CHANNEL NETWORK INITIATION AND SUBSEQUENT ADJUSTMENT IN THE UPLANDS OF NORTHERN ENGLAND, THE CASE OF THE WHITENDALE RIVER CATCHMENT

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ABSTRACT

This paper aims to highlight the spatial and temporal characteristics of channel network initiation. The selected study area is the Whitendale catchment located in the British uplands. Different types of channel heads are recognised in the field and classified accordingly, based on the relationship between source area and local valley slope. Depending on the type of channel head, it appears that the contributing area per unit contour length is related to the main trunk stream length. The comparison between channel heads observed in the field and those predicted from the DTM provides useful insights into the environmental controls of drainage morphometry.

KEYWORDS: FLUVIAL NETWORKS, CHANNEL INITIATION, CHANNEL HEAD, VALLEY SLOPE, BRITISH UPLANDS.

INTRODUCTION

The recent topographic evolution of natural drainage networks is fundamentally controlled by the interaction between two competing processes: aggradation and incision. Channel head locations in humid environments are generally found in unchanneled valleys or hollows (e.g. Hack, 1960; Dietrich et al., 1993). It has been widely considered since Smith and Bretherton's monumental paper (1972) that landscape dissection is primarily caused when advective processes dominate over diffusive sediment transport. In a somewhat similar statement, Montgomery and Dietrich (1989), considered that the position of each channel head represents a balance between slope processes that tend to fill the channel head, and stream processes that remove sediment and maintain or extend channels once a threshold has been reached This balance has its spatial expression in the planform of the network, and its temporal expression in the historical sequence of channel head expansion and contraction during and between major floods. Three different mechanisms responsible for channel initiation: incision by overland flow (Kirkby and Chorley, 1967), seepage erosion (Dunne, 1980) and shallow landsliding (Montgomery and Dietrich, 1989) have been proposed up to this date. However none of these is well documented. Here, a 4th order drainage basin, is thoroughly investigated, classifying channel heads depending on morphological characteristics and comparing these results with networks extracted from highly accurate digital elevation data, based on process considerations. The method depends on the acquisition of high resolution digital elevation data that allow us to compare the location of channel networks mapped in the field and networks derived from physical considerations.

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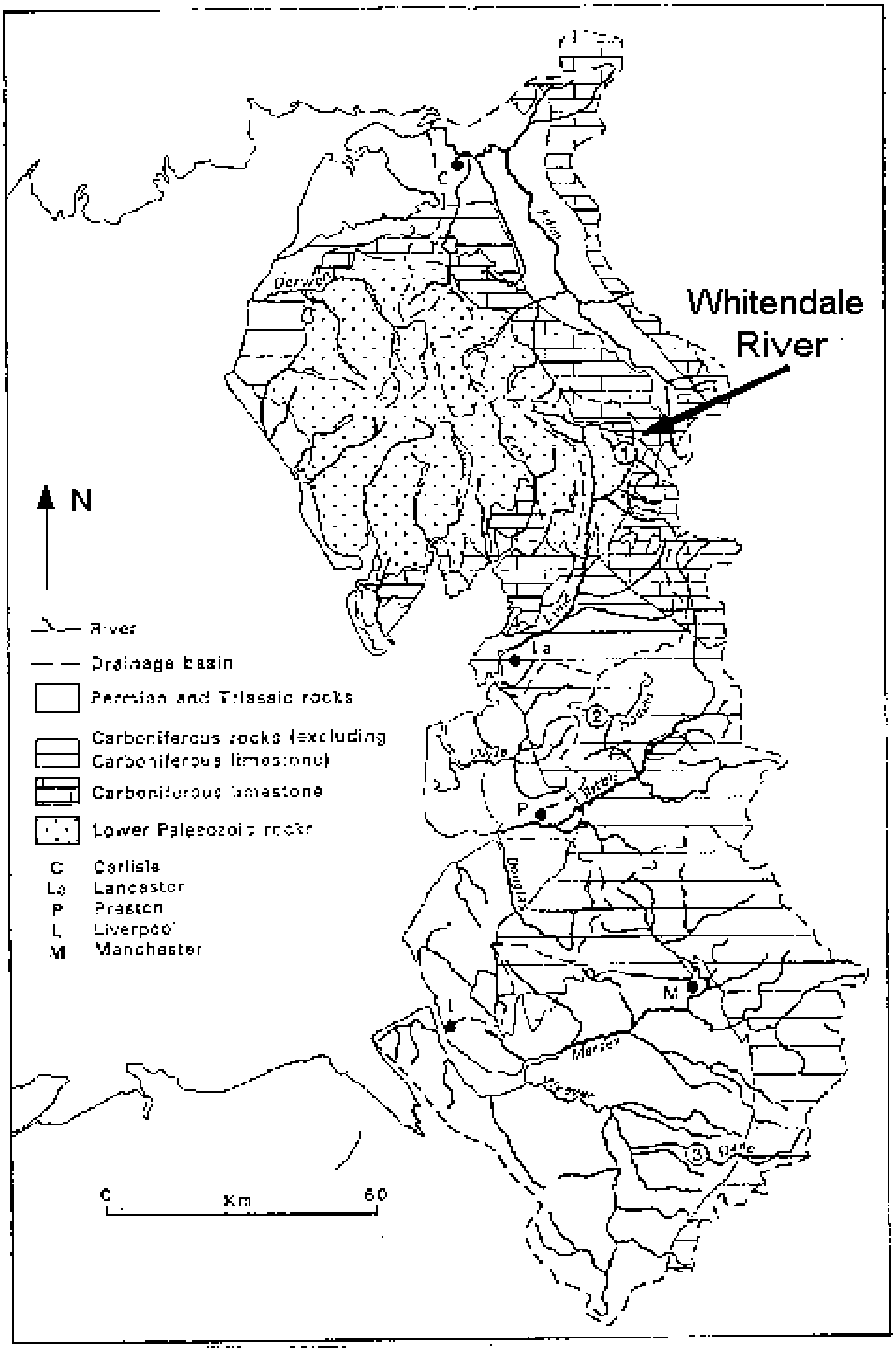

