show a marked decrease in values. This tendency is even more clearly marked in this stream then it was in the eastern tributary.

Skewness:-

The histogram showing the skewness values records a range from -0.30 Ø to +0.40 Ø with 98% of the readings

8

falling between 0.00 ϕ and + 0.40 ϕ, and with only 2% lying on the negative side of the histogram.

In the graph showing changes along the stream course no overall trend is to be discerned, and in this case there does not appear to be a decrease in the magnitude of the changes in a downstream direction.

In order to discover if relationships existed between mean particle size, sorting and skewness correlation and regression analysis was employed, following the plotting of these values in graphical form (Fig. 6.5). Marked relationships appeared to exist between the variables and in all three cases the correlation coefficients were higher than those obtained from the eastern tributary. All the correlation coefficients were tested using a students t test and the following results obtained:-

1. Mean values against sorting values

   t = 8.24 significant at 0.05% level.

2. Mean values against skewness values

   t = 2.91 significant at 0.05% level.

3. Sorting values against skewness values

   t = 3.62 significant at 0.05% level.

It was, therefore, concluded that significant relationships existed between mean values and sorting, Correlation and regression analysis of the statistical parameters, western tributary

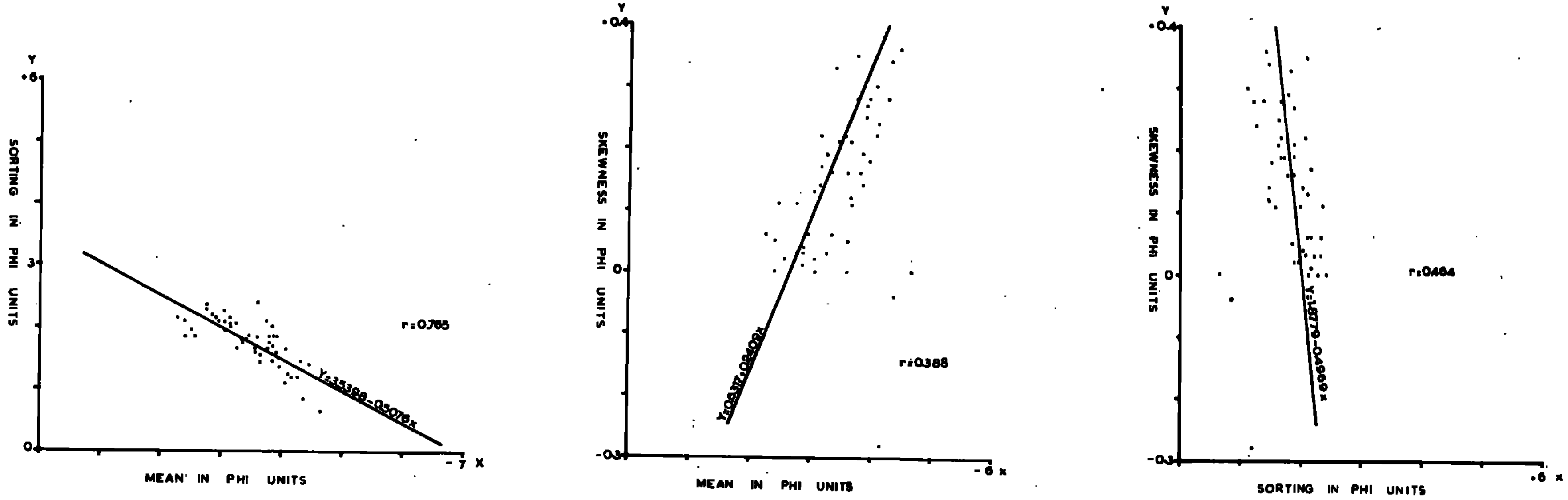


Fig. 6.5

between mean values and skewness and between sorting and skewness values.

Netherhearth Catchment:-

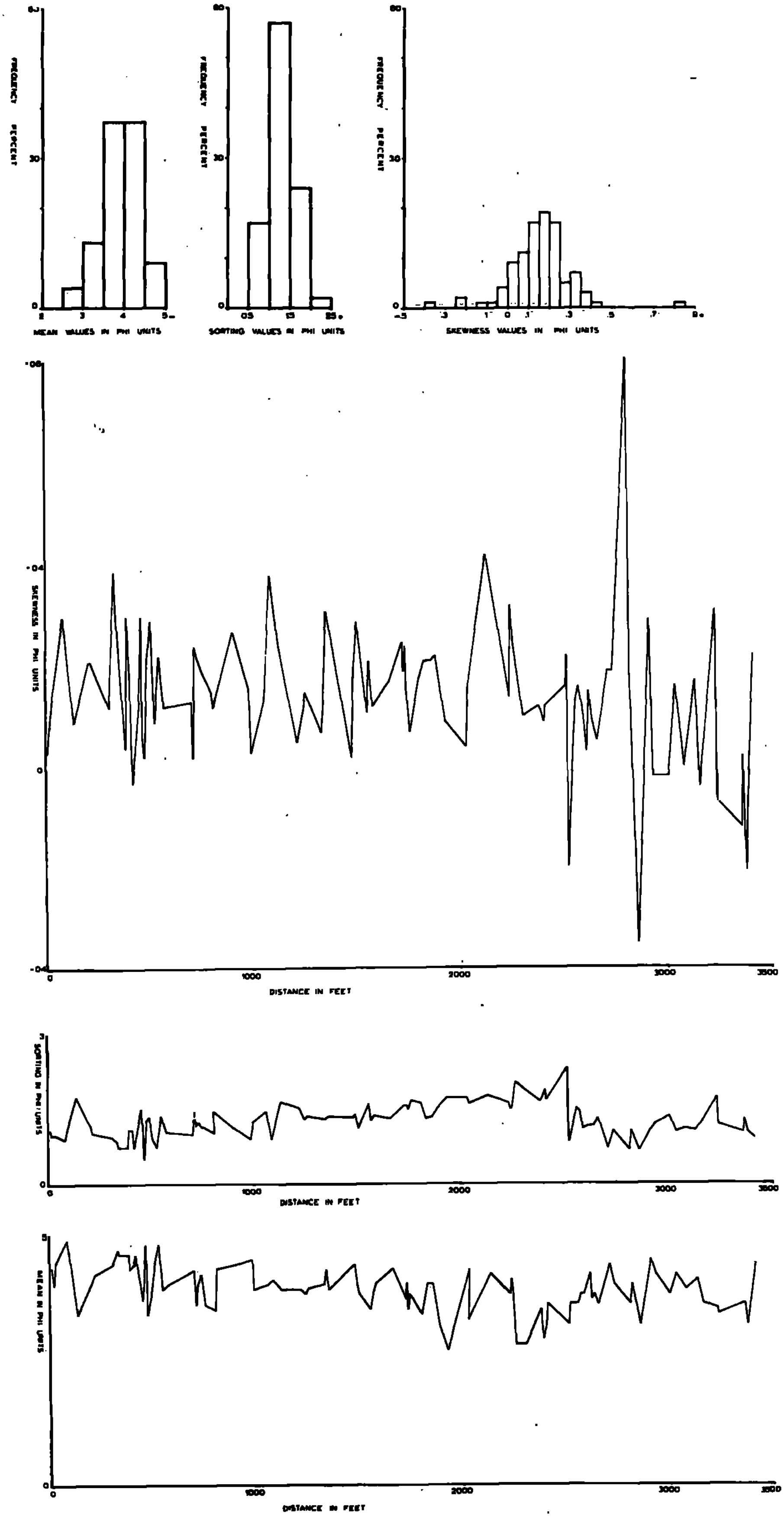
Mean particle size:- (See Fig. 6.6 and Appendix 2.C)

In the case of the Netherhearth Catchment a total of 100 samples of bottom material were used. The histogram showing mean particle size recorded a range varying from -2.0 Ø to -5.0 Ø with 74% of the observations falling between -3.5 Ø and -4.5 Ø. More than 90% of the observations fell between -3.0 Ø and -5.0 Ø.

In the graph showing changes in mean particle size along the stream it is seen that apparently random variations occur in the upper part of the stream channel, but that below 2,500 feet there is a noticeable tendency for the mean size expressed in Ø units to increase. This is somewhat strange and suggest that the mean particle size of the samples in millimetres is increasing in a downstream direction.

Sorting:-

The histogram showing sorting values records a range varying from +0.5 Ø and + 0.25 Ø with 57% of the observation falling between + 0.1 Ø and + 0.15 Ø, and with 95% falling between + 0.5 Ø and 0.2 Ø.



Histograms and graphs showing the distribution of the mean particle size, sorting and skewness values along the Netherhearth stream

Fig. 6.6

In the graph showing changes in sorting along the stream it is seen that the sorting values are relatively low in the upper part of the stream and then suddenly rise to particularly high values at a distance of 2500 feet above the starting point. Below this point the sorting values show a marked and persistent decrease indicating that the bedload becomes increasingly better sorted in a downstream direction.

<u>Skewness</u>:

The histogram showing the skewness values records a range covering from - 0.5 ø to + 0.9 ø with more than 90% of the observations falling in the positive portion of the histogram between 0.00 ø and + 0.5 ø. In the graph showing changes along the stream it is seen that negative skewness values tend to be concentrated in the uppermost reaches of the stream and that very little overall variation in the skewness occurs downstream of 2800 feet.

Analysis was also carried out to determine if there was any marked relationship between the mean, sorting and skewness values. All data were graphed and then regression lines and correlation coefficients calculated (Fig. 6.7). All the correlation coefficients were tested using a student's t test and the following results obtained.

Correlation and regression analysis of the statistical parameters, Netherhearth stream

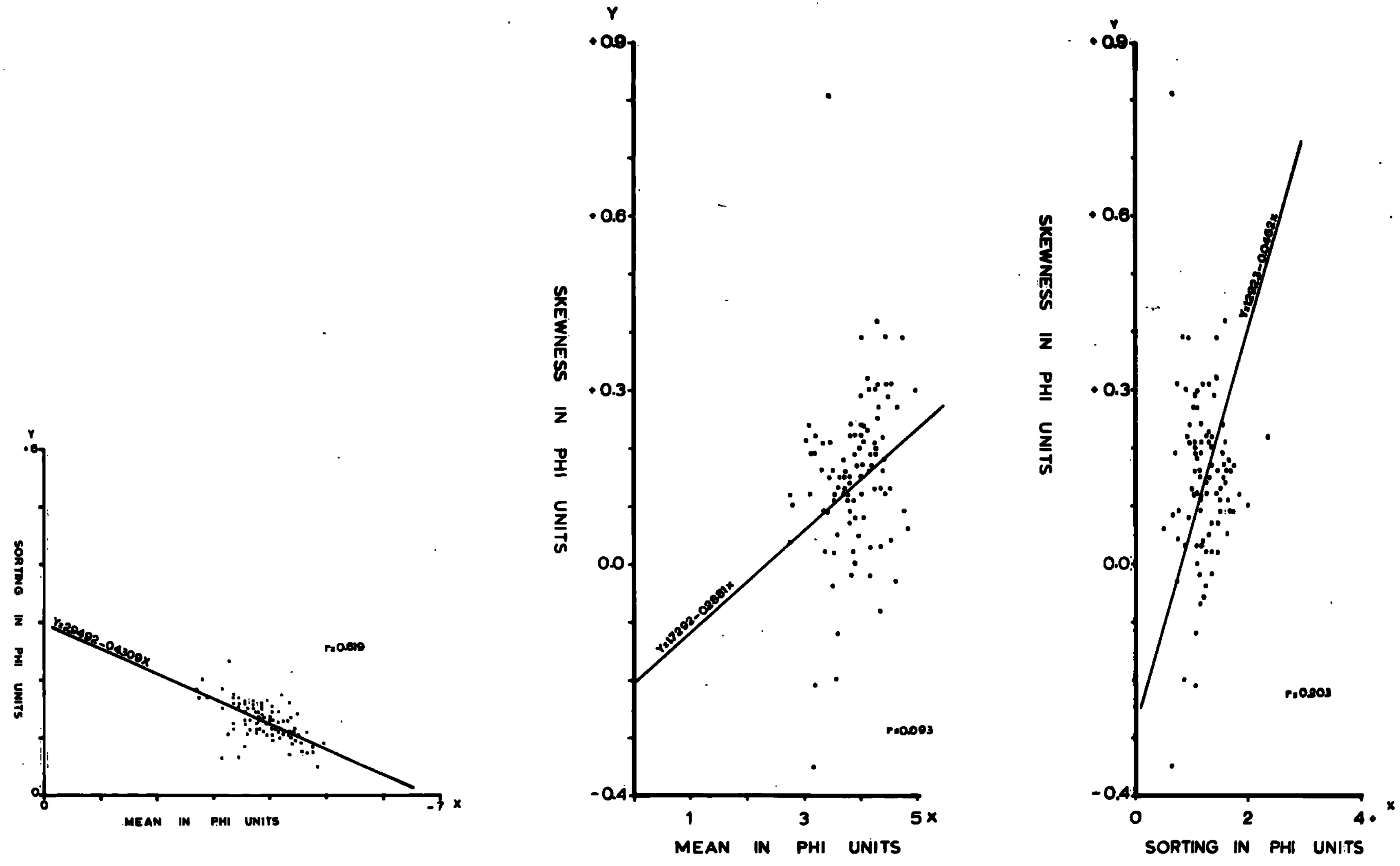


Fig. 6.7

1. Mean values against sorting values.

   t = 7.80 significant at 0.05% level.

2. Mean values against skewness values.

   t = 0.96 non-significant at 0.05% level.

3. Sorting values against skewness values.

   t = 2.05 significant at 0.05% level.

It was therefore concluded that significant relationships existed between mean values and sorting, and between sorting values and skewness values, but not between mean values and skewness values.

Stone Measurements:-

In the detailed particle size analysis of bed load samples already described only material of less than 2" in diameter was included. However in all three streams boulders with diameter commonly exceeding 2" were of common occurrence. In order to get some idea of the frequency of occurrence of these larger stones a simple sampling scheme was devised (see Chapter 5) in which all the stones with long axis of more than 2" were measured across the stream wherever a bed-load sample was obtained.

With this information it is possible to construct histograms showing the frequency of occurrence of stones of more than two inches in diameter along the three stream channels, and so make comparisons between the three small catchments.

Lanehead Catchment:-

1. Eastern Stream : (Fig 6.8)

Along this stream the largest rock encountered in the sampling procedure was 5 feet 11 inches in diameter, and in all a total of about 382 pebbles were measured. From figure 6.8 it can be seen that the vast majority (280) were less than 12 inches in diameter and only 25 were more than 3 feet in diameter.

Western Stream:- (Fig 6.9)

Along this stream the largest stone measured was 4 feet 1 inch in diameter out of a total of 411 stones. In this case most of the stones (333) were less than 12 inches in diameter and only 14 were more than 36 inches in diameter.

Netherhearth Catchment :- (Fig. 6.10)

In this Catchment the largest stone measured was 3 feet 10 inches in diameter out of a total of (923) stones. With this particular stream the relative proportions of stones less than 12 inches in diameter was even greater than in either of the two Lanehead streams (879) stones, only 9 stones were more than 36 inches in diameter.

Although the general shape of the histograms of stone sizes from the three stream channels showed marked

Histogram showing the distribution of material coarser than 2 inches measured atthe sampling points of the eastern tributary

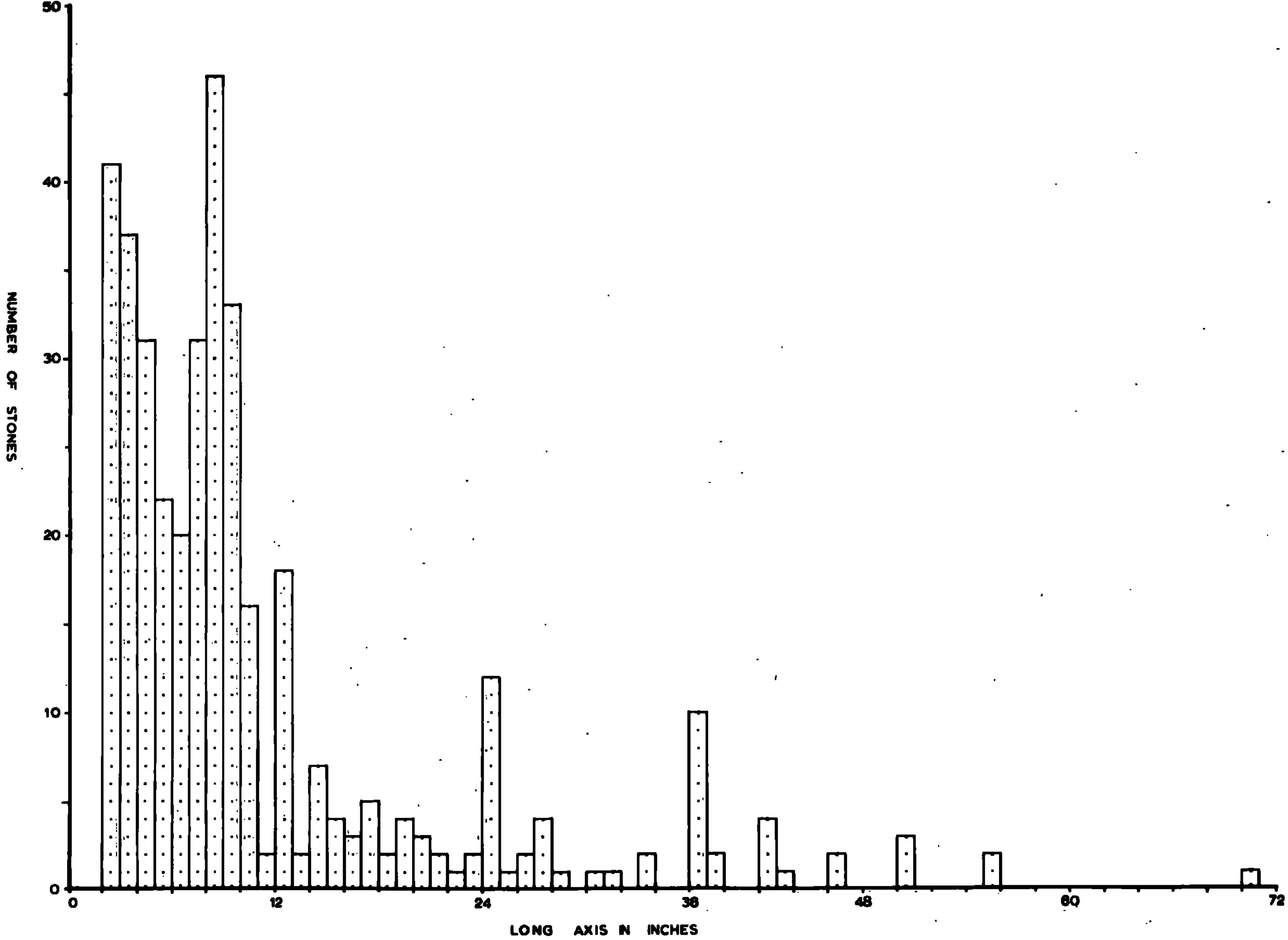


Fig. 6.8

Histogram showing the distribution of material coarser than two inches measured at the sampling points of the western tributary

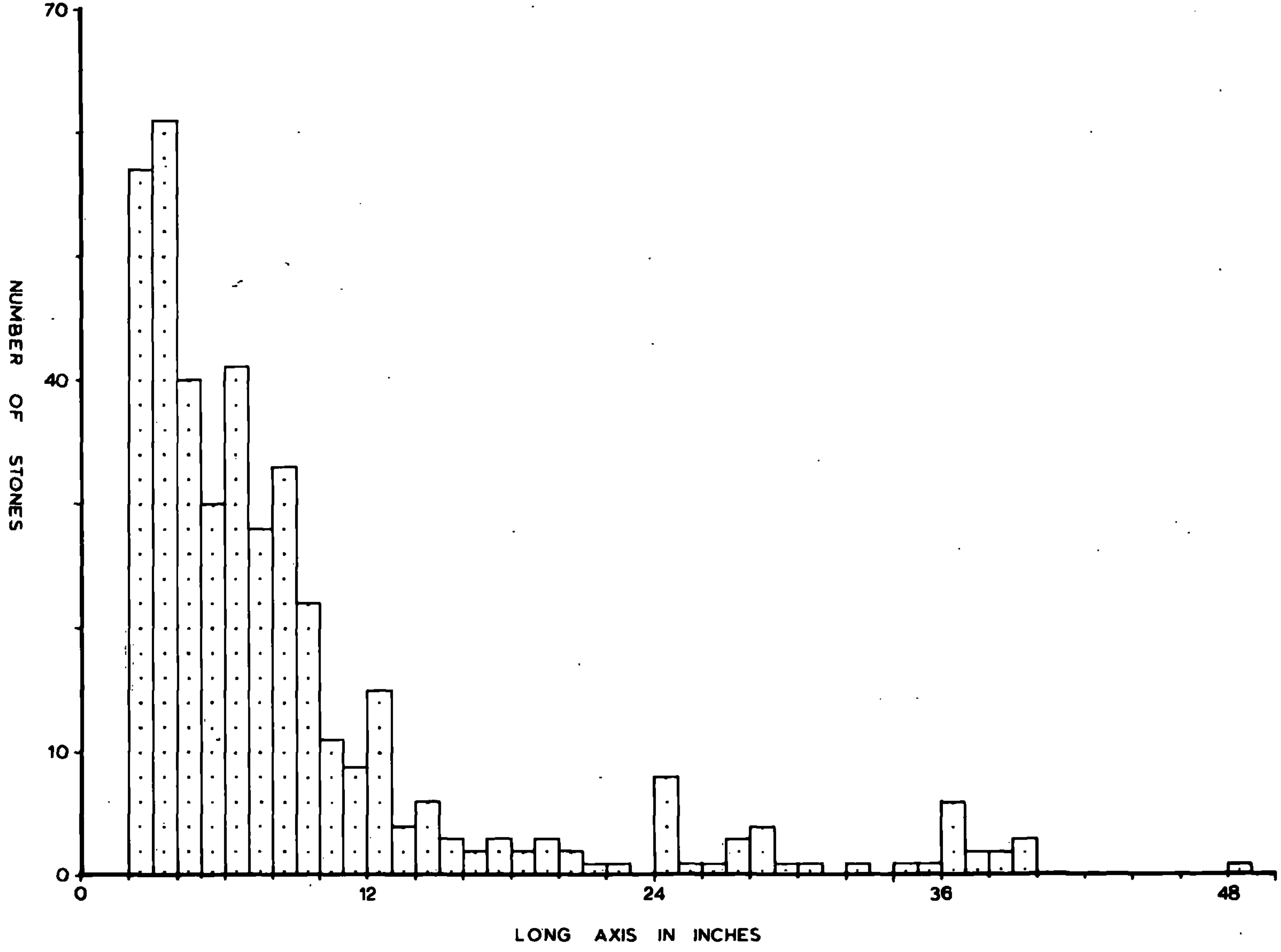


Fig. 6.9

Histogram showing the distribution of material coarser than two inches measured at the sampling points of the Netherhearth stream

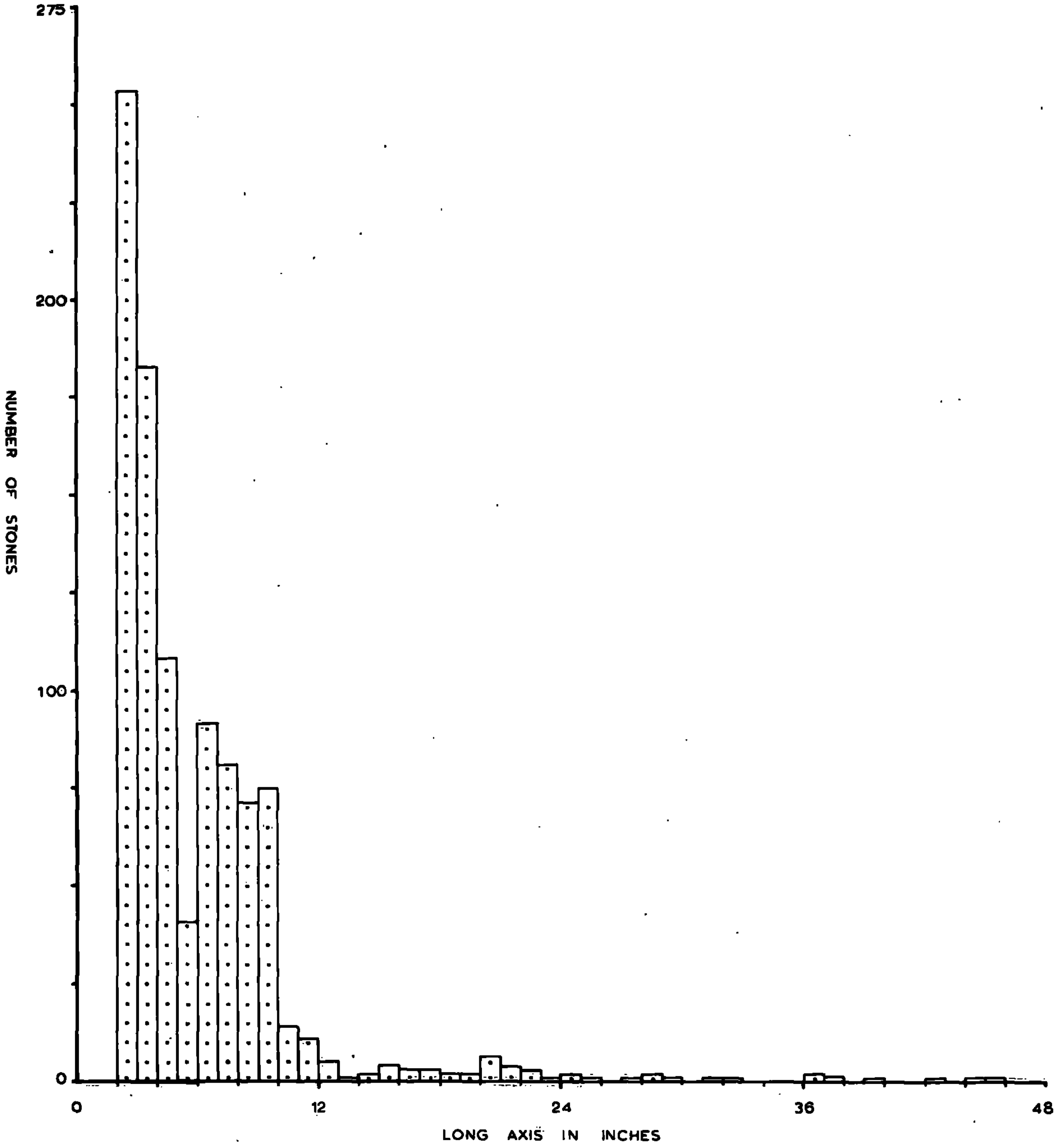


Fig. 6.10

visual similarities, it was decided that some statistical measure of the similarity or otherwise was necessary. To achieve this aim the non-parametric Kolmogorov - Smirnov test was selected. This test can be used to evaluate the hypothesis that two sample cumulative frequency distributions were drawn from a single population (Miller and Kahn, 1962). The test has several advantages. It can be used as a graphical procedure, thus reducing computations to minimum, and also a large number of samples can be tested against each other on the same plot.

The data depicted on the histograms in Figs 6.8, 6.9 and 6.10 were converted to cumulative frequency distributions in order to use the Kolmogorov - Smirnov test (see Appendix 3.A).

A null hypothesis was set up that the two sample frequency distributions of stone sizes from the streams of the Lanehead Catchment were drawn from populations having the same overall frequency distributions.

Similarly the results from the Netherhearth Catchment were compared with the results of both the east and west tributary streams at Lanehead. (For computation details see Appendix 3.B).

The results indicate that the sample cumulative frequency distributions of the three streams are statistically significantly different from each other. This is interpreted as an indication of the variability of stone sizes within the solifluction deposits from which the majority of these stones were obtained rather than owing to any differences in the transportive powers of the three streams.

Bank material samples:-

As the vast majority of the material forming the bed load of the streams in the two catchments had been derived from erosion and slumping of the stream banks rather than by erosion of the stream bed, it was decided to take samples of the banks material for particle size analysis.

The majority of the samples obtained (see Chapter 5) proved to be of unconsolidated material, chiefly solifluction deposits.

The samples were subjected to wet sieving analysis and the results tabulated and plotted in a similar manner to the bed load samples. The fine nature of many of the bank material samples made the calculation of the 16th percentiles to be impossible in many cases, and so calculations of mean, sorting and skewness values could not be attempted.

A comparison between the bank material and that along the stream channel could, therefore, be made in only a very general way.

It was therefore decided to utilise a simple visual assessment. To achieve this the results of the sample analyses of the bed material and bank material were plotted as total frequency distributions showing the percentages of gravel, sand and silt (+ clay).

Results:-

Eastern Tributary - Lanehead :-

In the case of the bed load samples from this stream channel it is seen (Fig 6.11) (see Appendix 4.A) that more than 94 percent of the samples contained 80 percent plus of gravel sized material, while in the majority of cases the samples sand content was less than 15 percent. Silt contents in all cases were less than 5 percent.

In contrast the analyses of the stream banks material indicated much more variability in the deposits. (See Fig. 6.12 and Appendix 4.D) All the gravel contents were more than 30 percent, but the majority of the samples had gravel contents of less than 70 percent. On the other hand sand and silt contents were in general considerably higher than in the case of the bed material samples. This was particularly well marked in the silt sized range where

PERCENTAGES GRAVEL, SAND, AND SILT OF THE EASTERN STREAM BED MATERIAL.

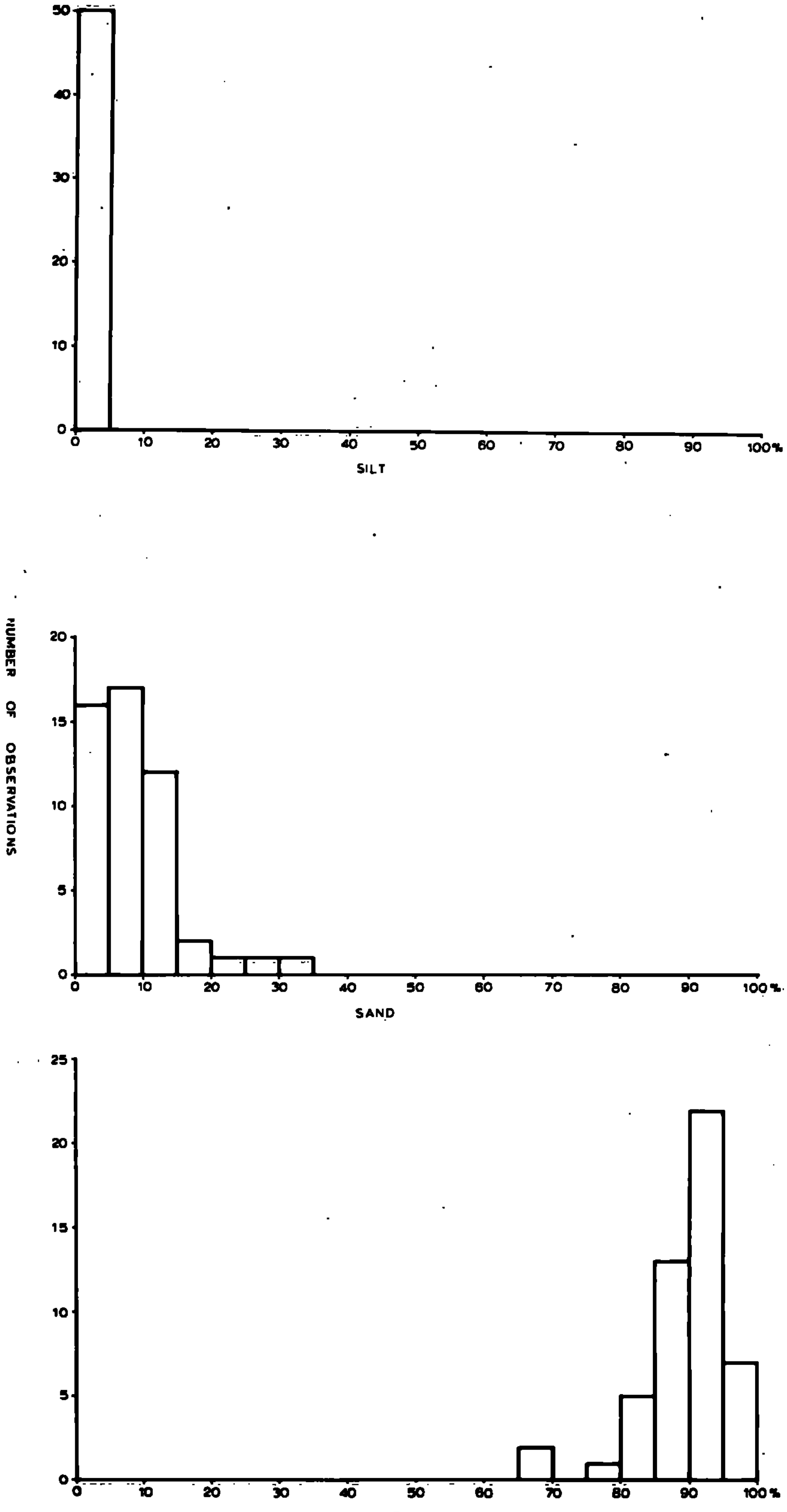


Fig. 6.11

PERCENTAGES GRAVEL, SAND, AND SILT OF THE EASTERN STREAM BANKS MATERIAL.

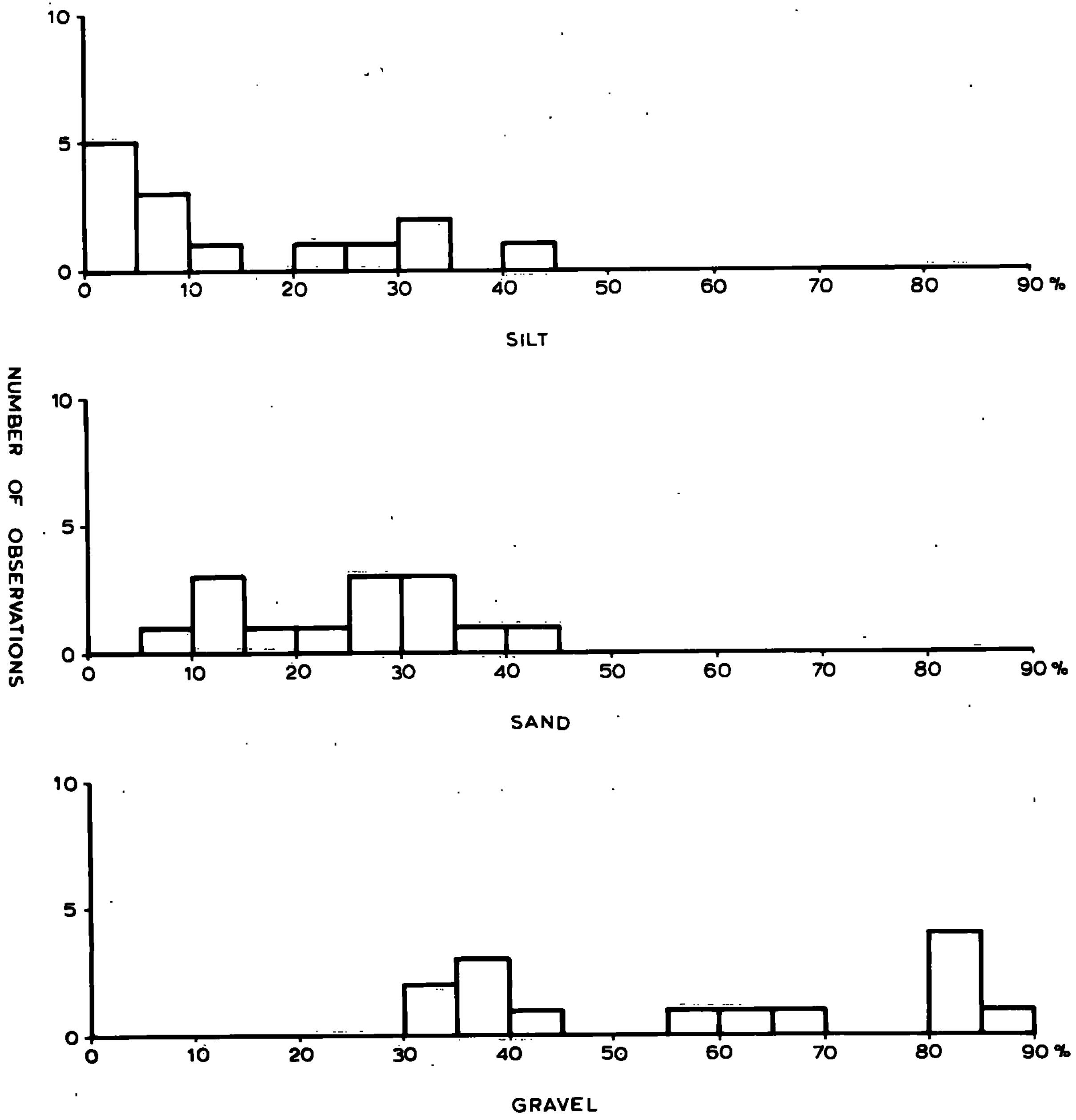


Fig. 6.12

more than 1.5 percent of the samples had silt contents of more than 5 percent, and a number of samples had silt contents of more than 30 percent.

Western Stream - Lanehead:-

Along this stream a similar pattern was noted to that along the eastern stream. Bed material samples showed high gravel contents with more than 92 percent of the samples having more than 80 percent of the total. Almost all the sand contents of the individual samples were less than 20 percent, and once more all the silt contents were less than 5 percent. (See Fig 6.13 and Appendix 4.B).

The banks material showed greater variability in its particle size distributions. Some samples had gravel contents of less than 30 percent, but none had gravel contents of more than 80 percent (See Fig 6.14 and Appendix 4.E). Sand contents varied absolutely from 15 to 70 percent although the majority of values were concentrated in the lower part of the range. Silt contents ranged from 5 to 40 percent, and along this stream section the majority of samples recorded values between 5 and 40 percent.

Nethearth Catchment:-

In this catchment exactly the same pattern as was

PERCENTAGES GRAVEL, SAND, AND SILT OF THE WESTERN STREAM BED MATERIAL.

