Working Paper 242

The pipeflow stream head - a type description

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ABSTRACT

The hydrology of dynamic contributing areas, in small drainage basins has in recent years received increasing attention. However, in Britain at least, detailed studies have been confined to sites that represent only part of the possible range of form and process types found in the landscape. This paper by describing, in general terms, a *pipeflow* as distinct from a *throughflow* stream head attempts to demonstrate how wide this range may be and why it is of significance to geomorphological studies.

THE PIPEFLOW STREAM HEAD - A TYPE DESCRIPTION

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1. Introduction

The role of saturated areas in very small drainage basins which act as source areas for storm runoffs is now widely recognised. The contributing or partial area concept (Dunne, Moore and Taylor, 1975; TVA, 1968; Yair *et al.*, 1978) is becoming an accepted part of hydrological theory. Several field studies of hydrologic processes in contributing areas have been carried out (eg. Anderson and Burt, 1977; Dunne and Black, 1970; Weyman, 1970) and these have established the importance of topography as a primary control on both the extent of saturated areas and catachment storm response. Zones of saturation have been shown to correlate with slope concavity and, in particular, contour convergence, expressed topographically as hollows. The relationship of saturation extent and drainage convergence parameters around such hollows has been mapped (Kirkby, 1978).

The hollows examined in field studies have been quite variable in nature, yet, even with the attention paid to the influence of topography, no studies have explicitly considered either the geomorphic processes in these areas or the relation of hollow topography to the general catchment physiography.

In Britain the majority of work has been carried out on hollows of simple shape developed on loamy brown earth soils. In this case the dominant hydrologic drainage process has been found to be saturated throughflow. This type of hollow is referred to here as a *throughflow* hollow or stream head. As part of a wider study of erosion from stream head hollows, it has been noted that different stream head morphologies associated with different physiographical/process conditions are common in the landscape, and that the *throughflow* hollow is by no means the dominant form. To illustrate both the range of form variation and the importance of the physiographical setting, the general features of a contrasting type of stream head, the *pipeflow* stream head are described here. In this latter case the dominant hydrologic drainage process is flow from natural pipe networks. These pipes are fed from saturated source areas developed on the flatter catchment summit, distal to the main stream hollow. The stream head morphology is strongly related to the development of these pipes, as are the drainage systems storm and sediment response characteristics.

2. Experimental site description

The observations resported here were made in two small instrumented catchments to the West of Ripponden, Yorkshire. The major, more fully instrumented catchment is that of the Slitheroe Clough (SCl), a perennially flowing side slope tributary to the upper Calder valley. The stream drains a 0.04 km^2 basin which receives on average 1,250 mm rainfall per year. The term Clough is a locally name for a stream with a significantly developed valley. The smaller catchment, designated SC2 is drained by a highly ephemeral stream contained in a much smaller valley (<3 m^2 in cross-section). The layout of the catchments is shown in figure 1.

The geology of the site is simple both catchment being underlain by massive flaggy members of the Kinderscout series of Carboniferous millstone grits. The rocks have an approximate 7^0 southerly regional dip and display small-scale flexural folding. Superficial drift and solifluction deposits are largely absent although some small clay lenses have been detected by auger survey.

The general physiography of the catchments is typical of the gritstone region of the Pennines. Both lie on a southerly facing convex slope (maximum declivity 16^0) rising from 310 m above O.D to a flatter ($1-2^0$) moorland top at 380 m. A small scarp is developed halfway up the slope where a more resistant member of the grit outcrops. The top of the catchments are cut off from the summit of the slope by a round contour flowing water supply 'catch-water' some 360 m above the stream gauging point.

The vegetation of the catchments shows a gradation with both altitude and drainage. The lower slopes are unimproved pasture grassland, with *Molinia sp* dominates. Further up the slope or in wetter areas the proportion of *Europhium sp* increases. On the upper moorland levels a *Caluna/Europhium* assemblage of the type described by Moss (1913) is found, whilst on the steeper, drier, scarp slopes considerable areas are covered by *Pteridium*.

Soils in the catchment range from deep (>2 m) fibrous and amorphous peats on the upper moorland levels to shallow sandy rankers lower down on the grassed slopes. The depth and character of these soils has been found to be closely related to drainage and slope conditions (figure 2). The banding noted in profile 1 of figure 2 is found only in soils developed in the floors of drainage lines.

3. Field experiments

The catchments, as part of a wider study of stream head erosion, have been instrumented to provide data on runoff and sediment sources. Rainfall is monitored using a Casella tipping bucket raingauge and checked against daily and weekly 5" manual gauges. Stream discharge is recorded using $\frac{1}{2}\,90^0$ thin plate metal weirs, constructed to BS 3640 (British Standards Institute, 1965) and drum stage recording equipment. To provide ordinal data on the spatial distribution of overland flow, soil saturation and saturated throughflow, networks of Crest stage tubes (Kirkby, *et al.*, 1976) and throughflow collecting tubes were installed. To give volumetric estimates of runoff and sediment production on the catchment slopes a further network of sediment traps (similar in design to Gerlach troughs) was set up. In addition, bank collapse and micro-head cutting around the stream lines were recorded using erosion pin grids and photographic survey points.

To record through storm variations in soil moisture, runoff generation and stream sediment concentrations a small electro-mechanical monitoring system was in operation. This system is fully described elsewhere.

4. Hydrologic and erosional characteristics of the catchments

The Slitheroe Clough catchments are of hydrological interest because of the occurance of saturated areas away from the main stream hollow, and the natural pipe networks that drain such areas.