Figure 1. Location map of the Whitendale catchment study area

ASSESSMENT OF THE FIELD STUDY AREA CATCHMENT

The Whitendale River (National Grid Reference SD653534, SD654589) is located in the uplands of the Forest of Bowland (Figure 1). The catchment is underlain by the Upper Bowland Shale Formation, which is a dark grey silty mudstone of Namurian (Upper Carboniferous) age, and also by the Brennand Grit Formation, which is a pale brown pebbly sandstone with interbedded siltstone and sandstone. The area has a cool, oceanic, temperate climate with mean annual precipitation of ca. 1400 mm, with wet, frosty winters and wet, cool summers. Gully development is mainly controlled by the rates of headwall recession and the basal incision/stabilisation behaviour (Harvey, 1992).

Shreve (1966) defined channel network sources as "the points further upstream in a channel network", a definition, which is considered by many (e.g Schumm, 1979) as rather vague. This definition has been subsequently improved, based on field data obtained from several soil-mantled regions of Oregon and California (Montgomery and Dietrich, 1988, 1992). In this study, source areas of all 1st order streams were measured from 1:10,000 Ordnance Survey maps, housed in the British Library, using a digital planimeter, and slopes were measured using a Brunton compass (Table 1) and subsequently verified in the field in the presence of one more observer. Identifying the exact channel head location was not a straightforward procedure as in many instances especially when the channel begins gradually, it can be a rather subjective matter. Source-basin length was determined as the distance from the channel head to the watershed measured up the axis of the hollow (unchannelled valley). The plot of source area vs. the tangent of the local catchment slope at channel heads reveals an inverse relationship (Figure 2). The scatter plot of the source basin length vs. the tangent of the local catchment slope (Figure 3) also yields an inverse relationship over a wide range of slopes. However this finding is in disagreement with the positive relation found in Kirkby's (1987) channel initiation model for saturation overland flow. This may indicate that there is a distinct threshold dictating channel initiation at this location and also that erosion is not dependent on saturation overland flow mechanisms.

DIGITAL TERRAIN MODEL ANALYSIS OF THE STUDY AREA CATCHMENT

Digital Terrain Models are viewed as one of a number of appropriate tools for a comprehensive study of landscape changes and channel networks in particular. The recent advent of DTMs holds enormous potential for the quantitative analysis of actual landscapes. A number of algorithms has been developed for the extraction of stream networks from those data sets, by various workers (e.g. O'Callaghan and Mark, 1984; Band, 1986; Tarboton et al., 1991). The most common method is to specify a critical support area that defines the minimum contributing area required to initiate a channel. Topographic digital data are becoming increasingly available, which introduced the matter of the appropriate resolution that is needed to pick up meaningful changes in network evolution. The use of DTMs was initially viewed as very promising for the quantitative comparison of the digitally extracted networks with the "blue line" networks derived from O/S maps. However, they have to an extent, failed to realise their potential for automated drainage detection, the reason being the lack of an unambiguous procedure for extracting them from elevation data. A further complication arises from the fact that DEM construction can be regarded as a classical interpolation problem of data irregularly distributed on a plane. The processing of this data is needed to obtain an accurate DEM, which is the numerical description of elevation values arranged on a regular georeferenced grid.