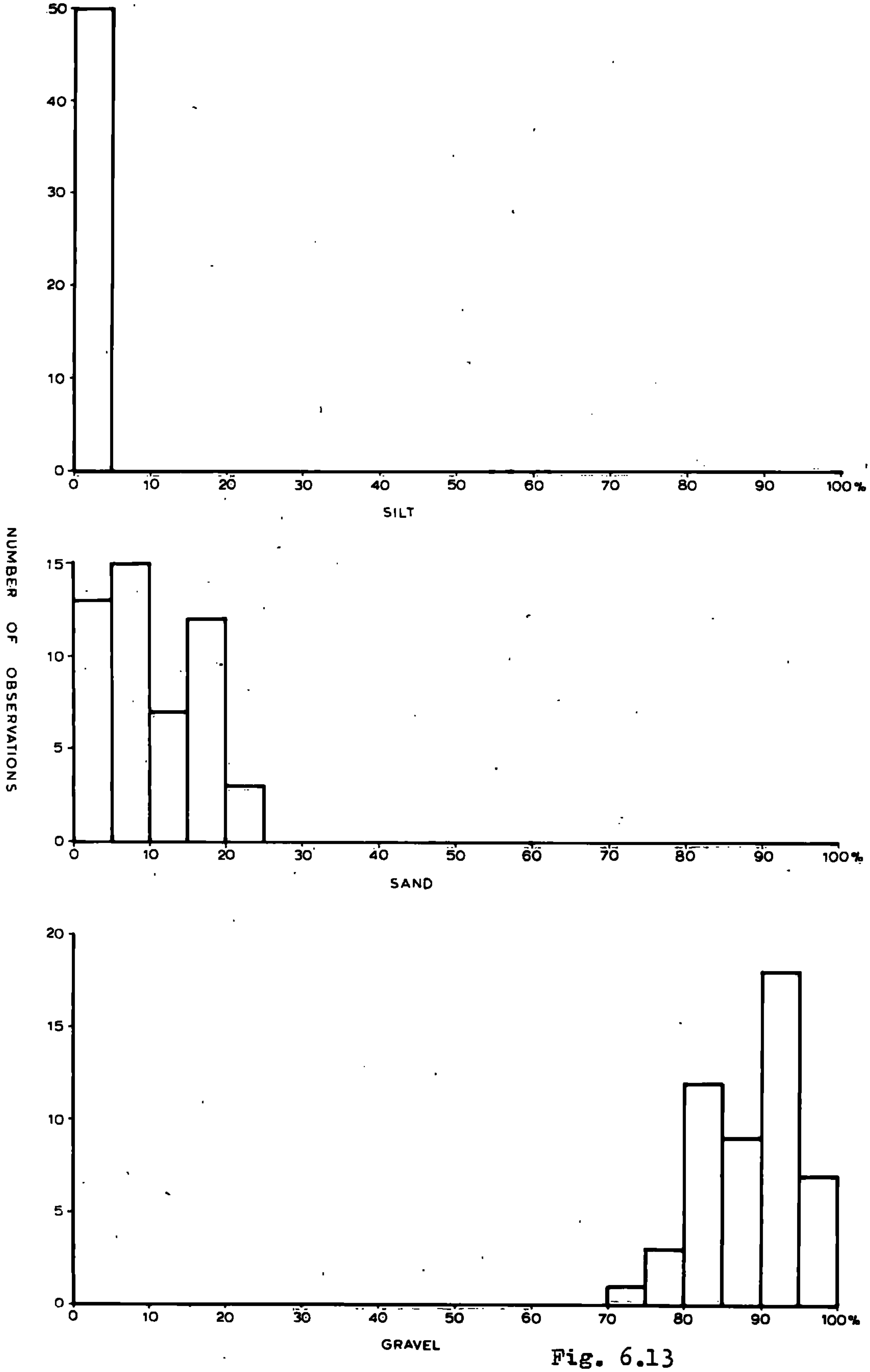
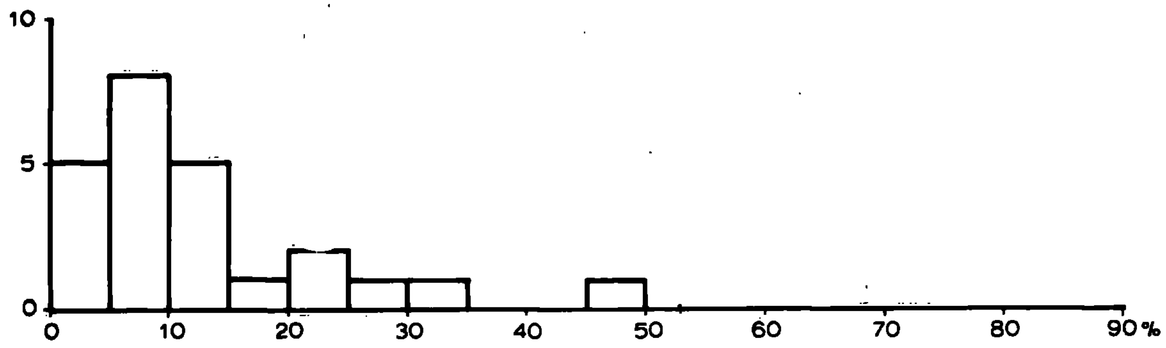
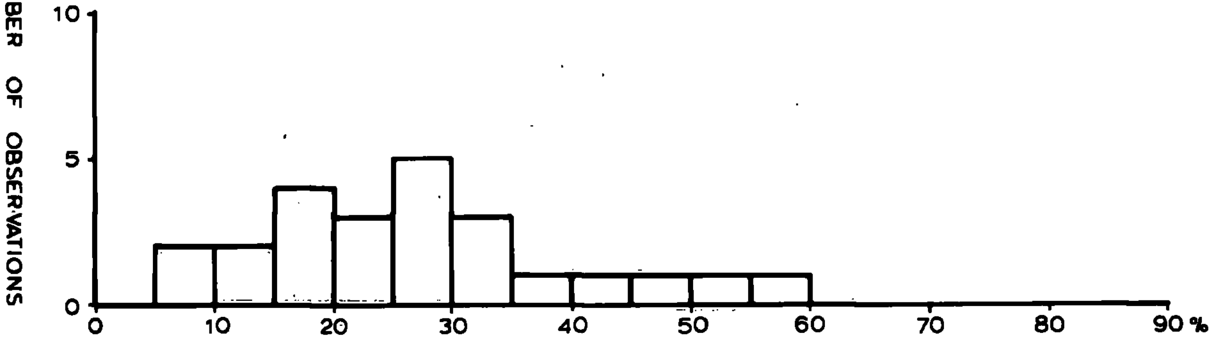


Fig. 6.13

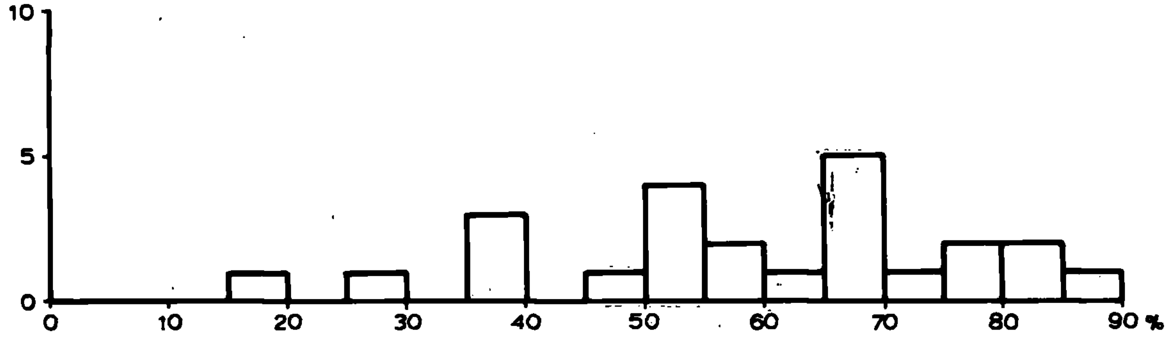
PERCENTAGES GRAVEL, SAND, AND SILT OF THE NETHERHEART BANKS MATERIAL.



SILT



SAND



GRAVEL

Fig. 6.14

observed in both the Lanehead Catchments was repeated, and owing to the larger number of samples available is more clearly seen.

In the case of the bed material, all samples analysed showed gravel contents of more than 80 percent, and sand contents less than 20 percent. Once again all the silt values were less than 5 percent. (See Fig 6.15 and also Appendix 4.C).

With the bank material samples it was again discovered that the greatest range of values was to be noted in the gravel sized material with values from 15 to 90 percent. Sand percentages ranged from 5 to 60 percent and silt percentages from 0 to 50 percent. (Fig. 6.16 and Appendix 4.F).

In both these cases the majority of observations were concentrated in the lower values.

Yet another simple method to compare the bed material samples with the bank material samples is in terms of their median diameters expressed in phi units. This is shown in (Figs. 6.17 and 6.18.).

From these figures it is immediately seen that the median values for the bed material of the three streams is very markedly concentrated with the vast majority of the values between -3 to -5 phi units.

PERCENTAGE'S GRAVEL, SAND, AND SILT OF THE NETHERHEARTY BED MATERIAL.

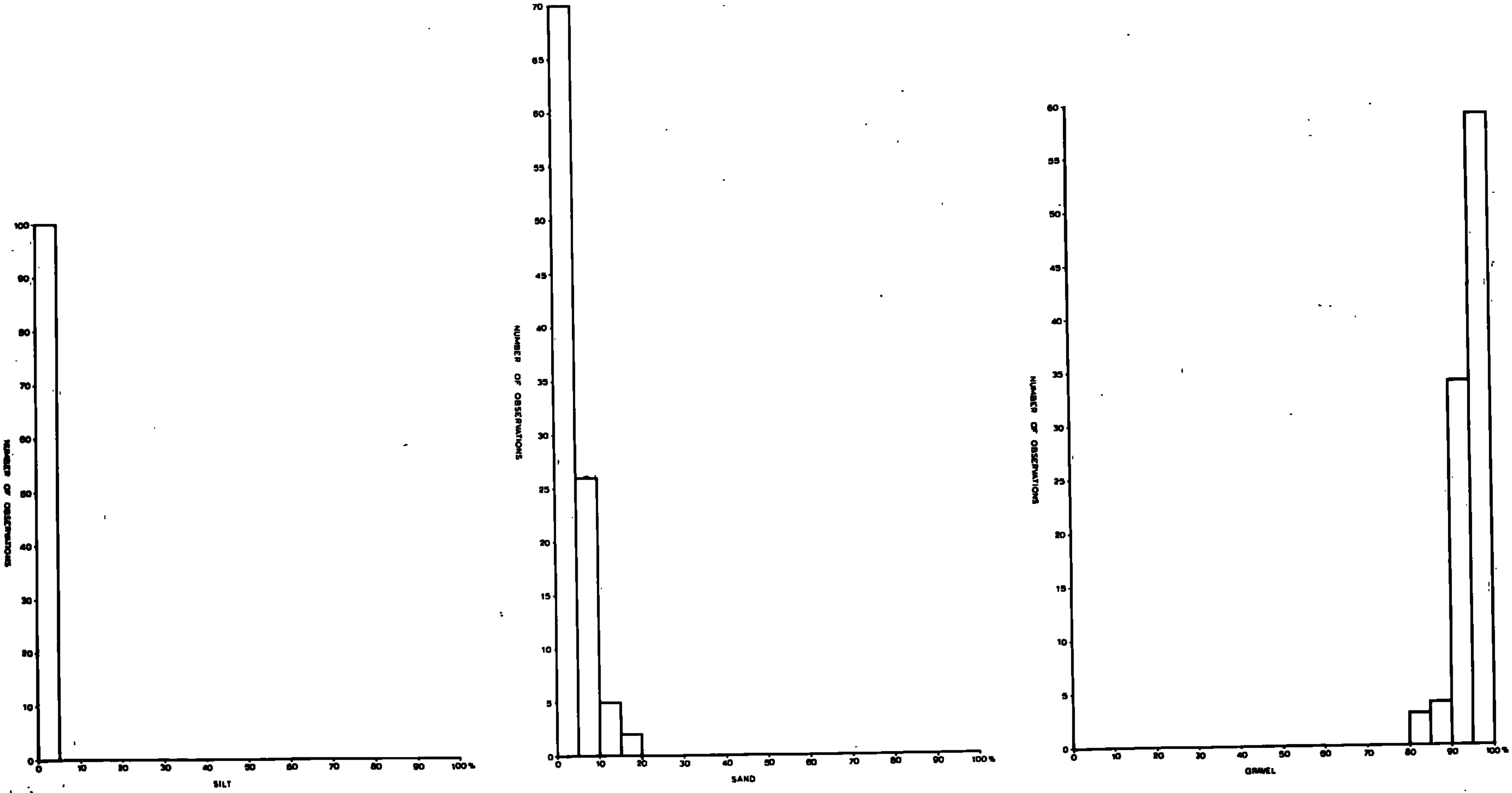


Fig. 6.15

PERCENTAGES GRAVEL, SAND, AND SILT OF THE WESTERN STREAM BANKS MATERIAL.

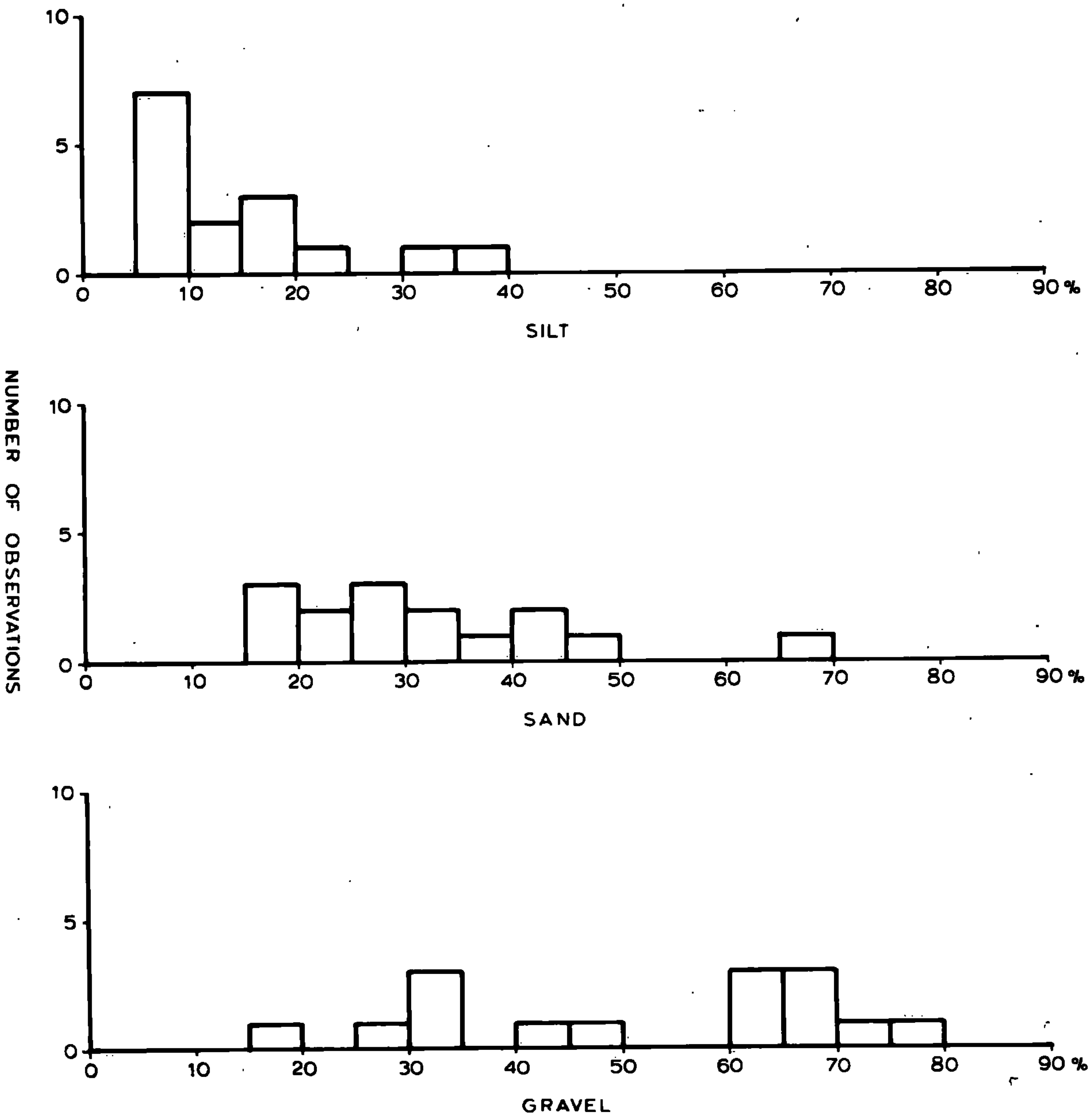


Fig. 6.16

HISTOGRAMS SHOWING MEDIAN VALUES OF THE BED MATERIAL IN THE NETHERHEARTH AND LANEHEAD CATCHMENTS

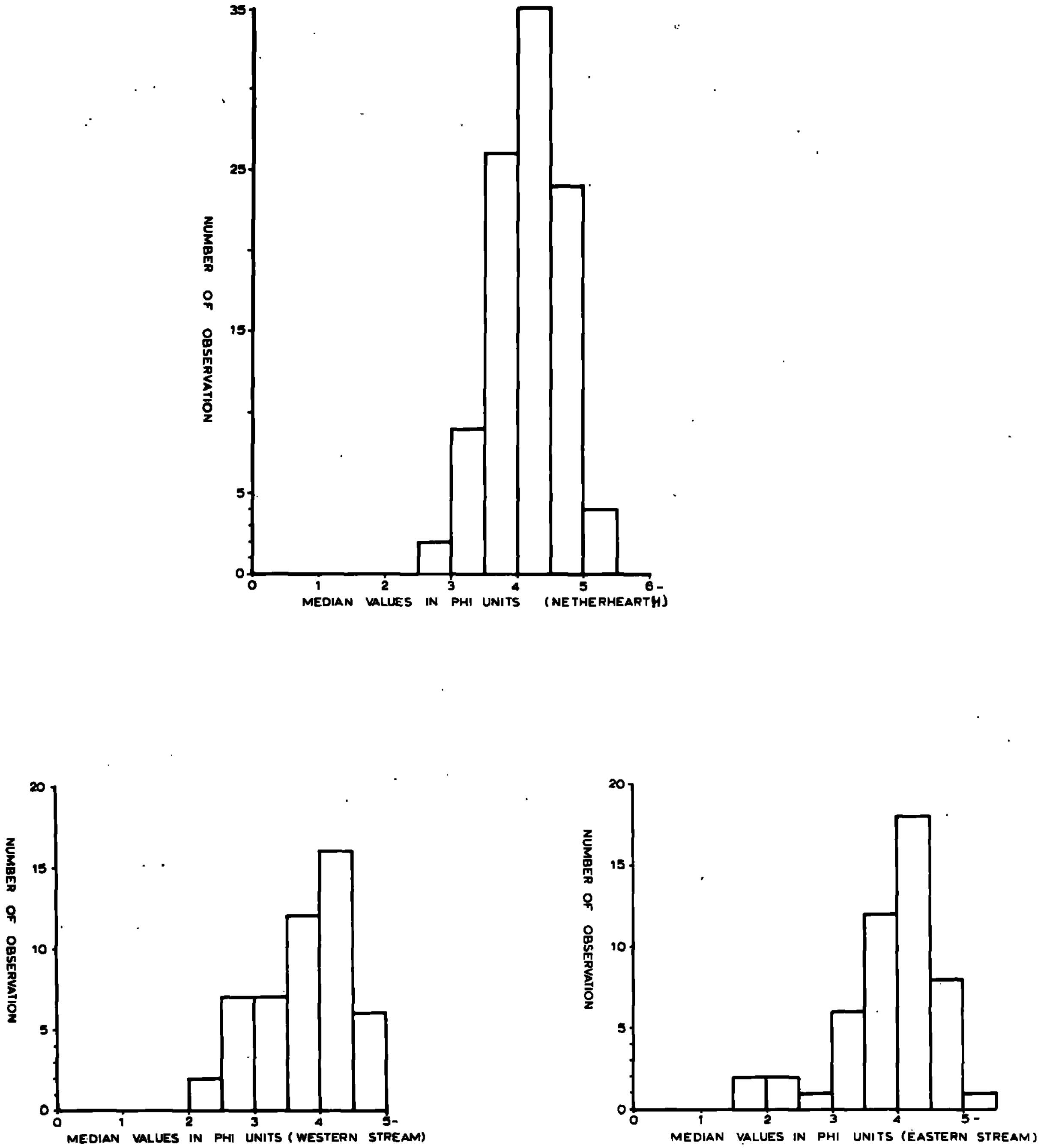
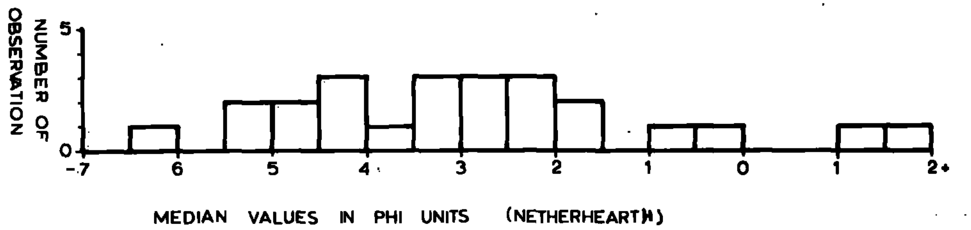


Fig. 6.17



HISTOGRAMS SHOWING MEDIAN VALUES OF THE BANKS MATERIAL IN THE NETHERHEARTH AND LANEHEAD CATCHMENT AREAS

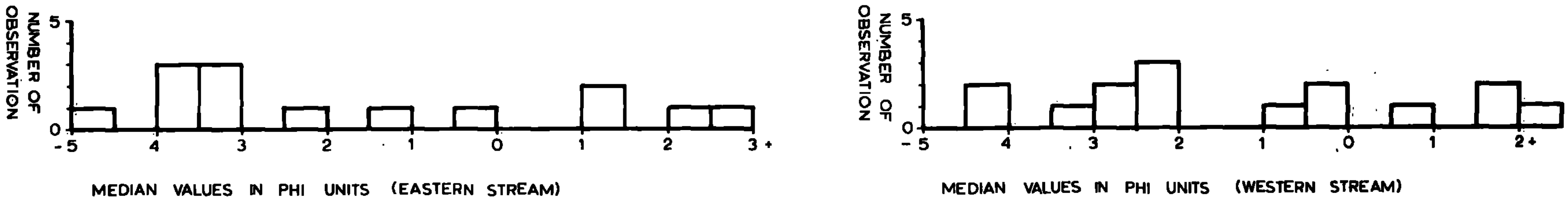


Fig. 6.18

8

These comparisons between the bed material samples and the bank material samples of the three streams clearly indicate the differences between the two sample types.

With the bank material samples one is dealing with deposits varying from solid rock to peat, but mostly composed of solifluction debris possessing often sizeable proportions of finer grained material within the sand and silt size ranges.

In contrast with the bed material samples one is dealing with a much more uniform deposit, which shows evidence of having been sorted to a large degree, and which possesses a much coarser average particle size with the dominance of gravel sized material.

From this one is led to conclude that under present day environmental conditions the relatively fine grained bank material once it is eroded and falls into the stream is rapidly sorted by water action.

The result of this is that the smaller sized material, chiefly the silt (+ clay) and the finer grained sand is completely removed from the deposit, possibly in suspension to leave a bed load composed of coarser sand and gravel which moves more slowly downstream by the combined processes of saltation and traction.

Chapter 7

Stone Counts Analysis

In order to gain some information concerning the lithologies of the material making up the stream bed and banks deposits simple stone counts were attempted. Material which remained on the ½ inch, ⅜ inch and ¼ inch sieves after analysis formed the sample particles, and these were identified into three main groupings sandstone (SST); shale (Sh) and Limestone (LST). The results were calculated as percentages for each sample, and were plotted for illustration in a series of bar graphs.

Lanehead Catchment

Eastern Tributary

a. Bed material (Fig 7.1 Appendix 5.A).

These samples were characterised by high percentages of sandstone and shale, and the virtual absence of limestone.

In the upper part of the stream section shale tended to be the dominant lithology. Downstream however the shale percentages of the samples decreased while those of sandstone tended to increase. Limestone percentages varied from 0 percent to 31 percent close to an outcrop of limestone in the stream bed. They did not however

Bar graphs showing the percentages of the main lithological types of the eastern tributary bed material

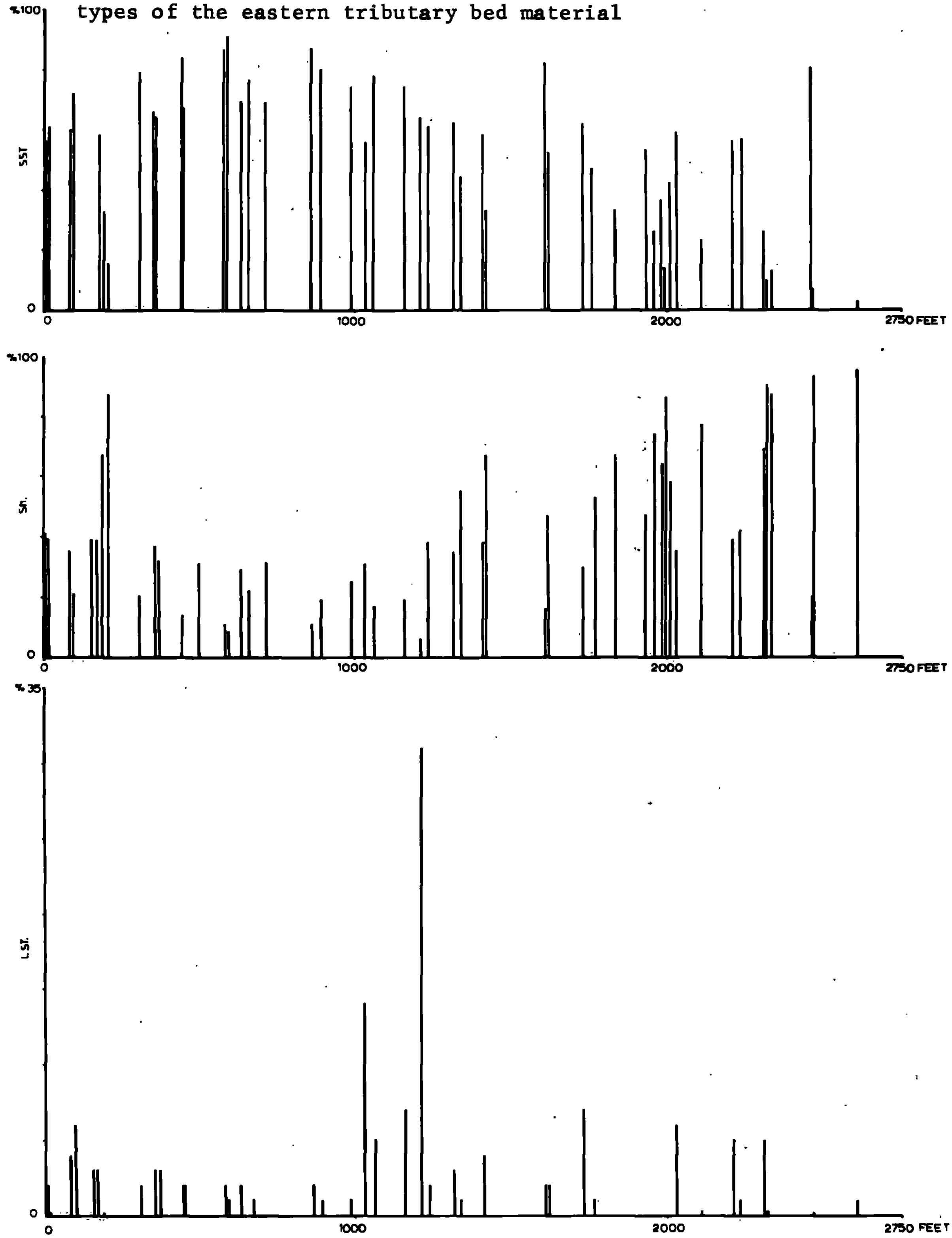


Fig. 7.1

show any trend in a downstream direction.

b. Bank Material (Fig. 7.2 Appendix 5.B).

These samples were characterised by extremely high percentages of sandstone commonly over 80 percent, and relatively low percentages of shale (with all values less than 25 percent).

Limestone percentages were always low (less than 10 percent), and in a number of samples no limestone at all was present.

These results suggest that the higher values of limestone and shale in the bed material are due to present day stream erosion of these rock types rather than mere incorporation of soliflucted debris.

Western Tributary

a. Bed Material (Fig 7.3 Appendix 5.C)'

The samples taken from the stream showed relatively uniform percentages of sandstone varying mostly from 50 - 80 percent and of shale varying mostly from 20 to 60 percent. Limestone values were always less than 5 percent, and the vast majority were less than 1 percent. No overall trend in the lithologies was discernible along the stream.

b. Bank Material (Fig 7.4 Appendix 5.D).

In contrast to the eastern tributary these samples were characterised by highly variable sandstone and

Bar graphs showing the percentages of the main lithological types of the eastern tributary bank material

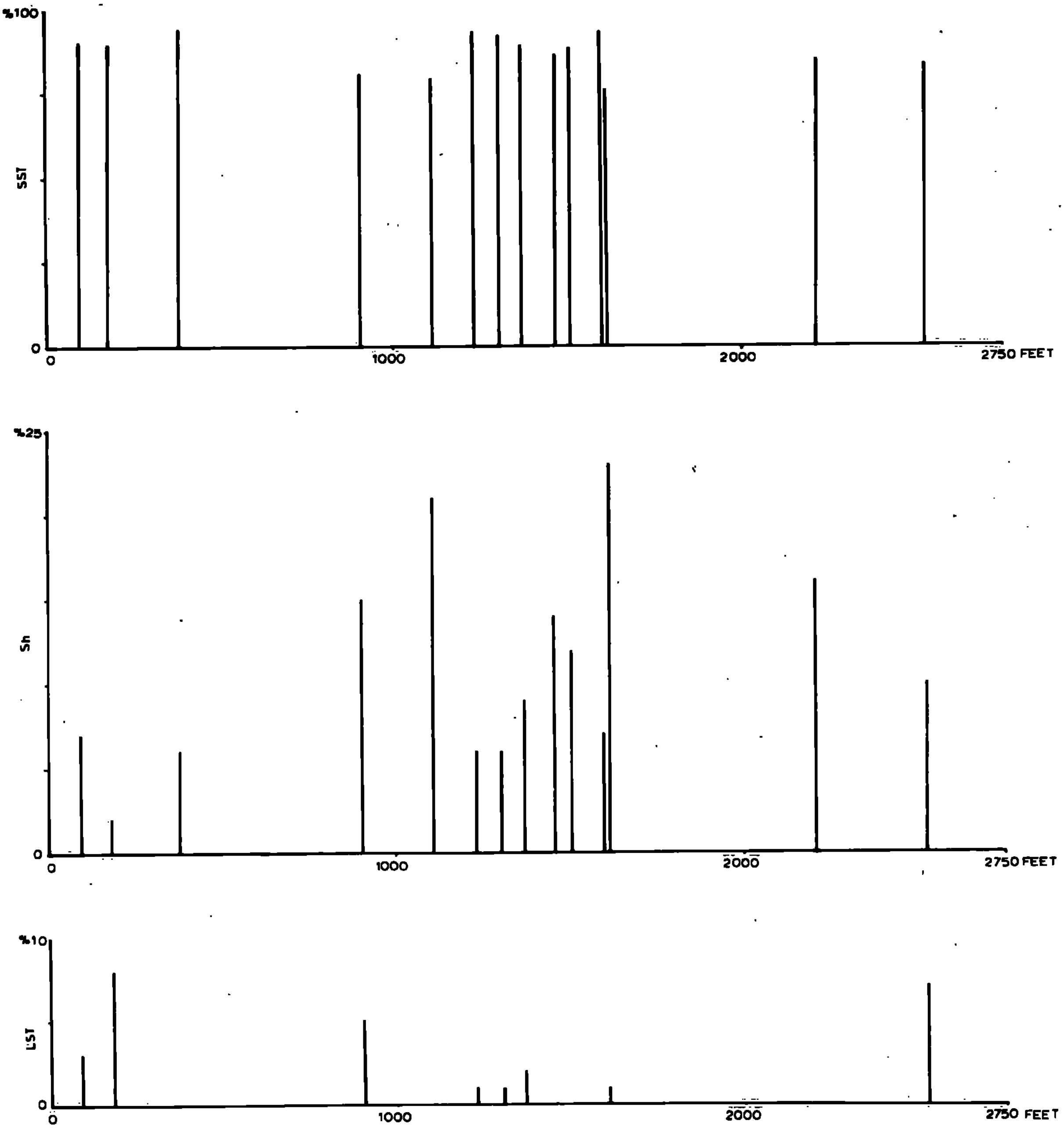


Fig. 7.2

Bar graphs showing the percentages of the main lithological types of the western tributary bed material

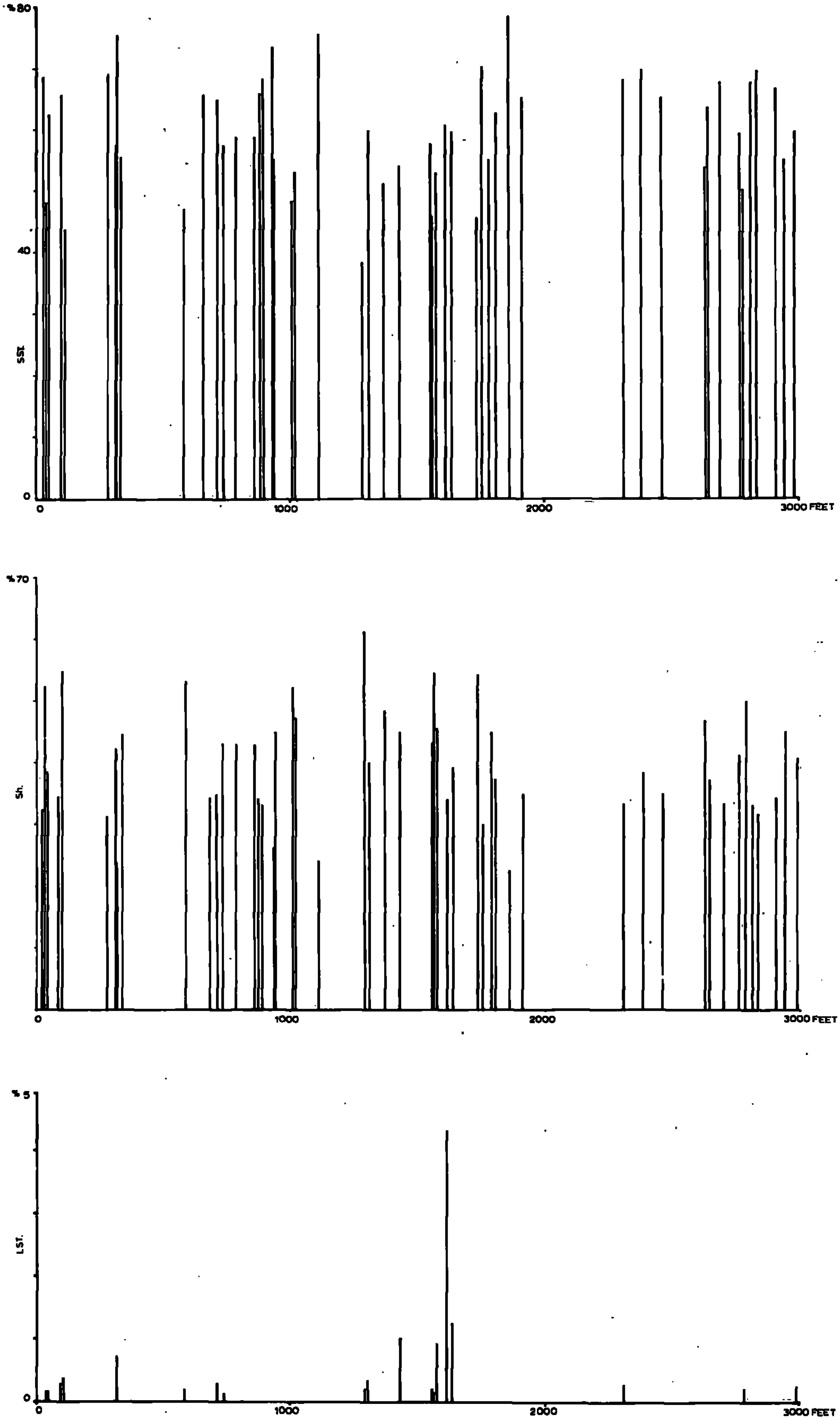
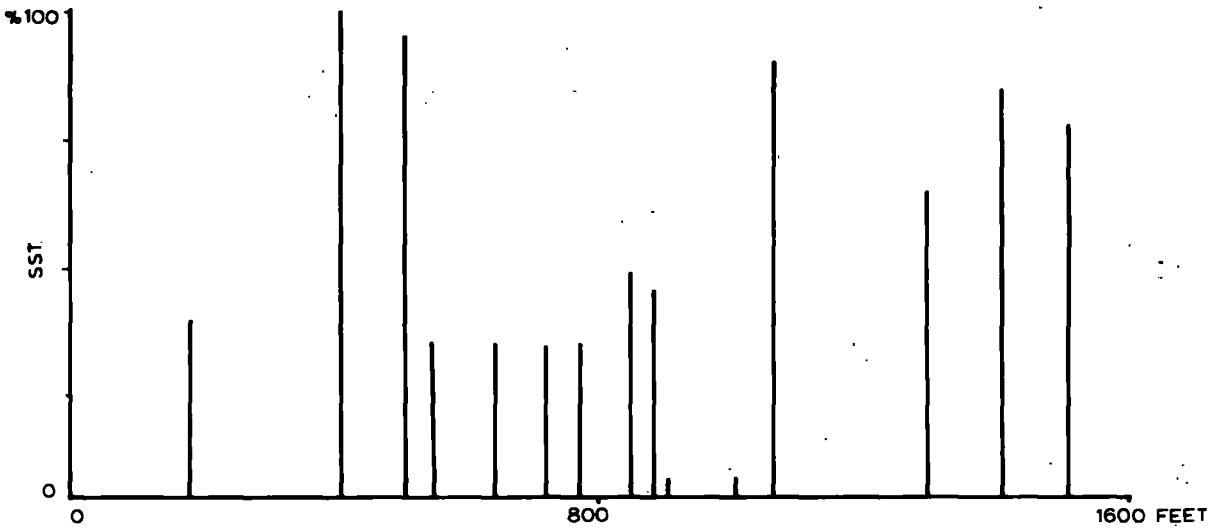


Fig. 7.3

Bar graphs showing the percentages of the main lithological types of the western tributary bank material



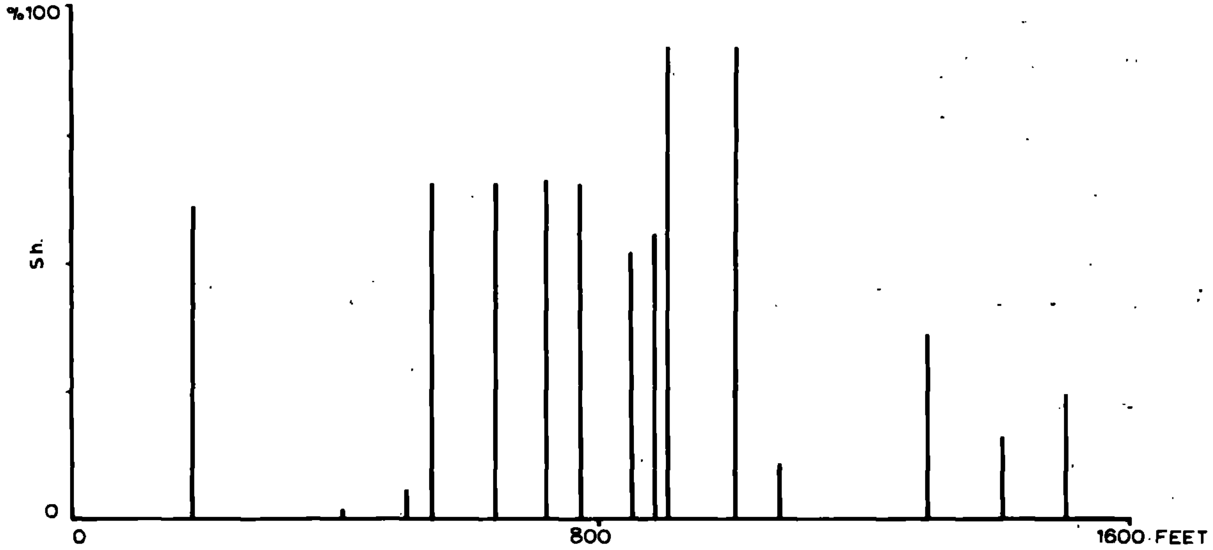


Fig. 7.4

shale percentages, and the complete absence of any limestone. No overall trends were observed along the stream course.