Hydrologically the catchment may be conveniently divided into three areas. The main hollow is a near permanently saturated linear area around the perennially flowing part of the stream. The maximum 'valley floor' width is only 10 m and is not significantly developed farther than 60 m above the catchment gauging station. The area of this hollow is only 0.3% of the total catchment area. To the west of the catchment, occupying 12% of the total area is a zone of drainage controlled by a large mid-slope bog. This bog is fed by both saturated throughflow and ephemeral pipes from upslope, but drains down to the main stream via wide (<3 m) lines of saturation, containing within them some perennially flowing pipes. Near the main valley the drainage lines converge to form a *Juncus* flush (the term flush is used here to have the same meaning as that given by Newson and Harrison, 1978). The drainage lines described above are similar in nature to the percolines described by Bunting (1964). To the east of the catchment and throughout the minor SC2 catchment an area of drainage (88% of SC1 and 100% of SC2) characterised by summit saturated areas and isolated patches of saturation connected to each other and the main stream by extensive ephemeral pipe networks is found. These networks are often discontinuous and as a consequence the relationship of a saturated area to a pipe may be either as a flow source *or* an outlet zone. In the main, the primary source areas for the pipe flows are the flatter heather moorland areas near the summit of the catchment. These areas act as large storages for precipitation and saturation rapidly spreads across them during storm periods. The spread of saturated area, with increasing discharge is seen in figure 3. The influence of the pipe networks on the catchments hydrology is seen in the storm hydrograph. For the storm and recession period shown in figure 4 the following features are noted:

(1) The hydrograph rises to a single peak

(2) The recession element shows no subsidiary peaks or pulses

(3) There is a small delay between the rainfall and runoff centroids.

From these observations, and the mapped extent of saturation it must be inferred that there is rapid evacuation of storm runoff from the distal saturated areas. Direct runoff from the main stream hollow cannot be regarded as the major hydrograph component since this area is too small (for the case of the example hydrograph being sufficient only to provide 1.6% of the peak flow). Similarly drainage from the bog controlled area cannot account for the peak, again due to its size but also because measured throughflow velocities (0.3 cm sec^{-1}, Weyman, 1973) are too slow to provide the rapid single storm peak. Only overland or pipeflow velocities would appear rapid enough to account for the hydrograph peakedness. Pipeflow velocities recorded in the catchment fall in a similar range to those recorded by Newson and Harrison (*op. cit.*). Taking an average velocity of 0.1 m sec^{-1} for pipeflow and 0.0025 m sec^{-1} for throughflow the average travel time for flow from the saturated areas in the catchment would be 30 mins and 20 hrs respectively.

The delays between rainfall and runoff centroids shown in the example hydrographs (figures 4 and 8) are typical of those observed throughout the experimental period, and fall between the values calculated above. Of course these are merely rough estimates but these sort of delays appear consistent with those due to infiltration and throughflow delivering water over short distances to the pipe heads. One should also consider that flow velocities in small pipes near the head of the network may be considerably less than 0.1 m sec^{-1}.

4.2 Erosional characteristics

4.2.1 Slope erosion

The general physiography of the catchment is simple yet there is pronounced micro-topography much of which displays evidence of contemporary erosional activity associated with natural pipes. The most common micro-topographic features are the linear depressions associated with the pipe networks (a similar association is noted by Gilman, 1972). These depressions range from indistinct (<20 cm amplitude) forms, presumably due to slight surface sagging, to fresh steep sided collapses (<1.5 m amplitude) exhibiting bare and unstable banks. The degradation of such collapses leads to a widening as well as infilling. This process leads to the third type of depression observed at the site; 'valley' like forms up to 6 times the width of the original pipe. In most examples of this type pipes reform in the 'valley floor' and along the crests of the depression sides continuous 'scarps' or free faces are developed. These would suggest that these drainage line side slopes are eroded by rainsplash and mass movement rather than the influx of overland flow from surrounding areas. The depth of drainage line associated depressions generally increases down slope towards the stream gauging point although nothing large enough to be termed a 'valley' is developed above the junction of the west and east drainage areas described previously.

At a finer scale of resolution the most conspicuous erosional features are micro-knick points or head steps often less than 10 cm in height. These form in drainage lines where flow is constrained between *Molinia* tussocks or some other natural obstacle. Such 'knick points' are often associated with discontinuous micro-cills fed by flow from a pipe resurgence. Rainsplash on the slopes of the catchment seems to be of little significance, vegetation mats mulching the soil surface, and thereby protecting it.

The techniques used to record catchment erosion have been outlined previously (section 3). For the purpose of the sediment trap experiments slope locations were divided into four classes:

(1) Main slope

(2) Active drainage line

(3) Passive drainage line

(4) Drainage line side slope.

The distinction between the 'active' and 'passive' drainage lines being based on visual evidence of surface water erosion, and a pilot CST experiment. Some preliminary results from the sediment traps are shown in figure 5, from this there is seen to be a clear relationship between slope location, and the totals and frequency of runoff and sediment transport. The importance to catchment erosion of concentrated drainage is seen in the high frequency/volume values of both the 'active' and 'passive' drainage line classes. Clearly the same process (turbulent flow erosion) is operative in each class, but more frequent in the former case. However the relationship between erosion frequency and slope position in these drainage lines is not a simple one with distance from the divide as might be expected from early works on stream head dynamics (eg. Blyth and Rhodda, 1973). The differences in flow frequency are attributable to the discrete nature of the drainage and the concomitant irregular increase in area drained per unit contour length with increasing distance downslope. This subject is discussed further in section 5.1.

The volumes of runoff and sediment produced on the drainage line side slopes are at first sight anomalously high. However the low dissolved solids concentration of the flow collected seems to confirm that rainsplash is the dominant process on these slopes. The totals for the main slope are not surprising although it should be pointed that this '*slope wash*' is by no means *sheet wash*-flow being concentrated in irregular, unincised drainage lines. The positions and courses of these flow lines being controlled by micro-topographic and vegetation irregularities.

The results of the erosion pin experiments are also summarised in figure 5. It is interesting to note the very slow rate of pipe outlet retreat. This suggests that 'plumes' of mineral sediment seen emanating from certain pipes in the catchment are derived from bed erosion *within* the pipe itself.

In explaining the pattern of erosion on the catchment slopes four important source areas are identified. The first is within the pipes themselves where runoff first reaches a velocity sufficient to erode mineral soil material. The second area is the unstable pipe collapse sides subject to rainsplash. The third type of source area and the one in which erosion is most frequent are the active drainage lines, particularly below pipe outlets, where surface channelised flow first occurs, erosion being concentrated at small long profile irregularities (micro-knick points). The final area is the main slope itself where flow is infrequent and the dominant component of the eroded sediment is organic litter and sub-humic material.

4.2.2 Stream erosion

The sediment dynamics of the catchment streams are typical of stream head areas. In the dissolved solids concentrations no dilution is seen with increasing discharge (figure 6). The apparent increase in dissolved solids is found to be due to the increasing proportion of flow from the easterly pipe network flow from the individual components displaying near constant concentrations (figure 7).