Table 1. First order stream source data from Whitendale River, NW England

Local slope (m/m)	Source Area (m^2)	Source Basin Length (m)
0.67	56	12
0.49	78	14
0.45	106	17
0.43	122	18
0.78	19	9
0.3	108	17
0.46	99	16
0.44	4	9
0.45	56	9
0.33	129	17
0.62	43	10
0.51	63	11
0.53	22	10
0.58	56	13
0.91	12	6
0.69	69	14
0.75	12	7
0.62	28	5
0.44	94	12
0.79	4	10
0.36	106	18
0.47	46	11
0.45	128	27
0.65	26	4
0.57	77	12
0.34	81	15
0.36	74	16
0.25	23	20
0.29	131	17
0.42	8	15
0.41	95	18
0.51	65	12
0.49	137	14
0.57	88	15
0.24	365	38
0.35	89	12
0.36	145	16
0.59	86	9
0.34	112	17
0.27	144	19
0.25	152	18
0.43	83	11
0.62	48	9
0.52	46	12
0.5	41	9
0.91	5	8
0.4	118	14
0.35	84	11
0.57	64	17
0.41	43	13
0.86	17	6
0.44	36	8
0.45	115	13
0.65	5	16

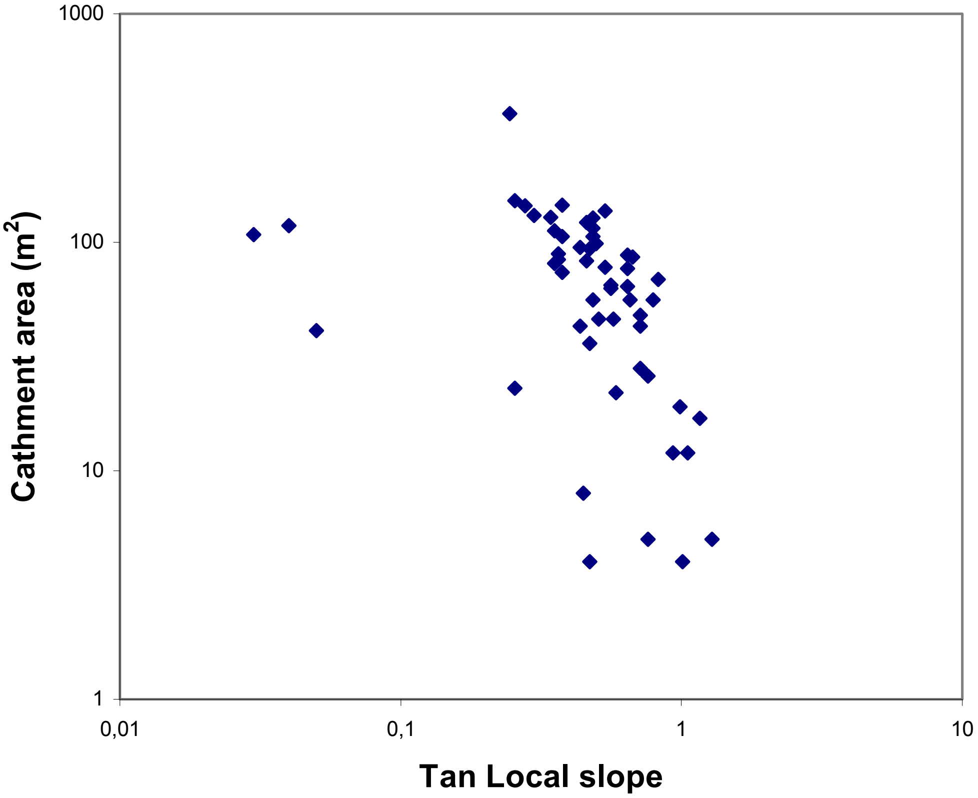

Figure 2. Log-log scatter plot of tangent of local slope vs. catchment area for 1st order channels of the Whitendale River