Netherhearth Catchment

a. Bed Material (Fig. 7.5, Appendix 5.E).

The pebble lithologies in the Netherhearth Catchment were, as in Lanehead dominated by high sandstone percentages, moderate shale percentages, and very low limestone percentages.

Sandstone values varied from 45 to 95 percent, and reaching their greatest concentrations at about 500 feet above the initial sampling point. Shale values varied from 10 to 55 percent with the lowest values coinciding with the highest sandstone figures. Limestone percentages were exceptionally low throughout the stream's length. Many samples contained no limestone at all and the highest recorded value was less than 1.5 percent.

b. Bank Material (Fig. 7.6, Appendix 5.F).

The samples of bank material were dominated by very high sandstone values, in many cases of more than 90 percent, and correspondingly low values of shale content. Limestone values were everywhere low and in all cases less than 1 percent of the total sample.

Bar graphs showing the percentages of the main lithological types of the Netherhearth bed material

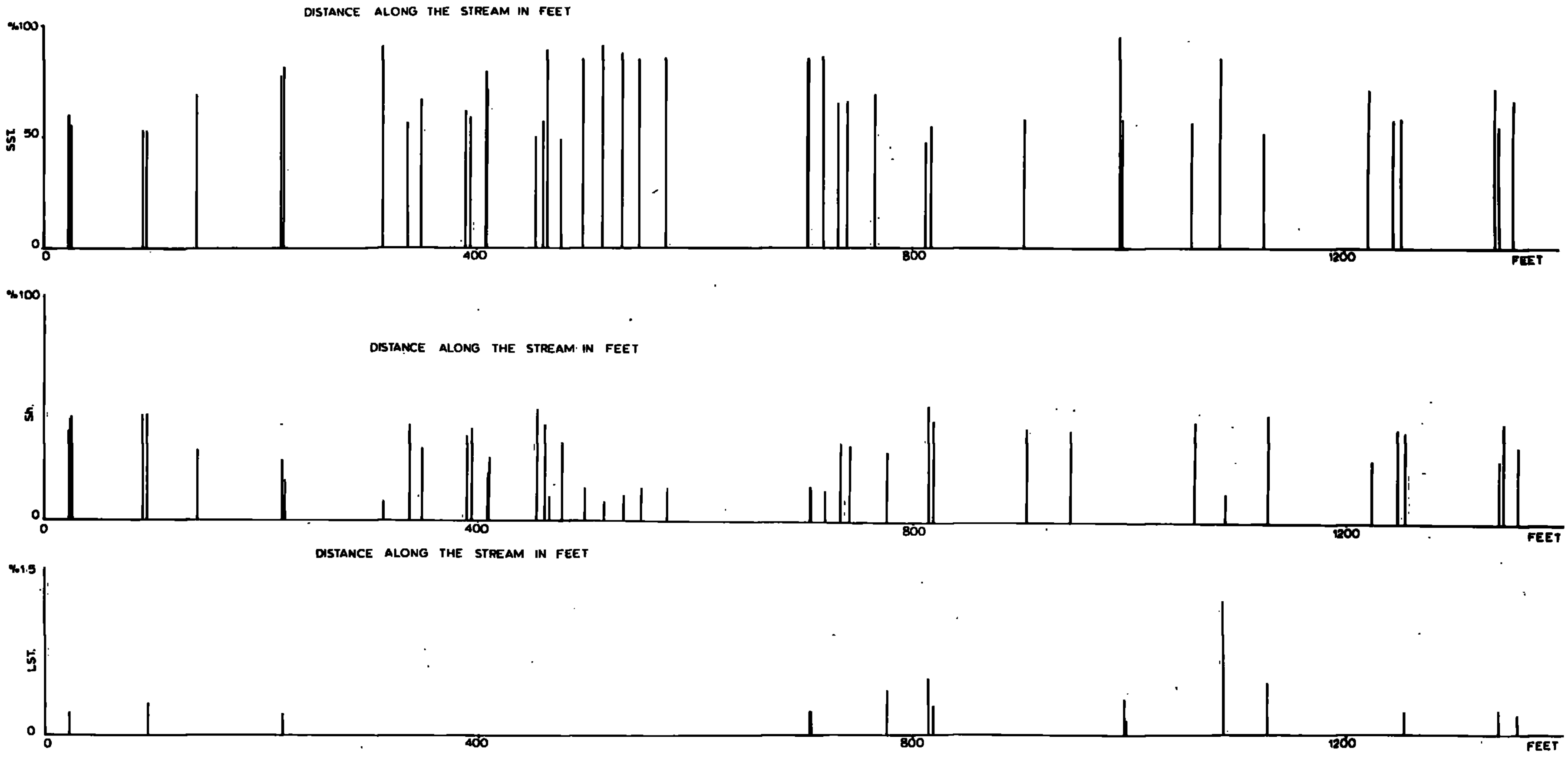


Fig. 7.5

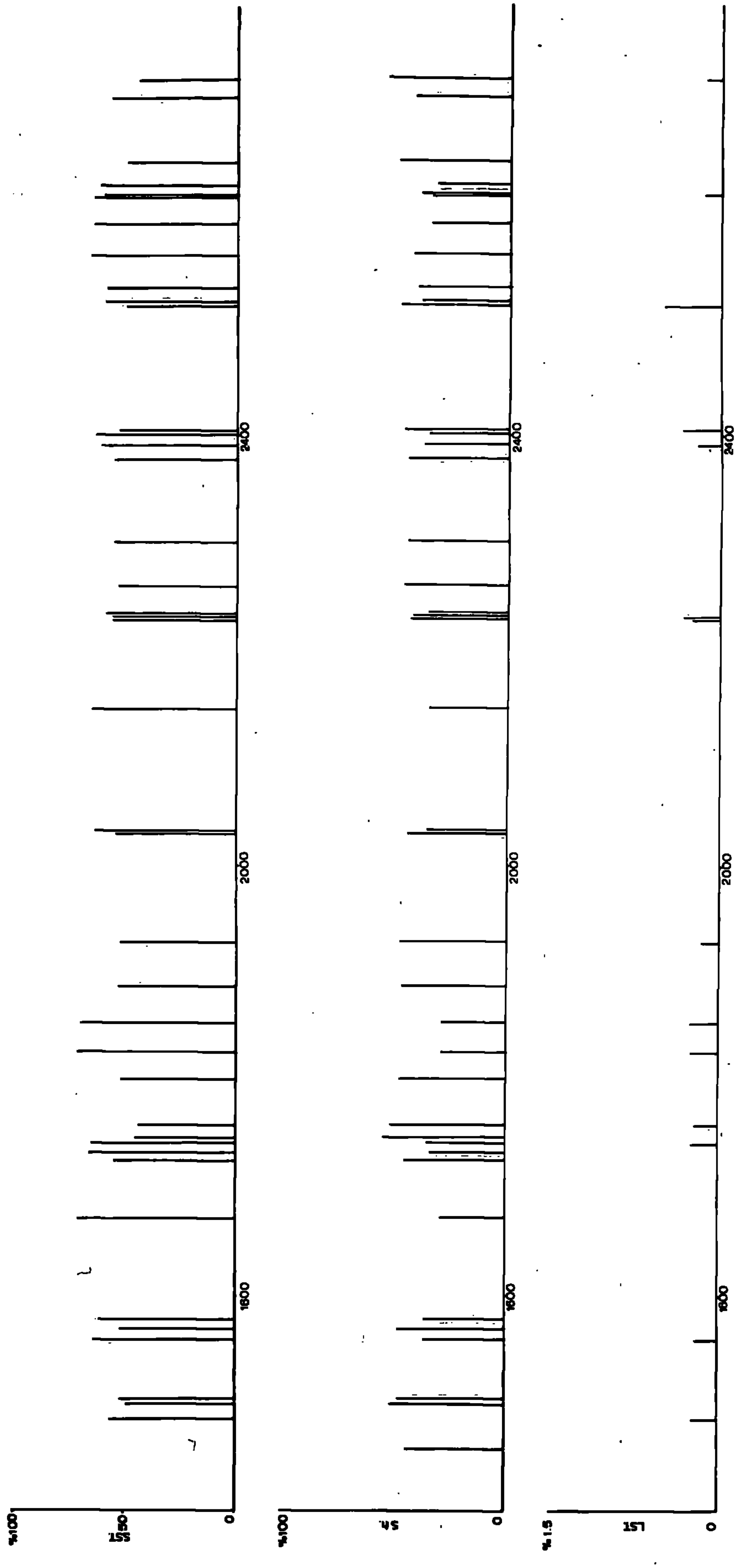

%100
155
0
1600
2000
2400
%100
45
0
1600
2000
2400
%1.5
157
0
1600
2000
2400

Fig. 7.5

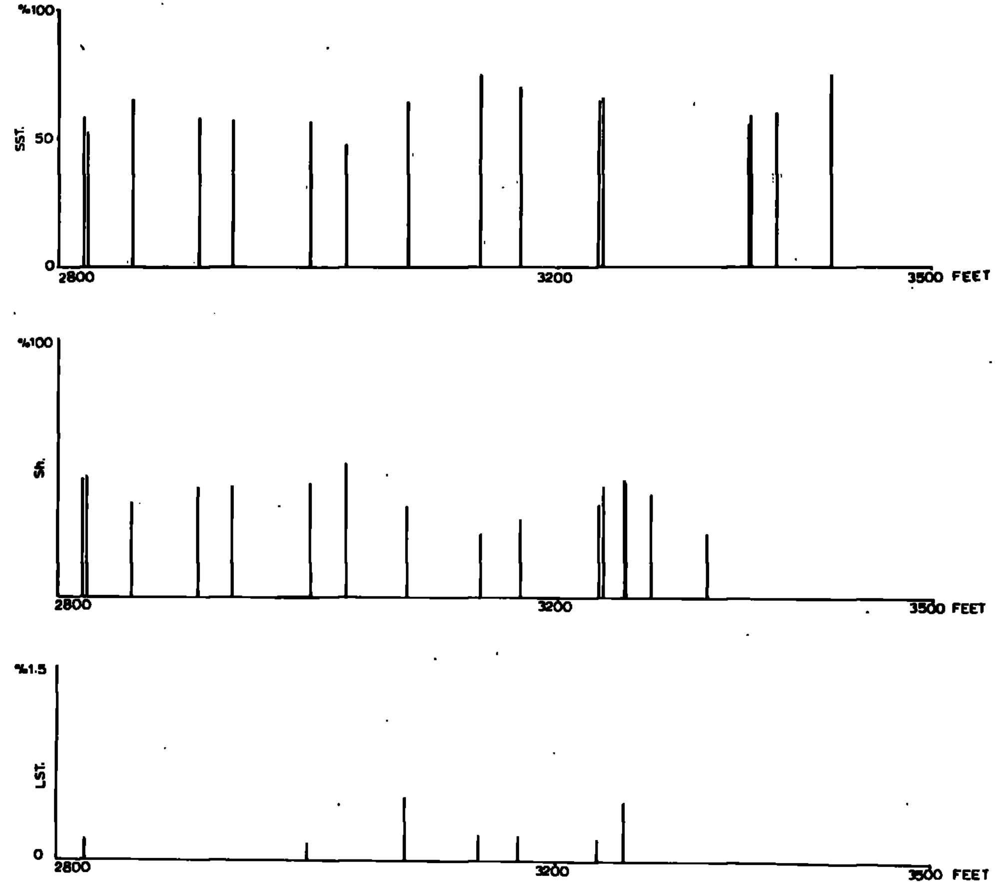

%100
50
0
SST.
2800
3200
3500 FEET
%100
Sh.
2800
3200
3500 FEET
%1.5
LST.
0
2800
3200
3500 FEET

Fig. 7.5

Bar graphs showing the percentages of the main lithological types of the Netherhearth bank material

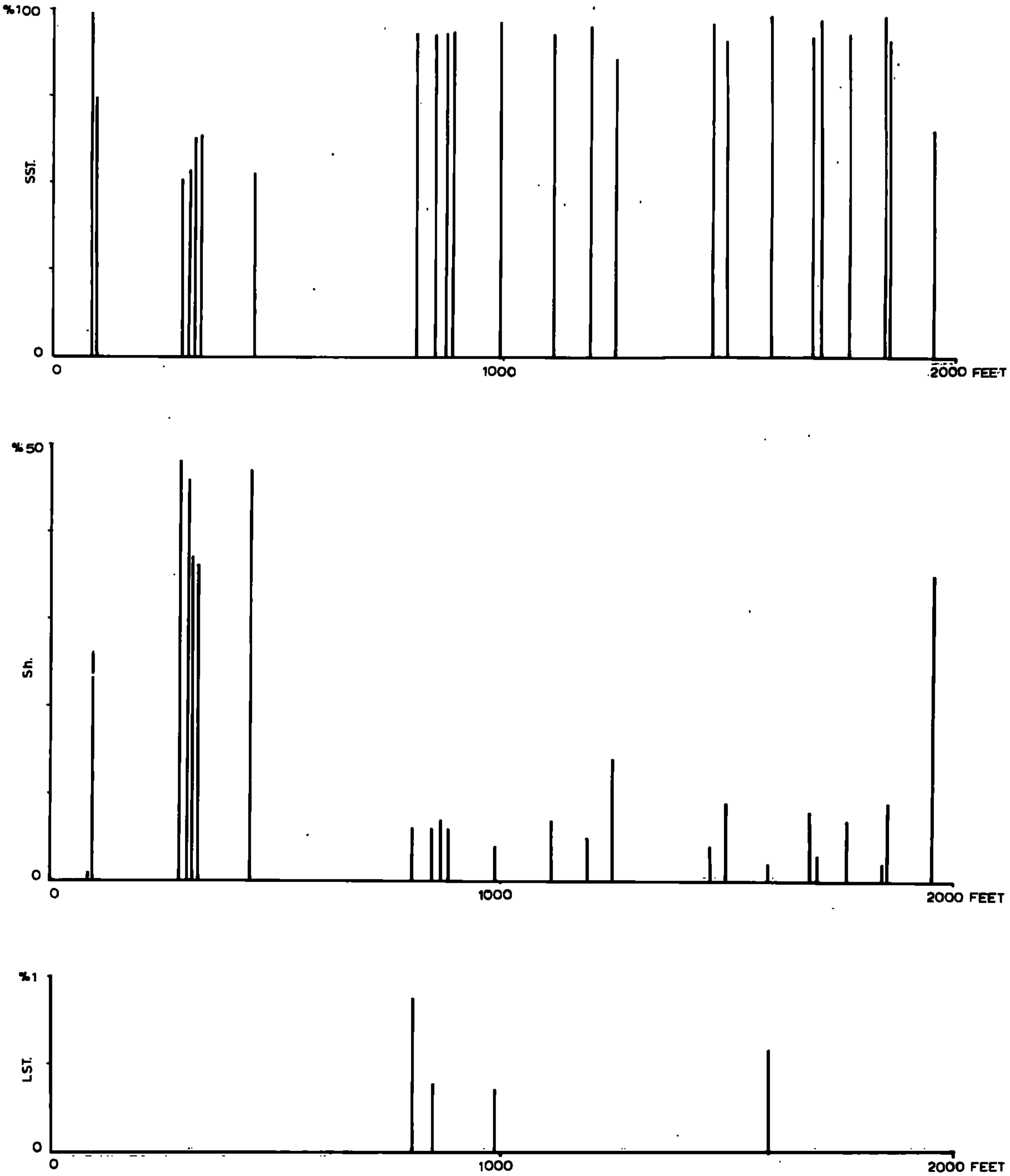


Fig. 7.6

Conclusions:-

These stone counts illustrated the overall composition in terms of lithologies of both bed and banks material, and showed the relative dominance of sandstone in almost all of the samples.

In general shale percentages did not show any marked features except a tendency in some cases to be inversely proportional to sandstone contents.

Limestone contents were everywhere low, and nearly always less than 5 percent.

Higher limestone percentages in the bed material samples appeared to be associated with bedrock outcrops of limestone, suggesting erosion of this lithology under present day conditions.

The general similarity between bed material and the bank material made it difficult to generalise to what extent present bed load is produced by erosion and slumping of bank material into the stream or by water erosion of the stream bed. Subjective visual assessment would ~~subject~~ suggest that both processes are important depending on local topographic conditions.

Chapter 8

Water Samples Analysis

Because of the nature of the geological invironment of the Lanehead Catchment, the writer thought it would be interesting to make a brief analysis of a few samples of the stream water to obtain some primary raw data concerning the amount and type of material at present being removed in solution. Necessarily the following description can only be regarded as interim a full study requiring several hundred samples taken throughout the year. The results of seven water samples are shown in Table 8.1.

It was thought by the writer that there might be some relationships between the Sodium, Potassium, Calcium and Magnesium and the average daily discharge. In periods of rainfall and consequently high discharge there would be a fairly rapid direct run off, in periods of lower discharge more water will be base flow and thus more directly influenced by the geological invironment.

Figure (8.1 A) shows the relationship between the Sodium, Potassium, Calcium and Magnesium and the average daily discharge. Few direct relationships are observed. Without more detailed and long term studies the reasons of this lack of correlation must remain doubtful.

Graphs showing the distribution and relationship between the calcium, sodium, potassium and magnesium, and the pH values against the average daily discharge in Cusecs.

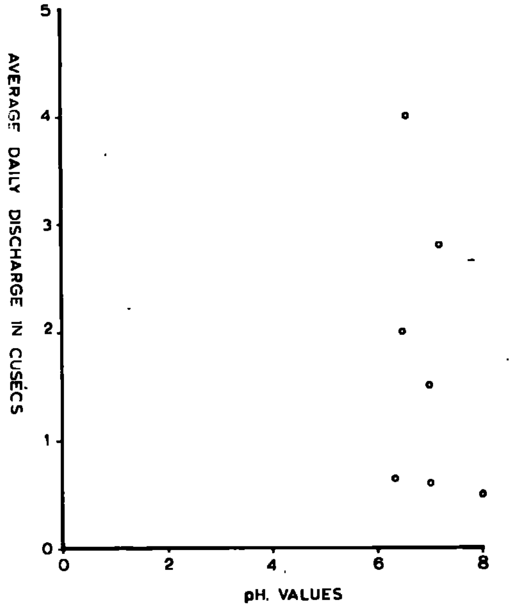


Fig. 8.1 A

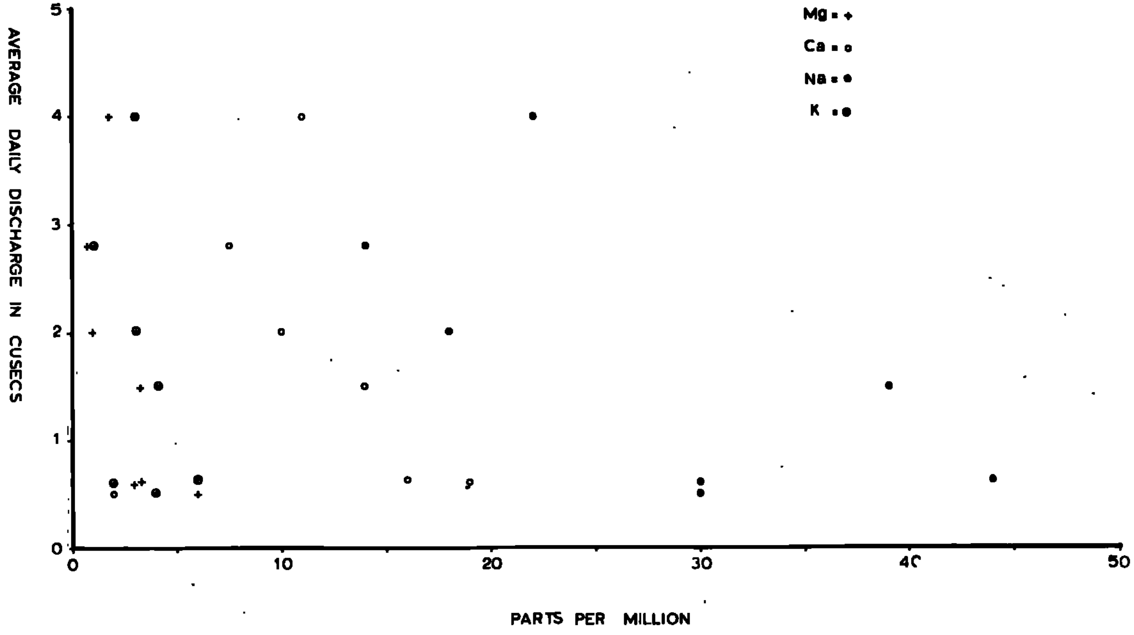


Fig. 8.1 B

Table 8.1

Samples No	Date of collection	Solid material gms. in 2 litre	PH. contents	K. ppm.	Na. ppm.	Ca. ppm.	Mg. ppm.	Average daily discharge in cusecs	Solid material in solution passing a fixed point in 24 hours : Kgs.
1	5.3.69.	0.1	8.0	4	30	2	6.0	0.5	61.171
2	12.3.69.	0.6	6.8	6	44	16	3.3	0.64	469.74
3	20.3.69.	0.12	7.0	2	30	19	3.2	0.6	88.08
4	2.4.69.	0.2	7.0	4	39	14	3.25	1.5	366.76
5	14.4.69.	0.5	6.7	3	22	11	1.95	4.0	2446.50
6	16.4.69.	0.1	6.6	3	18	10	1.0	2.0	244.5
7	8.5.69.	0.15	7.2	1	14	7.5	0.85	2.8	513.5

It is possible, however, ~~to~~ tentatively to suggest some of the possible reasons. Firstly it should be realized that at the time when the observation were made the area had a considerable snow cover and it is, therefore, possible that true base flow conditions were not reached a great deal of the discharge being due to snow melt.

Secondly, the initial amount of the Sodium, Potassium, Calcium and the Magnesium in the rain water falling on the Catchment was not known.

Figure (8.1 B) shows the relationship between average daily discharge and the PH. content of the water. No direct relationship is observed, this too, might in part be explained to extensive cover of snow, the melt water from which may have produced a buffering effect on the PH values which might otherwise have varied from relatively high PH's during periods of base flow to lower PH's with almost direct run off from the acid moorland.

In order to obtain some data indicating the total amount of material leaving the catchment in solution samples of water were evaporated and accurately weighed. (See Chapter 5). The calculated values was then multiplied by the average daily discharge to obtain the total figure, the results of seven such experiments are shown in Table 8.1.

The results would seem to indicate that a considerable amount of material is being removed from the Catchment. It would perhaps be dangerous to make more of such limited data. Certainly, however, a large area of limestone outcropping within the Catchment. Such high values were not totally unexpected.

Chapter 9

Movement of Material Downstream

To obtain some measure of the amount of material being transported past a fixed point in the Lanehead Catchment, trays were sunk in the bed of the stream (See Chapter 5) to trap moving bed load. The trays were visited and emptied on a total of 20 occasions during the year of field work between July 1968 and May 1969.

In the following table the date of visiting the site is shown together with the amount of material present within the trays.

Table 9.1

Date of Visit	Material in trays weight in Kgs.
18.7.1968	118.700
15.8.1968	No material present
10.9.1968	" " "
24.9.1968	113.000
3.10.1968	92.900
28.11.1968	122.50
5.12.1968	No material present
12.12.1968	" " "
7.1.1969	124.500

20.1.1969	72.400
27.1.1969	72.200
3.2.1969	10.800
26.2.1969	No material present
5.3.1969	" " "
14.3.1969	" " "
20.3.1969	" " "
2.4.1969	112.000
16.4.1969	354.000
24.4.1969	No material present
8.5.1969	91.0
Total	1284.0 Kgs.

In all a total of 1284.0 Kgs. was collected from the trays during the observation period. This figure proved to be a minimum value for the amount of material in transit by the stream at this point as it was soon found often after the installation of the trays that they were of insufficient volume to deal with the very large and unexpected amounts of material which proved to be in movement along the stream channel.

Having obtained a minimum figure for the amount of material passing a given point in the lower part of the Lanehead Catchment, the second aim of this particular experiment was to discover if the particle size characteristics of the material in movement was significantly different from that which had already been observed in the stream bed load.

To achieve this studies were made of both the coarse and fine material which was trapped by the trays on each collection date.

For the fine particle size analysis 4 grabe samples were taken from the material collected from the trays. These samples were of about 2 Kgs. in weight and each was subjected to dry sieving analysis in the normal way. (see Fig. 9.1).

When the data for the sieve analysis had been completed it was bulked together to obtain an average curve for the four samples which in turn was considered representative of all the material within the trays on the day of collection.

This cumulative frequency curve was then analysed in the normal manner and the median, mean and sorting values calculated. This procedure was repeated on each occasion that the trays were emptied.

The following table shows particle size analysis of material obtained from sampling trays. Average results of 4 samples per sampling date.

Particle size analysis of the find material collected
from the trays

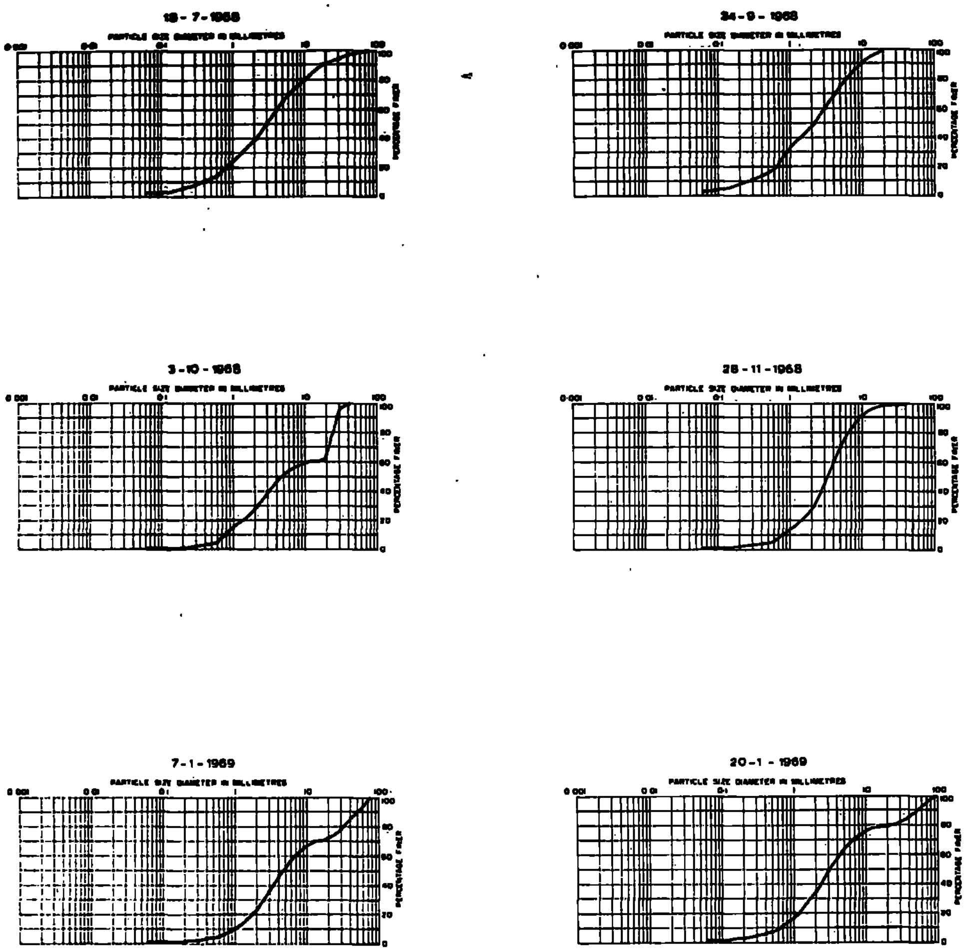


Fig. 9.1

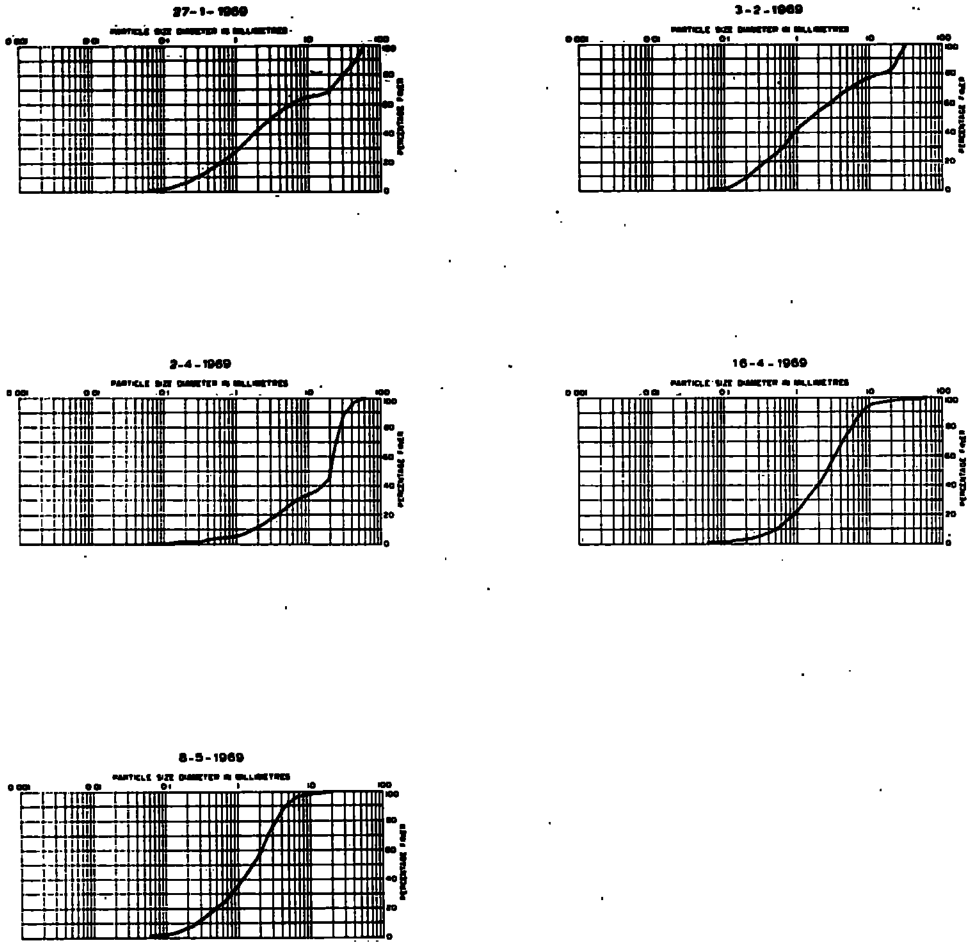

27-1-1969
PARTICLE SIZE DIAMETER IN MILLIMETRES
0.001
0.01
0.1
1
10
100
0
20
40
60
80
100
PERCENTAGE FINER
3-2-1969
2-4-1969
16-4-1969
8-5-1969

Fig. 9.1

Table 9.2

Date of sampling	Median phi	Mean phi	Sorting phi
18.7.68	- 1.3	- 1.17	+ 1.70
24.9.68	- 0.8	- 0.83	+ 1.55
3.10.68	- 1.6	- 1.83	+ 1.75
28.11.68	- 1.5	- 1.40	+ 1.05
7.1.69	- 1.6	- 2.10	+ 1.85
20.1.69	- 1.5	- 1.97	+ 2.10
27.1.69	- 1.3	- 1.53	+ 2.65
3.2.69	- 0.5	- 0.87	+ 2.60
2.4.69	- 3.4	- 2.80	+ 1.30
16.4.69	- 1.1	- 0.97	+ 1.30
8.5.69	- 0.5	- 0.30	+ 1.40

From table 9.2 it can be seen that the median size ranged from - 0.5 phi to - 3.4 phi ; the mean size from - 0.3 phi to - 2.80 phi, and the sorting from + 1.30 phi to +2.65 phi.

When these results are compared with the results obtained from the bed load samples of the two streams in the Lanehead Catchment it is seen that the samples obtained from the trays have in almost all cases much lower mean phi parameters, but similar overall sorting values.

This would suggest that during the period of observation (18th July 1968 to the 8th of May 1969) flood discharges along the stream were not sufficiently great to be competent to move the larger particles found along the stream bed.

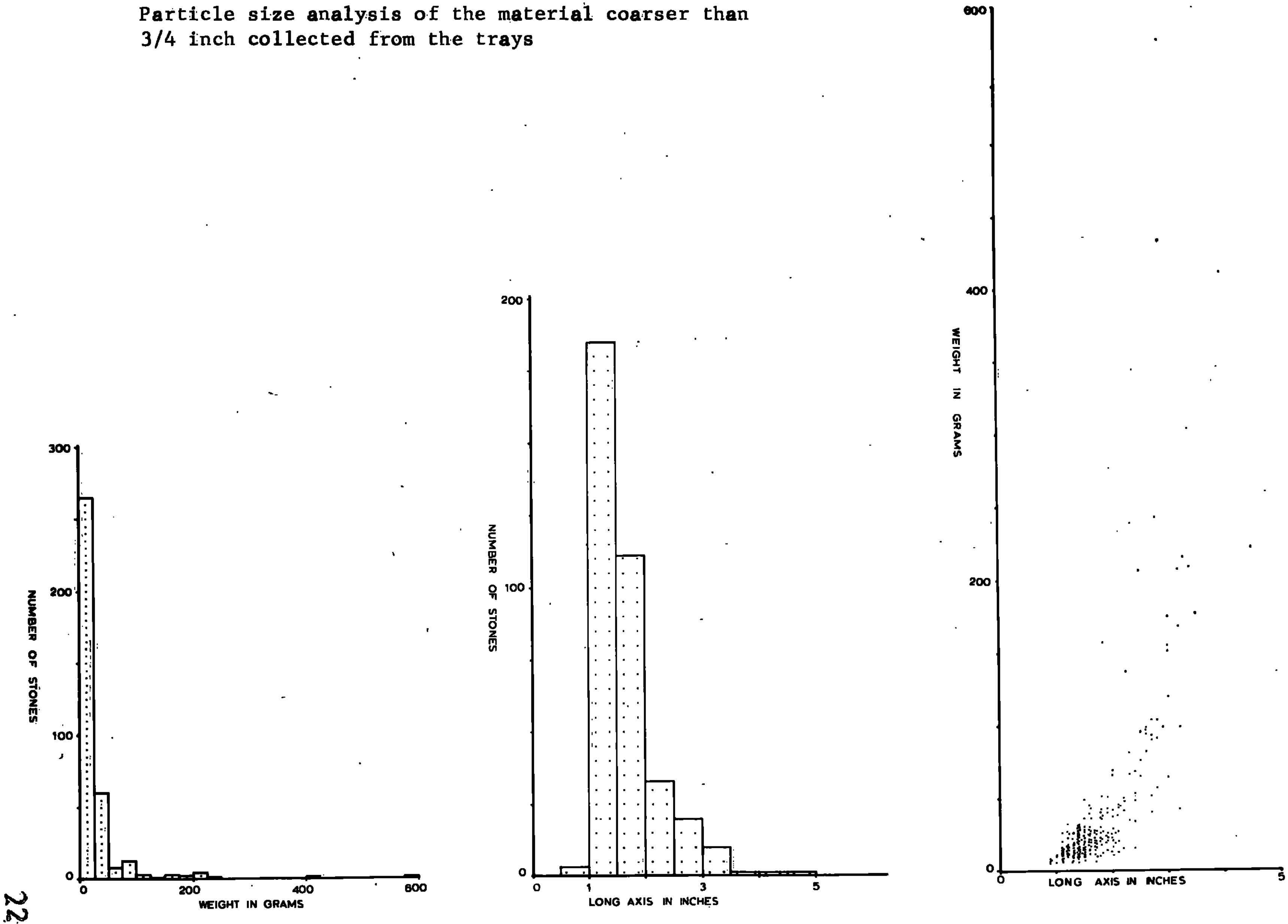
Material coarser than $\frac{3}{4}$ inches which was found in the trays was analysed in the following manner.

The long axes of the stones were measured to the nearest 0.1 of an inch and at the same time the weight was recorded to the nearest 0.1 of a gram (These data are produced in Appendix 6. A,B,C,D,E,F,G,H,I, and J.).

These data for each individual collection were plotted in a series of histograms showing the long axis and the weights. Graphs were also constructed with weight plotted against the long axis (see Figs. 9.2 A, B,C,D,E,F,G,H,I,J.).