Exactly why the pipe flows exhibit higher dissolved concentrations is not clear, but it may be related to the ephemeral nature of saturation in the source areas. Through the course of a storm no 'flushing' effect in the pipe flows has been observed, it seems probable therefore that *storm water* takes up soluble salts, actually during transmission through the solum.

The suspended sediment output of the catchment follows a poorly defined pattern both through the course of an event (figure 8) and with discharge generally (figures 9, 10). It is suggested that this arises because sediment is produced within the catchment by non-continuous 'events' such as micro-knick-point cutting and pipe collapse. Further, there is little sediment directly available to the stream either in the form of channel deposits or well defined, erodible banks.

5. The hydrological and morphological significance of piping

5.1 Hydrologic significance

At many levels of stream discharge saturated areas exist away from the main stream valley. With increases in discharge these saturated areas grow to occupy a larger percentage of the catchment (figures 3, 11). From figure 11 it is seen that the relationship between saturated area and discharge is not dissimilar from that shown by 'throughflow' stream heads, eg. the East twin catchment in the Mendips. However in this example there is not a smooth expansion of a continuous zone about the stream channel, rather the increase is an expansion and coalescence of patches of saturation. Also field observation has revealed that some saturated areas are not primary source areas. That is, some saturated areas are related to outflows of water at discontinuities in the pipe network.

The branching (although not truly dendritic) nature of this network leads to an irregular increase in the area drained (per unit width) with increasing distance downslope. This irregularity further explains the 'patchiness' of saturated areas, it tending to disturb the relationship of topography with saturated areas noted elsewhere (eg. Dunne, Moore and Taylor, 1975).

Pipe networks also offer rapid subsurface pathways for the evacuation of storm runoff. The onset of pipeflow has been found to be closely correlated to the occurance of saturation at points throughout the catchment. Observations have shown that flow does not begin at the start of rainfall and continues after it ends. This delayed response supports Gilman's (*op. cit.*) view that pipes flow only after an upslope source storage has been filled beyond some threshold level and continues until it drains below that threshold level. The pipe flow mechanism effectively 'short circuits' the slower throughflow process. The throughflow experiments described earlier detected, on the lower slopes, this type of flow only within the linear hollows always associated with overland flow and the probable reinfiltration of runoff. On the upper slopes in the peatier soils throughflow is more widespread although it displays a high degree of spatial variability, being strongly related to dessication cracks in the peat. Throughflow is therefore seen as a local process delivering water over short distances to increasingly large macro-pores which presumably feed into the pipes themselves.

To summarise four features are noteworthy:

(1) Discontinuous areas of saturation occur away from the actual stream head hollow

(2) Some saturated areas are not primary runoff sources, but are pipe outflow areas.

(3) Drainage occurs rapidly down discrete lines occupied extensively by pipes, rather than as laterally unconcentrated pulses of saturated throughflow.

(4) Throughflow is only a local hydrologic process delivering flow over short distances into pipes.

The above points and the preceding discussion demonstrate that in upland, piped catchments the concept of a smooth continuous extension of a saturated (contributing) area about a stream head hollow is unsuitable. Rather patches of saturation occur over the slope and become active contributing areas only at the onset of pipeflow, when a level of storage is exceeded. It is then, in this type of environment, better to consider the growth of contributing areas as an *integration* not just an *extension* of saturated source areas.

5.2 Morphological significance

As previously stated, the micro-topography of the catchment reflects the importance of the pipe network. It should be considered therefore whether these pipes are of long term significance to the morphologic development of a stream head. The pipeflow stream head described here, displays a high degree of lineation, with a network of minor tributary depressions extending towards distal source areas. This forms a strong contrast to the simpler shaped depressions or hollows found in areas where throughflow is the dominant hydrologic process. The description of erosion processes (section 4.2) above has illustrated that erosion by overland flow is both frequent and not confined to one specific area in the pipeflow case. The works of Calver (1978) and Finlayson (1977) implicitly suggest that in a *throughflow* stream head such erosion is confined to areas in, or adjacent to the stream channel and that significant particulate erosion occurs only at times of near complete saturation of the hollow. It is suggested therefore that in pipeflow stream heads erosion of mineral soil is greater in amount and frequency and occurs at a wider range of locations than in throughflow stream head. The principal loci for this erosion being the pipes themselves particularly the zones below pipe outflows, junctions and collapses. Another noteworthy point is that across a wide range of event sizes although the total and extent of erosion increases with event magnitude there is in *pipeflow* stream heads no change in dominant erosional process. In the *throughflow* example, there are considerable changes in process dominance with increasing event size. Small events give rise to saturation excess or 'return' overland sheet flow within the hollow, which may give rise to local rill activity, as runoff increases. During very large events this may become significant and new channel links become excavated. However a field investigation of the effects of large storms on stream heads suggests that the most important response to extreme events, shown by this type of stream head is one of small scale slope failure (presumably due to high pore water pressures).

The responses of the different types of stream head to different events sizes are dissimilar, and one suggests there is a far greater degree of linearity between sediment production and event size shown in the *pipeflow* stream head. By implication, the two different morphologies are determined by different 'formative' (cf. Wolman and Gerson, 1978) events. In the pipeflow example it seems probable that small-medium sized events are of greatest overall significance (the classic Wolman and Miller (1960) 'active dwarf' case) whereas the erosive inactivity of *throughflow* hollows in this range of event sizes and the large scale nature of their reactions to extreme storms suggests that it is such storms that control their morphologies.

6. The distribution, occurrance and relationships of pipeflow stream heads

6.1 Controls of pipe development

Jones (1971) has reviewed the causes described by various reports of piping in soils and lists these (in order of importance) as:

(1) The susceptibility of the soil to cracking in dry periods

(2) The occurance of periodic high intensity rainfall and devegetation

(3) The biotic break-up of the soil and a relatively impermeable basal horizon

(4) An erodible layer occuring above this basal layer.

The observations here generally support these views with the exception of condition 2. The pipes in the catchment occur either at the junction of peat with mineral horizons (a type of occurence reported from Plynlymon, Wales, by Newsom (1976) or, where the peat is less developed, lower in the mineral soil horizons (Bh/Cr junction). The requirements for pipe development within the experimental catchments may be generalised as:

(1) A discontinuity in the decreasing soil permeability with depth

(2) A saturated source area to feed the pipe

(3) A significant hydraulic gradient.