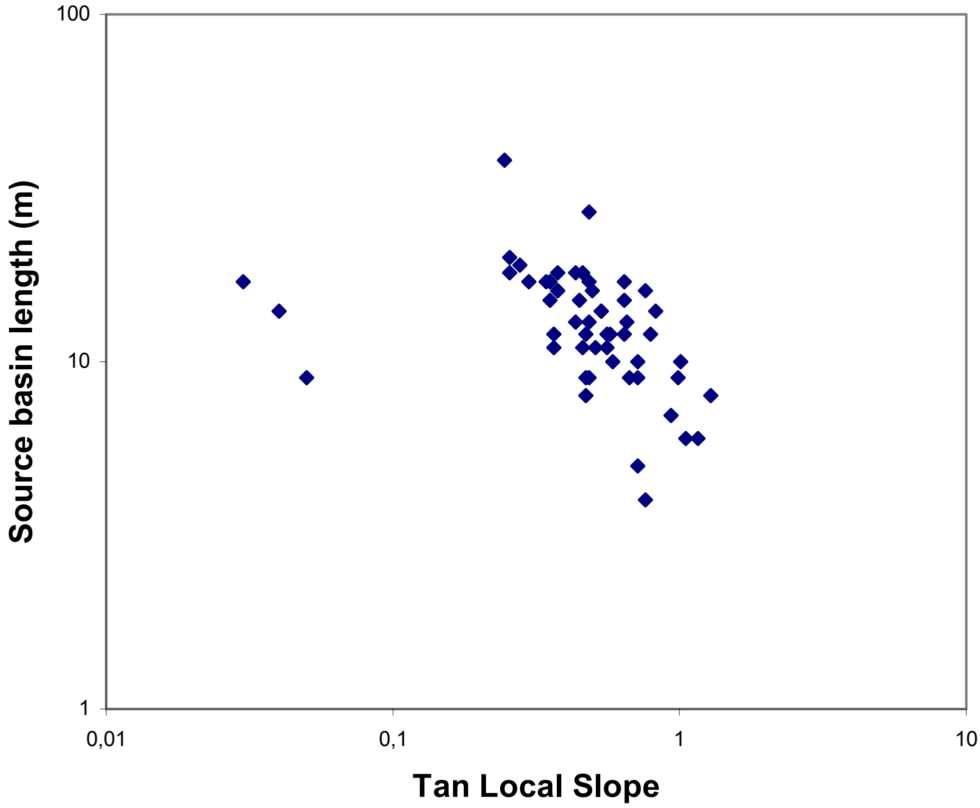

Figure 3. Log-log scatter plot of tangent of local slope vs. source basin length for 1st order channels of the Whitendale River

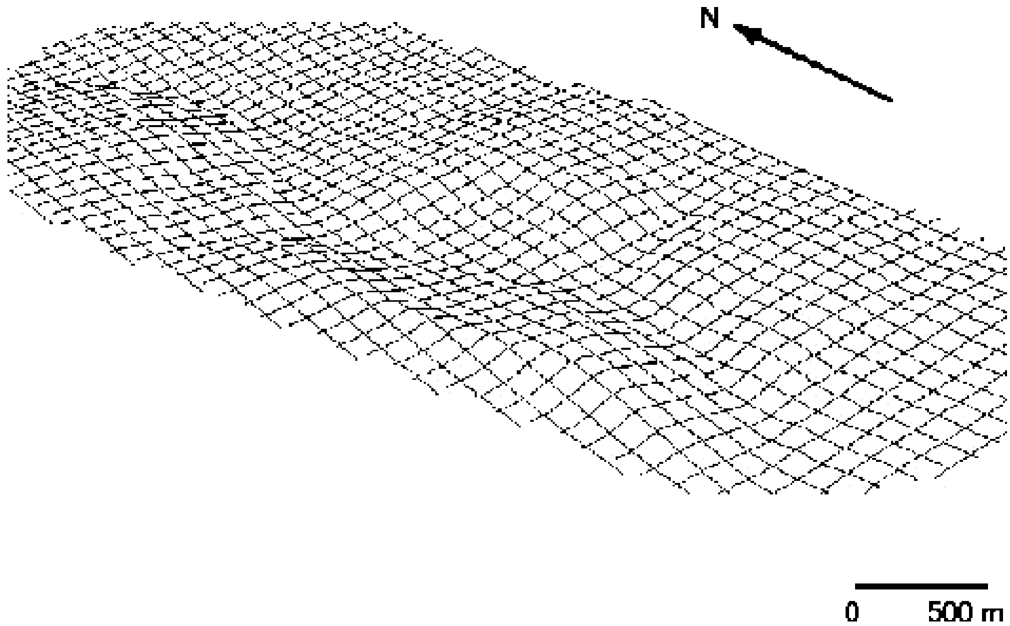

Figure 4. Digital fishnet surface of the Whitendale River catchment derived from stereodigitisation of aerial photography