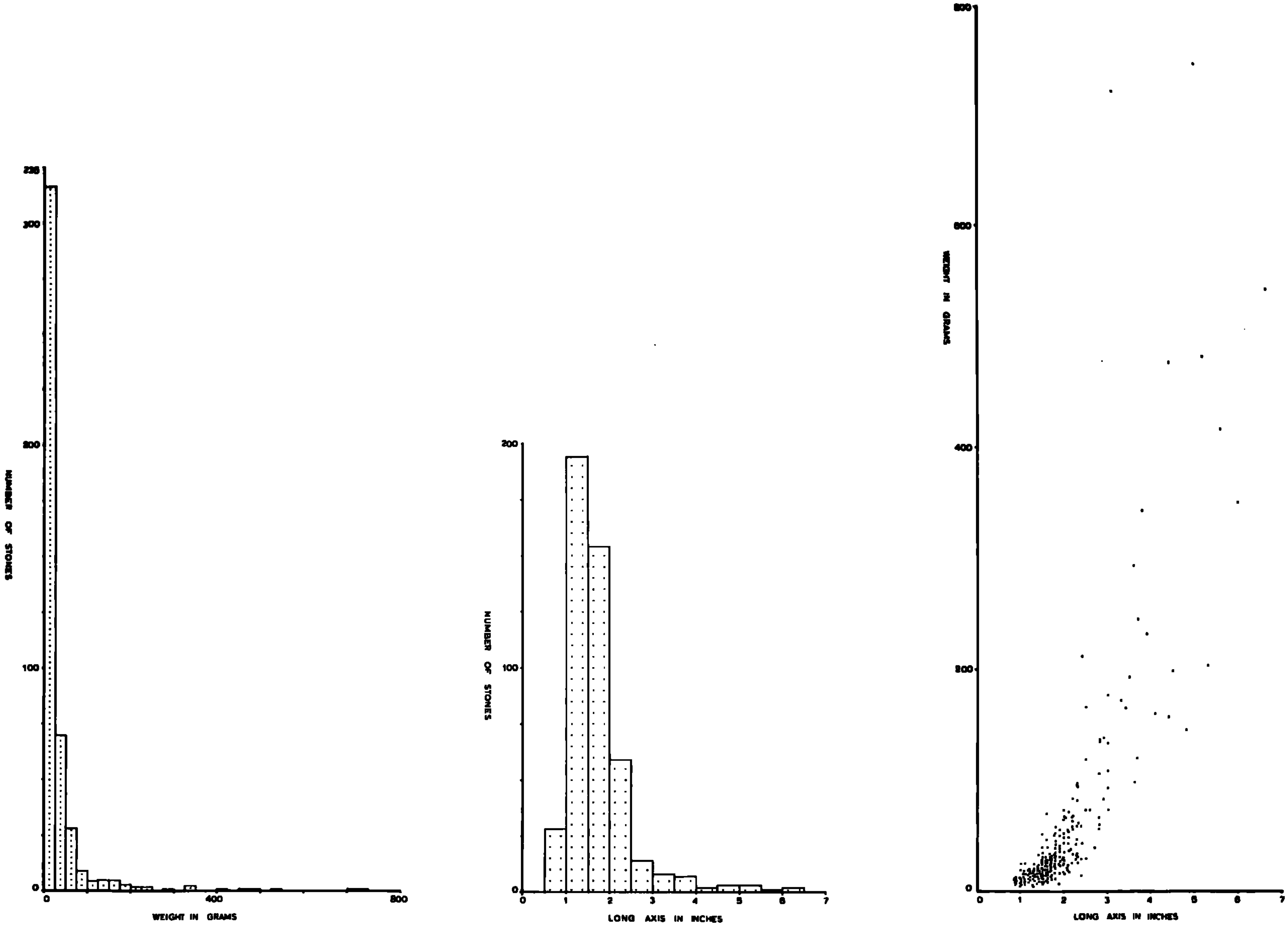
It is clear from the diagram that samples collected on the following dates, 18.7.68, 24.9.68, 28.11.68, 7.1.69, 20.1.69 and 2.4.69. Contained larger quantities of coarse material than samples collected on the 3.10.68, 27.1.69, 3.2.69, and 16.4.69. More than 85% of the material collected on these later dates was less than 2mm in diameter. A complete absence of coarse material (more than $\frac{3}{4}$ inches) was observed in the material collected on the 8th of May (1969). From the author's observation during the collection of these samples it was noticed that in the late Autumn of (1968) the

Particle size analysis of the material coarser than 3/4 inch collected from the trays



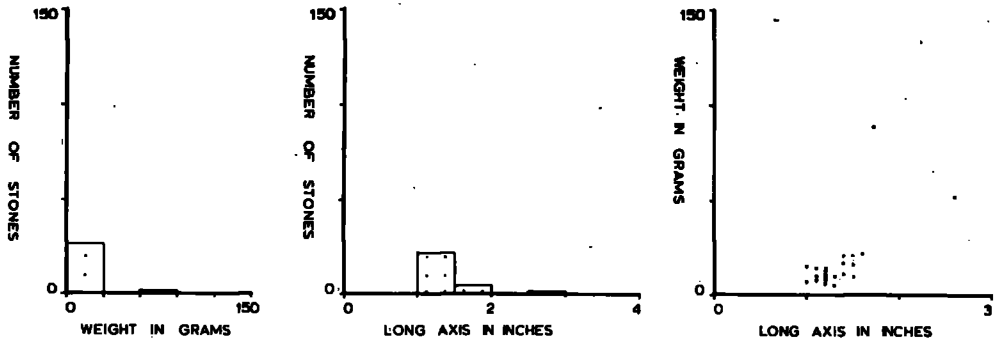
18-7-68

Fig. 9.2 A

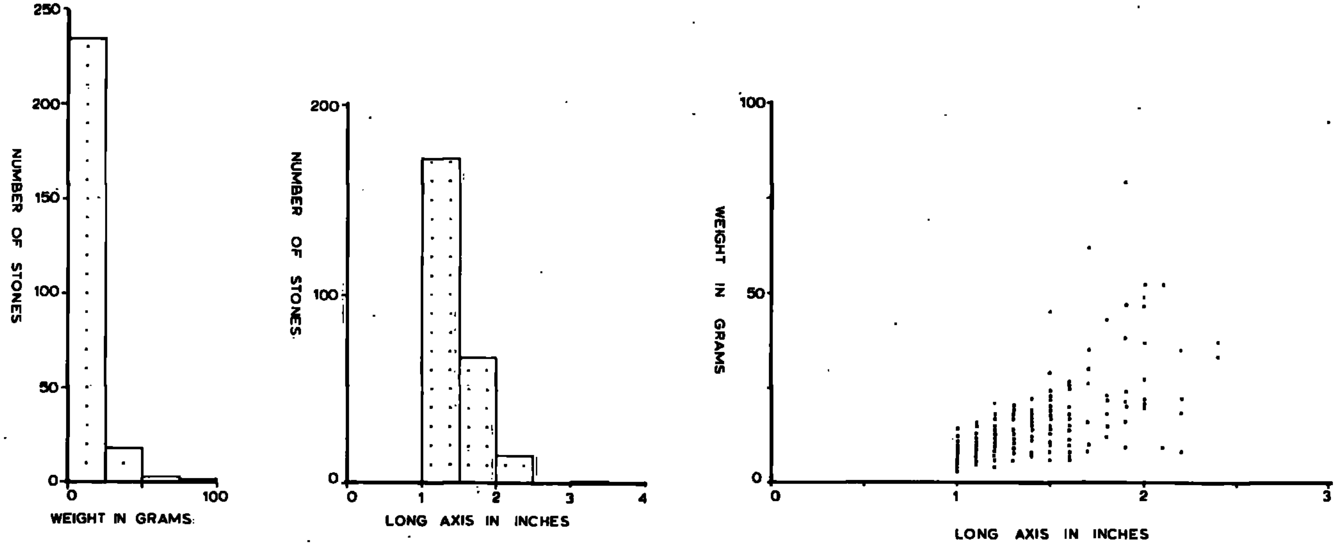


24-9-68

Fig. 9.2 B

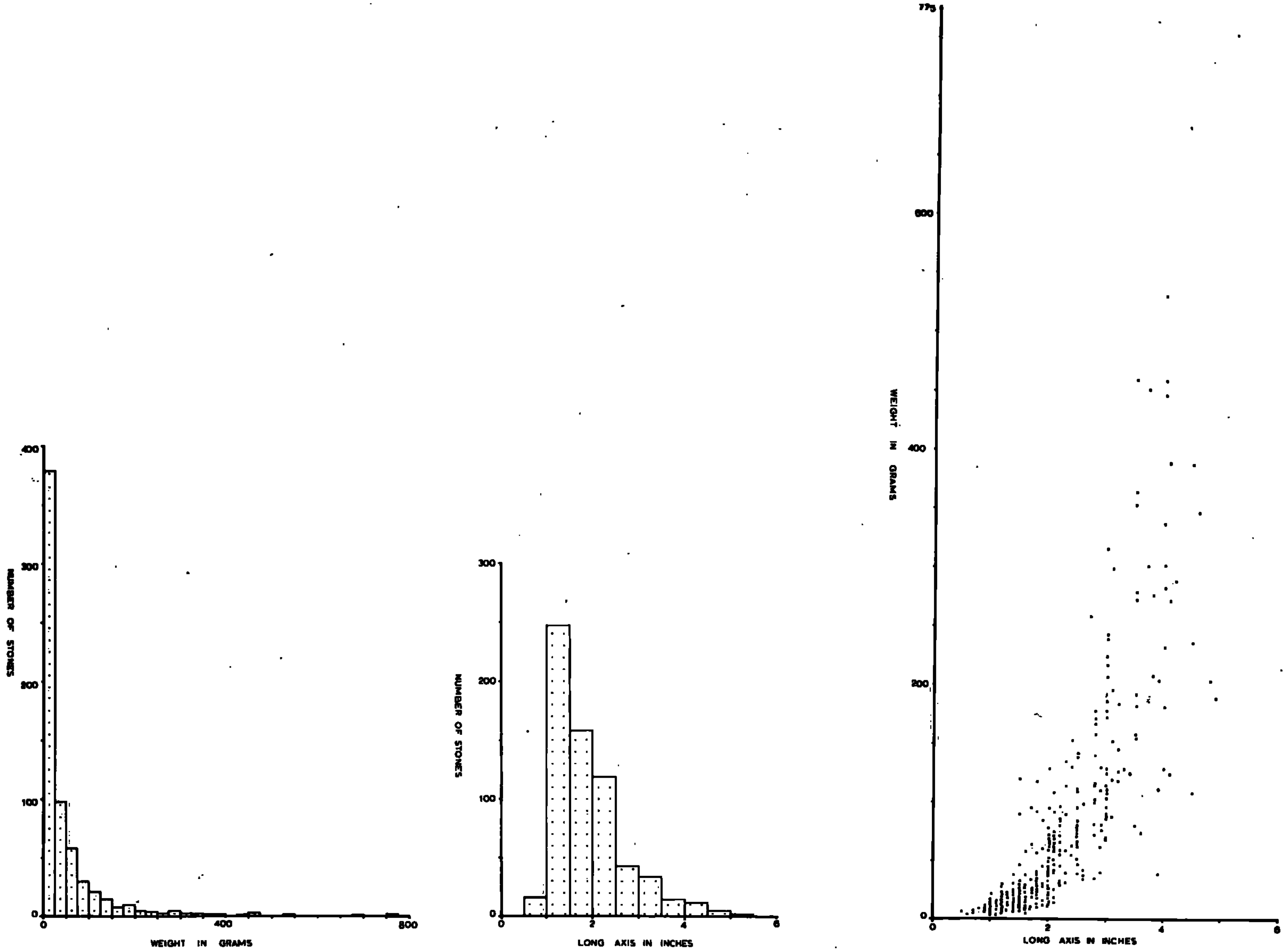


3-10-68



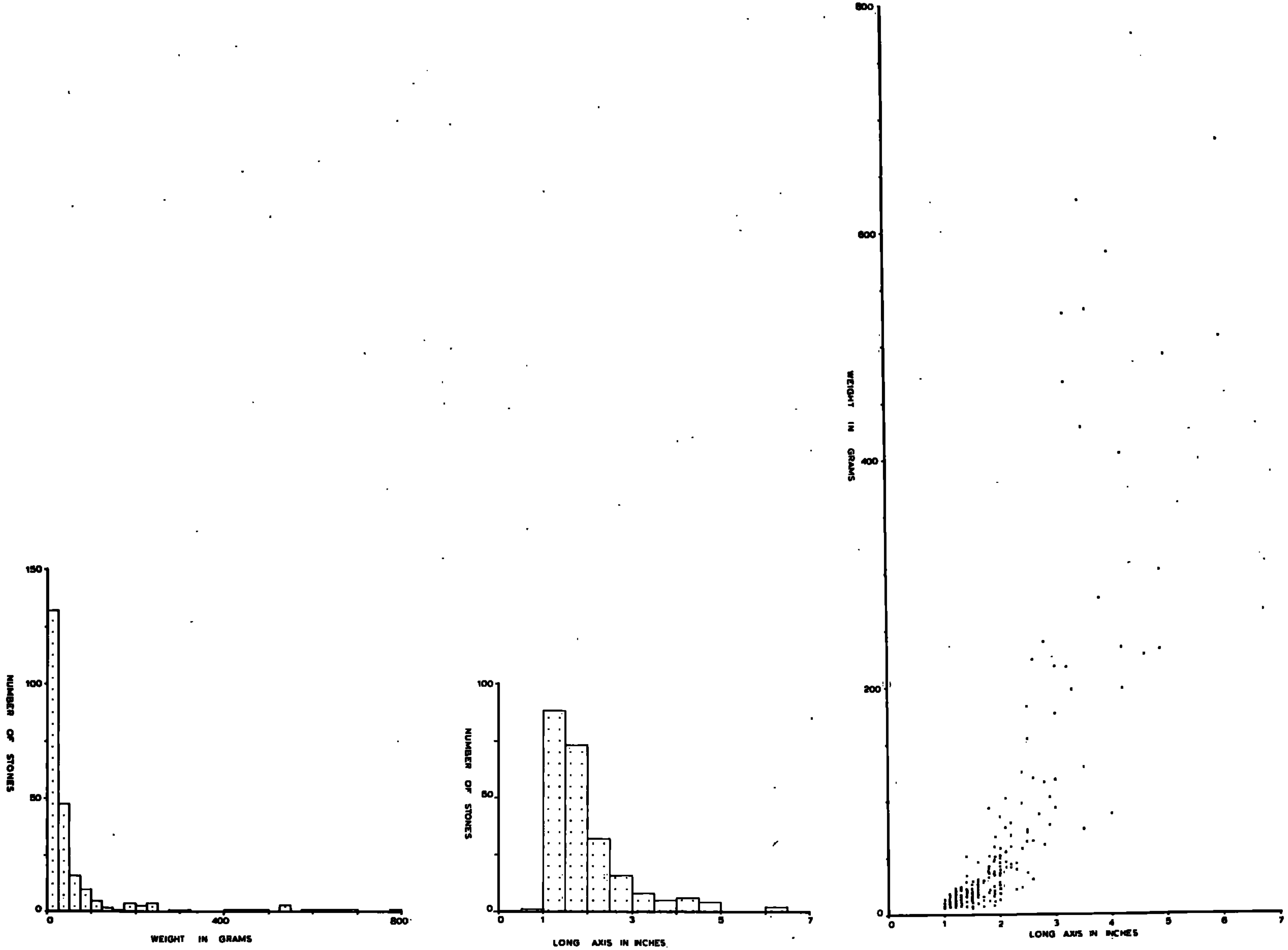
28-11-68

Figs. 9.2 C & D


NUMBER OF STONES
0
100
200
300
400
0
400
800
WEIGHT IN GRAMS
NUMBER OF STONES
0
100
200
300
0
2
4
6
LONG AXIS IN INCHES
WEIGHT IN GRAMS
0
200
400
600
775
0
2
4
6
LONG AXIS IN INCHES

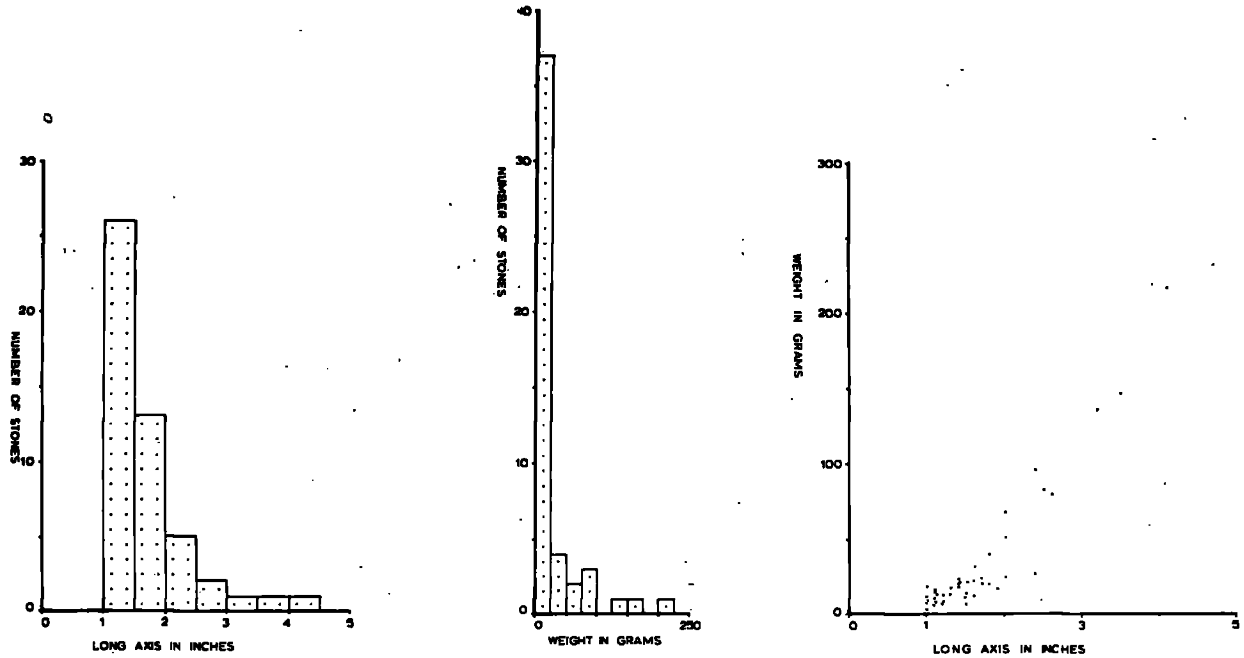
7-1-69

Fig. 9.2 E

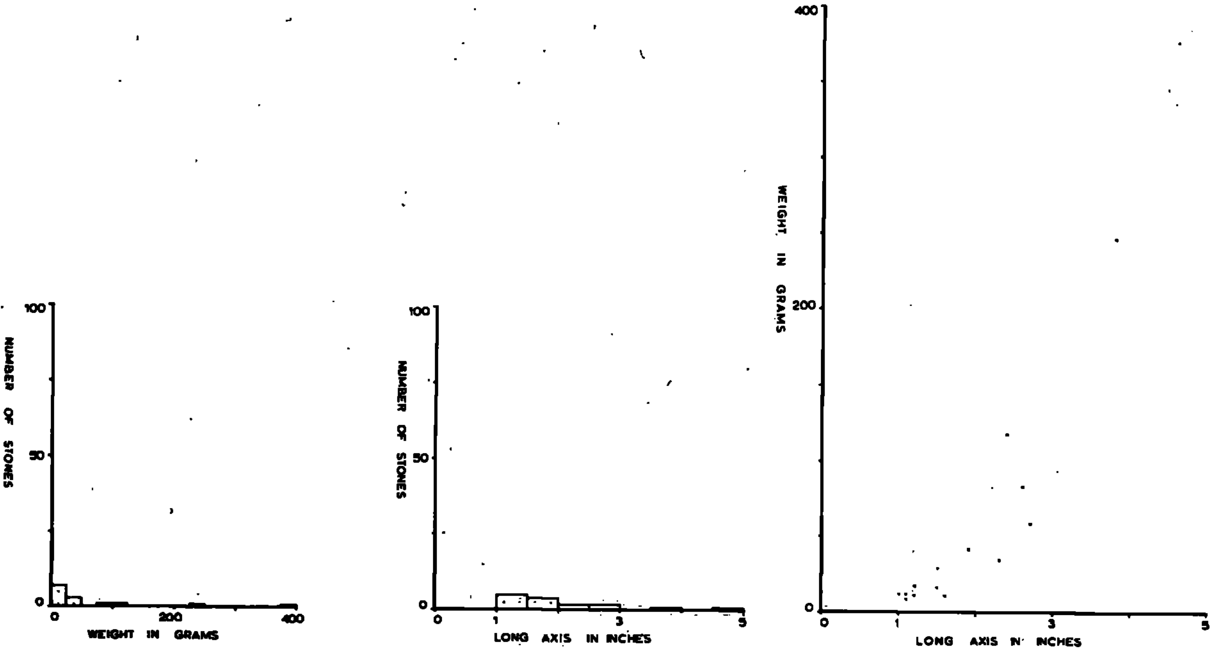


20-1-69

Fig. 9.2 F

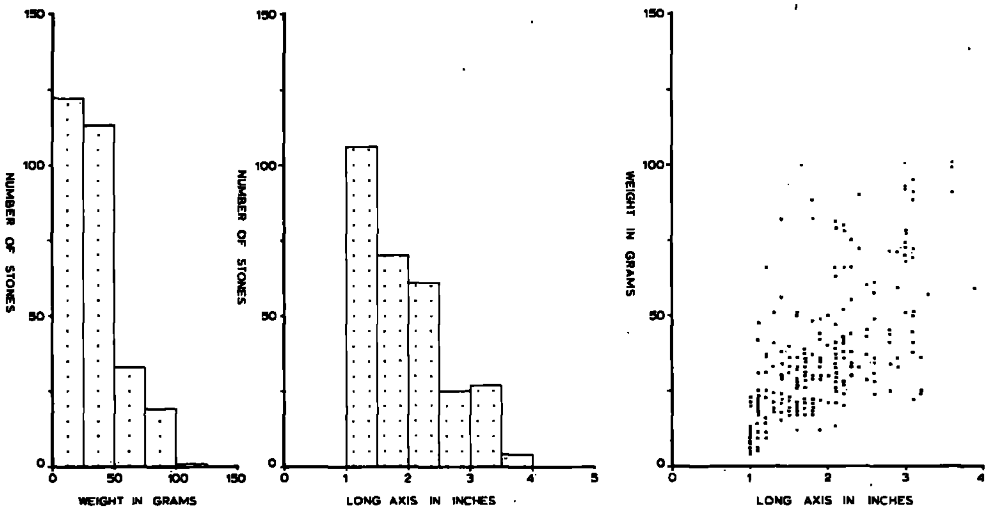


27-1-69

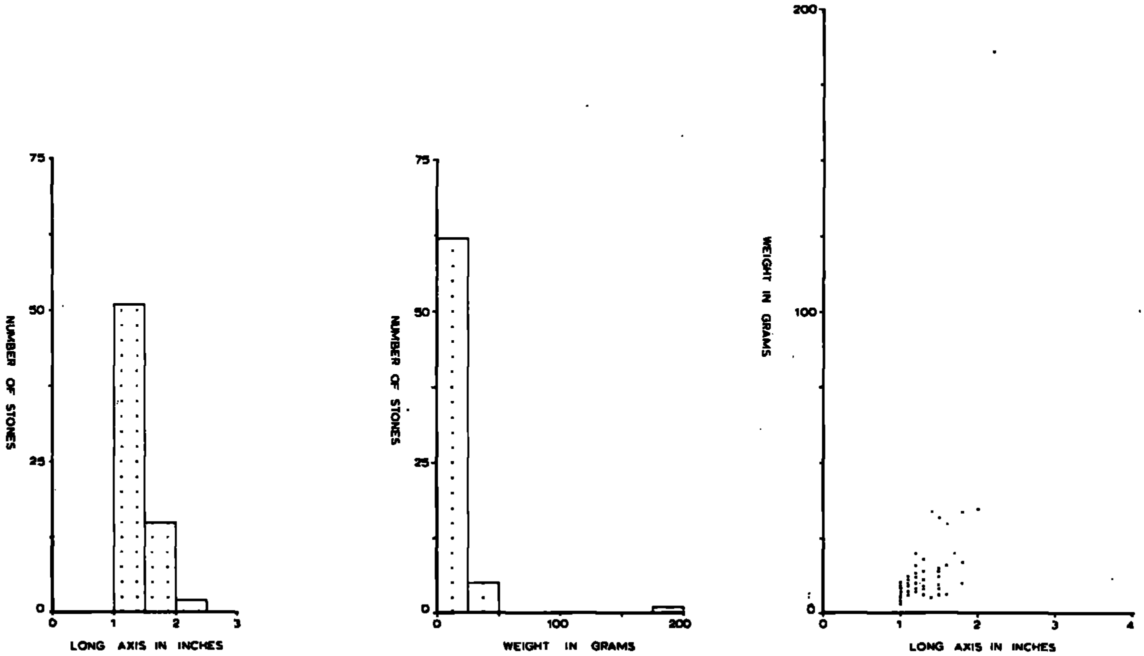


3-2-69

Figs. 9.2 G & H



2-4-69



16-4-69

Figs. 9.2 I & J

tray samples contained greater quantities of coarse particles than during the severe winter of 1968-69 when most of the material collected was less than 2mm in diameter.

This was probably due to the fact that severe frosts and snow melt loosened fine material from the stream banks causing it to fall into the stream bed. During high floods this material was then carried downstream.

The quantity of sediment carried by the stream is obviously related to stream discharge. The inability of the author to empty the trays on a daily basis meant however, that detailed correlations could not be made between sediment quantity and water discharge. However using information from a nearby stream gauge it was possible to obtain the highest water discharge which occurred during the tray sampling interval, and then this figure was plotted against the weight of sediment collected from the trays. (For details see the following table and Fig. 9.3).

Table 9.3

Date of collection	Weight in Kgs	Highest discharge in cusecs between sampling dates
18.7.1968	118.700	No available records for this period

Graph showing the relationship between the discharge and the sediment movement

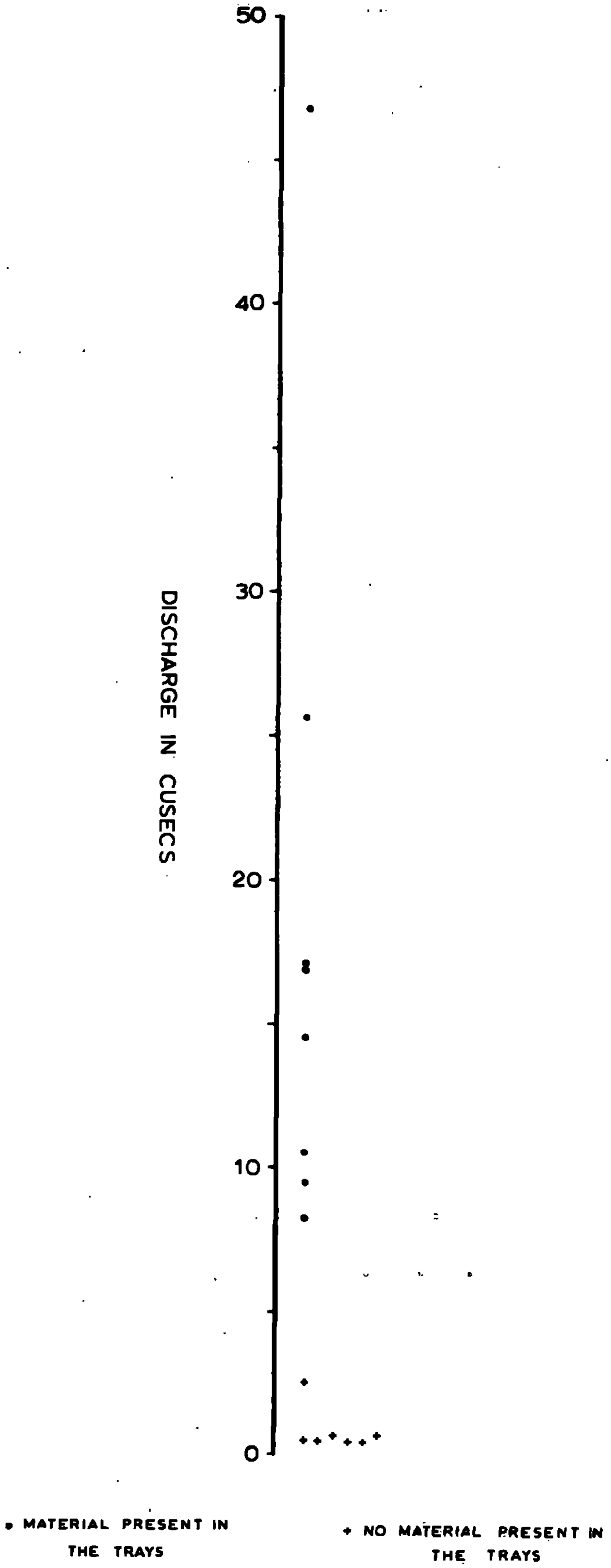


Fig. 9.3

15.8.1968	No material present	
10.9.1968	" " "	No available records for this period
24.9.1968	113.000	
3.10.1968	92.900	
28.11.1968	122.50	9.5
5.12.1968	No material present	0.6
12.12.1968	" " "	0.5
7.1.1969	124.500	46.8
20.1.1969	72.400	16.9
27.1.1969	72.200	14.5
3.2.1969	10.800	8.2
26.2.1969	No material present	0.5
5.3.1969	" " "	0.6
14.3.1969	" " "	0.5
20.3.1969	" " "	0.5
2.4.1969	112.000	25.6
16.4.1969	354.000	17.0
24.4.1969	No material present	2.5
8.5.1969	91.000	10.5

Total = 1284.00 Kgs.

This figure indicated that there was a general relationship between discharge and sediment movement, with the largest sediment concentrations being associated with the highest discharges. This type of correlation does, however, suffer from the fact that no estimate of the length of time of occurrence of flows of different magnitude can be made.

From the evidence presented in Table 9.3 it can be seen that there was apparently no sediment movement with maximum flows as high as 2.5 cusecs but that sediment movement was occurring with flows of 8.2 cusecs. This would suggest that for this particular stream there is a threshold value, in terms of discharge between 2.5 to 8.2 cusecs below which little or no sediment movement in terms of bed load takes place.

In order to gain some idea as to the distance of movement of individual stone particles over short time intervals along the streams. A simple experiment was devised. For this pebbles were used which had been caught in the bed load traps, and which were, therefore, known to be in movement along the stream bed under present day environmental conditions. In all a total of 212 pebbles were selected, mostly of hard sandstones and limestones which were best able to withstand corrosion, with long axes lengths varying from 1.0 to 5.6 inches, and with weights ranging from 9 to 738 grams.

These stones were obtained from material collected in the trays and removed from stream on September 24th 1968.

The collection of stones were then divided into two similar groups of 106 stones each, A and B.

The weight of the individual pebbles composing group A ranged from 9 to 718 grams, and the long axis length ranged from 1.0 to 5.1 inches (see Appendix 7.A).

In group B the weights of the pebbles ranged from 9 to 738 grams and the long axis from 1.0 to 5.6 inches (Appendix 7.B)

The pebbles were then painted with yellow marine paint to aid identification and each individual pebble in both groups numbered consecutively in black paint from 1 to 106.

On the 5th December 1968 the two groups of pebbles were taken to the Lanehead Catchment and placed in the bed of the streams. Points were selected 2,000 feet above the confluence of the two streams and the pebbles were placed on the stream bed at these points:-

Group A in the eastern stream

Group B in the western one

The distance travelled by these marked pebbles was measured on 27th January(1969),and 13th June(1969).

Unfortunately most of the pebbles used in this experiment were buried during the winter by the material falling from the banks which made the recovery of most of them difficult.

The results of this experiment (as it is clearly shown in Fig. 9.4), revealed that the western tributary was more powerful and more capable of moving coarser material than its eastern counterpart. Also, the figure shows that there is no direct relationship between the weight of each individual pebble and how far it travelled downstream.

Graphs showing the relationship between weight and distance of coarse sediment movement along the streams

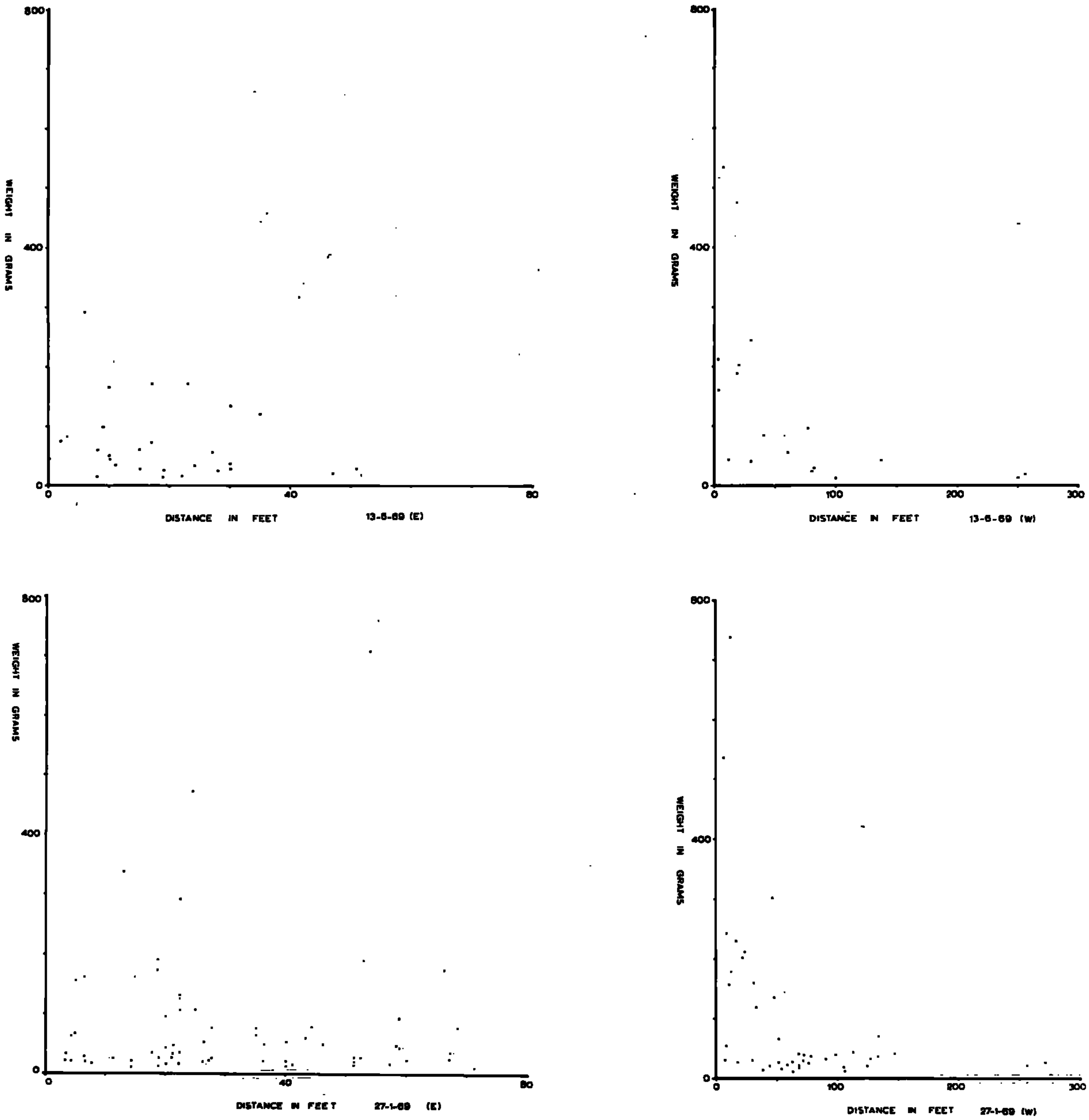


Fig. 9.4

SECTION THREE

CONCLUSION

It has been shown in this thesis that, in spite of the great similarities between the two catchments in terms of geology and vegetations cover quantitative and statistical measures of bed-load proved that great differences are present. Unfortunately, throughout this research the writer found great difficulties in trapping bed-load in the Netherhearth catchment. This was due to many factors, the most important being the writer's inability to secure the sediments trap into the stream bed which was composed of solid rock that was, due to the nearly horizontal strata, without many irregularities.

The analyses show that the average mean particle size within the stream beds of these two catchments ranges between -2.0φ to -5.0φ, but systematic changes in bed material characteristics occur. It appears to the writer that these changes are related mostly to the variations in flow during high and low flood periods.

The bed material was poorly and extremely poorly sorted. This conclusion was not surprising because these streams are still in a youthful stage and are highly erosive especially on banks where soliflucted material occurs.

The statistical comparisons show a very significant relationship between the mean partical size and the sorting with no relationship between the sorting and skewness in the case of the eastern stream in the Lanehead catchment. The Western stream in the Lanehead catchment shows a highly significant relationship were found between the mean particle size and the skewness of the bed-load samples.

A large amount of material in movement was obtained from the trays. During the study period a total of 1284 kgs were collected. Large amounts of material in the trays always corresponded with the high flood periods which occurred mostly during the snow melt period. The mean particle size of these materials, which ranges from -0.3ϕ to -2.8ϕ, revealed that this material is smaller in size than the actual material collected from the bed of the stream.

The analysis of this material indicated that there is no definite relationships between the mean particle size and the discharge, or between the sorting and discharge.

Stone counts of the sediments collected from the bed, banks and the trays revealed that the dominant types of rock within the bed and banks of the three streams are sandstones, shales and limestones. A very high percentage of sandstones and shale was found during the stone counts, with a very poor distribution of limestones, especially in the bank material. It has been shown that a great deal of limestone outcrops within the catchments and it must be concluded that the small amounts of limestone detected in either due to its lack of mechanical resistance or due to its solubility in the acidic peaty environments of the Pennine moorlands.

Stone measurements at the sampling points show that stone with long axes of up to 6 feet are present within the channels of the streams. The analyses indicated that in the Netherhearth catchment 255 particles were measured between 2 and 3 inches. In the western Lanehead stream the modal class, with 62 observations, lay between 3 and 4 inches, while in the eastern Lanehead stream the modal class, with 46 observations lay between 8 and 9 inches. These results for the three streams were tested with the Kolmogorov-Smirnov test which revealed that the material of these three streams were drawn from different populations.

The coarser material collected from the trays was also measured and weighed. These analyses show a great variation between the rainy periods and the snow melt periods and it proved that the sediment movement always occurs during high floods. The small experiments for measuring the capability of these streams to move coarse material as well as fine material revealed that in a few weeks these streams were able to move certain sizes of material to a considerable distance (see Appendix 7.A and 7.B)

The chemical analyses of the water samples indicated that there is no relationship between calcium, sodium, magnesium and potassium and the average daily discharge, or even between pH and the average daily discharge. This analysis revealed that large quantities of material in solutions are passing down the stream daily, although more samples are needed to quantify the results.

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APPENDICES

APPENDIX IA

Particle size data obtained from the eastern stream-bed material "Lanehead" (See Fig. 61A)

Sieves	Random Sampling Numbers								
No.	11	15	79	90	151	172	188	207	304
4	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-
$2\frac{1}{2}$	-	-	-	-	-	9.75	-	-	-
$1\frac{3}{4}$	3.32	-	2.60	-	-	24.53	-	22.61	-
$1\frac{1}{4}$	13.68	26.71	17.39	22.78	12.27	40.14	8.71	27.94	6.21
$\frac{3}{4}$	26.83	50.28	41.97	46.70	34.95	57.31	14.61	42.86	30.83
$\frac{1}{2}$	41.56	64.80	56.28	62.26	51.16	70.97	23.13	53.25	53.00
$\frac{3}{8}$	51.99	73.34	64.49	70.15	61.33	77.02	33.31	61.61	63.00
$\frac{1}{4}$	65.87	82.74	76.79	79.53	76.43	84.02	43.74	72.81	75.84
$\frac{3}{16}$	75.37	87.76	82.61	85.15	84.90	88.14	60.22	78.31	82.80
$\frac{1}{8}$	84.62	93.16	89.42	91.15	92.08	92.77	67.63	85.21	89.37
8	91.34	96.74	94.09	95.29	95.97	96.07	77.50	90.69	94.18
14	95.12	98.32	96.77	97.63	97.91	97.91	84.79	93.72	96.88
25	97.98	99.14	98.38	98.90	99.18	98.94	89.20	95.97	98.40
36	98.47	99.27	98.67	99.13	99.36	99.12	93.34	96.51	98.73
52	98.84	99.39	98.91	99.31	99.52	99.28	94.41	97.06	99.01
72	99.15	99.50	99.13	99.48	99.68	99.43	95.45	97.57	99.30
100	99.39	99.60	99.33	99.63	99.80	99.57	96.29	98.00	99.54
150	99.57	99.69	99.50	99.76	99.86	99.69	96.94	98.38	99.72
200	99.69	99.76	99.64	99.83	99.89	99.77	97.40	98.68	99.81
240	99.75	99.80	99.73	99.86	99.92	99.81	97.65	98.84	99.85
100%	99.97	99.97	100.00	100.00	99.97	99.98	97.94	100.00	99.96

APPENDIX IA (Contd.)