Surveys around the area directly adjacent to the catchment have indicated that pedology, particularly the amount of peat relative to sandy mineral soil, exerts a further control on the extent and stability of pipe networks. Where sandy mineral material is the dominant pedologic constituent the sides of any pipe collapse appear to degrade rapidly enough to allow reformation of a pipe in the infill. In this way pipe networks may be quite stable and of long term significance to the morphologic development of the stream head. Clearly, though, this sort of reformation can only occur where there is a particular dynamic balance between rates of infill and downvalley transport. Where infill rates are low, as in the case of the banks being peat, the pipes once collapsed remain unfilled and develop as gullies.

6.2 Distribution of pipeflow stream-heads

In the gritstone areas of the Pennines of Yorkshire and Derbyshire the flat topped nature of the moors and only moderate depths of peat provide the conditions necessary for the development of saturated runoff source areas away from stream hollows and into connecting pipe networks. That pipes are common in the Pennines is apparent from the reports of Johnstone (1957) and Radley (1962). Johnstone writes:

> "Peat moss on a gently undulating surface will develop a drainage system of its own by means of seepage which frequently causes the collapse of the peat surface eventually leading to an open channel and later a gully."

Radley states that:

> "Sub-peat tunnels open conspicuously at the heads of the Rivers Alport, Crowden and Westend in Derbyshire."

Evidence of pipeflow in areas other than the Pennines is widely reported in the literature, of the examples visited by this author all have shown an intimate relationship with local, dynamic saturated patches.

6.3 Relationship to other drainage types

Piping represents only one of the possible range of subsurface hydrologic transport processes in headwater regions. It seems probable that there exists a continuum of change (or dominance) between a '*throughflow*' and '*pipeflow*' stream head. However with the exception of Gilman (*op. cit.*) little work has been carried out to assess the relative significance of piping to a catchment's storm response. There are some reports, though, of the co-occurance of different processes. For example the networks of percolines described by Bunting (*op. cit.*) from Burbage brook, Derbys. appear to be a transitional state between diffuse (throughflow) and discrete (pipeflow) drainage. Jones (*op. cit.*) in a later study of this site found small pipes clustered in and around these percolines. Other investigations, notably Arnett (1974) and Knapp (1974) have found other grades of process co-occurance.

Arnett, in the North York Moors (Caydale) found large and local variations in interflow (throughflow) volumes between adjacent sites on a single slope segment with constant soil characteristics. The explanation for this variation appears to lie in the influence of macro-pores or pseudo pipes, concentrating drainage in some locations whilst at others true Darcian matrix flow occurs. Knapp's study (*op. cit.*) at Plynlymon reports significant volumes of both throughflow and pipeflow at the same site.

At this point one should consider the question of the relationship between pipe and gully systems. In areas of extensive peat development both pipes and gullies are found. Field investigation of peaty moorlands around Alston, Teesdale have confirmed Johnstone's (*op. cit.*) view that gullies form directly from pipe collapses. In the field survey many discontinuous gully systems were found to contain piped connections. In all cases the gully side walls were extremely well defined, and fresh. It appears, as might be expected that bank collapse, in peat, occurs by a process of undercutting and block collapse rather than rainsplash or wash.

7. Conclusions

The importance of natural pipe networks, in the example described here are seen in both the hydrological and erosional characteristics of a very small drainage basin. The pipes arise, principally as a response to the development of discontinuous saturated areas away from the main stream valley. The growth of these saturated areas with increasing discharge is not merely an *extension* of a single zone, but rather an integration and coalescence of contributing areas.

The effect of the pipe networks on the storm hydrograph is to produce a rapid single storm peak, which contrasts strongly with the delayed response shown by streams fed by throughflow. Erosion within the catchment is concentrated around the pipes, particularly their outlets and junctions. The influence of this erosion is reflected in the local morphology of the stream head, which is lineated, following the branching pattern of the pipe network.

The details above justify the identification of a *pipeflow* as distinct from a *throughflow* stream head. It must be recognised however, that a continuous gradation between the two will be seen in the natural environment. Also the process distinction, drawn here, although not the only way of classifying the range of contributing area forms, is certainly one important aspect of any classification, the theory of which can bepursued by applying the work of Beven *et al.* (1977) to the more detailed scale of local small hollows and sideslopes.

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THE SLITHEROE CLOUGH CATCHMENTS