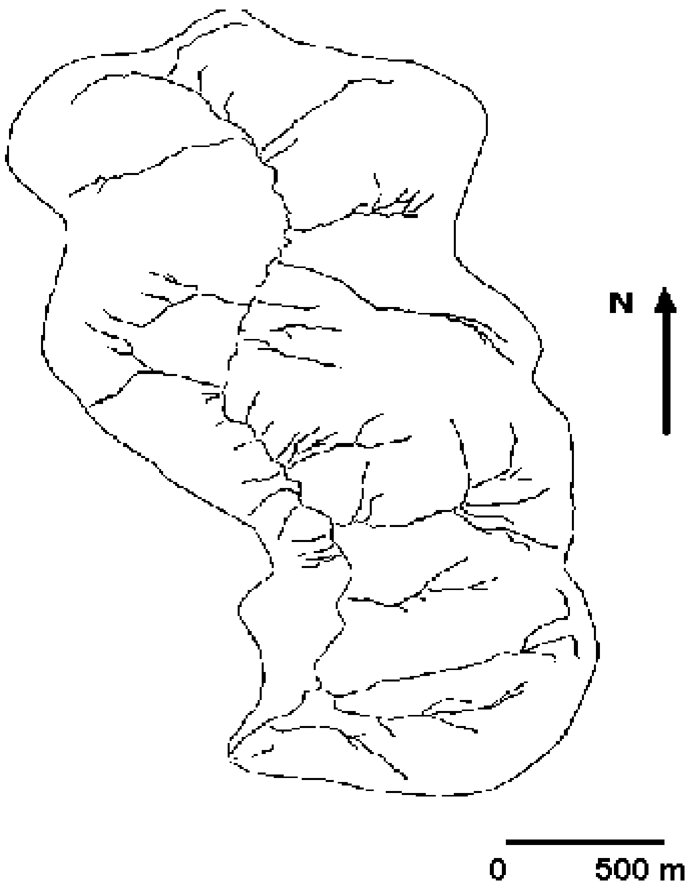

Figure 5. Drainage network of the Whitendale River derived from DTM extraction with specified threshold area.

Initially, digital elevation data were obtained at a density of about every 20 m for the 12.51 km^2 catchment from stereoscopically digitising 5 sets of low level black and white aerial photographs. Following that, O'Loughlin's (1986) computer model TOPOG was used to construct a digital surface (Figure 4). TOPOG also includes a second routine drawing the equivalent of flow lines across the contours from the valley towards the drainage divide at a user-specified interval. Jenson and Domingue's (1988) iterative approach for network extraction which also includes a procedure for "smoothing over" depressions and pits was then applied and the fluvial network of Whitendale River was finally extracted (Figure 5). The most important decision to make relates to what support area to use from the grid matrix available, in order to define the drainage accumulation function. For that reason, particular care was exercised to achieve the network derivation at the correct length scale. The commonly accepted method calls for defining a channel when all surrounding points are above some threshold. Pits (set of adjacent points surrounded by neighbours that have higher elevations) are due to sampling effects or data errors and were removed by applying a local "flooding" procedure where they were made to drain towards the point at which water would overflow from the pit. The accumulation area threshold was physically justifiable based on the Peuker and Douglas (1975) algorithm, which flags the pixel of the highest elevation from each possible square of four adjacent pixels. The selection of the support area follows the rules set by Montgomery and Foufoula-Georgiou (1993) according to which channel heads represent a transition in the dominant sediment transport process, implying a constant critical support area.

CONCLUSIONS

Field data collected from a typical English upland river network where hollow development is the dominant mechanism for channel initiation indicate that there is an inverse relationship between critical support area and local slope. This finding suggests that there is a distinct threshold dictating channel initiation at this location and also that erosion is not dependent on saturation overland flow. When this criterion is applied on a high resolution Digital Terrain Model it yields satisfactory results, implying that the extent of the channel network coincides with the transition from divergent to convergent slopes. These particular networks were subject to a variety of recent influences, among them stands out the recent deglaciation, which occurred about 12,000 yrs ago. It appears that drainage networks are striving to adjust to this new state of dynamic equilibrium imposed due to a major external forcing event.

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