Particle size data obtained from the eastern stream-bed material "Lanehead" (See Fig. 61A)

Sieves	Random Sampling Numbers								
No.	361	364	449	450	579	588	641	671	723
4	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-
$2\frac{1}{2}$	-	-	-	-	-	-	-	-	-
$1\frac{3}{4}$	6.42	14.48	7.38	-	6.94	27.37	4.61	8.61	4.94
$1\frac{1}{4}$	33.96	28.85	27.47	10.05	20.09	47.19	19.48	23.99	33.98
$\frac{3}{4}$	66.23	53.35	40.68	27.85	40.90	70.34	43.91	47.62	44.11
$\frac{1}{2}$	77.41	63.07	50.89	56.08	52.07	78.55	55.83	56.84	53.73
$\frac{3}{8}$	82.12	70.19	55.21	69.92	59.23	82.57	59.94	61.52	59.41
$\frac{1}{4}$	86.83	79.17	64.97	76.22	67.77	87.19	69.48	67.84	67.65
$\frac{3}{16}$	89.34	83.85	71.42	84.21	72.79	89.87	75.13	71.99	73.62
$\frac{1}{8}$	92.16	89.77	79.81	88.73	78.95	92.62	82.51	78.05	81.89
8	95.01	94.06	86.62	93.12	84.11	95.01	88.49	84.35	88.63
14	96.66	96.68	91.30	95.70	87.95	96.78	92.73	89.07	92.98
25	97.99	98.37	95.46	97.40	91.88	98.29	95.61	93.51	96.31
36	98.29	98.69	96.43	98.57	93.06	98.65	96.19	94.69	97.05
52	98.58	98.95	97.33	99.82	94.36	99.01	96.69	95.90	97.73
72	98.87	99.18	98.14	99.07	95.75	99.32	97.10	97.06	98.32
100	99.15	99.38	98.64	99.32	97.03	99.56	97.44	98.02	98.80
150	99.37	99.55	99.06	99.54	98.17	99.72	97.68	98.75	99.16
200	99.52	99.65	99.28	99.71	98.78	99.81	97.84	99.13	99.38
240	99.60	99.70	99.38	99.80	99.01	99.85	97.92	99.27	99.48
100%	99.98	99.94	99.84	99.91	99.92	99.96	98.26	100.00	99.95

APPENDIX IA (Contd.)

Particle size data obtained from the eastern stream-bed material "Lanehead" (See Fig. 61A)

Sieves	Random Sampling Numbers								
No.	872	891	996	1033	1055	N1163	1218	1244	1323
4	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-
2½	-	-	-	-	-	-	-	-	-
1¾	14.96	23.27	18.43	10.60	7.28	-	18.28	11.82	-
1¼	36.93	40.25	28.53	20.25	22.63	18.35	32.47	20.71	26.48
¾	52.25	58.06	41.01	35.91	39.24	39.27	61.00	41.62	50.78
½	64.51	67.28	49.89	49.02	52.03	50.71	67.83	55.17	63.91
⅜	71.10	72.82	56.44	56.14	60.23	57.89	73.41	62.97	71.54
¼	80.31	80.67	65.43	65.86	70.43	66.81	79.83	74.04	79.40
3/16	84.83	84.99	71.70	72.38	76.09	72.76	83.03	80.46	83.93
⅛	90.09	90.40	79.12	79.92	82.61	80.43	87.67	87.66	89.11
8	93.86	94.01	85.60	86.23	87.91	86.72	91.35	92.77	93.04
14	96.15	96.25	90.94	91.14	91.40	90.93	93.73	96.13	95.20
25	97.69	97.40	95.62	95.51	94.85	94.58	95.96	98.34	96.87
36	98.04	98.30	96.56	96.53	95.84	95.53	96.57	98.74	97.25
52	98.47	98.63	97.41	97.41	96.80	96.52	97.11	99.04	97.63
72	98.90	98.93	98.16	98.21	97.60	97.46	97.54	99.30	97.97
100	99.25	99.20	98.74	98.78	98.33	98.19	97.92	99.52	98.30
150	99.49	99.44	99.24	99.22	98.90	98.76	98.35	99.69	98.71
200	99.62	99.59	99.49	99.46	99.22	99.11	98.75	99.78	99.08
240	99.68	99.66	99.59	99.57	99.35	99.27	98.93	99.82	99.23
100%	99.95	99.97	99.92	99.95	99.86	99.98	100.00	99.95	99.99

APPENDIX IA (Contd.)

Particle size data obtained from the eastern stream-bed material "Lanehead" (See Fig. 61A)

Sieves	Random Sampling Numbers								
No.	1344	1403	1424	1609	1623	1727	1772	1843	1940
4	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-
$2\frac{1}{2}$	-	-	-	-	-	-	-	-	-
$1\frac{3}{4}$	4.67	5.99	8.35	5.83	-	-	17.72	-	6.51
$1\frac{1}{4}$	28.12	21.77	18.28	26.65	4.22	7.56	44.82	8.81	27.86
$\frac{3}{4}$	55.87	36.77	26.54	50.39	35.94	27.84	78.31	16.85	48.20
$\frac{1}{2}$	64.93	47.39	36.40	67.20	45.19	54.45	87.56	24.05	56.98
$\frac{3}{8}$	69.10	52.26	43.48	72.96	52.17	64.55	90.24	28.54	62.25
$\frac{1}{4}$	75.89	62.44	57.19	81.64	63.32	70.59	94.15	36.71	68.90
$\frac{3}{16}$	80.66	70.34	64.71	86.46	70.20	78.54	96.13	44.18	73.79
$\frac{1}{8}$	86.67	78.85	74.14	91.22	78.96	83.04	97.67	56.25	80.20
8	91.60	86.14	82.57	94.71	85.90	88.33	98.89	68.81	86.29
14	94.87	92.05	88.59	96.97	90.72	92.84	99.32	79.44	90.84
25	97.44	96.35	93.49	98.18	94.61	95.50	99.55	88.67	95.05
36	97.94	97.21	94.55	98.44	95.48	97.48	99.61	90.66	96.04
52	98.37	97.94	95.50	98.72	96.34	97.95	99.67	92.63	96.91
72	98.73	98.61	96.34	99.05	97.19	98.35	99.73	94.47	97.67
100	99.02	99.09	97.04	99.30	97.90	98.69	99.80	95.99	98.27
150	99.25	99.42	97.60	99.55	98.41	98.97	99.86	97.17	98.71
200	99.40	99.60	98.04	99.70	98.74	99.13	99.90	97.82	98.99
240	99.48	99.69	98.31	99.76	98.92	99.19	99.92	98.17	99.12
100%	99.95	100.00	99.95	99.93	99.97	99.58	99.98	99.94	100.00

APPENDIX IA (Contd.)

Particle size data obtained from the eastern stream-bed material "Lanehead" (See Fig. 61A)

Sieves	Random Sampling Number								
No.	1965	1985	1996	2017	2026	2104	2215	2243	2317
4	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-
2½	-	-	-	-	-	-	-	-	-
1¾	6.73	10.96	-	9.39	3.69	-	20.43	-	43.26
1¼	19.48	47.16	8.66	29.26	25.65	-	43.31	15.19	52.63
¾	33.08	64.72	28.59	55.63	56.59	3.38	63.16	43.41	65.53
½	43.08	70.89	43.90	69.59	71.63	6.68	74.30	59.57	74.03
⅜	49.65	76.22	52.62	75.66	79.84	11.19	80.43	67.46	78.53
¼	58.94	82.67	64.85	83.46	87.80	25.64	86.25	76.94	83.86
3/16	66.21	86.33	72.22	87.73	91.54	37.62	89.82	82.12	86.71
⅛	75.36	90.50	79.98	90.55	94.79	53.38	93.02	87.73	89.88
8	83.09	93.53	85.84	94.58	96.75	66.49	95.49	92.01	92.58
14	88.40	95.54	90.45	96.24	98.02	76.47	97.04	94.70	94.97
25	92.98	97.09	94.76	97.59	98.86	85.86	98.23	96.65	97.09
36	94.13	97.50	95.91	97.96	99.05	88.41	98.51	97.12	97.65
52	95.18	97.91	96.89	98.34	99.23	90.80	98.76	97.57	98.15
72	96.14	98.34	97.78	98.70	99.39	93.08	98.97	98.06	98.58
100	96.95	98.73	98.42	99.01	99.57	94.64	99.17	98.49	98.92
150	97.61	99.04	98.89	99.26	99.72	95.87	99.37	98.84	99.19
200	98.07	99.24	99.20	99.43	99.80	96.62	99.55	99.06	99.38
240	98.30	99.34	99.35	99.52	99.84	97.03	99.63	99.19	99.49
100%	99.94	99.97	99.97	99.96	99.96	99.92	99.94	99.95	99.97

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APPENDIX IA (Contd.)

Particle size data obtained from the eastern stream-bed material "Lanehead" (See Fig. 61A)

Sieve	Random Sampling Numbers				
No.	2320	2342	2471	2472	2604
4	-	-	-	-	-
3	-	-	-	-	-
2½	-	-	-	-	-
1¾	24.74	23.03	-	-	16.73
1¼	37.67	37.37	4.84	3.24	47.83
¾	53.27	53.47	19.79	9.88	65.92
½	63.35	65.80	29.70	21.34	74.82
⅜	67.96	71.24	39.10	31.12	79.62
¼	75.72	78.28	53.07	47.23	85.07
3/16	80.19	82.66	61.10	56.05	87.91
⅛	85.47	87.91	71.45	67.73	91.35
8	89.90	91.84	80.33	77.29	94.09
14	93.11	94.36	86.96	84.14	95.84
25	95.83	96.27	92.60	90.28	97.32
36	96.53	96.76	94.00	91.94	97.73
52	97.16	97.22	95.26	93.47	98.14
72	97.71	97.64	96.37	94.82	98.53
100	98.14	98.00	97.19	95.88	98.84
150	98.49	98.33	97.78	96.74	99.10
200	98.76	98.62	98.17	97.32	99.28
240	98.91	98.80	98.39	97.61	99.39
100%	99.97	99.97	99.90	99.96	99.97

APPENDIX IB

Particle size data obtained from the western stream-bed material "Lanehead" (See Fig. 61B)

Sieves	Random Sampling Numbers								
No.	32	45	49	95	103	282	318	320	336
4	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-
$2\frac{1}{2}$	-	-	-	-	-	-	-	-	-
$1\frac{3}{4}$	3.80	3.68	-	-	9.43	12.00	7.93	-	-
$1\frac{1}{4}$	19.10	27.75	22.24	8.96	24.79	38.99	37.75	4.08	1.94
$\frac{3}{4}$	61.67	52.49	44.48	29.83	49.03	60.17	59.00	19.70	14.62
$\frac{1}{2}$	75.40	65.93	56.52	55.59	61.63	73.35	73.30	30.79	24.29
$\frac{3}{8}$	80.02	73.36	64.11	68.80	67.77	79.74	78.98	38.79	33.75
$\frac{1}{4}$	86.08	82.23	74.40	74.79	75.12	86.24	86.52	51.87	48.22
$\frac{3}{16}$	89.38	86.64	80.08	83.04	80.06	89.92	90.27	59.64	57.62
$\frac{1}{8}$	93.11	91.62	87.56	87.06	86.65	93.71	94.61	70.33	70.77
8	96.17	95.21	92.93	91.58	92.38	96.48	97.31	79.54	80.20
14	97.85	97.27	96.08	94.85	95.79	98.18	98.65	86.20	86.53
25	99.02	98.64	98.13	96.97	98.44	99.20	99.27	92.59	92.55
36	99.25	98.91	98.53	98.44	98.88	99.37	99.37	94.20	94.13
52	99.43	99.15	98.85	98.75	99.18	99.49	99.46	95.70	95.66
72	99.58	99.37	99.12	99.01	99.40	99.59	99.55	97.10	97.14
100	99.71	99.55	99.33	99.26	99.57	99.68	99.64	98.16	98.20
150	99.79	99.68	99.48	99.46	99.69	99.76	99.69	98.82	98.87
200	99.84	99.76	99.60	99.61	99.77	99.82	99.79	99.14	99.20
240	99.87	99.80	99.66	99.71	99.81	99.85	99.83	99.28	99.36
100%	100.00	100.00	99.99	99.94	100.00	100.00	99.99	99.95	99.42

APPENDIX IB (Contd.)

Particle size data obtained from the western stream-bed material "Lanehead" (See Fig. 61B)

Sieves No.	Random Sampling Numbers								
	593	668	719	746	789	859	877	879	935
4	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-
$2\frac{1}{2}$	-	-	-	-	-	-	-	-	-
$1\frac{3}{4}$	-	14.57	-	10.89	17.04	-	-	-	8.32
$1\frac{1}{4}$	6.81	24.65	15.06	18.23	34.20	12.30	20.53	17.39	15.65
$\frac{3}{4}$	19.78	52.42	39.26	42.62	48.32	36.20	36.48	38.58	46.30
$\frac{1}{2}$	29.25	63.25	49.61	57.23	60.51	51.07	49.32	49.42	57.55
$\frac{3}{8}$	35.26	69.31	57.10	65.88	67.47	56.62	55.61	56.16	62.79
$\frac{1}{4}$	46.50	77.61	67.85	77.03	75.25	66.39	64.20	64.67	70.40
$\frac{3}{16}$	54.51	82.72	74.84	83.35	80.56	72.78	69.54	69.52	75.05
$\frac{1}{8}$	65.56	88.68	83.44	90.16	86.75	81.79	76.28	75.79	80.90
8	75.42	93.15	90.43	94.98	91.97	88.70	82.85	81.79	86.24
14	83.46	95.96	94.56	97.48	95.50	93.40	88.35	87.14	90.68
25	91.15	97.97	97.42	98.82	97.91	97.09	93.80	93.27	95.12
36	93.17	98.38	98.01	99.04	98.38	98.82	95.16	94.99	96.22
52	95.15	98.73	98.48	99.21	98.78	98.37	96.39	96.48	97.32
72	97.02	99.04	98.90	99.36	99.10	99.79	97.49	97.78	98.25
100	98.34	99.28	99.24	99.49	99.32	99.08	98.30	98.65	98.91
150	99.04	99.44	99.46	99.59	99.48	99.29	98.79	99.12	99.30
200	99.42	99.60	99.60	99.67	99.61	99.43	99.09	99.37	99.49
240	99.62	99.61	99.67	99.71	99.68	99.52	99.23	99.48	99.59
100%	100.00	99.90	99.96	99.94	99.95	99.96	99.96	99.96	99.94

APPENDIX IB (Contd.)

Particle size data obtained from the western stream-bed material "Lanehead" (See Fig. 61B)

Sieves	Random		Sampling			Numbers			
No.	946	1004	1024	1118	1295	1308	1371	1428	1551
4	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-
2½	-	-	-	-	-	-	-	-	-
1¾	23.01	8.41	7.82	-	-	14.12	9.84	25.14	11.57
1¼	37.02	20.11	17.27	15.27	7.24	30.25	17.39	29.89	24.32
¾	55.14	32.32	35.41	29.69	23.58	53.90	35.36	52.43	46.99
½	65.23	42.28	46.17	40.11	31.96	64.47	42.68	62.71	60.40
⅜	70.36	48.43	52.64	46.66	37.95	69.52	47.39	67.84	68.78
¼	79.46	57.85	61.59	54.88	46.94	76.84	58.15	76.01	80.30
3/16	84.22	64.63	67.52	61.07	53.75	80.62	65.11	80.39	86.05
⅛	89.58	73.97	75.77	69.44	63.57	85.83	75.49	85.72	90.92
8	93.65	82.15	83.35	77.89	73.10	90.42	84.36	90.35	94.61
14	96.24	88.17	88.84	85.13	80.92	93.92	90.95	93.91	97.20
25	98.06	93.74	94.20	92.12	89.73	97.02	96.21	97.04	98.75
36	98.45	95.13	95.47	93.88	92.18	97.74	97.31	97.74	98.98
52	98.73	96.35	96.75	95.61	94.47	98.34	98.08	98.34	99.16
72	98.94	97.50	97.91	97.18	96.50	98.84	98.63	98.83	99.31
100	99.10	98.31	98.73	98.28	97.89	99.18	98.97	99.14	99.45
150	99.20	98.82	99.16	98.91	98.63	99.38	99.22	99.34	99.57
200	99.31	99.10	99.40	99.22	99.01	99.54	99.39	99.49	99.67
240	99.36	99.24	99.51	99.37	99.24	99.61	99.47	99.57	99.73
100%	99.61	99.96	99.94	99.96	99.96	99.94	99.94	99.93	100.00

APPENDIX IB (Contd.)

Particle size data obtained from the western stream-bed material "Lanehead" (See Fig. 61B)

Sieves	Random Sampling Numbers								
No.	1558	1575	1616	1634	1746	1751	1789	1801	1859
4	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-
$2\frac{1}{2}$	-	-	-	-	-	-	-	-	-
$1\frac{3}{4}$	-	-	12.01	9.62	22.26	13.73	10.79	-	24.89
$1\frac{1}{4}$	12.74	23.45	30.65	16.66	44.35	29.38	26.03	-	32.09
$\frac{3}{4}$	29.29	64.29	78.04	34.68	55.11	44.63	36.10	6.73	41.95
$\frac{1}{2}$	37.73	74.44	90.94	42.11	59.86	54.97	43.63	20.69	48.59
$\frac{3}{8}$	43.68	79.54	94.36	45.75	63.87	60.94	49.16	31.71	53.84
$\frac{1}{4}$	56.26	86.74	97.75	54.17	69.58	70.87	59.39	38.20	62.17
$\frac{3}{16}$	63.62	90.22	98.70	60.23	74.02	76.74	66.31	50.49	67.93
$\frac{1}{8}$	73.63	94.15	99.30	70.35	80.52	83.77	76.31	59.41	76.34
8	82.44	96.62	99.59	79.68	87.08	89.55	84.78	71.24	84.10
14	88.87	98.08	99.70	86.59	91.79	93.58	90.78	81.07	89.89
25	94.77	98.84	99.76	93.48	96.05	96.42	95.96	87.93	95.29
36	96.11	98.99	99.77	95.04	97.01	97.43	97.05	93.63	96.52
52	97.19	99.14	99.78	96.34	97.76	98.07	97.91	94.98	96.62
72	98.03	99.31	99.80	97.48	98.37	98.65	98.55	96.22	97.48
100	98.66	99.48	99.83	98.28	98.82	99.07	98.99	97.06	98.03
150	99.04	99.62	99.85	98.74	99.09	99.32	99.21	97.56	98.32
200	99.27	99.72	99.89	99.07	99.31	99.49	99.43	97.85	98.54
240	99.94	99.77	99.90	99.23	99.41	99.58	99.63	97.98	98.66
100%	99.96	100.00	99.96	99.95	99.94	99.95	99.95	98.69	99.03

APPENDIX IB

Particle size data obtained from the western stream-bed material "Lanehead" (See Fig. 61B)

Sieves	Random Sampling Numbers								
No.	1920	2309	2394	2464	2639	2649	2696	2759	2783
4	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-
2½	-	-	-	-	-	16.98	14.14	-	-
$1\frac{3}{4}$	-	-	21.73	4.86	11.58	21.15	16.22	8.89	-
$1\frac{1}{4}$	16.55	18.42	33.86	32.46	16.99	23.97	22.16	18.21	27.26
$\frac{3}{4}$	35.13	41.97	48.71	51.01	32.63	40.55	39.38	28.30	36.29
½	39.42	55.75	57.70	63.92	43.79	50.15	52.24	36.44	42.69
$\frac{3}{8}$	44.15	63.22	63.79	69.40	51.03	56.57	59.59	43.60	47.07
$\frac{1}{4}$	52.41	72.09	72.76	76.49	60.80	66.46	71.68	56.18	56.94
$\frac{3}{16}$	58.87	78.02	78.83	80.35	66.82	72.79	77.85	63.70	63.72
$\frac{1}{8}$	69.13	84.87	85.62	85.64	74.87	80.17	85.07	73.31	73.14
8	79.19	90.50	90.90	90.32	82.37	86.88	90.37	81.45	82.11
14	86.20	94.11	94.20	93.67	88.29	91.65	93.84	87.76	88.63
25	92.89	96.79	96.86	96.79	94.09	96.02	96.84	93.70	94.76
36	94.54	97.42	97.48	97.54	95.49	97.06	97.56	95.13	96.14
52	95.99	98.00	98.03	98.16	96.67	97.90	98.21	96.38	97.26
72	97.30	98.55	98.57	98.66	97.72	98.59	98.77	97.49	98.20
100	98.21	99.00	99.02	99.06	98.49	99.07	99.19	98.29	98.81
150	98.70	99.28	99.23	99.32	98.98	99.31	99.42	98.78	99.14
200	99.06	99.47	99.43	99.50	99.23	99.51	99.57	99.11	99.37
240	99.23	99.55	99.52	99.60	99.35	99.59	99.67	99.27	99.48
100%	99.95	99.96	99.91	100.00	99.98	99.98	99.94	99.95	99.95

APPENDIX IB

Particle size data obtained from the western stream-bed material "Lanehead" (See Fig. 61B)

Sieves	Random Sampling Numbers				
No.	2815	2832	2907	2949	2993
4	-	-	-	-	-
3	-	-	-	-	-
2½	-	-	-	-	-
$1\frac{3}{4}$	6.53	28.11	14.00	7.45	36.00
$1\frac{1}{4}$	24.54	45.52	36.81	22.08	50.63
$\frac{3}{4}$	41.32	68.01	51.93	40.55	66.37
½	54.95	73.99	64.10	51.65	74.52
$\frac{3}{8}$	66.06	78.84	70.00	58.44	80.04
$\frac{1}{4}$	76.11	84.77	78.25	70.15	86.20
$\frac{3}{16}$	81.66	88.11	82.87	75.78	89.66
$\frac{1}{8}$	88.23	92.10	88.00	83.08	93.16
8	93.16	95.11	92.22	88.95	95.72
14	96.34	97.13	95.09	92.85	97.41
25	98.31	98.57	97.49	96.24	98.59
36	98.68	98.89	98.06	96.99	98.87
52	98.95	99.15	98.55	97.72	99.11
72	99.17	99.37	98.96	98.39	99.35
100	99.34	99.54	99.26	98.91	99.55
150	99.45	99.66	99.41	99.25	99.66
200	99.57	99.74	99.56	99.44	99.76
240	99.63	99.78	99.62	99.52	99.81
100%	99.99	99.96	99.93	99.95	99.99

APPENDIX IC

Particle size data obtained from the Netherhearth bed material
Teesdale (See Fig.6.1C)

Random Sampling Numbers

Sieves No.	23	25	26	91	95	141	219	221	312
4	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-
2½	-	-	-	-	-	-	-	-	-
$1\frac{3}{4}$	19.03	-	-	44.47	29.28	4.74	6.57	7.06	-
$1\frac{1}{4}$	27.64	16.34	-	60.27	51.49	17.17	28.75	29.17	33.47
$\frac{3}{4}$	57.67	42.61	12.75	78.04	68.49	37.37	53.66	61.52	63.66
½	75.86	65.08	29.36	87.58	80.90	47.55	69.07	75.35	80.65
$\frac{3}{8}$	84.68	78.56	60.05	92.17	86.07	55.64	77.44	82.30	88.04
$\frac{1}{4}$	91.43	90.88	78.06	96.96	93.63	67.55	87.12	89.32	95.41
$\frac{3}{16}$	94.66	94.96	85.92	98.53	96.45	75.30	91.76	92.80	97.77
$\frac{1}{8}$	97.52	98.12	93.54	99.56	98.61	84.00	95.75	96.03	99.13
8	98.98	99.53	96.41	99.89	99.49	90.68	97.94	97.93	99.68
14	99.59	99.87	98.52	99.95	99.73	94.68	98.87	98.85	99.84
25	99.83	99.93	99.60	99.96	99.84	98.04	99.20	99.48	99.91
36	99.86	99.94	99.86	99.97	99.87	98.69	99.56	99.60	99.92
52	99.88	99.95	99.91	99.98	99.89	99.13	99.66	99.70	99.93
72	99.90	99.96	99.92	99.99	99.91	99.41	99.75	99.78	99.94
100	99.92	99.97	99.93	100	99.93	99.61	99.83	99.85	99.96
150	99.94	99.98	99.94	100	99.94	99.74	99.89	99.90	99.98
200	99.95	99.99	99.95	100	99.95	99.81	99.92	99.93	99.99
240	99.96	99.99	99.96	100	99.96	99.84	99.93	99.95	100
100%	99.97	100	99.97	100	99.97	99.96	99.97	99.98	100

APPENDIX IC (Contd.)

Particle size data obtained from the Netherhearthbed material Teesdale (See Fig. 6.1C)

Random Sampling Numbers

Sieves No.	336	348	390	394	409	410	454	461	465
4	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-
2½	-	-	-	-	-	-	-	-	-
$1\frac{3}{4}$	-	5.23	-	8.06	19.69	-	7.27	7.64	15.50
$1\frac{1}{4}$	21.02	43.56	-	42.73	35.75	33.64	22.90	22.67	40.54
$\frac{3}{4}$	60.11	74.05	31.45	60.09	63.34	69.34	43.78	60.98	88.09
½	77.33	86.13	72.78	73.52	78.20	86.47	54.77	73.49	94.91
$\frac{3}{8}$	86.03	89.80	86.95	79.61	84.33	91.99	63.34	79.74	97.22
$\frac{1}{4}$	90.66	94.88	92.25	86.97	90.87	96.98	74.11	88.07	98.87
$\frac{3}{16}$	95.60	96.83	96.19	91.35	93.98	98.27	81.36	92.25	99.35
$\frac{1}{8}$	97.55	98.38	97.49	95.01	96.74	99.30	89.82	96.22	99.73
8	98.74	99.21	98.55	97.22	98.15	99.73	95.22	98.19	99.85
14	99.41	99.58	99.12	98.51	98.82	99.87	97.59	99.07	99.89
25	99.68	99.81	99.42	99.41	99.33	99.91	99.09	99.62	99.91
36	99.85	99.86	99.68	99.59	99.48	99.92	99.38	99.74	99.92
52	99.89	99.89	99.74	99.71	99.60	99.93	99.58	99.82	99.93
72	99.92	99.91	99.80	99.79	99.71	99.94	99.72	99.87	99.94
100	99.94	99.93	99.85	99.87	99.82	99.95	99.82	99.91	99.95
150	99.96	99.95	99.91	99.92	99.90	99.96	99.88	99.94	99.96
200	99.97	99.96	99.95	99.94	99.94	99.97	99.91	99.95	99.97
240	99.98	99.97	99.97	99.95	99.95	99.98	99.93	99.96	99.98
100%	99.99	99.98	99.99	99.98	99.98	99.99	99.98	99.97	99.99

APPENDIX 1C (Contd.)

Particle size data obtained from the Netherhearth bed material
Teesdale (See Fig. 6.1C)

Sieves No.	Random	Sampling	Numbers						
	477	498	516	543	550	574	705	706	719
4	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-
2½	-	-	-	-	-	-	-	-	-
$1\frac{3}{4}$	8.11	6.83	7.34	-	-	5.90	10.64	4.33	7.22
$1\frac{1}{4}$	10.48	18.69	45.00	45.90	20.05	16.97	31.12	15.82	20.07
$\frac{3}{4}$	26.66	48.03	63.47	80.39	49.17	47.23	55.36	31.01	53.88
½	42.23	61.03	78.21	90.39	61.40	68.62	77.35	50.72	70.71
$\frac{3}{8}$	55.75	69.52	85.09	94.32	70.10	78.13	84.61	61.32	77.36
$\frac{1}{4}$	73.19	79.46	92.15	97.40	81.78	86.57	94.14	75.35	85.37
$\frac{3}{18}$	81.89	85.37	94.78	98.66	87.06	90.09	97.53	82.53	89.71
$\frac{1}{8}$	88.56	90.75	97.08	99.43	93.16	93.87	99.37	89.84	93.86
8	92.51	94.68	98.59	99.73	96.92	96.77	99.79	94.55	96.74
14	94.89	97.01	99.29	99.83	98.60	98.39	99.85	97.29	98.28
25	97.08	98.67	99.64	99.88	99.37	99.30	99.87	98.84	99.14
36	97.70	99.02	99.71	99.89	99.50	99.47	99.88	99.14	99.32
52	98.31	99.30	99.76	99.90	99.60	99.59	99.89	99.37	99.46
72	98.84	99.52	99.81	99.92	99.68	99.69	99.90	99.54	99.57
100	99.26	99.69	99.86	99.94	99.78	99.80	99.92	99.69	99.70
150	99.54	99.81	99.90	99.96	99.86	99.89	99.94	99.80	99.81
200	99.69	99.87	99.93	99.97	99.90	99.93	99.95	99.86	99.86
240	99.75	99.90	99.94	99.98	99.92	99.95	99.96	99.88	99.89
100%	99.94	99.96	99.96	99.99	99.97	99.99	99.97	99.95	99.95

APPENDIX 1C (Contd.)

Particle size data obtained from the Netherhearthbed material Teesdale (See Fig. 6.1C)

Random Sampling Numbers

Sieves No.	733	742	767	814	819	905	994	996	1060
4	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-
2½	-	-	-	-	-	-	-	-	-
$1\frac{3}{4}$	10.68	12.06	-	6.59	3.04	-	-	-	4.92
$1\frac{1}{4}$	36.59	31.59	9.08	15.25	35.94	38.45	34.11	19.91	37.95
$\frac{3}{4}$	53.62	55.77	37.17	36.59	62.35	66.37	64.73	45.44	57.10
½	69.07	71.50	56.00	52.17	75.90	77.43	84.23	62.90	67.64
$\frac{3}{8}$	77.56	78.75	67.82	61.88	82.70	83.91	90.85	74.50	74.02
$\frac{1}{4}$	85.77	87.39	81.40	73.92	89.97	91.05	96.79	85.16	81.09
$\frac{3}{16}$	90.27	92.01	87.99	80.53	93.29	94.28	98.26	90.05	85.49
$\frac{1}{8}$	94.51	96.17	93.51	87.42	96.10	96.85	99.24	94.00	90.19
8	97.22	98.03	96.64	92.31	97.59	98.21	99.66	96.57	93.58
14	98.69	98.93	98.16	95.78	98.50	98.96	99.78	98.14	95.95
25	99.49	99.51	99.12	98.40	99.25	99.46	99.83	99.28	98.12
36	99.62	99.64	99.34	98.95	99.47	99.59	99.84	99.48	98.60
52	99.71	99.74	99.51	99.30	99.63	99.70	99.85	99.62	98.97
72	99.77	99.81	99.63	99.53	99.74	99.79	99.87	99.73	99.30
100	99.83	99.88	99.74	99.70	99.83	99.88	99.89	99.83	99.59
150	99.88	99.92	99.82	99.81	99.89	99.93	99.92	99.89	99.78
200	99.91	99.94	99.86	99.86	99.92	99.96	99.93	99.92	99.87
240	99.92	99.95	99.88	99.88	99.93	99.97	99.94	99.93	99.91
100%	99.96	99.97	99.96	99.96	99.96	99.99	99.95	99.96	99.98

APPENDIX 1C (Contd.)

Particle size data obtained from the Netherhearth bed material Teesdale (See Fig. 6.1C)

Random Sampling Numbers

Sieves No.	1086	1127	1224	1247	1254	1341	1345	1358	1485
4	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-
2½	-	-	-	-	-	-	-	-	-
$1\frac{3}{4}$	4.91	-	15.99	-	-	7.09	-	14.41	-
$1\frac{1}{4}$	14.94	4.28	24.08	18.25	23.26	27.76	18.73	26.45	41.68
$\frac{3}{4}$	54.59	30.42	45.17	43.25	45.88	50.11	43.92	42.29	62.33
½	74.65	46.46	63.00	58.99	60.62	67.64	57.43	58.08	73.47
$\frac{3}{8}$	81.45	60.41	70.49	67.79	72.08	74.68	65.88	68.78	79.59
$\frac{1}{4}$	88.87	68.43	79.87	79.03	83.45	83.69	79.45	83.01	88.59
$\frac{3}{16}$	92.57	80.01	85.23	85.92	89.15	88.77	85.76	90.18	93.30
$\frac{1}{8}$	95.20	84.96	89.93	90.97	93.74	93.17	92.56	96.19	96.93
8	97.13	90.12	93.29	94.24	96.42	95.92	96.66	98.88	98.93
14	98.35	93.75	95.53	96.32	98.00	97.35	98.37	99.66	99.59
25	99.22	96.05	97.82	98.50	99.19	98.50	99.18	99.82	99.82
36	99.39	98.30	98.44	98.99	99.46	98.86	99.37	99.85	99.85
52	99.54	98.90	98.93	99.37	99.64	99.19	99.53	99.87	99.88
72	99.66	99.33	99.29	99.61	99.75	99.45	99.66	99.89	99.91
100	99.78	99.59	99.57	99.77	99.84	99.67	99.77	99.92	99.94
150	99.87	99.77	99.74	99.86	99.90	99.81	99.85	99.95	99.96
200	99.91	99.87	99.82	99.91	99.93	99.87	99.89	99.97	99.97
240	99.93	99.89	99.85	99.93	99.94	99.89	99.91	99.98	99.98
100%	99.97	99.94	99.96	99.97	99.97	99.95	99.97	100	99.99

APPENDIX 1C (Contd.)

Particle size data obtained from the Netherhearthbed material
Teesdale (See Fig. 6.1C)

Sieves No.	Random				Sampling			Numbers	
	1499	1504	1559	1569	1578	1672	1726	1733	1742
4	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-
2½	-	-	-	-	-	-	-	-	-
$1\frac{3}{4}$	10.80	-	-	5.73	9.23	18.22	-	21.91	-
$1\frac{1}{4}$	33.56	12.63	14.75	15.56	34.08	41.15	21.29	34.50	12.92
$\frac{3}{4}$	54.58	32.27	36.60	39.55	50.49	60.01	43.55	58.84	37.90
½	64.27	64.05	54.90	59.06	62.47	72.71	58.69	69.64	51.88
$\frac{3}{8}$	71.51	72.87	65.46	69.00	70.86	78.84	66.11	76.18	60.48
$\frac{1}{4}$	80.94	84.97	79.58	81.36	81.36	86.17	75.21	81.62	74.24
$\frac{3}{16}$	86.69	91.00	87.79	87.21	87.83	89.06	80.86	84.83	80.22
$\frac{1}{8}$	92.25	95.63	94.82	92.30	94.29	92.21	86.51	88.20	87.24
8	95.91	97.57	98.51	94.47	98.00	94.90	91.01	91.41	92.71
14	97.83	98.33	99.53	95.11	99.28	96.96	94.48	94.26	96.24
25	98.96	98.88	99.74	95.22	99.68	98.61	97.37	97.19	98.42
36	99.25	99.02	99.76	95.24	99.74	98.94	98.02	97.92	98.82
52	99.48	99.17	99.78	95.25	99.78	99.21	98.55	98.51	99.13
72	99.65	99.31	99.80	95.27	99.82	99.45	98.97	99.00	99.37
100	99.79	99.43	99.84	95.30	99.87	99.65	99.35	99.40	99.58
150	99.87	99.51	99.88	95.33	99.91	99.79	99.62	99.67	99.74
200	99.91	99.54	99.90	95.34	99.93	99.86	99.75	99.79	99.83
240	99.93	99.55	99.91	95.35	99.94	99.89	99.80	99.84	99.86
100%	99.97	99.57	99.93	95.38	99.97	99.97	99.97	99.97	99.97

APPENDIX 1C (Contd.)

Particle size data obtained from the Netherhearth bed material
Teesdale (See Fig. 6.1C)

Random Sampling Numbers

Sieves No.	1747	1759	1802	1827	1854	1888	1929	2030	2033
4	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-
2½	-	-	-	-	-	-	-	-	-
$1\frac{3}{4}$	-	-	-	-	6.94	-	-	6.83	33.29
$1\frac{1}{4}$	12.66	23.41	4.50	25.37	32.62	9.29	6.87	15.38	51.50
$\frac{3}{4}$	24.96	44.99	37.16	52.10	53.09	27.88	20.10	32.93	62.29
½	41.36	57.36	52.66	67.25	64.37	40.62	30.64	50.52	69.76
$\frac{3}{8}$	56.60	65.39	61.19	74.04	71.63	52.64	40.83	57.79	74.92
$\frac{1}{4}$	64.95	75.20	71.88	83.42	81.91	67.96	56.46	69.87	81.53
$\frac{3}{16}$	77.54	80.47	77.62	87.55	87.14	76.37	66.18	76.70	85.55
$\frac{1}{8}$	86.02	85.74	83.67	92.36	92.34	83.88	76.43	83.46	89.41
8	92.98	90.00	88.39	95.79	95.77	88.94	83.50	89.27	92.94
14	95.62	93.31	91.85	97.99	97.39	92.31	89.18	93.45	95.68
25	97.44	96.56	96.13	99.21	98.84	95.46	94.35	96.80	98.02
36	97.76	97.46	97.18	99.41	99.13	96.46	95.71	97.53	98.55
52	98.04	98.27	98.07	99.56	99.36	97.49	97.03	98.15	98.95
72	98.26	98.93	98.80	99.68	99.55	98.52	98.17	98.66	99.26
100	98.45	99.32	99.30	99.79	99.71	99.15	98.92	99.14	99.53
150	98.59	99.64	99.62	99.87	99.83	99.54	99.44	99.48	99.71
200	98.67	99.76	99.76	99.91	99.89	99.72	99.67	99.64	99.80
240	98.70	99.81	99.82	99.93	99.91	99.79	99.76	99.71	99.84
100%	98.80	99.97	99.97	99.98	99.96	99.96	99.96	99.95	99.96

APPENDIX 1C (Contd.)

Particle size data obtained from the Netherhearthbed material
Teesdale (See Fig. 6.1C)

Sieves No.	Random Sampling Numbers								
	2146	2229	2232	2235	2260	2301	2378	2391	2401
4	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-
2½	15.32	-	-	-	-	-	-	-	-
1¾	29.27	14.27	16.76	-	- -	-	7.56	4.52	10.44
1¼	39.77	25.46	41.78	7.67	11.56	7.40	18.64	7.25	16.40
¾	56.84	44.55	62.45	33.56	25.20	24.47	35.57	22.86	34.96
½	67.28	58.98	70.60	50.08	37.19	35.74	53.24	34.71	46.41
3/8	73.59	67.07	75.54	60.72	45.46	45.09	59.98	44.82	54.63
1/4	81.03	76.50	82.32	69.15	58.52	56.67	72.42	62.01	66.60
3/16	85.03	81.86	86.19	78.35	65.48	64.87	79.34	70.83	73.43
1/8	90.00	87.46	90.26	83.06	74.31	73.95	85.69	78.96	80.77
8	93.45	92.18	93.41	88.20	82.18	81.74	90.32	84.70	86.69
14	95.60	95.70	95.83	92.43	87.60	87.17	93.05	88.62	90.79
25	98.08	98.16	97.93	95.58	94.02	91.50	96.55	92.80	95.50
36	98.60	98.66	98.43	98.03	95.68	93.07	97.48	94.37	96.46
52	99.04	99.04	98.85	98.52	97.09	94.50	98.30	96.20	97.46
72	99.34	99.33	99.20	98.92	98.19	95.78	98.96	97.91	98.49
100	99.60	99.56	99.49	99.25	98.95	96.46	99.42	98.82	99.09
150	99.77	99.72	99.69	99.51	99.44	96.91	99.69	99.41	99.50
200	99.85	99.81	99.79	99.61	99.66	97.10	99.81	99.66	99.70
240	99.88	99.85	99.84	99.65	99.74	97.20	99.86	99.76	99.79
100%	99.96	99.96	99.97	99.76	99.96	97.39	99.96	99.99	100

APPENDIX IC (Contd.)