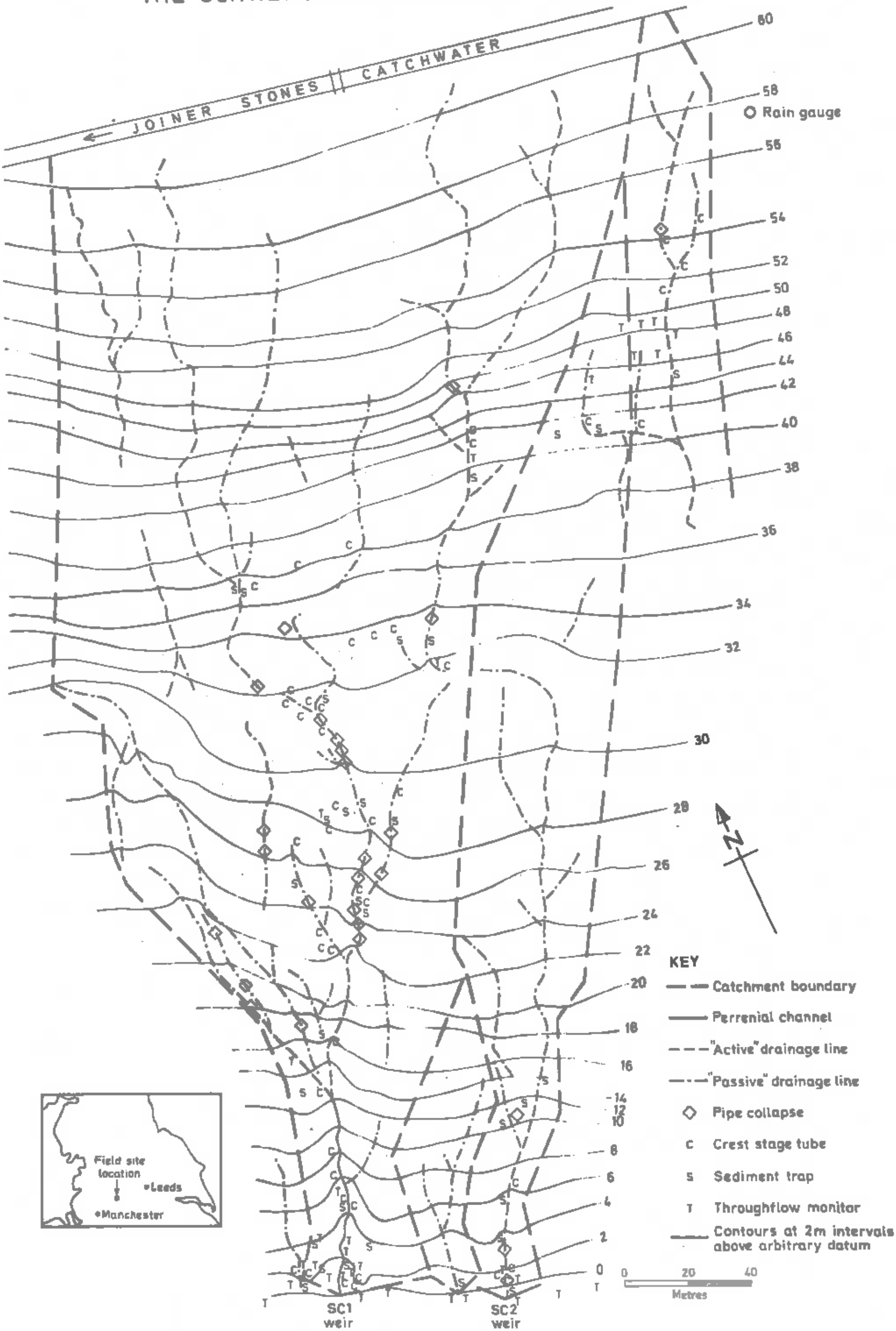

Figure 2. Soil description sheet

	Profile 1	Profile 2
Location	Within the hollow	On the slope 33 m from the hollow
Vegetation	Grasses in clumps	Short, evenly distributed grasses
Land use	Unimproved pasture	Unimproved pasture
Slope	Level ground	5^0
Aspect	S.W. facing slope	S.W. facing slope
Depth*	90 cm	13-18 cm
Moisture state	Semi permanent saturation	Saturation never observed.
Description:	(i) Horizon 'O'. 0-14 cm	(i) Horizon 'O'. 0-5 cm
	Fleshy and amorphous peat, gradual increase in grit with depth. Fairly sharp basal boundary. No stones.	Fibrous and fleshy peat, grades rapidly into sandy peat. Few small stones
	Colour: 5YR 2/1	Colour: 2.5Y 2/0
	(ii) Horizon 'Bh'. 14-83 cm	(ii) Horizon 'BC'. 5-14 cm
	Shows intermixing of organic and sandy mineral particles. Sometimes distinct bands are shown, band width varies between 1-3 mm. Practically no clay some silt. Not a true 'B' horizon. Some mottles.	Rapid increase of sand and grit size particles with depth. Light colour of sand dominates horizon.
	Colour: 5YR 3/2	Colour: 7.5YR 3/2
	(iii) Horizon 'Cr'. 84-86 cm	(iii) Horizon 'R'
	Highly weathered millstone grit. Breaks like biscuit and particles are detached when rubbed.	Massive millstone grit of the Kinderscout series.
	(iv) Horizon 'R'	
	Massive millstone grit of the Kinderscout series.	

*depth to bedrock.

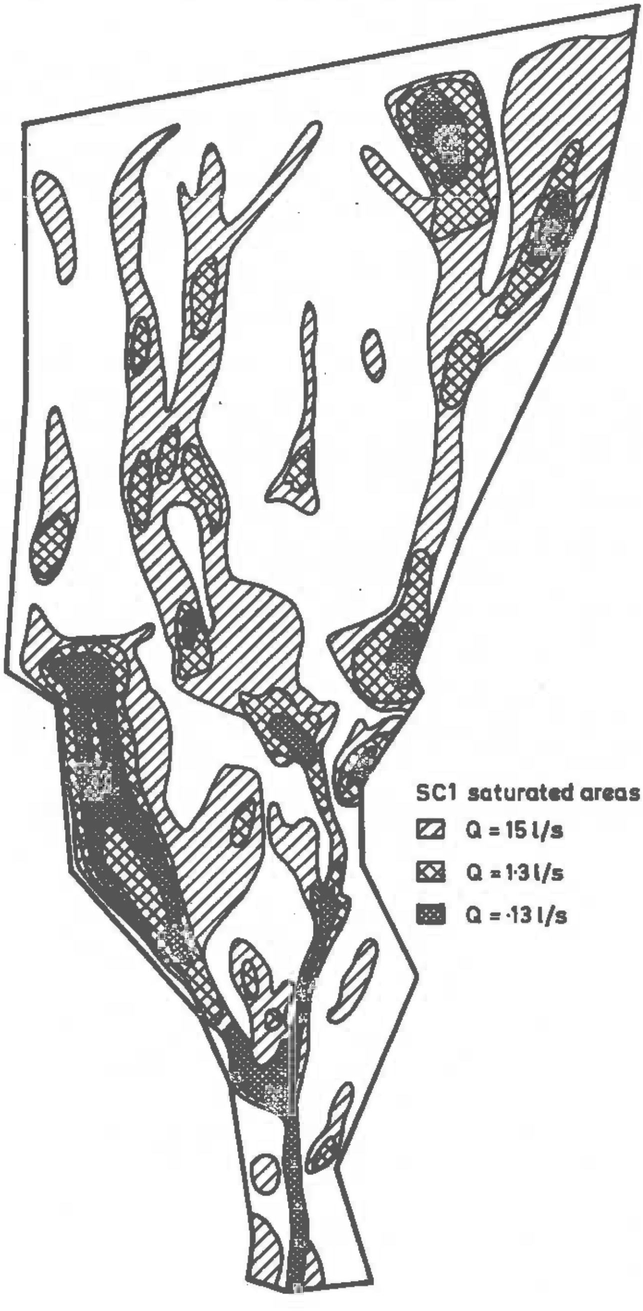

Fig.(iii). Areas of saturations

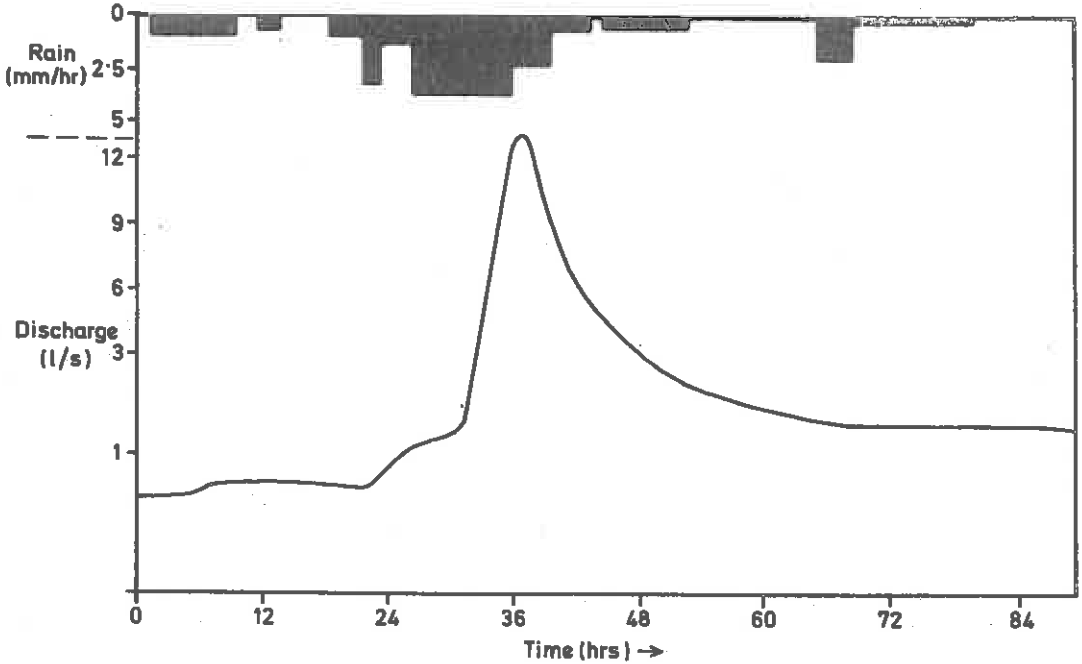

Fig. (iv) Example hydrograph (1)

Figure 5. Erosion data

(a) Sediment trap data

Slope Class	Solid sediment transport mgm^{-1}	Mean of class medians (per event) solid sed mgm^{-1}	Dissolved sediment transport gm^{-1}	Runoff cm^{-1}	Frequency of flow % of all obs.
Slope	433.3	7.4	0.1	2.8	22
Drainage line (active)	12,042.0	131.2	1,156.0	46.8	52.4
Drainage line (passive)	822.3	19.8	62.5	19.8	41.5
Drainage line side slope	1,207.0	29.6	45.0	18.9	36

Significance of differences between groups analysed using Kruskall-Wallis rank AOV test, result: H = 236.2, significant at 0.1% level.

(b) Erosion pin data

Site	Max. lateral erosion (cm)	Mean lateral erosion (cm)	Min. lateral erosion (cm)
Pipe outlets	0.9	0.25	0
Pipe collapse sides	10.0	2.7	0

Observations calculated to October 1977 - March 1978, except for flow frequency which are for the water year September 1977 - September 1978.