Particle size data obtained from the Netherhearth bed material Teesdale (See Fig. 6.1C)

Sieves	Random Sampling Numbers								
No.	2405	2520	2524	2537	2568	2597	2622	2624	2633
4	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-
2½	-	-	-	-	-	-	-	-	-
1¾	6.66	16.30	22.35	6.87	7.21	-	-	-	4.95
1¼	22.40	28.15	32.67	20.12	28.13	10.66	29.06	7.14	14.78
¾	41.25	42.32	53.76	38.46	45.36	36.78	50.30	38.32	37.39
½	56.11	52.83	70.37	55.19	59.38	59.53	66.02	58.67	59.32
⅜	63.33	60.79	77.29	63.37	67.71	71.94	78.62	71.19	73.34
¼	74.03	72.46	86.42	76.85	77.61	85.17	89.67	83.44	84.32
3/16	79.43	79.04	90.42	82.85	83.00	90.07	92,77	88.75	88.92
⅛	85.54	85.45	94.21	88.62	88.51	93.82	95.01	93.37	92.17
8	90.10	89.93	96.31	92.71	92.88	95.84	96.30	95.45	93.98
14	93.37	92.92	97.60	95.73	95.95	96.81	97.00	96.51	94.98
25	96.53	95.70	98.92	98.10	98.17	97.75	97.81	97.61	96.41
36	97.40	96.54	99.26	98.64	98.60	98.12	98.14	97.99	96.98
52	98.14	97.42	99.50	99.05	98.97	98.55	98.54	98.46	97.69
72	98.77	98.27	99.66	99.32	99.28	99.03	98.98	98.98	98.51
100	99.27	98.94	99.78	99.54	99.54	99.44	99.37	99.38	99.15
150	99.58	99.36	99.86	99.70	99.72	99.72	99.65	99.66	99.59
200	99.73	99.55	99.90	99.79	99.84	99.85	99.79	99.80	99.79
240	99.79	99.63	99.92	99.83	99.85	99.90	99.85	99.85	99.87
100%	99.95	99.96	99.96	99.97	99.96	100.00	99.98	99.98	100.00

APPENDIX IC (Contd.)

Particle size data obtained from the Netherhearth bed material
Teesdale (See Fig. 6.1C)

Sieves	Random Sampling Numbers								
No.	2654	2714	2731	2820	2823	2859	2912	2939	3001
4	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-
$2\frac{1}{2}$	-	-	-	-	-	-	10.86	-	-
$1\frac{3}{4}$	5.23	-	8.50	-	3.30	-	17.38	16.58	15.15
$1\frac{1}{4}$	15.20	-	27.56	13.25	12.21	15.74	47.14	27.09	17.13
$\frac{3}{4}$	37.87	19.31	47.46	41.72	45.95	38.08	62.38	47.80	38.07
$\frac{1}{2}$	51.22	65.52	63.72	57.15	65.29	54.78	78.44	68.06	55.56
$\frac{3}{8}$	63.21	84.74	75.51	70.97	76.92	69.95	85.66	78.59	67.17
$\frac{1}{4}$	77.55	91.79	86.57	83.46	88.16	86.16	93.96	88.93	83.59
$\frac{3}{16}$	84.27	96.53	91.78	88.83	92.84	91.78	96.66	92.96	90.37
$\frac{1}{8}$	89.84	98.22	94.61	92.66	96.11	95.81	98.31	96.16	95.13
8	92.78	98.89	96.18	94.56	97.55	97.54	98.93	97.76	97.01
14	94.40	99.19	96.96	95.61	98.12	98.33	99.20	98.46	97.84
25	96.11	99.34	97.89	96.83	98.65	98.84	99.42	98.96	98.48
36	96.75	99.48	98.24	97.32	99.86	99.02	99.50	99.13	98.72
52	97.53	99.54	98.64	97.92	99.10	99.23	99.60	99.32	99.00
72	98.35	99.62	99.06	98.58	99.36	99.46	99.71	99.52	99.29
100	98.99	99.70	99.44	99.14	99.59	99.67	99.82	99.70	99.56
150	99.44	99.81	99.71	99.52	99.76	99.82	99.89	99.83	99.75
200	99.65	99.89	99.84	99.70	99.85	99.89	99.93	99.89	99.84
240	99.73	99.93	99.89	99.77	99.89	99.92	99.94	99.91	99.88
100%	99.92	99.96	100.00	99.96	99.98	99.98	99.97	99.97	99.97

APPENDIX IC (Contd.)

Particle size data obtained from the Netherhearth bed material
Teesdale (See Fig. 6.1C)

Sieves No.	3030	3079	3138	3170	3233	3236	3353	3354	3375
	Random	**Sampling**	**Numbers**						
4	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-
$2\frac{1}{2}$	-	-	-	-	-	-	-	-	-
$1\frac{3}{4}$	8.40	8.40	5.43	6.55	4.22	7.45	9.34	-	-
$1\frac{1}{4}$	32.79	18.01	22.49	14.22	15.57	10.86	11.52	12.53	-
$\frac{3}{4}$	56.17	39.61	51.30	30.43	42.18	23.30	32.98	31.28	17.66
$\frac{1}{2}$	71.98	57.46	69.38	49.38	58.16	39.40	47.46	50.61	31.10
$\frac{3}{8}$	80.60	69.06	79.09	63.51	68.69	52.94	58.62	61.42	42.52
$\frac{1}{4}$	90.06	83.00	88.23	79.26	81.72	73.20	75.82	77.37	62.81
$\frac{3}{16}$	93.80	88.70	92.25	88.07	87.87	83.76	83.45	85.22	76.19
$\frac{1}{8}$	96.44	93.19	95.33	93.71	92.96	92.13	91.54	91.91	87.55
8	97.81	95.24	97.15	95.73	95.62	95.62	95.40	95.22	93.65
14	98.46	96.32	98.03	96.46	96.78	96.78	96.87	96.66	96.00
25	98.90	97.30	98.65	97.65	97.85	97.85	97.90	97.80	97.45
36	99.05	97.70	98.88	98.07	98.22	98.20	98.25	98.19	97.90
52	99.24	98.20	99.13	98.54	98.63	98.63	98.66	98.64	98.39
72	99.44	98.74	99.39	99.00	99.07	99.10	99.06	99.11	98.90
100	99.64	99.19	99.64	99.41	99.42	99.47	99.46	99.45	99.37
150	99.79	99.52	99.81	99.68	99.66	99.73	99.72	99.69	99.68
200	99.86	99.68	99.89	99.80	99.78	99.85	99.84	99.80	99.81
240	99.89	99.74	99.92	99.85	99.83	99.90	99.88	99.85	99.86
100%	99.97	99.95	100.00	99.96	99.96	100.00	99.98	99.96	99.96

APPENDIX IC (Contd.)

Particle size data obtained from the Netherhearth bed material Teesdale (See Fig. 6.1C)

Sieve No.	Random Sampling Number
	3419
4	-
3	-
$2\frac{1}{2}$	-
$1\frac{3}{4}$	7.23
$1\frac{1}{4}$	39.47
$\frac{3}{4}$	66.71
$\frac{1}{2}$	81.76
$\frac{3}{8}$	88.60
$\frac{1}{4}$	93.37
$\frac{3}{16}$	96.30
$\frac{1}{8}$	98.28
8	99.31
14	99.72
25	99.86
36	99.88
52	99.90
72	99.92
100	99.94
150	99.96
200	99.97
240	99.98
100%	99.99

APPENDIX ID

Particle size data obtained from the eastern stream bank material "Lanehead" (See Fig. 6.1D)

Sieves	Random	Sampling	Numbers						
No.	99	184	382	903	1105	1233	1303	1374	1466
4	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-
2½	12.36	-	-	-	-	-	-	-	-
1¾	18.97	-	-	15.9	-	16.84	-	-	-
1¼	38.00	12.91	-	38.23	11.20	21.40	7.54	18.02	8.67
¾	44.30	29.69	1.26	61.17	23.37	41.28	36.75	-	14.58
½	52.84	47.25	7.09	73.97	32.78	55.34	48.63	20.58	18.15
⅜	56.74	56.44	12.16	77.19	38.99	61.57	55.91	23.97	20.11
¼	63.97	66.46	19.39	80.96	45.53	67.53	64.13	30.29	23.49
3/16	68.85	72.61	24.36	83.62	50.55	71.45	69.55	34.24	25.58
⅛	74.84	77.99	30.56	86.57	56.08	76.15	75.57	39.71	28.26
8	81.43	82.26	36.28	89.14	61.83	80.52	80.77	45.20	30.72
14	86.80	85.42	41.44	91.42	66.77	84.53	85.16	50.30	33.35
25	91.71	88.37	47.17	93.33	73.11	89.07	89.77	56.56	36.77
36	92.86	89.39	49.06	93.89	75.40	90.43	91.07	58.86	38.14
52	94.00	90.69	51.66	94.55	78.13	91.84	92.42	62.39	40.07
72	95.14	92.47	56.54	95.39	81.83	93.32	94.05	68.26	44.06
100	96.23	94.34	61.34	96.20	85.77	94.81	95.36	75.48	48.40
150	97.03	96.02	67.08	96.96	89.63	96.08	96.47	82.11	54.04
200	97.43	96.84	70.87	97.40	91.79	96.78	97.06	85.36	57.65
240	97.58	97.11	72.42	97.55	92.60	97.01	97.26	86.61	58.81
100%	97.68	97.25	73.17	97.70	93.10	97.20	97.41	87.38	59.03

APPENDIX ID (Contd.)

Particle size data obtained from the eastern stream bank material "Lanehead" (See Fig. 6.1D)

Sieve	Random Sampling No's.				
No.	1502	1600	1610	2207	2525
4	-	-	-	-	-
3	-	-	-	-	-
$2\frac{1}{2}$	-	-	-	-	-
$1\frac{3}{4}$	39.16	29.66	-	-	-
$1\frac{1}{4}$	-	-	18.88	4.13	-
$\frac{3}{4}$	41.53	34.03	20.63	16.20	7.66
$\frac{1}{2}$	49.08	45.18	21.33	18.94	18.82
$\frac{3}{8}$	53.39	49.81	23.30	22.62	25.18
$\frac{1}{4}$	58.21	54.49	27.96	26.96	33.23
$\frac{3}{16}$	61.34	57.17	31.22	29.77	39.63
$\frac{1}{8}$	65.26	61.18	35.66	33.26	47.39
8	69.00	65.15	39.49	36.71	55.58
14	72.40	69.01	43.16	39.95	63.20
25	76.46	73.40	47.93	44.12	73.65
36	78.15	75.07	49.84	45.62	76.97
52	80.36	77.55	52.29	47.45	80.54
72	83.22	80.94	55.62	50.16	84.44
100	86.50	84.20	59.90	54.08	87.93
150	89.54	87.40	64.81	60.22	90.86
200	91.11	89.14	68.17	65.88	92.38
240	91.67	89.77	69.65	68.15	92.91
100%	92.05	90.13	70.15	69.21	93.24

APPENDIX IE

Particle Size data obtained from the western stream banks material "Lanehead" (See Fig. 6.1E)

Sieves No.	Random Sampling Numbers								
	193	411	508	546	641	720	770	845	881
4	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-
$2\frac{1}{2}$	-	-	-	-	-	-	-	-	-
$1\frac{3}{4}$	-	-	-	28.42	12.30	-	-	31.14	-
$1\frac{1}{4}$	-	-	-	-	18.70	-	9.26	41.88	18.81
$\frac{3}{4}$	2.80	-	15.48	51.60	27.90	13.25	26.12	49.53	32.20
$\frac{1}{2}$	4.24	3.08	29.00	54.90	35.33	25.63	37.07	55.48	41.90
$\frac{3}{8}$	7.10	7.73	35.36	56.76	39.72	29.76	43.14	59.73	47.20
$\frac{1}{4}$	13.06	15.53	43.13	59.16	47.94	41.40	51.95	65.72	56.76
$\frac{3}{16}$	19.20	22.37	48.06	61.22	53.40	48.18	57.14	69.03	61.32
$\frac{1}{8}$	25.65	31.32	56.99	63.23	59.74	55.69	62.67	73.14	67.43
8	31.66	41.00	65.36	65.09	64.97	62.74	68.48	76.75	72.25
14	36.64	49.82	71.43	66.99	69.37	69.05	73.80	80.19	76.00
25	44.19	62.46	78.90	70.60	75.56	77.54	79.92	84.55	81.25
36	46.21	66.54	80.88	72.23	77.69	79.86	81.97	86.05	82.84
52	49.23	70.97	82.99	74.14	80.41	82.47	84.27	87.71	84.81
72	53.42	75.41	85.28	76.96	85.02	85.89	87.08	89.58	87.32
100	57.41	78.43	86.90	80.13	87.62	88.27	89.73	91.42	89.37
150	62.08	81.83	88.67	83.27	90.18	90.53	91.90	92.94	91.35
200	64.82	84.28	89.95	85.19	91.66	92.78	93.21	93.80	92.51
240	65.73	85.60	90.63	85.86	92.42	93.35	93.78	94.18	93.06
100%	66.51	86.35	91.19	86.33	92.88	93.89	94.39	94.35	93.50

Appendix IE (Contd.)

Particle Size data obtained from the western stream banks material "Lanehead" (See Fig. 6.1E)

Sieves No.	904	1005	1070	1299	1413	1504
4	-	-	-	-	-	-
3	-	-	-	-	-	-
$2\frac{1}{2}$	-	-	-	-	-	-
$1\frac{3}{4}$	-	-	-	-	21.83	-
$1\frac{1}{4}$	-	-	-	-	-	5.66
$\frac{3}{4}$	8.40	-	-	-	25.03	11.67
$\frac{1}{2}$	28.20	4.42	1.64	2.51	30.34	12.61
$\frac{3}{8}$	40.55	7.47	5.39	3.46	32.12	14.97
$\frac{1}{4}$	50.45	12.89	13.29	5.54	35.19	18.90
$\frac{3}{16}$	55.82	17.34	18.57	7.96	38.00	21.81
$\frac{1}{8}$	61.99	22.59	28.52	11.99	42.23	27.13
8	67.15	27.56	34.05	17.01	47.44	33.26
14	72.14	32.88	42.27	24.02	53.04	39.40
25	72.68	39.69	51.93	35.70	59.93	49.85
36	73.66	42.09	55.19	40.73	62.59	53.18
52	75.35	45.31	59.60	48.21	66.20	57.75
72	77.50	49.44	68.09	59.13	71.68	66.74
100	79.20	54.15	71.59	69.87	77.29	72.81
150	80.95	59.25	76.16	77.77	81.62	77.79
200	81.99	62.43	79.07	81.97	83.97	80.51
240	82.44	63.95	80.65	83.57	85.05	81.68
100%	82.79	65.29	82.15	84.82	86.04	82.37

APPENDIX IF

Particle size data obtained from Netherhearth banks material (Teesdale) (See Fig. 6.1F)

Sieves No.	82	98	290	315	323	333	471	804	847
4	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-
$2\frac{1}{2}$	-	-	23.67	-	-	-	24.21	-	-
$1\frac{3}{4}$	-	29.63	37.69	-	-	-	56.39	54.64	-
$1\frac{1}{4}$	30.19	38.89	47.99	19.90	-	25.16	59.10	60.85	-
$\frac{3}{4}$	54.22	53.25	57.53	25.73	11.22	40.44	66.23	75.46	9.01
$\frac{1}{2}$	67.54	59.72	67.97	28.62	26.24	50.233	69.65	80.37	21.63
$\frac{3}{8}$	73.11	63.36	72.77	29.56	36.90	56.65	71.95	83.75	29.19
$\frac{1}{4}$	79.25	69.76	79.23	31.04	48.22	65.29	75.19	86.81	40.41
$\frac{3}{16}$	81.97	73.85	82.69	31.93	54.58	69.70	77.14	88.16	45.96
$\frac{1}{8}$	84.73	78.90	86.84	33.60	61.55	74.65	79.26	89.81	51.97
8	87.28	83.05	90.71	35.84	66.74	79.40	80.84	91.13	57.03
14	89.90	86.67	93.60	39.20	70.11	83.66	82.64	92.46	62.69
25	92.72	91.06	96.24	47.01	74.69	88.55	85.28	94.23	72.85
36	93.66	92.74	96.88	51.28	76.61	90.07	86.41	94.89	76.93
52	94.73	94.19	97.39	57.31	78.72	91.55	87.60	95.64	81.27
72	95.92	95.46	97.77	65.56	80.95	92.91	88.87	96.42	85.45
100	97.10	96.61	98.07	74.10	83.30	94.00	90.05	97.21	89.30
150	97.95	97.43	98.27	81.08	85.51	94.92	91.12	97.86	92.12
200	98.34	97.85	98.36	84.46	86.60	95.34	91.67	98.18	93.40
240	98.48	98.00	98.39	85.61	86.96	95.47	91.83	98.29	93.77
100%	98.55	98.12	98.42	86.19	87.30	95.60	91.96	98.37	93.96

APPENDIX IF (Contd.)

Particle size data obtained from Netherhearth banks material
(Teesdale) (See Fig. 6.1F)

Sieves No.	867	889	995	1114	1192	1245	1470	1497	1591
4	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	57.38	-
$2\frac{1}{2}$	-	-	-	-	-	-	-	-	-
$1\frac{3}{4}$	-	-	-	-	27.92	35.65	14.46	-	-
$1\frac{1}{4}$	-	15.20	9.48	18.10	44.82	-	18.81	62.40	-
$\frac{3}{4}$	3.92	20.88	10.60	39.57	61.35	42.06	34.25	71.86	15.80
$\frac{1}{2}$	4.68	30.28	16.21	48.36	71.01	45.60	38.37	75.70	33.47
$\frac{3}{8}$	5.26	38.17	20.79	53.01	75.14	46.76	41.79	77.71	41.34
$\frac{1}{4}$	6.71	49.04	27.83	59.47	79.35	49.05	47.61	81.22	49.67
$\frac{3}{16}$	9.59	55.82	31.73	62.17	81.42	50.47	50.41	83.24	54.64
$\frac{1}{8}$	13.24	63.28	35.70	64.86	83.70	52.06	53.72	85.38	59.79
8	18.00	70.10	39.79	66.93	85.37	53.37	57.08	87.27	63.92
14	25.42	77.29	46.75	69.36	87.29	55.40	61.16	89.44	68.09
25	29.44	86.03	62.91	72.99	91.19	58.09	68.57	92.79	74.27
36	35.88	88.42	69.52	74.50	92.83	59.52	71.69	93.91	77.05
52	47.53	90.79	76.74	76.56	94.27	61.68	75.11	94.99	86.76
72	59.95	92.83	83.39	79.34	95.44	65.29	79.24	96.02	85.42
100	71.30	94.49	88.53	82.31	96.46	70.51	83.42	97.03	89.99
150	76.65	95.74	91.71	85.41	97.23	76.80	86.92	97.82	93.17
200	78.30	96.37	92.94	87.20	97.62	80.82	88.58	98.20	94.46
240	78.39	96.61	93.36	87.86	97.74	82.29	89.11	98.36	94.90
100%	78.94	96.83	93.71	88.22	97.84	82.88	89.31	98.48	95.19

APPENDIX IF (Contd.)

Particle size data obtained from Netherhearth banks material
(Teesdale) (See Fig. 6.1 F)

Sieve No.	1677	1693	1776	1847	1861	1964
4	-	-	-	-	-	-
3	-	-	-	-	-	-
$2\frac{1}{2}$	-	-	-	-	-	-
$1\frac{3}{4}$	13.13	-	8.50	-	23.15	27.33
$1\frac{1}{4}$	23.80	9.50	15.59	6.96	39.45	-
$\frac{3}{4}$	34.81	30.51	31.72	19.22	49.41	35.31
$\frac{1}{2}$	45.01	44.70	36.89	26.99	53.92	43.29
$\frac{3}{8}$	49.61	52.51	40.78	29.60	56.60	47.94
$\frac{1}{4}$	56.63	61.64	45.27	34.34	60.02	53.64
$\frac{3}{16}$	61.01	66.86	47.98	36.70	62.15	56.83
$\frac{1}{8}$	66.33	72.47	51.01	40.93	65.51	61.04
8	71.51	76.79	54.13	46.56	69.48	64.81
14	76.23	80.42	57.69	53.82	74.91	68.79
25	81.80	84.45	62.19	65.39	82.68	75.94
36	83.68	85.85	63.81	69.14	85.22	79.01
52	85.96	87.33	65.53	73.36	87.82	82.72
72	88.68	89.06	67.32	78.04	90.32	86.77
100	91.40	91.04	69.17	83.18	92.64	90.06
150	93.58	92.83	70.67	87.60	94.36	92.76
200	94.59	93.76	71.43	89.81	95.18	94.03
240	94.93	94.13	71.70	90.53	95.40	94.44
100%	95.21	94.45	71.87	90.86	95.60	94.74

APPENDIX 2A

Statistical analysis of particle size distribution curves of the eastern tributary Lanehead

		$\frac{(\phi 16 + \phi 50 + \phi 84)}{3}$	$\frac{(\phi 84 - \phi 16)}{2}$	$\frac{(\text{Mean } \phi - \text{Median } \phi)}{(\text{Sorting } \phi)}$
	Random No.	Mean Phi	Sorting Phi	Skewness Phi
1	11	- 3.23	+ 1.6	+ 0.04
2	15	- 3.93	+ 1.4	+ 0.19
3	79	- 3.67	+ 1.45	+ 0.16
4	90	- 3.4	+ 2.0	+ 0.2
5	151	- 3.63	+ 1.7	+ 0.04
6	172	- 4.47	+ 1.2	+ 0.11
7	188	- 3.03	+ 1.9	+ 0.04
8	207	- 3.67	+ 1.9	+ 0.07
9	304	- 3.48	+ 1.23	+ 0.18
10	361	- 4.2	+ 1.05	+ 0.29
11	364	- 3.9	+ 1.55	+ 0.26
12	449	- 3.3	+ 1.95	+ 0.15
13	450	- 4.05	+ 1.28	+ 0.20
14	579	- 3.23	+ 2.0	+ 0.24
15	588	- 4.48	+ 1.28	+ 0.33
16	641	- 3.5	+ 1.75	+ 0.29
17	671	- 3.45	+ 2.03	+ 0.32
18	723	- 3.47	+ 1.85	+ 0.23
19	872	- 3.97	+ 1.5	+ 0.22
20	891	- 4.08	+ 1.6	+ 0.23
21	996	- 3.37	+ 2.15	+ 0.11
22	1033	- 3.3	+ 2.0	+ 0.1
23	1055	- 3.75	+ 1.78	+ 0.53
24	1163	- 3.3	+ 1.9	+ 0.21
25	1218	- 3.95	+ 1.7	+ 0.29
26	1244	-3.65	+ 1.63	+ 0.15
27	1323	- 3.85	+ 1.45	+ 0.28
28	1344	- 3.77	+ 1.65	+ 0.38
29	1403	- 3.2	+ 1.9	+ 0.11

APPENDIX 2-A (Contd.)

	Random No.	Mean Phi	Sorting Phi	Skewness Phi
30	1424	- 2.97	+ 2.08	+ 0.01
31	1609	- 3.77	+ 1.55	+ 0.28
32	1623	- 3.02	+ 1.63	+ 0.17
33	1727	- 3.83	+ 1.5	+ 0.31
34	1772	- 4.67	+ 0.8	+ 0.16
35	1843	- 1.97	+ 2.0	- 0.04
36	1940	- 3.43	+ 2.0	+ 0.34
37	1965	- 2.7	+ 2.05	+ 0.24
38	1985	- 4.18	+ 1.45	+ 0.46
39	1996	- 3.03	+ 1.7	+ 0.16
40	2017	- 4.02	+ 1.35	+ 0.24
41	2026	- 4.12	+ 1.1	+ 0.21
42	2104	- 1.3	+ 1.1	+ 0.36
43	2215	- 4.33	+ 1.25	+ 0.30
44	2243	- 3.63	+ 1.45	+ 0.26
45	2317	- 4.4	+ 1.5	+ 0.4
46	2320	- 3.87	+ 1.85	+ 0.23
47	2342	- 4.0	+ 1.65	+ 0.18
48	2471	- 2.57	+ 1.95	+ 0.12
49	2472	- 2.13	+ 1.9	+ 0.14
50	2604	- 4.35	+ 1.3	+ 0.38

APPENDIX 2B

Statistical analysis of particle size distribution curves of the western tributary Lanehead

		$\frac{(\phi 16 + \phi 50 + \phi 84)}{3}$	$\frac{(\phi 84 - \phi 16)}{2}$	$\frac{(\text{Mean } \phi - \text{Median } \phi)}{(\text{Sarting } \phi)}$
	Random No.	Mean Phi	Sarting Phi	Skewness Phi
1	32	- 4.07	+ 1.1	+ 0.3
2	45	- 3.95	+ 1.38	+ 0.28
3	49	- 3.67	+ 1.6	+ 0.21
4	95	- 4.33	+ .85	- 0.04
5	103	- 3.75	+ 1.63	+ 0.28
6	282	- 4.17	+ 1.2	- 0.28
7	318	- 4.27	+ 1.2	+ 0.28
8	320	- 2.49	+ 1.99	+ 0.11
9	336	- 2.4	+ 1.85	+ 0.05
10	593	- 2.28	+ 2.18	+ 0.06
11	668	- 3.93	+ 1.5	+ 0.18
12	719	- 3.37	+ 1.73	+ 0.16
13	746	- 3.63	+ 1.45	+ 0.12
14	789	- 3.87	+ 1.7	+ 0.19
15	859	- 3.28	+ 1.68	+ 0.19
16	877	- 3.13	+ 2.15	+ 0.17
17	879	- 3.15	+ 2.03	+ 0.22
18	935	- 3.4	+ 1.8	+ 0.33
19	946	- 4.03	+ 1.65	+ 0.22
20	1004	- 2.97	+ 2.1	+ 0.06
21	1024	- 3.13	+ 2.0	+ 0.14
22	1118	- 2.75	+ 2.38	+ 0.11
23	1295	- 2.4	+ 2.1	0.00
24	1308	- 3.8	+ 1.75	+ 0.29
25	1371	- 3.07	+ 1.95	+ 0.02
26	1428	- 3.85	+ 1.88	+ 0.19
27	1551	- 3.85	+ 1.45	+ 0.14
28	1558	- 2.83	+ 2.0	+ 0.04
29	1575	- 4.1	+ 1.25	+ 0.24
30	1616	- 4.65	+ 0.65	0.00

APPENDIX 2B (Contd.)

	Random No.	Mean Phi	Sorting Phi	Skewness Phi
31	1634	- 2.83	+ 2.2	+ 0.03
32	1746	- 3.77	+ 2.1	+ 0.35
33	1751	- 3.6	+ 1.85	+ 0.16
34	1789	- 3.22	+ 2.05	+ 0.03
35	1801	- 2.57	+ 1.85	+ 0.02
36	1859	- 3.37	+ 2.3	+ 0.06
37	1920	- 2.73	+ 2.3	+ 0.03
38	2309	- 3.53	+ 1.65	+ 0.22
39	2394	- 3.8	+ 1.85	+ 0.16
40	2464	- 3.9	+ 1.85	+ 0.27
41	2639	- 3.03	+ 2.1	+ 0.13
42	2649	- 3.6	+ 2.4	0.00
43	2696	- 3.6	+ 1.85	+ 0.05
44	2759	- 2.88	+ 2.18	+ 0.01
45	2783	- 3.05	+ 2.25	0.00
46	2815	- 3.63	+ 1.55	+ 0.11
47	2832	- 4.30	+ 1.45	+ 0.34
48	2907	- 3.9	+ 1.6	+ 0.25
49	2949	- 3.42	+ 1.83	+ 0.21
50	2993	- 4.45	+ 1.4	+ 0.36

APPENDIX 2C

Statistical analysis of particle size distribution curves of the Netherhearth stream

		$\frac{(\phi 16 + \phi 50 + \phi 84)}{3}$	$\frac{(\phi 84 - \phi 16)}{2}$	$\frac{(\text{Mean } \phi - \text{Median } \phi)}{\text{Sorting } \phi}$
	Random No.	Mean Phi	Sorting Phi	Skewness Phi
1	23	- 4.32	+ 1.1	+ 0.03
2	25	- 4.02	+ 0.98	+ 0.08
3	26	- 4.37	+ 1.0	+ 0.13
4	91	- 4.93	+ 0.9	+ 0.3
5	95	- 4.65	+ 1.1	+ 0.27
6	141	- 3.35	+ 1.73	+ 0.09
7	219	- 4.05	+ 1.18	+ 0.21
8	221	- 4.23	+ 1.03	+ 0.21
9	312	- 4.43	+ 0.98	+ 0.12
10	336	- 4.72	+ 0.85	+ 0.39
11	348	- 4.57	+ 0.75	+ 0.31
12	390	- 4.57	+ 0.75	+ 0.04
13	394	- 4.27	+ 1.1	+ 0.3
14	409	- 4.4	+ 1.1	+ 0.18
15	410	- 4.62	+ 0.73	- 0.03
16	454	- 3.7	+ 1.5	+ 0.13
17	461	- 4.17	+ 1.1	+ 0.3
18	465	- 4.82	+ 0.5	+ 0.06
19	477	- 3.37	+ 1.25	+ 0.02
20	498	- 3.8	+ 1.35	+ 0.22
21	516	- 4.43	+ 0.95	+ 0.39
22	534	- 4.78	+ 0.75	+ 0.09
23	550	- 3.9	+ 1.35	+ 0.22
24	574	- 4.02	+ 1.05	+ 0.12
25	705	- 4.27	+ 1.0	+ 0.13
26	706	- 3.57	+ 1.45	+ 0.02
27	719	- 4.02	+ 1.18	+ 0.24
28	733	- 4.12	+ 1.28	+ 0.22
29	742	- 4.18	+ 1.18	+ 0.19

APPENDIX 2C (Contd.)

	Random No.	Mean Phi	Sorting Phi	Skewness Phi
30	767	- 3.63	+ 1.15	+ 0.15
31	814	- 3.53	+ 1.45	+ 0.12
32	819	- 4.32	+ 1.03	+ 0.27
33	905	- 4.42	+ 1.13	+ 0.16
34	994	- 4.52	+ 0.9	+ 0.03
35	996	- 3.93	+ 1.25	+ 0.14
36	1060	- 4.03	+ 1.45	+ 0.39
37	1086	- 4.07	+ 0.95	+ 0.24
38	1127	- 3.97	+ 1.63	+ 0.05
39	1224	- 3.88	+ 1.5	+ 0.11
40	1247	- 3.8	+ 1.3	+ 0.15
41	1254	- 3.9	+ 1.35	+ 0.07
42	1341	- 4.0	+ 1.3	+ 0.15
43	1345	- 4.3	+ 1.3	+ 0.31
44	1358	- 3.87	+ 1.35	+ 0.02
45	1485	- 4.38	+ 1.35	+ 0.2
46	1499	- 4.0	+ 1.4	+ 0.29
47	1504	- 3.78	+ 1.13	+ 0.11
48	1559	- 3.47	+ 1.6	+ 0.21
49	1569	- 3.75	+ 1.28	+ 0.12
50	1578	- 3.97	+ 1.35	+ 0.17
51	1672	- 4.27	+ 1.3	+ 0.25
52	1726	- 3.7	+ 1.55	+ 0.19
53	1733	- 4.03	+ 1.55	+ 0.24
54	1742	- 3.47	+ 1.55	+ 0.15
55	1747	- 3.8	+ 1.45	+ 0.07
56	1759	- 3.7	+ 1.65	+ 0.18
57	1802	- 3.37	+ 1.6	+ 0.21
58	1827	- 4.03	+ 1.3	+ 0.21
59	1854	- 4.0	+ 1.35	+ 0.22
60	1888	- 3.17	+ 1.5	+ 0.09
61	1929	- 2.73	+ 1.7	+ 0.04
62	2030	- 3.33	+ 1.7	+ 0.16
63	2033	- 4.33	+ 1.6	+ 0.42

APPENDIX 2C (Contd.)

	Random No.	Mean Phi	Sorting Phi	Skewness Phi
64	2146	- 4.2	+ 1.75	+ 0.17
65	2229	- 3.82	+ 1.6	+ 0.14
66	2232	- 4.12	+ 1.48	+ 0.32
67	2235	- 3.83	+ 1.55	+ 0.24
68	2260	- 2.8	+ 2.0	+ 0.1
69	2301	- 2.77	+ 1.85	+ 0.12
70	2378	- 3.52	+ 1.62	+ 0.11
71	2391	- 2.9	+ 1.7	+ 0.09
72	2401	- 3.17	+ 1.85	+ 0.12
73	2405	- 3.58	+ 1.65	+ 0.16
74	2520	- 3.28	+ 2.33	+ 0.22
75	2524	- 3.57	+ 0.85	- 0.2
76	2537	- 3.6	+ 1.5	+ 0.13
77	2568	- 3.77	+ 1.45	+ 0.16
78	2597	- 3.77	+ 1.1	+ 0.12
79	2622	- 4.17	+ 1.15	+ 0.03
80	2624	- 3.73	+ 1.15	+ 0.15
81	2633	- 3.8	+ 1.15	+ 0.09
82	2654	- 3.63	+ 1.3	+ 0.05
83	2714	- 4.37	+ 0.7	+ 0.19
84	2731	- 3.95	+ 1.05	+ 0.19
85	2820	- 3.45	+ 0.68	+ 0.81
86	2823	- 3.96	+ 1.05	+ 0.20
87	2859	- 3.17	+ 0.65	- 0.35
88	2912	- 4.5	+ 1.05	+ 0.29
89	2939	- 4.17	+ 1.18	- 0.02
90	3001	- 3.83	+ 1.35	- 0.02
91	3030	- 4.23	+ 1.05	+ 0.16
92	3079	- 3.9	+ 1.1	0.0
93	3138	- 4.07	+ 1.09	+ 0.17
94	3170	- 3.55	+ 1.23	- 0.04
95	3233	- 3.47	+ 1.7	+ 0.31
96	3236	- 3.38	+ 1.18	- 0.07

APPENDIX 2C (Contd.)

	Random No.	Mean Phi	Sorting Phi	Skewness Phi
97	3353	- 3.62	+ 1.03	- 0.12
98	3354	- 3.58	+ 1.28	+ 0.02
99	3375	- 3.22	+ 1.03	- 0.21
100	3419	- 4.4	+ 0.9	+ 0.22

APPENDIX 3-A

Data showing the Kolmogerov-Smirnov test results of the eastern and western streams at Lanehead catchment.

	Eastern Stream (Lanehead)		Western stream Lanehead		
Class interval in inches	Cumulative Frequency Distribution	Max. Deviation %	Cumulative Frequency Distribution	Max. Deviation %	Max. Deviation Eastern-Western %
2 - 4	78	20.47	118	28.85	8.38
4 - 6	131	34.38	188	45.97	11.59
6 - 8	182	47.77	257	62.84	15.07
8 - 10	261	68.50	312	76.28	7.78
10 - 12	279	73.23	332	81.17	7.94
12 - 14	299	78.48	351	85.82	7.34
14 - 16	310	81.36	360	88.02	6.66
16 - 18	318	83.46	365	89.24	5.78
18 - 20	324	85.04	370	90.46	5.42
20 - 22	329	86.35	373	91.20	4.85
22 - 24	332	87.14	374	91.44	4.30
24 - 26	345	90.55	383	93.64	3.09
26 - 28	351	92.13	387	94.62	2.49
28 - 30	352	92.39	391	95.60	3.21
30 - 32	354	92.91	392	95.84	2.93
32 - 34	356	93.44	393	96.09	2.65
34 - 36	356	93.44	395	96.58	3.14
36 - 38	368	96.59	403	98.53	1.94
38 - 40	368	96.59	408	99.76	3.17
40 - 42	373	97.90	408	99.76	1.81
42 - 44	373	97.90	408	99.76	1.86
44 - 46	375	98.43	408	99.76	1.33
46 - 48	375	98.43	408	99.76	1.33
48 - 50	378	99.21	409	100.00	0.79
50 - 52	378	99.21	-	100.00	0.79
52 - 54	379	99.48	-	100.00	0.52
54 - 56	380	99.74	-	100.00	0.26
56 - 58	380	99.74	-	100.00	0.26

APPENDIX 3-A (Contd.)