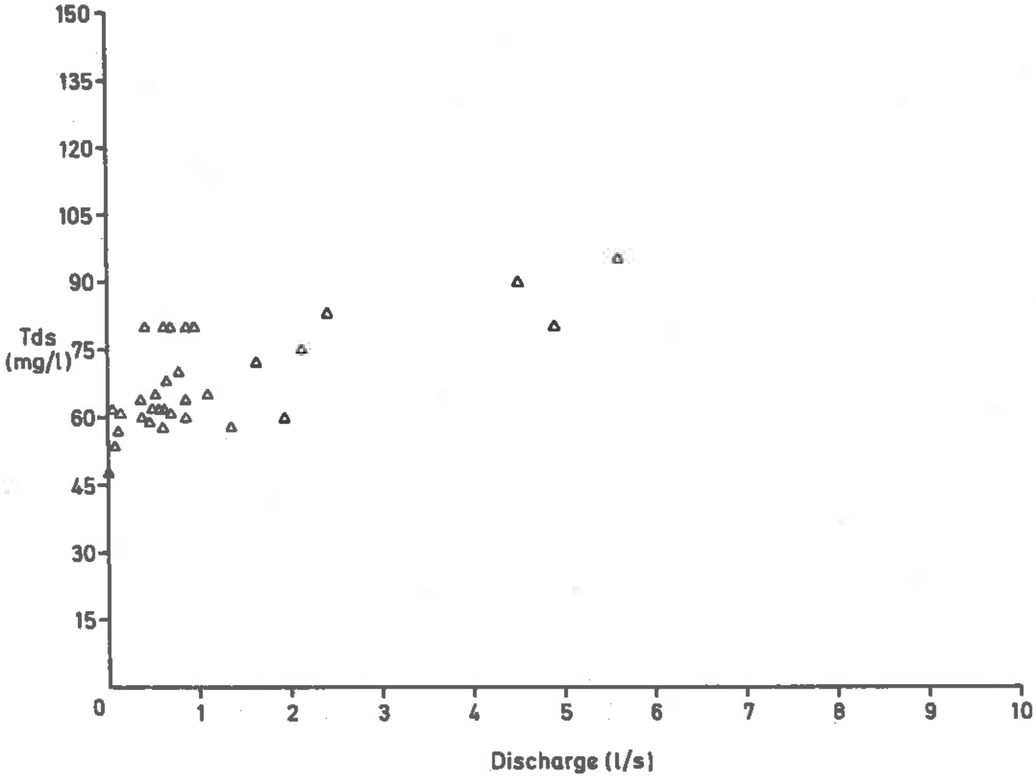

Fig.(vi). Dissolved solids discharge relationship

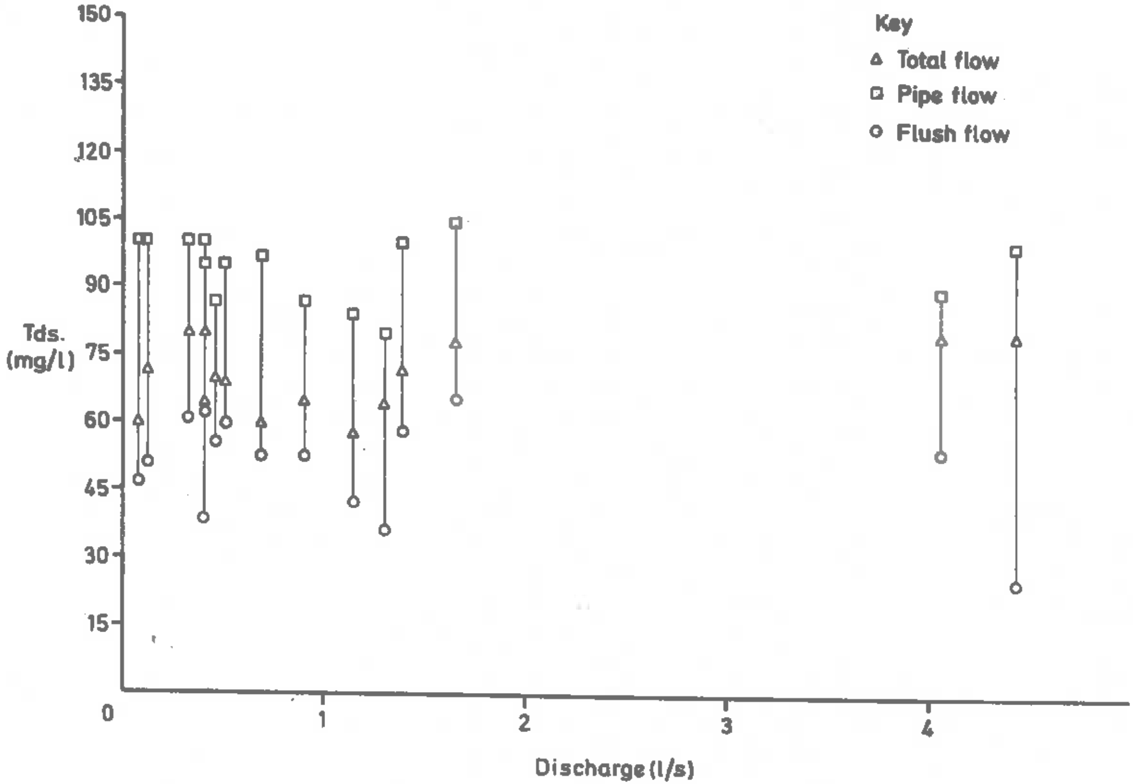

Fig.(vii) Dissolved solids discharge relationship - component parts

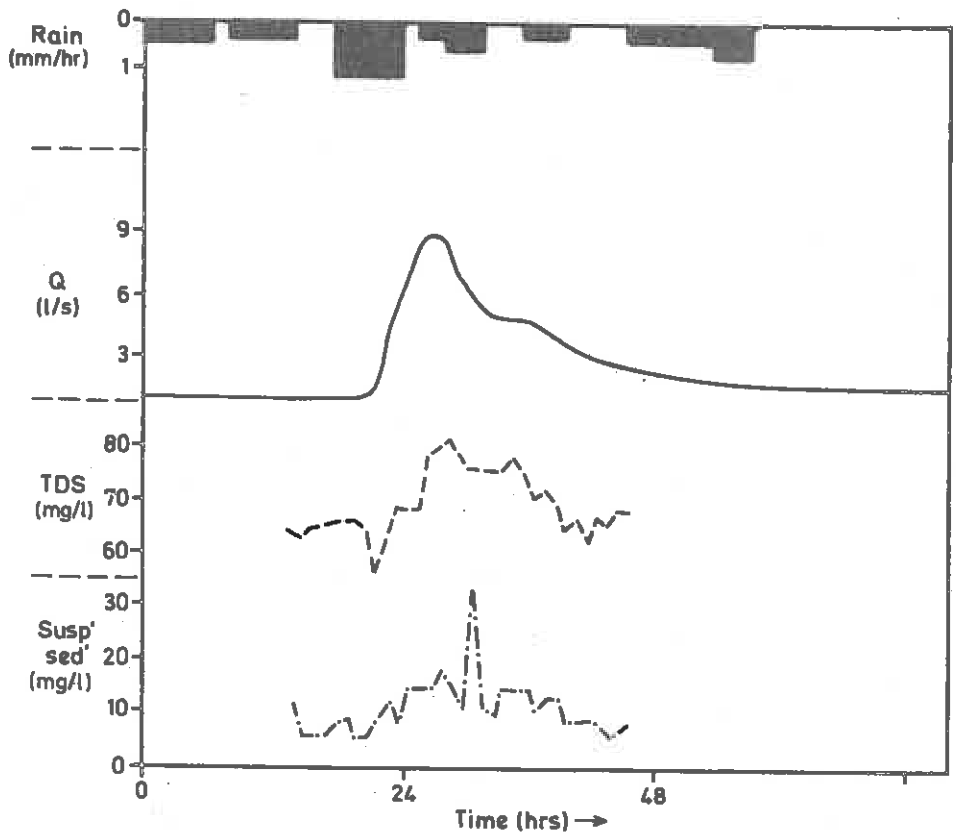

Fig. (viii) Example hydrograph (2) Sediment concentrations

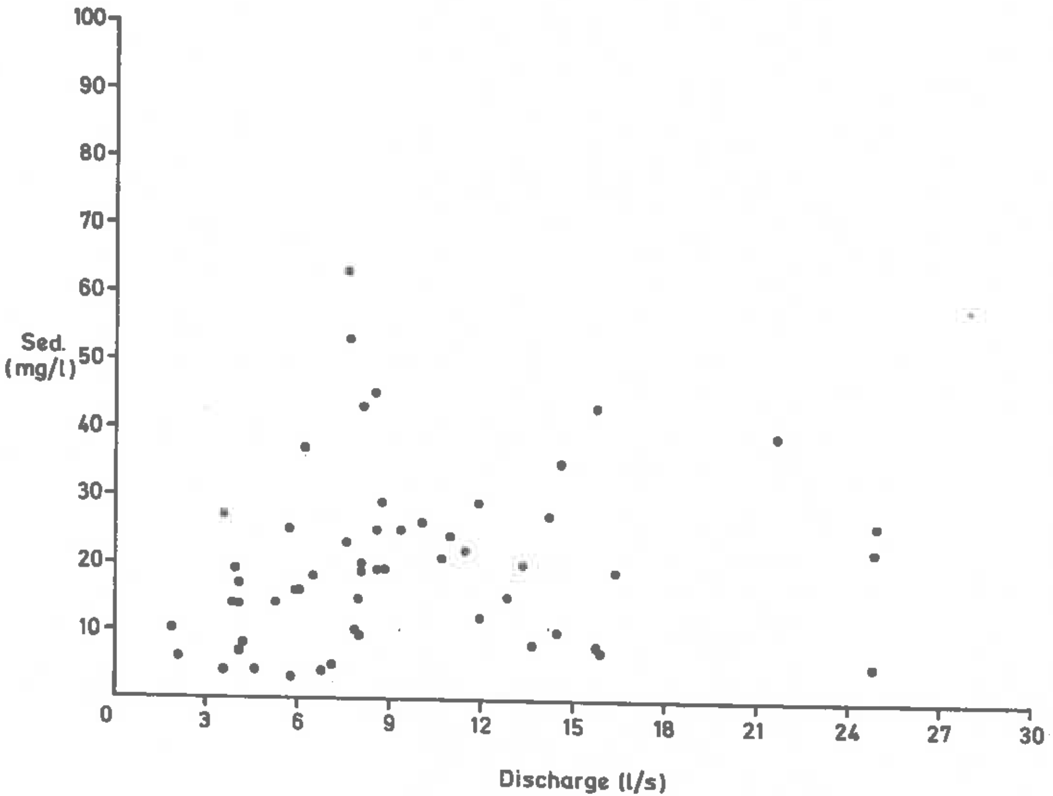

Fig. (ix). Suspended sediment - discharge relationship, rising stage

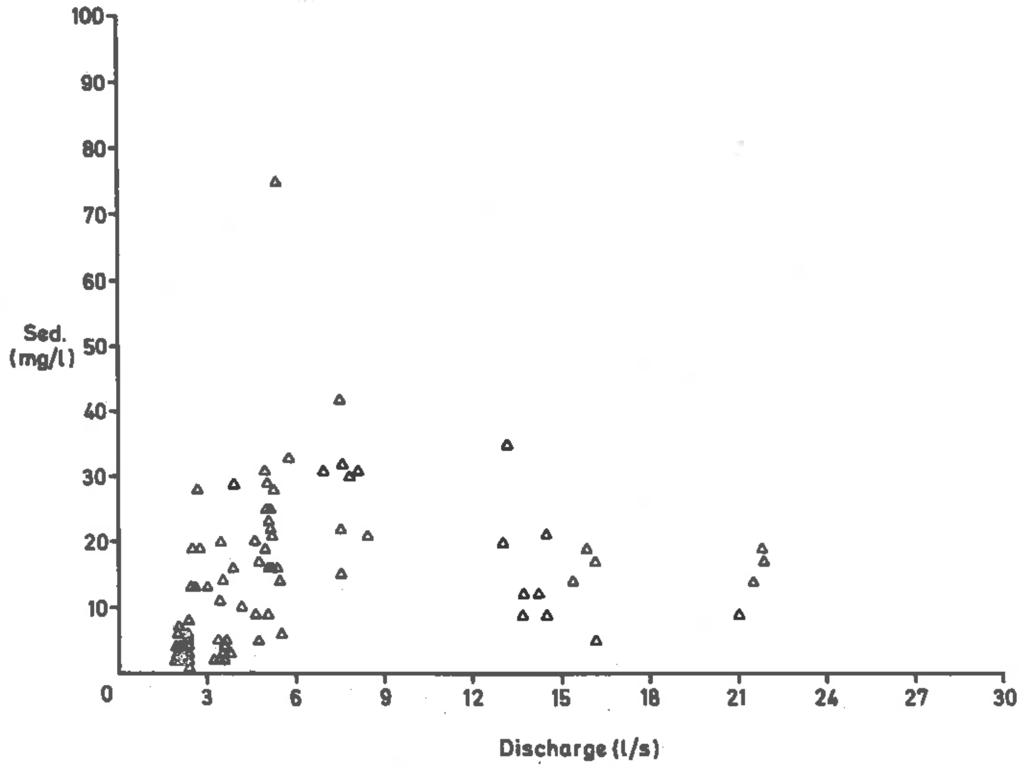

Fig. (x). Suspended sediment-discharge relationship, falling stage

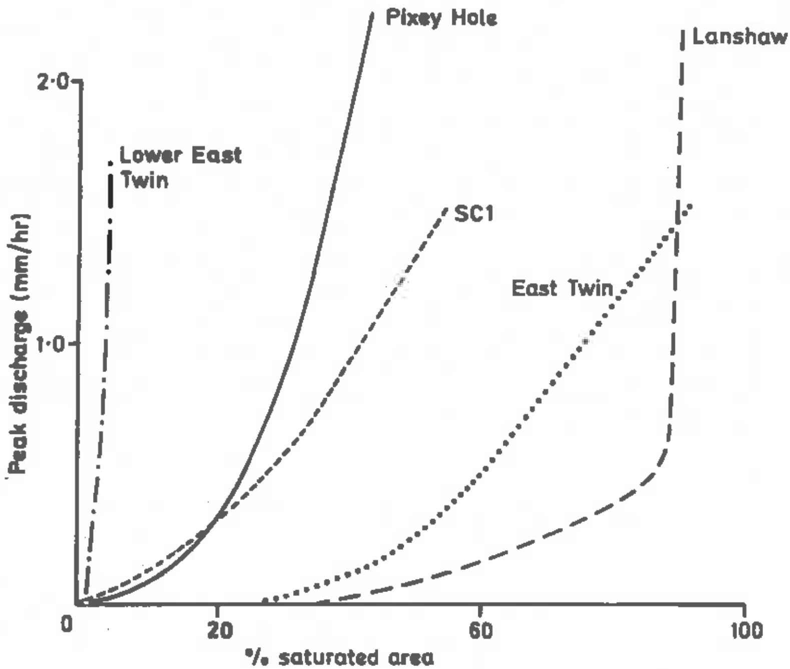

Fig. (xi). Saturated area - discharge relationship