	Eastern Stream (Lanehead)		Western stream Lanehead		
Class interval in inches	Cumulative frequency Distribution	Max. Deviation %	Cumulative Frequency Distribution	Max. Deviation %	Max. Deviation Eastern-Western %
58 - 60	380	99.74	-	100.00	0.26
60 - 62	380	99.74	-	100.00	0.26
62 - 64	380	99.74	-	100.00	0.26
64 - 66	380	99.74	-	100.00	0.26
66 - 68	380	99.74	-	100.00	0.26
68 - 70	381	100.00	-	100.00	0.00

$$N = \frac{(X \times Y)}{(X + Y)} =$$

$$N = \frac{381 \times 409}{381 + 409} = \frac{155829}{709} = 219.7870$$

$$= 9\%$$

APPENDIX 3B

Data obtained from the Kolmogerov-Smirnov test of the Netherhearth against the eastern and western streams at Lanehead Catchment

Class Interval in inches	Cumulative Frequency Distribution of Netherheart	Max. Deviation of the Netherhearth	Max. of the Netherhearth against the eastern and the western stream. Lanehead	
			Neth-Eastern %	Neth-western %
2 - 4	436	41.92	21.45	13.07
4 - 6	645	62.02	27.64	16.05
6 - 8	817	78.56	30.79	15.72
8 - 10	963	92.60	24.10	16.32
10 - 12	988	95.00	21.77	13.83
12 - 14	994	95.56	17.08	9.74
14 - 16	1000	96.15	14.79	8.13
16 - 18	1006	96.73	13.27	7.49
18 - 20	1010	97.12	12.08	6.66
20 - 22	1020	98.08	12.11	6.88
22 - 24	1024	98.46	11.32	7.02
24 - 26	1027	98.75	8.20	5.11
26 - 28	1028	98.85	6.72	4.23
28 - 30	1031	99.13	6.74	3.53
30 - 32	1032	99.23	6.32	3.39
32 - 34	1033	99.33	5.89	3.24
34 - 36	1033	99.33	5.89	2.75
36 - 38	1036	99.62	3.03	1.09
38 - 40	1037	99.71	3.12	0.05
40 - 42	1037	99.71	1.81	0.05
42 - 44	1038	99.81	1.11	0.05
44 - 46	1040	100.00	1.57	0.24
46 - 48	-	100.00	1.57	-
48 - 50	-	100.00	0.79	-
50 - 52	-	100.00	0.79	-
52 - 54	-	100.00	0.52	-

APPENDIX 3B

Class Interval in inches	Cumulative Frequency Distribution of Netherhearth	Max. Deviation of the Netherhearth	Max. dev. of the Netherhearth against the eastern and the western stream. Lanehead Neth-Eastern %	 Neth-western %
54 - 56	-	100.00	0.26	-
56 - 58	-	100.00	0.26	-
58 - 60	-	100.00	0.26	-
60 - 62	-	100.00	0.26	-
62 - 64	-	100.00	0.26	-
64 - 66	-	100.00	0.26	-
66 - 68	-	100.00	0.26	-
68 - 70	-	100.00	00.00	-

(1) Netherhearth against the eastern stream.

$$N = \frac{(X \times Y)}{(X + Y)}$$

$$N = \frac{1040 \times 381}{1040 + 381} = \frac{296240}{1421} = 278.84588$$

$$= 8\%$$

(2) Netherhearth against the western stream.

$$N = \frac{(X \times Y)}{(X + Y)}$$

$$N = \frac{1040 \times 409}{1040 + 409} = \frac{425360}{1449} = 293.55417$$

$$= 7.5\%$$

APPENDIX 4A

Percentages Gravel, Sand and Silt of the eastern stream bed material - Lanehead

	Percentages		
Sample No.	Gravel	Sand	Silt
11	91	8.7	0.3
15	97	2.9	0.1
79	93	6.8	0.2
90	95.5	4.0	0.5
151	96	3.9	0.1
172	96	3.8	0.2
188	85.5	13.5	1.0
207	91	8	1.0
304	94	5.9	0.1
361	95	4.5	0.5
364	94.5	5	0.5
449	87.1	11.9	1.0
450	97	2.9	0.1
579	84.5	15.1	0.4
588	95	4.7	0.3
641	88.5	10.1	1.4
671	84.4	13.2	2.4
723	89.6	8	2.4
872	94.4	4.6	1.0
891	94	5.6	0.4
996	86	13.7	0.3
1033	86	12.2	1.8
1055	88	10	2.0

APPENDIX 4A (Contd.)

	Percentages		
Sample No.	Gravel	Sand	Silt
1163	87	10	3.0
1218	91	8.9	0.1
1244	93	6.8	0.2
1323	93	6.2	0.8
1344	92	6.0	2.0
1403	87	12.0	1.0
1424	84	13	3
1609	95	4.9	0.1
1623	86	12	2
1727	94	5	1
1772	98	1.5	0.5
1843	69	2.9	2.0
1940	86	13	1.0
1965	84.5	14	1.5
1985	94.5	5	0.5
1996	86	13	1.0
2017	95	4.5	0.5
2026	96	3.9	0.1
2104	66	3.1	4
2215	95	4.7	0.3
2243	93.2	6.7	0.1
2317	93	6	1.0
2320	90	9	1.0
2342	92.5	7	0.5
2471	80	18	2
2472	78	21	1
2604	93	6.8	0.4

APPENDIX 4B

Percentages grave, Sand and silt of the western stream bed material - Lanehead

Sample No.	Percentages Gravel	 Sand	 Silt
32	96	3	1.0
45	95	4	1.0
49	93.5	5.5	1.0
95	95	4	1.0
103	92.5	6.5	1.0
282	96.5	2.5	1.0
318	97	2	1.0
320	90	9	1.0
336	90.5	9	0.5
593	76	23	1.0
668	93	5.5	0.5
719	90	8	2.0
746	95	4.5	0.5
789	93	6	1.0
859	89	10.5	0.5
877	83	16	1.0
879	82	17	1.0
935	86	13.5	0.5
946	94	5	1.0
1004	82.5	17	0.5
1024	83.7	16	0.3
1118	78	21	1.0
1295	74	24	2.0
1308	90.5	9	0.5
1371	85	14	1.0
1428	90.6	9	0.4
1551	95	4	1.0
1558	83	16.5	0.5
1575	97	2.8	0.2
1616	99	0.9	0.1

APPENDIX 4B (Contd.)

Sample No.	Percentages Gravel	 Sand	 Silt
1634	81	18	1.0
1746	87	12	1.0
1751	90.5	9	0.5
1789	86	13.3	0.7
1801	82	17	1.0
1859	84	15.6	0.4
1920	79	20	1
2309	92	6.5	1.5
2394	92	7.6	0.4
2464	90	9	1.0
2639	83	16.5	0.5
2649	88	11.5	0.5
2696	90.2	8.8	1.0
2759	82	17.4	0.6
2783	83	16.7	0.3
2815	94	5	1.0
2832	96	3.9	0.1
2907	92	7.4	0.6
2949	89	10.8	0.2
2993	96.5	3	0.5

APPENDIX 4C

Percentages gravel, sand and silt of the Netherhearth bed material

	Percentages		
Sample No.	Gravel	Sand	Silt
23	99	0.5	0.5
25	99	0.7	0.3
26	99	0.4	0.6
91	99	0.5	0.5
95	99	0.8	0.2
141	91	8.9	0.1
219	98	1.6	0.4
221	98	1.4	0.6
312	99	0.9	0.1
336	99	0.8	0.2
348	99	0.7	0.3
390	99	0.5	0.5
394	97	2.8	0.2
409	98	1.6	0.4
410	99	0.8	0.2
454	95	3.9	1.1
461	98	1.9	0.1
465	99	0.7	0.3
477	93	6.8	0.2
498	95	4.9	0.1
516	99	0.8	0.2
534	99	0.7	0.3
550	97	2.7	0.3
574	97	2.9	0.1
705	99	0.8	0.2
706	95	4.7	0.3
719	96	3.2	0.8
733	97	2.4	0.6
742	98	1.5	0.5
767	97	2.4	0.6
814	92	7.6	0.4

APPENDIX 4C Contd.

Percentages grave, sand and silt of the Netherhearth bed material

Sample No.	Percentages Gravel	 Sand	 Silt
819	98	1.7	0.3
905	98	1.4	0.6
994	99	0.7	0.3
996	97	2.9	0.1
1060	94.5	5.2	0.3
1086	97	2.7	0.3
1127	94	5.9	0.1
1224	93	6.8	0.2
1247	94	5.7	0.3
1254	96.5	2.5	1.0
1341	96	3.2	0.8
1345	98	1.9	0.1
1358	99	0.9	0.1
1485	99	0.7	0.3
1499	96	3.8	0.2
1504	98	1.6	0.4
1599	99	0.8	0.2
1569	95	4.6	0.4
1578	98	1.7	0.3
1672	95.4	3.5	1.1
1726	91	8.7	0.3
1733	91	8.5	0.5
1742	93	6.8	0.2
1747	96	3.8	0.2
1759	90	9.7	0.3
1802	88	11.6	0.4
1827	96	3.5	0.5
1854	97	2.9	0.1
1888	89	10.5	0.5
1929	84	15.9	0.1
2030	89	10.4	0.6

APPENDIX 4C (Contd.)

Sample No.	Gravel	Sand	Silt
2033	93	6.4	0.6
2146	93.5	5.2	1.3
2229	92	7.6	0.4
2232	93	6.4	0.6
2235	92	7.4	0.6
2260	92.6	6.9	0.5
2301	82	17.3	0.7
2378	90	9.3	0.7
2391	85	14.6	0.4
2401	87	12.8	0.2
2405	90	9.7	0.3
2520	90	8.9	1.1
2524	96	3.7	0.3
2537	93	6.8	0.2
2568	93	6.9	0.1
2597	96	3.7	0.3
2622	96	3.6	0.4
2624	95	4.9	0.1
2633	94	5.2	0.8
2654	93	6.4	0.6
2714	99	0.6	0.4
2731	96	3.4	0.6
2820	95	4.5	0.5
2823	98	1.7	0.3
2859	98	1.1	0.9
2912	99	0.5	0.5
2939	98	1.8	0.2
3001	97	2.6	0.4
3030	98.5	1.2	0.3
3079	95	4.9	0.1
3138	97	2.8	0.2

APPENDIX 4C(Contd.)

Sample No.	Gravel	Sand	Silt
3170	96	3.8	0.2
3233	96	3.5	0.5
3236	96	3.7	0.3
3353	95	4.4	0.6
3354	95	4.1	0.9
3375	94	5.2	0.8
3419	99	0.6	0.4

APPENDIX 4D

Percentages gravel, sand, silt of the eastern stream banks material

Sample No.	Percentages Gravel	 Sand	 Silt
99	81	18	1.0
184	82	15	3.0
382	36	35	29
903	89	9	2.0
1105	62	30	8.0
1233	82	15	3.0
1303	82	14	4.0
1374	45	41	14
1466	31	28	41
1502	69	22	9
1600	35	40	25
1610	39	30	31
2207	37	31	32
2525	57	35	8.0

APPENDIX 4E

Percentages gravel, sand and silt of the western stream banks material

Samples No.	Percentages Gravel	 Sand	 Silt
193	32	34	34
411	41	43	16
508	65	26	9
546	65	20	15
641	66	26	8
720	64	29	7
770	69	25	6
845	77	17	6
881	73	20	7
904	67	25	8
1005	28	35	37
1070	34	44	22
1299	17	66	17
1413	47	38	15
1504	33	48	19

APPENDIX 4F

Percentages grave, sand and silt of the Netherhearth banks material

	Percentages		
Samples No.	Gravel	Sand	Silt
82	87	10	3.0
98	53	33	15
290	67	18	15
315	37	48	15
323	55	21	24
333	79	16	5.0
471	82	10	8.0
804	36	18	46
847	57	36	7.0
867	18	60	22
889	70	26	4.0
995	40	53	7.0
1114	67	21	12
1192	85	13	2.0
1245	53	29	18
1470	57	32	11
1497	30	35	35
1591	64	30	6.0
1677	72	22	6.0
1693	77	16	7.0
1776	55	15	30
1861	69	26	5.0
1847	47	43	10
1964	66	28	6.0

APPENDIX 5A

Stone count data obtained from the Lanehead eastern tributary bed material (Percentages)

		LST	SH	SST	Total	%LST	%SH	%SST
1	11	11	197	263	471	2.34	41.83	55.84
2	15	1	242	378	621	0.16	38.97	60.87
3	79	27	217	370	614	4.40	35.34	60.26
4	90	38	128	436	602	6.31	21.26	72.43
5	151	17	241	355	613	2.77	39.31	57.91
6	172	11	149	227	387	2.84	38.50	58.66
7	188	1	369	183	553	0.18	66.73	33.09
8	207	-	466	71	537	-	86.78	13.22
9	304	12	153	612	777	1.54	19.69	78.76
10	361	11	160	258	429	2.56	37.30	66.43
11	364	17	161	318	496	3.43	32.46	64.11
12	449	10	77	447	534	1.87	14.42	83.71
13	450	15	209	452	676	2.22	30.92	66.86
14	579	9	56	452	517	1.74	10.83	87.43
15	588	2	19	231	252	0.79	7.54	91.17
16	641	14	179	434	627	2.23	28.55	69.22
17	671	3	80	283	366	0.82	21.86	77.32
18	723	-	188	416	604	-	31.13	68.87
19	872	8	58	443	509	1.57	11.39	87.03
20	891	4	70	295	369	1.08	18.97	79.95
21	996	4	73	219	296	1.35	24.66	73.99
22	1033	54	117	210	381	14.17	30.71	55.12
23	1055	28	102	459	589	4.75	17.32	77.93
24	1163	22	59	232	313	7.03	18.85	74.12
25	1218	97	18	201	316	30.70	5.70	63.61
26	1244	18	397	638	1053	1.71	37.70	60.59
27	1323	18	188	337	543	3.31	34.62	62.06
28	1344	3	175	142	320	0.94	54.69	44.38
29	1403	17	161	244	422	4.03	38.15	57.82
30	1424	-	289	144	433	-	66.74	33.26

APPENDIX 5A (Contd.)

		LST	SH	SST	TOTAL	%LST	%SH	%SST
31	1609	12	80	421	513	2.34	15.59	82.07
32	1623	7	219	242	468	1.50	46.79	51.71
33	1727	27	112	230	369	7.32	30.35	62.33
34	1772	2	132	117	251	0.80	52.59	46.61
35	1843	-	207	104	311	-	66.56	33.44
36	1940	-	135	151	286	-	47.20	52.80
37	1965	-	368	132	500	-	73.60	26.40
38	1985	-	311	174	485	-	64.12	35.88
39	1996	-	540	90	630	-	85.71	14.29
40	2017	-	288	211	499	-	57.72	42.28
41	2026	39	233	394	666	5.86	34.98	59.16
42	2104	2	638	191	831	0.24	76.77	22.98
43	2215	16	121	173	310	5.16	39.03	55.81
44	2243	7	228	311	546	1.28	41.76	56.96
45	2317	29	409	152	590	4.92	69.32	25.76
46	2320	1	433	47	481	0.21	90.02	9.77
47	2342	-	515	75	590	-	87.29	12.71
48	2471	-	105	410	515	-	20.39	79.61
49	2472	1	559	44	604	0.17	92.55	7.28
50	2604	10	493	14	517	1.93	95.36	2.70

APPENDIX 5-B

Stone Counts data obtained from the Lanehead eastern Tributary Banks material.

	Random No.	LST	SH	SST	Total	%LST	%SH	%SST
1	99	8	16	206	230	3.48	6.96	89.57
2	184	17	5	189	211	8.06	2.37	89.57
3	382	-	10	161	171	-	5.85	94.15
4	785	Sand Stone Fragments						
4	903	5	16	87	108	4.63	14.81	80.56
5	1105	-	31	118	149	-	20.81	79.19
6	1233	2	10	151	163	1.23	6.13	92.64
7	1303	3	15	213	231	1.30	6.49	92.21
8	1374	2	8	84	94	2.13	8.51	89.36
9	1466	-	7	44	51	-	13.73	86.27
10	1502	-	12	89	101	-	11.88	88.12
11	1600	-	8	99	107	-	7.48	92.52
12	1610	1	18	61	80	1.25	22.50	76.25
13	2207	-	20	109	129	-	15.50	84.50
14	2525	12	18	148	178	6.74	10.11	83.15

APPENDIX 5-C

Stone Counts data obtained from the Lanehead western stream bed material.

						Percentages		
		LST	SH	SST	TOTAL	% LST	% SH	% SST
1	32	-	103	218	321	-	32.09	67.91
2	45	1	307	280	588	0.17	52.21	47.62
3	49	1	222	366	589	0.17	37.69	62.14
4	95	1	131	254	386	0.26	33.94	65.80
5	103	1	153	122	276	0.36	55.43	44.20
6	282	-	140	305	445	-	31.46	68.54
7	318	3	182	246	431	0.70	42.23	57.08
8	320	-	112	352	464	-	24.14	75.86
9	336	-	255	320	575	-	44.35	55.65
10	593	1	311	275	587	0.17	52.98	46.85
11	668	-	155	295	450	-	34.44	65.56
12	719	1	114	210	325	0.31	35.08	64.62
13	746	1	323	433	757	0.13	42.67	57.20
14	789	-	165	232	397	-	41.56	58.44
15	859	-	223	313	536	-	41.60	58.40
16	877	-	147	285	432	-	34.03	65.97
17	879	-	121	262	383	-	31.59	68.41
18	935	-	94	254	348	-	27.01	72.99
19	946	-	214	266	480	-	44.58	55.42
20	1004	-	235	220	455	-	51.65	48.35
21	1024	-	179	198	377	-	47.48	52.52
22	1118	-	98	309	407	-	24.08	75.92
23	1295	1	316	198	515	0.19	61.36	38.45
24	1308	1	113	172	286	0.35	39.51	60.14
25	1371	-	233	248	481	-	48.44	51.56
26	1428	6	263	320	589	1.02	44.65	54.33
27	1551	1	212	285	498	0.20	42.57	57.23
28	1558	1	337	283	621	0.16	54.27	45.57
29	1575	4	192	220	416	0.96	46.15	52.88
30	1616	11	85	151	247	4.45	34.41	61.13

APPENDIX 5-C (Contd.)

		LST	SH	SST	TOTAL	% LST	% SH	% SST
31	1634	5	159	239	403	1.24	39.45	59.31
32	1746	-	197	167	364	-	54.12	45.88
33	1751	-	162	382	544	-	29.78	70.22
34	1789	-	179	218	397	-	45.09	54.91
35	1801	-	210	357	567	-	37.04	62.96
36	1859	-	124	441	565	-	21.95	78.05
37	1920	-	112	209	321	-	34.89	65.11
38	2309	1	129	263	393	0.25	32.82	66.92
39	2394	-	149	332	481	-	37.91	69.02
40	2464	-	124	232	356	-	34.83	65.17
41	26.39	-	185	213	398	-	46.48	53.52
42	2649	-	131	222	353	-	37.11	62.89
43	2696	-	162	335	497	-	32.60	67.40
44	2759	-	197	287	484	-	40.70	59.30
45	2783	1	217	220	438	0.23	49.54	50.23
46	2815	-	125	254	379	-	32.98	67.02
47	2832	-	97	214	311	-	31.19	68.81
48	2907	-	132	252	384	-	34.38	65.63
49	2949	-	225	278	503	-	44.73	55.27
50	2993	1	168	239	408	0.25	41.18	58.58

APPENDIX 5-D

Stone counts data obtained from the Lanehead western stream-banks material

						Percentages		
		LST	SH	SST	TOTAL	% LST	% SH	% SST
1	193	-	60	39	99	-	60.61	39.39
2	411	-	2	136	138	-	1.45	98.55
3	508	-	11	176	187	-	5.88	94.12
4	546	-	51	28	79	-	64.56	35.44
5	641	-	141	76	217	-	64.98	35.02
6	720	-	172	88	260	-	66.15	33.85
7	770	-	131	72	203	-	64.53	35.47
8	845	-	94	84	178	-	52.81	47.19
9	881	-	117	95	212	-	55.19	44.81
10	904	-	280	21	301	-	93.02	6.98
11	1005	-	114	8	122	-	93.44	6.56
12	1070	-	19	154	173	-	10.98	89.02
13	1299	-	12	21	33	-	36.36	63.63
14	1413	-	13	69	82	-	15.85	84.15
15	1504	-	17	57	74	-	22.97	77.03

APPENDIX 5-E

Stone counts data obtained from the Netherhearth bed material

						Percentages		
		LST	SH	SST	TOTAL	%LST	%SH	% SST
1	23	1	181	273	455	0.22	39.78	60
2	25	-	230	276	506	-	45.45	54.54
3	26	-	161	188	349	-	46.13	53.87
4	91	-	152	171	323	-	47.06	52.94
5	95	1	161	182	344	0.29	46.80	52.91
6	141	-	140	305	445	-	31.46	68.54
7	219	1	110	380	491	0.20	22.40	77.39
8	221	-	61	282	343	-	17.78	82.22
9	312	-	46	451	497	-	9.26	90.74
10	336	-	115	150	265	-	43.40	56.60
11	348	-	81	168	249	-	32.53	67.47
12	390	-	95	156	251	-	37.85	62.15
13	394	-	133	195	328	-	40.55	59.45
14	409	-	84	307	391	-	21.48	78.52
15	410	-	107	270	377	-	28.38	71.62
16	454	-	216	214	430	-	50.23	49.77
17	461	-	172	226	398	-	43.22	56.78
18	465	-	12	102	114	-	10.53	89.47
19	477	-	240	335	689	-	34.83	48.62
20	498	-	64	363	427	-	14.99	85.01
X 21	516	-	27	268	295	-	9.15	90.85
22	534	-	28	205	233	-	12.02	87.98
23	550	-	54	307	361	-	14.96	85.04
24	574	-	55	322	377	-	14.59	85.41
25	705	1	71	378	450	0.22	15.78	84.00
26	706	1	67	388	456	0.22	14.69	85.09
27	719	-	55	388	393	-	13.99	86.01
28	733	-	110	202	312	-	35.26	64.74
29	742	-	140	272	412	-	33.98	66.02
30	767	2	152	344	498	0.40	30.52	69.08

APPENDIX 5-E (Contd.)

		LST	SH	SST	TOTAL	Percentages % LST	 % SH	 % SST
31	814	3	305	280	588	0.51	51.87	47.62
32	819	1	203	251	455	0.22	44.62	55.16
33	905	-	180	249	429	-	41.96	58.04
34	994	1	13	293	307	0.33	4.23	95.44
35	996	1	311	428	740	0.14	42.03	57.84
36	1060	-	166	207	373	-	44.50	55.50
37	1086	1	11	71	83	1.20	13.25	85.54
38	1127	2	201	220	423	0.47	47.52	52.01
39	1224	-	95	247	342	-	27.78	72.22
40	1247	-	169	233	402	-	42.04	57.96
41	1254	1	193	281	475	0.21	40.63	59.16
42	1341	1	126	324	451	0.22	27.94	71.84
43	1345	-	252	309	561	-	44.92	55.08
44	1358	1	178	343	522	0.19	34.10	65.71
45	1485	1	193	244	438	0.23	44.06	55.71
46	1499	-	143	137	280	-	51.07	48.93
47	1504	-	305	337	642	-	47.51	52.49
48	1559	1	177	311	489	0.20	36.20	63.60
49	1569	-	266	283	549	-	48.45	51.55
50	1578	-	141	246	387	-	36.43	63.57
51	1672	-	103	258	361	-	28.53	71.47
52	1726	-	188	230	418	-	44.98	55.02
53	1733	-	85	168	253	-	33.60	66.40
54	1742	1	147	277	425	0.24	34.59	65.18
55	1747	-	344	283	627	-	54.86	45.14
56	1759	1	267	210	478	0.21	55.86	43.93
56	1759	1	267	210	478	0.21	55.86	43.93
57	1802	-	289	316	605	-	47.77	52.23
58	1827	1	115	287	403	0.25	28.54	71.22
59	1854	1	116	278	395	0.25	29.37	70.38
60	1888	-	262	295	557	-	47.04	52.96
61	1929	1	304	332	637	0.16	47.72	52.12
62	2030	-	219	273	492	-	44.51	55.49
63	2033	-	105	183	288	-	36.46	63.54

APPENDIX 5-E (Contd.)

		LST	SH	SST	TOTAL	% LST	% SH	% SST
64	2146	-	133	251	384	-	34.64	65.36
65	2229	1	177	226	404	0.25	43.81	55.94
66	2232	1	136	177	314	0.32	43.31	56.37
67	2235	-	165	238	403	-	40.94	59.06
68	2260	-	207	235	442	-	46.83	53.17
69	2301	-	265	319	584	-	45.38	54.62
70	2378	-	213	258	471	-	45.22	54.78
71	2391	1	180	288	469	0.21	38.38	61.41
72	2401	-	205	363	568	-	36.09	63.91
73	2405	2	268	304	574	0.35	46.69	52.96
74	2520	3	288	293	584	0.51	49.32	50.17
75	2524	-	165	244	409	-	40.34	59.66
76	2537	-	226	319	545	-	41.47	58.53
77	2568	-	210	274	484	-	43.39	65.61
78	2597	-	193	359	552	-	34.96	65.04
79	2622	-	176	323	499	-	35.27	64.73
80	2624	1	241	367	609	0.16	39.57	60.26
81	2633	-	244	398	642	-	38.01	61.99
82	2654	-	284	283	567	-	50.09	49.91
83	2714	-	146	197	343	-	42.56	57.43
84	2731	1	378	307	686	0.15	55.10	44.75
85	2820	-	239	325	564	-	42.38	57.62
86	2823	1	278	317	596	0.17	46.64	53.19
87	2859	-	297	555	852	-	34.86	65.14
88	2912	-	217	295	512	-	42.38	57.62
89	2939	-	275	365	640	-	42.97	57.03
90	3001	1	311	398	710	0.14	43.80	56.06
91	3030	-	195	183	378	-	51.59	48.41
92	3079	3	213	386	602	0.50	35.38	64.12
93	3138	1	121	370	492	0.20	24.59	75.20
94	3170	1	153	356	510	0.20	30.0	69.80
95	3233	1	213	373	587	0.17	36.29	63.54

APPENDIX 5-E (Contd.)

		LST	SH	SST	TOTAL	% LST	% SH	% SST
96	3236	-	273	366	639	-	42.72	57.28
97	3353	-	188	234	422	-	44.55	55.45
98	3354	3	264	386	653	0.46	40.43	59.11
99	3375	-	249	370	619	-	40.23	59.77
100	3419	-	64	193	257	-	24.90	75.10

APPENDIX 5-F

Stone Counts data obtained from the Netherhearth banks material

		LST	SH	SST	TOTAL	% LST	% SH	% SST
1	82	-	1	166	167	-	00.60	99.40
2	98	-	81	227	308	-	26.30	73.70
3	290	-	122	132	254	-	48.03	51.97
4	315	-	121	144	265	-	45.66	54.34
5	323	-	39	67	106	-	36.79	63.21
6	333	-	78	139	217	-	35.94	64.06
7	471	-	72	82	154	-	46.75	53.25
8	804	1	7	105	113	00.88	6.19	92.92
9	847	1	16	241	258	00.39	6.20	93.41
10	867	-	28	351	379	-	7.39	92.61
11	889	-	16	274	290	-	5.52	94.48
12	995	1	10	267	278	00.36	3.60	96.04
13	1114	-	13	171	184	-	7.07	92.93
14	1192	-	7	147	154	-	4.55	95.45
15	1245	-	10	62	72	-	13.89	86.11
16	1470	-	6	136	142	-	4.23	95.77
17	1471							
18	1497	-	14	137	151	-	9.27	90.73
19	1591	1	3	165	169	00.59	1.78	97.63
20	1605							
21	1677	-	19	206	225	-	8.44	91.56
22	1693	-	7	214	221	-	3.17	96.83
23	1776	-	12	168	180	-	6.67	93.33
24	1847	-	2	81	83	-	2.41	97.59
25	1861	-	16	172	188	-	8.51	91.49
26	1964	-	69	128	197	-	35.03	64.97

APPENDIX 6-A

Material coarser than 3/4 inch collected from the trays on 18th July, 1968

Long axis in inches	weight in grams	Long axis in inches	Weight in grams	Long axis in inches	Weight in grams	Long axis in inches	Weight in grams
4.0	412	3.2	43	1.9	25	2.0	26
4.5	222	2.3	82	1.8	38	2.1	20
2.9	576	2.2	48	1.6	39	1.6	26
3.0	176	2.0	70	1.8	20	1.8	19
3.3	216	2.1	38	1.7	25	1.1	26
3.5	178	2.6	82	2.4	35	1.5	29
3.2	207	1.9	52	1.9	24	1.3	26
3.0	151	2.0	43	1.7	28	1.9	20
3.4	210	2.1	46	1.8	27	1.6	23
3.2	168	2.1	43	1.6	25	1.7	19
2.8	242	2.0	66	1.8	37	1.7	21
3.0	155	2.3	35	1.6	30	1.3	20
3.0	120	1.9	44	1.5	30	1.5	17
2.5	206	1.8	51	1.6	43	1.6	25
2.2	137	2.2	41	1.4	26	1.3	20
2.7	94	1.9	28	1.4	24	1.5	16
3.2	100	2.1	43	1.5	37	1.3	22
2.8	104	1.8	38	1.6	23	1.2	18
2.7	91	1.6	29	1.6	45	1.4	19
2.7	105	2.0	28	2.0	26	1.3	17
2.8	92	1.6	50	1.4	31	1.4	14
2.6	98	1.5	37	1.8	37	1.6	25
2.4	49	2.0	41	1.2	32	1.3	20
2.5	66	1.8	37	1.8	27	1.2	28
2.8	58	1.6	22	2.1	13	1.5	28
2.9	99	1.7	44	2.1	14	1.6	19
2.6	98	2.1	36	1.7	27	1.6	21
3.0	65	1.8	40	1.6	20	1.6	19
2.4	87	2.7	41	2.0	16	1.4	20
2.5	76	2.2	52	1.9	27	1.8	23
2.3	66	2.7	53	1.7	20	1.8	13
2.6	95	2.4	53	1.7	21	1.7	21

APPENDIX 6-A (Contd.)

Long axis in inches	Weight in grams	Long axis in inches	Weight in grams	Long axis in inches	Weight in grams	Long axis in inches	Weight in grams
2.5	97	2.0	22	1.5	17	1.7	16
1.9	23	1.9	23	1.7	18	1.1	10
1.1	21	1.4	14	1.3	12	1.5	14
1.8	22	1.4	17	1.3	10	1.3	15
1.5	17	2.0	12	1.4	13	1.5	16
1.8	30	1.9	15	1.3	13	1.3	16
1.3	23	2.4	17	1.1	10	1.3	14
1.4	14	1.5	21	1.2	9	1.2	15
1.3	12	1.4	12	1.1	12	1.2	10
1.8	21	1.7	14	1.1	11	1.5	17
1.5	16	1.5	13	1.1	11	1.4	11
1.2	18	1.6	18	1.1	14	1.2	11
2.2	16	1.5	15	1.0	10	1.2	14
2.0	21	1.5	13	1.1	11	1.1	10
1.6	26	1.8	11	1.2	11	1.2	9
1.6	14	1.5	13	1.3	21	1.4	11
1.8	27	1.6	13	1.4	29	1.2	12
1.6	15	1.3	15	1.3	11	1.4	11
1.6	19	1.2	14	1.3	11	1.4	12
1.6	18	1.3	18	1.1	15	1.5	12
1.6	22	1.5	18	1.7	17	1.4	12
1.1	15	1.8	13	1.7	20	1.0	10
1.6	20	1.4	17	1.5	12	1.1	9
1.3	15	2.0	14	1.7	7	1.2	13
1.6	18	1.2	16	1.5	10	1.1	10
1.2	18	1.3	15	1.4	16	1.4	16
1.2	15	1.2	23	1.3	12	1.3	13
1.3	20	1.1	13	1.2	14	1.3	14
1.3	20	1.7	15	1.3	18	1.5	21
1.3	26	1.9	21	1.4	28	1.2	15
1.3	19	1.3	13	1.4	19	1.1	13
1.4	16	1.5	16	1.2	14	1.2	11
1.5	18	1.5	12	1.1	15	1.1	8

APPENDIX 6-A (Contd.)

Long axis in inches	Weight in grams	Long axis in inches	Weight in grams	Long axis in inches	Weight in grams	Long axis in inches	Weight in grams
1.2	13	1.3	1.3	1.2	11	1.1	16
1.4	15	1.1	6	1.5	12	1.1	8
1.3	8	1.5	13	1.4	6	1.4	17
1.4	13	1.3	10	1.1	10	1.3	11
1.5	16	1.2	11	1.3	13	1.0	10
1.4	11	1.1	6	1.0	11	1.8	13
1.1	10	1.0	9	1.3	8	1.3	8
1.3	16	1.0	11	1.0	10	1.3	9
1.3	11	1.2	10	1.0	9	1.3	21
1.7	12	1.1	10	1.0	10	1.4	13
1.7	15	1.0	6	1.0	11	1.4	12
1.6	12	1.5	10	1.1	13	1.3	8
1.3	9	1.2	11	1.1	13	1.3	12
1.0	12	1.3	14	1.0	6	1.2	12
1.2	10	1.1	10	1.2	12	1.0	7
1.0	11	1.2	11	1.0	6	1.5	8
1.4	10	1.1	8	0.9	9	1.1	9
1.3	10	1.4	12	1.1	12	1.2	12
1.3	10	1.2	9	0.9	7	1.1	14
1.3	13	1.1	10	1.2	15	1.2	8
1.1	9	1.3	7	1.3	8	1.4	9
1.1	8	1.3	10	1.5	9	1.0	4
1.0	10	1.0	9	1.1	18	1.1	7
1.1	7	1.1	4	1.0	6	1.1	11
1.2	5	1.0	9	0.9	7	1.2	7
1.1	13	1.0	10	-	-	-	-

APPENDIX 6-B

Material coarser than 3/4 inch collected from the trays on 24th September, 1968

Long axis in inches	Weight in grams	Long axis in inches	Weight in grams	Long axis in inches	Weight in grams	Long axis in inches	Weight in grams
5.0	746	2.6	74	1.3	12	1.1	13
5.6	416	2.4	44	1.1	16	1.1	9
4.7	475	2.1	44	1.9	24	1.4	21
5.2	481	2.2	63	1.3	17	1.4	11
6.4	541	1.5	52	1.5	11	1.6	9
3.1	721	2.0	68	1.2	14	1.2	15
3.6	294	2.0	52	1.3	15	1.2	10
3.8	343	2.0	36	1.4	17	1.3	6
3.9	232	2.1	55	1.4	15	1.1	11
5.3	203	1.6	70	1.1	6	0.9	9
6.0	350	1.0	12	1.1	14	0.9	8
4.5	189	1.4	24	1.6	15	1.0	8
3.7	245	0.9	11	1.8	30	1.1	7
4.4	157	3.4	165	3.0	133	1.3	9
4.1	160	2.3	98	2.0	67	1.0	9
2.5	165	2.0	50	2.3	47	1.0	10
2.4	211	2.3	34	1.9	25	2.0	64
3.8	99	2.2	26	2.3	26	1.3	16
4.8	146	2.3	59	1.3	20	2.3	43
2.5	119	2.1	20	1.4	15	1.6	28
3.0	74	2.0	25	1.5	18	1.3	13
2.2	84	2.3	29	1.5	14	1.7	33
2.8	66	1.7	24	1.4	14	1.7	28
1.8	59	1.5	35	1.5	15	1.6	26
2.9	82	1.9	24	1.3	14	1.2	16
2.1	71	2.0	29	1.3	9	1.4	17
1.6	47	1.7	21	1.6	19	1.7	13
2.3	35	1.9	17	1.2	12	1.2	11
1.9	38	1.3	14	1.0	11	2.8	106
1.5	28	1.4	15	1.4	18	1.8	50
1.8	35	1.0	8	1.5	27	1.8	31

APPENDIX 6-B (Contd.)

Long axis in inches	Weight in grams	Long axis in inches	Weight in grams	Long axis in inches	Weight in grams	Long axis in inches	Weight in grams
1.6	23	1.0	19	1.5	7	2.0	28
1.1	25	1.2	18	2.1	18	1.5	24
1.6	16	1.5	19	1.0	7	1.3	14
2.8	135	2.4	58	1.4	20	1.3	17
2.1	44	2.9	139	1.2	9	1.6	40
1.9	13	2.2	64	1.6	13	1.4	19
1.4	7	2.3	97	1.2	17	1.7	22
2.1	20	2.2	68	1.7	28	1.9	25
1.8	23	2.0	49	1.2	11	0.9	10
1.5	24	1.8	39	1.6	26	1.3	14
1.6	30	2.2	58	1.1	13	2.8	136
1.5	21	1.8	28	1.5	17	2.0	44
1.2	17	1.9	41	1.1	7	1.7	25
1.8	21	1.9	36	1.6	25	2.3	95
1.1	19	1.7	11	1.3	18	2.5	72
1.5	24	1.2	13	1.5	6	1.9	50
1.5	17	1.8	17	3.5	193	2.3	61
1.2	14	1.7	28	3.0	176	2.1	54
1.9	22	2.3	31	2.2	76	2.4	30
1.3	15	1.6	29	1.9	56	1.7	22
1.5	27	1.0	25	3.0	109	1.4	23
1.4	12	1.5	14	3.7	120	1.7	22
1.1	14	1.6	28	2.3	82	1.1	14
1.3	20	1.3	19	2.8	60	1.5	40
1.7	27	1.7	13	2.2	33	2.0	17
1.2	12	1.7	28	2.1	49	1.6	12
1.0	10	1.7	29	2.4	15	1.8	11
1.5	9	1.7	32	1.5	18	1.7	13
1.7	13	1.2	10	1.3	5	1.4	16
1.2	10	1.5	8	1.4	13	1.1	11
1.0	9	1.1	7	2.7	40	1.3	20
1.0	6	1.0	8	1.9	40	1.4	14
1.2	9	1.6	14	1.8	46	1.7	25
2.0	44	1.2	11	1.5	13	1.2	13

APPENDIX 6-B (Contd.)

Long axis in inches	Weight in grams	Long axis in inches	Weight in grams	Long axis in inches	Weight in grams	Long axis in inches	Weight in grams
2.8	57	1.2	20	1.4	33	1.0	13
0.9	9	1.3	13	1.0	5	1.5	25
1.0	9	1.0	11	1.2	13	1.2	13
1.0	11	1.1	7	1.3	9	1.5	12
1.0	11	1.5	14	1.1	14	1.5	8
1.2	12	1.6	8	1.2	18	1.2	6
1.1	12	1.5	18	1.8	51	1.3	10
2.1	36	1.3	15	1.4	29	1.6	14
1.7	28	3.0	93	1.9	32	1.2	7
1.4	23	3.3	172	1.4	14	1.2	17
2.0	73	2.2	56	1.3	14	1.1	10
1.5	18	2.1	21	1.6	31	1.0	10
1.5	14	2.5	30	1.7	21	1.4	10
1.6	19	1.8	51	2.1	24	1.3	11
1.9	7	1.7	22	1.5	30	1.5	10
1.3	12	1.2	11	1.7	33	1.4	19
1.4	16	1.6	8	1.5	24	1.2	12
1.1	10	1.6	8	1.2	11	1.1	10
1.1	10	1.6	16	1.4	24	2.0	16
1.5	10	2.1	20	1.3	16	1.8	25
1.5	14	1.8	21	1.9	24	1.1	9
1.3	13	1.4	16	2.0	24	1.6	12
1.7	12	1.4	16	2.0	30	1.6	25
1.5	18	1.3	11	1.3	25	1.4	12
1.4	7	1.5	12	1.8	43	1.2	14
1.2	11	1.4	9	1.3	15	1.3	18
1.1	12	1.5	16	1.4	12	1.6	12
1.1	7	1.3	12	1.6	19	1.2	10
1.1	8	1.4	14	1.5	18	1.2	12
1.3	10	1.2	13	1.7	21	1.2	7
1.2	6	1.2	9	1.2	14	1.3	12
1.5	19	1.0	12	1.7	21	1.2	9
1.6	12	1.5	8	1.0	11	1.8	24
1.2	9	1.0	10	1.7	28	1.8	33
1.4	15	1.2	23	1.5	17	1.6	19

APPENDIX 6-B (Contd.)

Long axis in inches	Weight in grams	Long axis in inches	Weight in grams	Long axis in inches	Weight in grams	Long axis in inches	Weight in grams
1.8	42	1.4	7	1.2	13	1.3	20
1.4	19	1.7	16	1.0	12	1.2	15
1.4	14	1.0	4	1.0	8	1.7	8
1.5	18	1.0	9	1.0	7	1.5	6
1.1	13	1.0	6	1.0	5	1.1	9
1.1	10	1.2	21	1.0	5	2.2	8
1.1	12	2.1	52	1.5	9	1.5	8
1.2	8	1.6	7	1.0	9	1.2	14
1.1	8	1.4	22	1.0	7	2.1	9
1.1	8	1.5	22	1.1	9	1.5	14
1.1	6	1.3	13	1.0	9	1.6	6
1.2	7	1.4	15	1.5	11	1.4	8
1.2	10	1.2	15	1.0	9	1.2	8
1.1	5	1.2	10	1.0	12	1.2	13
1.5	10	1.4	11	1.1	13	1.0	10
1.1	6	1.1	12	1.0	7	1.2	7
1.1	5	1.4	12	1.0	9	1.2	9
1.2	7	1.2	15	1.0	6	1.2	13
1.1	12	1.3	18	1.3	19	1.4	7
1.2	8	1.5	19	1.0	6	1.1	10
1.1	6	1.2	19	1.0	9	1.0	8
1.0	10	1.2	15	1.0	6	1.0	11
1.0	6	1.5	14	1.1	7	1.1	9
1.0	7	1.4	9	1.0	7	1.1	7
1.0	5	1.2	12	1.0	9	1.5	6
1.0	10	1.3	12	1.0	10	1.2	12
1.0	5	1.1	10	1.4	12	1.0	10
1.0	8	1.2	8	1.0	5	1.2	9
1.0	7	1.2	7	1.2	11	1.1	9
1.0	6	2.2	22	1.2	11	1.3	10
1.0	10	1.8	15	1.5	7	1.0	10
1.0	4	1.2	12	1.0	6	–	–
1.0	3	1.4	14	1.0	6	–	–
1.0	9	1.6	6	1.0	8	–	–

APPENDIX 6-B (Contd.)

Long axis in inches	Weight in grams	Long axis in inches	Weight in grams	Long axis in inches	Weight in grams	Long axis in inches	Weight in grams
2.0	15	1.0	13	1.3	9	1.3	13
1.8	19	1.1	12	1.7	30	0.9	8
1.7	24	1.0	11	1.7	22	1.4	23
1.0	11	1.1	10	1.0	10	1.4	14
0.9	8	1.3	12	1.8	23	1.5	18
1.8	26	1.8	30	1.4	8	1.8	7
1.5	20	1.4	12	1.4	9	1.7	26
1.0	11	1.2	13	1.6	12	1.4	10
2.1	23	1.3	12	1.5	10	1.2	18
1.1	8	1.3	9	1.2	11	1.5	16
1.3	9	1.2	9	1.5	9	1.1	12
1.3	11	1.0	9	1.0	8	0.9	7
1.6	12	1.1	10	1.1	15	1.1	4
1.0	8	1.5	17	1.2	6	-	-

APPENDIX 6-C

Material coarser than 3/4 inches collected from the trays on 3rd October, 1968

Long axis in inches	Weight in grams	Long axis in inches	Weight in grams	Long axis in inches	Weight in grams	Long axis in inches	Weight in grams
2.6	52	1.6	22	1.5	21	1.4	17
1.1	14	1.5	16	1.4	11	12	9
1.5	10	1.2	10	1.4	11	1.4	21
1.1	10	1.2	6	1.3	5	1.5	16
1.3	10	1.2	6	1.2	9	1.2	13
1.1	14	1.0	15	1.2	14	1.1	10
1.1	8	1.0	7	1.1	8	1.2	11

APPENDIX 6-D

Material coarser than 3/4 inch collected from the trays on 28th November, 1968

Long axis in inches	Weight in grams	Long axis in inches	Weight in grams	Long axis in inches	Weight in grams	Long axis in inches	Weight in grams
3.0	95	1.9	24	1.1	15	2.0	49
2.4	35	1.6	26	1.0	9	1.8	23
1.3	18	1.6	27	1.1	11	2.2	18
1.9	47	1.2	12	1.2	15	1.2	14
2.4	33	1.5	29	2.0	27	1.4	16
1.7	26	1.6	14	1.2	17	2.0	20
1.5	23	1.3	8	1.6	11	1.5	13
1.9	16	1.5	20	1.2	12	1.6	8
1.8	23	1.8	18	1.9	9	1.5	11
1.7	62	1.5	45	1.0	4	1.7	10
2.0	22	1.8	15	1.0	7	1.2	18
1.9	20	1.5	15	1.0	7	1.4	15
1.5	15	1.5	17	1.0	7	1.5	11
1.5	8	1.1	9	1.0	9	1.2	14
1.7	30	1.6	17	1.0	6	1.2	18
1.4	14	1.5	10	1.2	7	1.4	8
1.6	18	1.2	10	1.3	6	1.2	4
1.2	10	1.1	10	1.1	16	1.3	10
1.4	8	1.4	15	1.5	11	1.5	10
1.3	17	2.0	21	1.0	10	1.1	12
1.3	14	1.7	35	1.0	8	1.2	7
1.0	7	2.0	47	1.0	14	1.3	6
1.0	9	2.4	37	1.2	9	1.6	10
1.2	6	1.8	12	1.3	11	1.3	9
1.6	20	1.5	24	1.0	10	1.2	11
1.2	9	1.6	25	1.6	7	1.1	9
1.0	8	1.8	22	1.7	16	1.2	14
2.0	37	1.2	15	1.2	11	1.2	18
2.0	52	1.6	15	1.3	12	1.2	14
1.9	38	1.8	12	1.4	18	1.5	9
1.9	79	1.9	21	1.0	11	1.3	11

APPENDIX 6-E

Material coarser than 3/4 inch collected from the trays on the 7th January, 1969

Long axis in inches	Weight in grams	Long axis in inches	Weight in grams	Long axis in inches	Weight in grams	Long axis in inches	Weight in grams
4.2	288	2.1	61	1.2	18	0.9	9
4.0	302	1.8	92	1.0	10	1.0	14
3.5	193	2.4	62	1.0	8	1.1	9
2.7	258	2.0	44	1.0	8	1.4	12
4.6	347	2.0	46	1.0	6	1.0	17
3.5	364	2.1	40	1.0	6	1.2	5
3.0	183	1.5	36	1.0	11	1.0	8
2.8	167	1.8	37	1.3	18	1.6	11
3.2	119	2.0	28	1.2	13	1.0	10
3.8	277	1.6	58	2.0	13	1.1	11
2.8	167	2.2	66	1.4	23	4.5	236
2.2	84	2.0	28	1.6	13	4.0	129
3.0	125	2.8	35	1.2	16	3.5	279
2.8	178	1.5	47	1.8	20	2.2	86
4.4	675	2.6	35	1.5	24	2.5	109
3.2	184	1.8	24	1.2	20	2.1	33
3.0	109	2.0	20	1.2	13	2.1	46
3.1	88	2.1	18	1.5	17	1.6	21
3.5	155	1.9	60	1.5	14	2.0	35
3.0	109	1.5	35	1.9	19	2.0	49
3.9	111	1.4	41	1.2	13	2.8	73
2.1	65	1.9	33	1.4	17	4.9	189
2.5	79	1.4	38	1.3	16	2.0	95
3.5	182	1.0	7	1.1	21	2.8	115
2.2	84	1.0	10	1.2	8	2.5	111
2.4	55	1.0	10	1.2	9	2.3	90
3.0	90	1.0	10	1.4	8	3.0	129
2.1	72	1.0	6	1.1	9	2.9	110
2.5	51	1.0	8	1.1	7	2.2	80
2.2	84	1.7	21	1.2	9	2.0	46
2.5	77	1.6	23	1.4	7	2.1	108
2.0	68	1.3	17	1.5	9	2.6	42
3.0	87	2.0	32	1.3	11	2.0	59

Long axis in inches	Weight in grams	Long axis in inches	Weight in grams	Long axis in inches	Weight in grams	Long axis in inches	Weight in grams
1.8	118	1.6	12	1.3	12	2.5	142
2.0	66	1.9	24	1.2	7	2.4	153
2.1	50	1.3	11	1.3	7	1.6	34
1.7	64	1.6	12	1.3	11	2.5	84
1.6	59	1.1	17	1.0	9	2.1	25
1.8	40	1.1	17	1.0	9	2.0	54
2.1	60	1.0	17	1.4	9	1.6	48
2.0	34	1.4	8	1.2	8	1.8	44
1.6	27	1.5	12	4.0	182	2.0	38
2.1	35	1.6	14	3.0	186	2.1	68
1.5	21	1.8	10	3.5	272	2.3	19
1.8	17	1.4	10	4.1	125	1.7	66
1.2	18	1.3	15	3.0	206	2.0	36
1.7	23	1.1	18	3.0	116	2.3	65
2.0	14	1.5	16	2.0	46	2.0	38
2.0	11	1.5	14	2.1	52	2.3	62
1.2	20	1.4	9	2.5	65	1.8	33
1.5	15	1.5	19	3.0	70	2.8	18
2.0	17	1.4	16	2.5	110	2.1	58
1.3	14	1.7	24	2.8	102	2.2	50
1.6	19	1.4	8	2.1	64	1.8	19
1.7	25	1.5	8	2.5	63	1.4	30
1.0	7	1.8	11	2.5	138	1.3	28
1.0	8	1.6	8	2.2	96	2.0	21
1.0	7	1.3	5	3.3	129	1.8	49
1.0	10	1.1	12	2.2	67	1.9	36
1.0	9	1.2	16	2.2	64	1.6	17
1.0	11	1.5	10	2.3	40	2.0	18
1.0	7	1.3	17	2.3	39	1.6	22
1.0	7	1.3	8	2.2	83	1.3	27
1.0	8	1.0	7	2.4	130	1.3	26
1.1	13	1.0	11	2.5	95	1.6	18
1.2	14	1.2	12	2.1	37	1.8	19
1.5	26	1.7	9	5.2	755	2.0	19

APPENDIX 6-E (Contd.)

Long axis in inches	Weight in grams	Long axis in inches	Weight in grams	Long axis in inches	Weight in grams	Long axis in inches	Weight in grams
1.5	17	2.0	18	4.8	204	1.8	29
1.5	14	1.3	11	3.8	756	1.6	27
1.3	13	1.5	12	4.0	459	1.6	22
1.5	16	1.5	23	2.6	99	2.0	39
1.0	11	1.3	14	3.0	68	1.8	35
1.0	6	1.7	10	4.5	388	1.5	29
1.0	15	1.6	16	3.0	111	1.4	24
1.1	11	2.0	14	3.4	125	2.1	18
1.2	11	1.8	18	3.2	127	1.5	22
1.3	14	1.8	13	4.0	233	1.1	9
1.6	27	1.3	14	3.8	208	1.2	9
1.4	9	1.1	9	3.5	74	1.2	7
1.5	22	1.3	11	2.8	116	1.0	16
1.4	11	1.6	8	3.0	244	1.0	9
2.0	18	1.2	13	2.8	81	1.0	6
1.8	10	1.4	7	2.5	46	1.0	6
1.6	12	1.2	15	2.0	38	1.2	9
2.0	13	1.2	21	1.2	22	1.4	14
1.6	19	1.2	13	1.8	25	1.4	15
1.7	22	1.1	13	2.2	58	1.7	19
1.4	12	1.0	10	2.4	63	1.4	7
1.3	12	1.1	16	2.2	72	1.5	13
1.0	10	1.1	17	2.9	40	1.7	33
1.0	8	1.1	8	2.8	171	1.5	15
1.0	9	1.1	14	3.0	173	1.0	21
1.0	7	1.0	11	1.5	120	1.6	17
1.0	9	1.2	15	1.6	37	2.0	15
1.4	20	1.2	9	2.0	63	1.5	24
1.5	10	1.0	13	1.7	34	1.4	30
1.5	10	1.9	30	2.1	41	1.3	18
1.1	18	2.0	38	2.5	39	1.4	17
1.1	16	1.9	28	1.5	32	1.3	21
1.4	11	3.2	145	2.5	62	1.2	13
1.5	12	40	447	2.0	66	1.3	11

APPENDIX 6-E (Contd.)

Long axis in inches	Weight in grams	Long axis in inches	Weight in grams	Long axis in inches	Weight in grams	Long axis in inches	Weight in grams
1.1	11	3.1	299	2.6	37	1.4	16
1.5	7	3.0	239	2.5	66	1.1	16
1.5	26	2.0	45	2.1	58	1.1	8
1.0	5	2.0	67	2.0	52	1.5	15
1.2	28	2.2	58	2.0	21	1.1	13
1.2	15	4.0	283	2.0	23	1.1	8
1.3	12	3.5	158	1.6	9	1.0	6
1.2	20	2.8	158	2.1	14	1.0	9
1.4	13	2.3	85	1.9	31	1.3	14
1.4	10	2.0	53	1.9	45	1.0	10
1.5	19	2.9	76	1.7	95	1.1	11
1.1	14	1.5	90	1.7	26	0.9	6
1.1	20	2.0	65	2.0	33	0.6	4
1.3	13	3.0	315	2.2	45	0.7	5
1.0	18	3.0	112	2.0	53	1.1	4
1.1	7	2.3	135	1.6	20	3.9	204
1.3	7	2.9	130	1.8	19	3.7	301
1.6	5	2.1	70	2.0	11	3.0	224
1.2	12	3.0	104	1.2	30	4.1	388
1.2	9	2.5	72	1.2	16	4.0	531
1.3	18	2.0	74	1.6	15	2.9	62
1.2	5	3.0	88	1.3	22	3.7	451
1.0	17	2.2	58	1.6	29	3.1	119
1.2	9	2.5	80	1.6	22	3.1	196
1.5	12	2.2	33	1.5	26	3.5	352
1.0	9	3.5	460	1.4	21	2.8	140
1.0	10	2.0	129	1.5	21	3.1	152
4.0	337	2.2	31	1.5	13	2.5	80
3.0	114	3.0	96	1.5	9	2.9	39
3.0	178	2.3	39	1.5	19	2.1	92
4.1	272	2.3	16	1.5	15	2.2	31
2.0	61	1.3	22	1.2	9	1.0	8
2.1	71	1.7	30	1.4	7	0.9	9
2.2	29	1.5	28	1.5	10	1.0	11

APPENDIX 6-E (Contd.)

Long axis in inches	Weight in grams	Long axis in inches	Weight in grams	Long axis in inches	Weight in grams	Long axis in inches	Weight in grams
2.0	26	1.5	32	1.7	14	1.5	16
2.0	61	1.4	23	0.5	6	1.0	9
1.9	84	1.5	30	1.0	12	1.0	12
2.3	114	1.6	20	1.1	11	1.3	4
1.8	56	1.7	18	1.2	11	1.4	11
2.0	68	1.5	18	0.7	5	1.0	6
4.5	109	1.5	24	0.7	6	1.3	11
2.5	84	1.6	21	0.9	12	1.5	8
2.9	81	1.5	22	1.0	6	1.0	9
1.8	38	1.2	20	1.0	9	1.0	7
2.0	40	1.7	23	1.0	7	1.2	7
1.8	34	1.4	18	1.4	9	1.2	4
2.2	55	1.9	14	1.1	8	1.0	7
1.8	30	1.2	23	1.2	12	1.0	10
2.0	41	1.5	26	1.4	20	0.5	6
2.0	39	1.2	20	1.0	15	1.4	6
2.0	40	1.2	26	1.3	8	1.0	11
1.9	12	1.5	12	0.9	11	1.0	16
1.8	16	1.8	20	1.0	8	1.3	9
1.6	17	1.3	11	1.0	7	1.0	5
1.4	31	1.2	23	0.9	6	1.0	8
2.1	35	1.0	11	1.0	7	1.0	4
1.8	19	1.1	15	1.0	10	1.1	10
1.7	21	1.4	22	1.1	8	0.9	8
1.9	39	1.5	13	1.5	11	1.2	7
1.7	22	1.5	13	0.9	7	1.0	7
2.2	24	1.6	12	0.7	7	1.0	6
1.5	24	1.2	26	1.0	7	0.8	9
1.2	14	1.2	11	1.2	10	1.0	6
1.6	38	1.4	18	1.3	12	-	-

APPENDIX 6-F

Material coarser than 3/4 inch collected from the trays on the 20th January, 1969

Long axis in inches	Weight in grams	Long axis in inches	Weight in grams	Long axis in inches	Weight in grams	Long axis in inches	Weight in grams
4.5	775	2.5	74	1.9	38	1.8	43
4.0	582	3.0	94	2.3	45	1.4	18
4.0	492	2.9	79	1.8	36	1.6	27
2.8	240	2.6	120	2.3	40	1.6	10
4.2	405	2.2	80	1.6	31	2.0	46
3.5	130	2.7	89	1.6	22	1.9	21
3.5	629	2.1	103	2.4	58	1.8	41
4.9	302	2.0	86	1.9	35	2.6	31
3.2	469	2.4	98	2.1	55	2.2	43
3.3	198	1.8	94	1.6	30	1.4	39
3.2	528	1.9	60	2.0	52	2.4	24
2.8	117	2.1	42	1.6	27	2.0	35
2.6	224	1.9	51	1.6	26	1.7	30
3.0	119	2.0	59	2.0	43	2.0	36
3.0	177	1.8	51	1.7	29	2.2	60
4.0	88	1.6	47	2.0	23	1.5	20
3.6	75	2.0	40	1.8	38	1.8	20
2.5	72	2.1	47	1.9	69	1.6	17
2.9	104	2.3	23	2.0	50	2.0	13
6.0	681	2.5	37	1.9	37	1.5	13
6.0	509	2.6	65	1.9	25	1.6	25
4.2	235	2.8	61	1.4	51	1.7	8
4.2	199	2.2	70	1.9	48	1.4	35
3.8	278	2.1	77	1.1	18	1.5	20
4.6	239	2.5	64	1.5	19	1.8	33
3.6	531	2.2	45	1.9	12	1.9	17
4.9	233	1.6	46	1.5	23	1.6	36
3.2	218	2.0	35	1.5	18	1.2	17
3.5	428	2.0	26	1.5	14	1.5	30
2.4	125	1.9	49	1.5	17	1.6	19
2.5	183	2.0	19	1.4	29	1.2	23

APPENDIX 6-F (Contd.)

Long axis in inches	Weight in grams	Long axis in inches	Weight in grams	Long axis in inches	Weight in grams	Long axis in inches	Weight in grams
3.0	218	2.0	29	1.8	13	1.3	24
2.5	155	1.5	27	1.6	26	1.7	13
1.2	17	1.9	18	1.1	19	1.2	8
1.2	19	1.1	19	1.1	11	1.2	9
1.3	23	1.1	10	1.2	14	1.1	7
1.2	10	1.0	7	1.1	13	1.0	7
1.3	17	1.1	10	1.0	13	1.1	8
1.2	14	1.5	11	1.2	9	1.0	8
1.5	8	1.1	12	1.0	8	1.0	11
1.5	11	1.5	12	1.1	9	1.5	13
1.7	29	1.6	18	1.0	10	1.5	13
1.2	16	1.1	16	1.0	10	1.0	9
1.4	23	1.5	13	1.1	10	1.2	19
1.4	22	1.1	16	1.5	6	1.4	20
1.1	18	1.3	11	1.4	7	0.9	10
1.2	21	1.1	17	1.0	9	1.4	19
1.5	11	1.1	16	1.2	12	1.3	17
1.5	12	1.5	16	1.1	13	1.1	13
1.2	10	1.5	20	1.2	10	1.2	19
2.0	17	1.4	12	1.3	16	1.3	16
1.8	22	1.8	12	1.3	8	1.1	12
1.4	19	1.7	16	1.4	10	1.3	15
1.1	14	1.5	18	1.6	17	1.4	23
1.4	16	1.4	11	1.2	9	1.3	13
1.6	25	1.3	14	1.0	11	1.9	8
1.3	10	1.1	13	1.0	13	1.3	12
1.6	18	1.5	9	1.1	10	1.0	9
1.4	21	1.1	16	1.2	11	1.3	17
1.1	16	-	-	-	-	-	-

APPENDIX 6-G

Material coarser than 3/4 inch collected from the trays on the 27 January 1969

Long axis in inches	Weight in grams	Long axis in inches	Weight in grams	Long axis in inches	Weight in grams	Long axis in inches	Weight in grams
3.2	136	1.2	13	4.1	217	1.1	15
3.5	174	1.0	12	2.5	83	1.1	12
2.6	80	1.0	11	2.4	96	1.2	14
2.4	27	1.1	10	1.9	17	1.1	8
1.8	20	1.5	6	1.6	32	1.1	6
2.0	52	1.1	11	2.0	68	1.2	6
1.4	21	1.0	4	1.8	40	1.0	7
1.7	20	1.0	9	1.5	14	1.0	9
1.4	18	1.6	22	1.5	24	1.4	22
2.0	25	1.3	17	1.4	20	1.1	17
1.2	9	1.5	21	1.6	12	1.0	9
1.5	11	1.5	14	1.3	13	1.1	16
1.2	8	-	-	-	-	-	-

APPENDIX 6-H

Material coarser than 3/4 inch collected from the trays on 3rd February 1969

Long axis in inches	Weight in grams	Long axis in inches	Weight in grams	Long axis in inches	Weight in grams	Long axis in inches	Weight in grams
4.6	377	3.8	247	2.6	83	2.4	117
2.3	35	2.7	58	1.9	42	1.5	29
1.5	16	1.2	17	1.6	11	1.0	12
1.1	12	1.2	11	1.1	9	-	-

APPENDIX 6-I

Material coarser than 3/4 inch collected from the trays on 2nd April, 1969

Long axis in inches	Weight in grams	Long axis in inches	Weight in grams	Long axis in inches	Weight in grams	Long axis in inches	Weight in grams
1.7	35	3.3	57	1.9	30	1.0	9
1.5	40	1.6	50	1.3	21	2.3	24
1.8	48	1.4	21	2.1	34	3.2	49
2.2	52	1.2	36	3.0	51	3.0	73
2.5	60	3.1	52	3.2	36	2.1	41
3.0	78	2.2	78	1.7	17	1.7	39
3.1	22	2.3	38	1.8	22	1.8	29
1.4	56	1.9	29	1.0	20	1.9	33
2.9	71	2.9	36	1.0	11	2.6	28
2.1	81	1.4	82	1.0	8	2.8	41
1.9	49	3.1	91	2.1	28	1.7	36
1.5	23	2.1	63	1.8	17	1.1	22
1.6	32	1.1	22	1.6	29	1.0	9
1.9	42	1.0	20	1.9	33	1.0	7
2.0	21	1.0	11	1.1	9	1.0	8
1.5	18	1.0	10	1.1	6	2.3	44
1.6	12	2.1	36	1.1	5	2.4	72
1.9	12	2.2	42	3.1	50	2.6	49
2.3	75	2.4	33	2.4	90	1.7	30
1.2	66	3.1	41	2.5	29	1.2	25
1.4	24	3.1	72	1.6	19	1.5	18
1.3	51	3.0	78	2.6	24	2.5	37
2.6	57	1.1	19	1.2	37	3.6	99
1.8	82	1.2	14	1.1	31	2.2	28
1.7	33	2.1	79	1.0	13	1.3	21
2.1	36	2.2	80	1.3	19	1.4	34
3.2	25	3.0	93	1.7	26	2.6	39
1.9	36	1.8	88	2.8	34	1.9	22
1.1	21	1.6	28	3.1	38	1.7	19
1.0	9	1.3	33	16	26	1.6	17
2.3	66	1.1	14	1.7	21	2.8	25

APPENDIX 6-I (Contd.)

Long axis in inches	Weight in grams	Long axis in inches	Weight in grams	Long axis in inches	Weight in grams	Long axis in inches	Weight in grams
1.1	45	1.2	16	1.2	22	1.2	36
1.4	21	2.2	36	1.1	11	2.2	40
1.1	19	1.0	5	2.1	29	3.1	44
1.1	21	1.0	9	2.0	30	2.1	36
2.1	36	1.0	8	2.5	43	1.1	25
1.1	12	2.1	33	1.5	33	2.1	36
2.2	22	1.1	9	1.7	19	1.1	42
1.0	9	1.4	15	1.5	17	2.1	37
1.0	5	2.3	34	1.6	21	1.7	28
1.0	6	1.1	12	2.1	26	1.8	19
3.0	92	1.0	10	2.2	41	1.3	41
2.1	63	1.0	9	1.1	21	1.4	17
2.2	66	1.0	11	1.0	6	1.4	29
2.8	71	1.0	13	1.0	9	3.1	38
1.9	44	1.0	23	1.1	11	1.5	22
1.6	33	3.0	70	2.1	29	1.6	51
2.1	21	2.6	49	2.3	30	2.1	47
1.8	81	1.6	36	1.4	38	1.7	31
3.0	77	1.4	22	1.6	27	1.8	18
2.6	61	1.3	19	1.9	35	1.2	12
1.5	36	2.1	39	2.8	44	2.2	20
2.5	45	1.1	17	3.6	101	1.3	24
2.1	39	1.1	19	1.2	31	1.4	30
1.1	23	1.6	12	1.1	5	1.6	33
1.0	11	1.3	18	1.4	15	1.0	10
1.0	13	1.2	9	2.1	29	1.0	12
1.0	16	1.2	16	2.2	52	1.0	4
1.5	31	2.1	13	1.6	18	1.0	7
1.7	22	1.6	20	3.0	74	2.1	63
1.8	37	3.1	69	2.0	50	3.1	88
2.2	24	2.9	59	2.1	29	1.1	17
1.9	36	1.7	22	1.1	20	1.1	31
3.6	91	1.8	30	1.6	26	2.1	21
2.1	71	2.2	36	1.9	36	1.1	17

APPENDIX 6-I (Contd.)

Long axis in inches	Weight in grams	Long axis in inches	Weight in grams	Long axis in inches	Weight in grams	Long axis in inches	Weight in grams
2.3	55	1.1	9	2.8	45	2.0	40
1.1	14	1.0	5	2.1	33	11	18
1.0	6	1.0	9	1.0	11	3.0	68
2.2	52	1.8	37	2.6	36	1.7	22
1.0	11	1.0	10	1.5	19	2.6	31
2.5	43	1.6	26	3.1	95	1.2	31
1.1	23	1.4	17	3.9	59	2.9	33
2.1	25	1.8	21	-	-	-	-

APPENDIX 6-J

Material coarser than 3/4 inch collected from the trays on 16th April 1969

Long axis in inches	Weight in grams	Long axis in inches	Weight in grams	Long axis in inches	Weight in grams	Long axis in inches	Weight in grams
2.3	186	1.2	8	1.0	4	1.3	14
1.6	30	1.0	9	1.0	5	1.0	8
2.0	35	1.0	10	1.0	8	1.5	12
1.8	17	1.1	9	1.0	7	1.0	4
1.5	32	1.0	8	1.0	3	1.2	16
1.2	20	1.3	6	1.5	6	1.0	7
1.6	16	1.5	6	1.0	5	1.3	18
1.8	34	1.2	18	1.1	6	1.0	5
1.5	14	1.1	7	1.0	7	1.1	11
1.7	20	1.5	9	1.1	12	1.1	7
1.4	34	1.6	6	1.0	8	1.3	11
1.5	8	1.3	8	1.0	10	1.2	7
1.2	12	1.0	8	1.1	10	1.2	7
1.2	16	1.0	6	1.5	15	1.0	8
1.4	5	1.0	7	1.2	16	1.0	6
1.8	10	1.0	8	1.1	9	1.1	9
1.3	8	1.1	11	1.2	10	1.0	6

APPENDIX 7A

Date: 13.6.69

Long axis, weight and distanced moved by the yellow stones in the eastern tributary "Lanehead"

No.	Long axis in inches	Weight in grams	Distance in feet
1	1.1	13	-
2	1.0	11	-
3	1.0	12	-
4	1.1	15	8
5	1.0	13	-
6	1.2	12	-
7	1.0	10	-
8	1.1	13	19
9	2.0	14	-
10	1.0	10	-
11	1.1	15	-
12	1.1	13	-
13	1.1	13	-
14	2.0	14	-
15	2.2	17	-
16	2.0	12	-
17	1.3	17	-
18	1.4	16	-
19	2.0	19	-
20	1.3	14	-
21	2.4	26	-
22	1.0	12	-
23	1.0	12	-
24	2.1	18	-
25	1.3	16	-
26	1.9	19	-
27	2.1	16	22
28	2.4	24	28
29	2.0	19	-
30	2.3	23	-

Date: 13.6.69

No.	Long axis in inches	Weight in grams	Distance in feet
31	1.0	15	-
32	1.3	20	-
33	1.3	27	51
34	1.9	26	-
35	1.4	20	-
36	1.4	27	15
37	2.1	23	-
38	1.1	18	-
39	1.9	24	-
40	2.1	21	-
41	2.1	24	-
42	2.1	33	-
43	2.2	34	11
44	1.9	34	-
45	2.1	24	-
46	2.3	30	-
47	1.9	25	19
48	2.9	35	-
49	1.6	28	-
50	1.6	24	33
51	2.2	32	-
52	1.4	19	-
53	1.3	19	-
54	2.1	20	47
55	2.2	23	-
56	1.3	24	-
57	1.5	27	-
58	1.5	27	30
59	2.3	19	-
60	2.9	46	-
61	1.8	28	-
62	1.7	28	-
63	2.7	39	-
64	1.8	22	-
65	1.9	39	-

Date: 13.6.69

APPENDIX 7-A (Contd.)

No.	Long axis in inches	Weight in grams	Distance in feet
66	2.9	50	-
67	2.8	55	27
68	3.1	67	-
69	2.4	51	-
70	2.2	60	15
71	3.6	51	-
72	2.1	30	-
73	2.2	33	-
74	2.2	36	30
75	1.9	30	-
76	2.6	47	-
77	1.8	44	10
78	1.9	57	-
79	2.4	50	10
80	2.6	44	1
81	2.8	63	-
82	1.2	58	-
83	2.3	52	8
84	1.6	73	-
85	1.4	72	17
86	2.3	62	-
87	2.2	74	00
88	3.1	82	-
89	3.1	105	-
90	3.3	135	-
91	2.4	74	2
92	2.4	81	3
93	3.2	133	30
94	2.7	95	-
95	3.0	120	35
96	2.9	98	9
97	3.1	171	17
98	2.9	66	-
99	3.4	175	-

APPENDIX 7-A (Contd.)

No.	Long axis in inches	Weight in grams	Distance in feet
100	3.0	192	-
101	2.9	291	6
102	3.1	165	10
103	4.1	171	23
104	3.3	155	-
105	3.7	344	-
106	5.1	718	00

APPENDIX 7-A (Contd.)

Date: 27.1.69

No.	Long axis in inches	Weight in grams	Distance in feet
1	1.1	13	-
2	1.0	11	-
3	1.0	12	71
4	1.1	15	-
5	1.0	13	40
6	1.2	12	-
7	1.0	10	-
8	1.1	13	19
9	2.0	14	-
10	1.0	10	-
11	1.1	15	27
12	1.1	13	-
13	1.1	13	-
14	2.0	14	-
15	2.2	17	20
16	2.0	12	-
17	1.3	17	57
18	1.4	16	51
19	2.0	19	-
20	1.3	14	14
21	2.4	26	-
22	1.0	12	-
23	1.0	12	-
24	2.1	18	8
25	1.3	16	-
26	1.9	19	26
27	2.1	16	41
28	2.4	24	-
29	2.0	19	51
30	2.3	23	60
31	1.0	15	-
32	1.3	20	-
33	1.3	27	-

APPENDIX 7-A (Contd.)

Date: 27.1.69

No.	Long axis in inches	Weight in grams	Distance in feet
34	1.9	26	28
35	1.4	20	7
36	1.4	27	67
37	2.1	23	36
38	1.1	18	-
39	1.9	24	3
40	2.1	21	-
41	2.1	24	40
42	2.1	33	21
43	2.2	34	3
44	1.9	34	-
45	2.1	24	14
46	2.3	30	52
47	1.9	25	27
48	2.9	35	-
49	1.6	28	-
50	1.6	24	4
51	2.2	32	6
52	1.4	19	-
53	1.3	19	-
54	2.1	20	-
55	2.2	23	-
56	1.3	24	-
57	1.5	27	-
58	1.5	27	19
59	2.3	19	-
60	2.9	46	59
61	1.8	28	11
62	1.7	28	51
63	2.7	39	18
64	1.8	22	-
65	1.9	39	67
66	2.9	50	36

APPENDIX 7-A (Contd.)

Date: 27.1.69

No.	Long axis in inches	Weight in grams	Distance in feet
67	2.8	55	-
68	3.1	67	-
69	2.4	51	-
70	1.2	60	43
71	3.6	51	-
72	2.1	30	-
73	2.2	33	-
74	2.2	36	21
75	1.9	30	-
76	2.6	47	21
77	1.8	44	20
78	1.9	57	26
79	2.4	50	46
80	2.6	44	22
81	2.8	63	58
82	1.2	58	4
83	2.3	52	40
84	1.6	73	-
85	1.4	72	68
86	2.3	62	35
87	2.2	74	35
88	3.1	82	44
89	3.1	105	22
90	3.3	135	22
91	2.4	74	28
92	2.4	81	-
93	3.2	133	22
94	2.7	95	59
95	3.0	120	25
96	2.9	98	20
97	3.1	171	19
98	2.9	66	5
99	3.4	175	67

APPENDIX 7-A (Contd.)

Date: 27.1.69

No.	Long axis in inches	Weight in grams	Distance in feet
100	3	192	19
101	2.9	291	22
102	3.1	165	6
103	4.1	471	24
104	3.3	155	5
105	3.7	344	13
106	5.1	718	54

APPENDIX 7-B

Date: 13.6.69

Long axis, weight and distance moved by the Yellow stones in the western stream "Lanehead"

No.	Long axis in inches	Weight in grams	Distance in feet
1	1.2	16	-
2	1.0	14	-
3	1.0	11	-
4	1.0	10	-
5	1.1	12	-
6	1.0	9	-
7	1.1	11	-
8	1.4	11	-
9	1.3	15	-
10	1.1	11	100
11	1.5	16	-
12	1.0	12	-
13	1.2	15	-
14	2.0	16	-
15	1.5	12	-
16	1.3	12	-
17	1.3	12	250
18	1.8	13	-
19	1.1	23	
20	1.3	25	-
21	1.3	21	-
22	1.1	10	-
23	1.1	18	-
24	2.0	21	-
25	1.7	14	-
26	1.3	18	-
27	1.1	18	-
28	1.3	24	80
29	1.7	27	-
30	1.1	16	-
31	1.6	22	-
32	1.5	23	-

APPENDIX 7-B (Contd.)

Date: 13.6.69

Long axis, weight and distance moved by the Yellow stones in the western stream "Lanehead"

No.	Long axis in inches	Weight in grams	Distance in feet
33	1.7	25	-
34	1.4	17	-
35	1.5	26	-
36	1.1	18	-
37	1.3	22	-
38	1.1	19	-
39	1.2	16	-
40	1.4	27	-
41	2.1	28	-
42	1.9	28	-
43	2.1	43	-
44	2.2	25	-
45	1.0	11	-
46	1.3	30	-
47	1.9	40	-
48	2.1	22	-
49	1.3	35	-
50	1.7	21	-
51	1.7	28	-
52	1.6	25	-
53	2.0	16	-
54	1.2	19	256
55	1.6	28	-
56	1.4	31	-
57	1.3	30	-
58	1.4	39	-
59	1.6	22	-
60	1.5	44	-
61	1.2	30	-
62	1.1	32	-
63	1.8	28	-
64	1.6	40	30
65	2.1	33	-

APPENDIX 7-B (Contd.)

Date: 13.6.69

No.	Long axis in inches	Weight in grams	Distance in feet
66	1.9	49	-
67	2.0	56	-
68	1.4	43	-
69	2.1	50	-
70	1.6	43	11
71	1.4	43	-
72	1.2	29	82
73	2.0	36	-
74	2.2	29	-
75	1.9	37	-
76	2.3	66	-
77	2.1	30	-
78	1.5	60	-
79	1.9	47	-
80	2.1	41	137
81	1.8	57	-
82	1.9	55	-
83	2.3	71	-
84	2.7	70	-
85	1.8	72	-
86	2.1	55	-
87	1.7	56	60
88	2.8	85	40
89	1.9	95	-
90	3.1	135	-
91	3.0	96	77
92	2.9	109	-
93	1.5	93	-
94	3.3	211	3
95	2.2	119	-
96	2.9	142	-
97	3.2	160	3
98	2.9	202	20

Date: 13.6.69

No.	Long axis in inches	Weight in grams	Distance in feet
99	3.7	230	-
100	3.1	243	30
101	2.4	158	-
102	3.2	188	18
103	3.3	301	00
104	4.1	477	18
105	4.9	536	7
106	5.6	738	-

APPENDIX 7-B (Contd.)

Date: 27.1.1969

No.	Long axis in inches	Weight in grams	Distance in feet
1	1.2	16	-
2	1.0	14	-
3	1.0	11	-
4	1.0	10	-
5	1.1	12	-
6	1.0	9	-
7	1.1	11	-
8	1.4	11	63
9	1.3	15	38
10	1.1	11	-
11	1.5	16	-
12	1.0	12	-
13	1.2	15	-
14	2.0	16	-
15	1.5	12	-
16	1.3	12	-
17	1.3	12	-
18	1.8	13	-
19	1.1	23	-
20	1.3	25	-
21	1.3	21	-
22	1.1	10	-
23	1.1	18	68
24	2.0	21	256
25	1.7	14	-
26	1.3	18	105
27	1.1	18	-
28	1.3	24	-
29	1.7	27	271
30	1.1	16	-
31	1.6	22	-
32	1.5	23	59
33	1.7	25	-

APPENDIX 7-B (Contd.)

Date: 27.1.69

No.	Long axis in inches	Weight in grams	Distance in feet
34	1.4	17	-
35	1.5	26	76
36	1.1	18	-
37	1.3	22	-
38	1.1	19	-
39	1.2	16	-
40	1.4	27	51
41	2.1	28	17
42	1.9	28	-
43	2.1	43	-
44	2.2	25	-
45	1.0	11	106
46	1.3	30	-
47	1.9	40	98
48	2.1	22	124
49	1.3	35	-
50	1.7	21	68
51	1.7	28	-
52	1.6	25	-
53	2.0	16	54
54	1.2	19	-
55	1.6	28	63
56	1.4	31	7
57	1.3	30	72
58	1.4	39	78
59	1.6	22	44
60	1.5	44	-
61	1.2	30	-
62	1.1	32	90
63	1.8	28	-
64	1.6	40	72
65	2.1	33	127
66	1.9	49	-

APPENDIX 7-B (Contd.)

Date: 27.1.69

No.	Long axis in inches	Weight in grams	Distance in feet
67	2.0	56	-
68	1.4	43	113
69	2.1	50	-
70	1.6	43	147
71	1.4	43	-
72	1.2	29	-
73	2.0	36	-
74	2.2	29	-
75	1.9	37	133
76	2.3	66	51
77	2.1	30	30
78	1.5	60	-
79	1.9	47	68
80	2.1	41	-
81	1.8	57	-
82	1.9	55	8
83	2.3	71	-
84	2.7	70	134
85	1.8	72	-
86	2.1	55	-
87	1.7	56	-
88	2.8	85	-
89	1.9	95	-
90	3.1	135	48
91	3.0	96	-
92	2.9	109	-
93	1.5	93	
94	3.3	211	24
95	2.2	119	33
96	2.9	142	-
97	3.2	160	32
98	2.9	202	23
99	3.7	230	17

APPENDIX 7-B (Contd.)

Date: 27.1.69

No.	Long axis in inches	Weight in grams	Distance in feet
100	3.1	243	9
101	2.4	158	10
102	3.2	188	-
103	3.3	301	46
104	4.1	477	-
105	4.9	536	7
106	5.6	738	12