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THE GEOLOGICAL CONTEXT OF THE SAND/GRAVEL AREAS, HOLDERNESS PLAIN, KINGSTON UPON HULL, ENGLAND

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ABSTRACT: *The clay till are interspersed with layers and lenses of sand and gravels of varying extent. Both the predominance of clay tills and the changing depths and thickness of the sand/gravel were confirmed in the Holderness Till. The uniformity coefficients, the ratio of sand to silt, and the percentages of gravel, sand, silt, and clay were calculated for all the catchment samples. Firstly, to determine precisely the extent of the sand/gravel areas within the glacial till and secondly, to establish whether the sand/gravel and the clay areas of the catchment behaved in hydrologically distinctive ways. The results confirmed that the higher the ratios and uniformity coefficients are for the sand areas which contributes to the higher permeability and hydraulic conductivity and that the lower ratios and uniformity coefficients are associated with the areas of clay which contributes to the lower permeability and hydraulic conductivity. The effective size is an indicator commonly used in the application of particle-size distribution to hydrological and hydraulic study.*

KEYWORDS: Sand, Gravel, Clay, Glacial

INTRODUCTION

The term glacial tills normally taken to mean the deposits which resulted from the depositional and erosional activity by ice in advance and in retreat, or the deposits laid down directly by glaciers or ice-sheets on a land surface (West,1977; Whittow,1984; Small and Witherick,1986). These deposits have undergone little sorting action by water and consequently have a characteristically unsorted and unstratified appearance, all size grades from clay to boulders being mixed together, although the matrix is very clayey in the kind of till known as low relief, in which the glacial deposits vary greatly in thickness, being greatest over the bed rock hollows and thinnest over ridges and hills(Whittow,1984). According to Madgett, and Catt (1978), and Boston et al, (2010) glaciers may have over-ridden the North Sea glacier, forming a two-tiered surge ice sheet.

Till comprises a wide range of material size from clay to large boulders, hence the commonly used term "boulder clay". Sometimes this material is deposited in a relatively structured way over extensive areas, C.F. sub-ice clays and other fines. In other cases localised water-borne outwash deposits of coarser material are laid down in a clearly sorted and stratified sequence. In still other cases discontinuous, unsorted and unstratified deposits result from the letting down of the coarse fragments from on or within the melting ice sheet or from sub-ice water-borne materials.

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THE EXTENT OF GLACIAL TILL IN HOLDERNESS

Holderness is that low lying part of North Humberside which is bounded to the east by the North Sea, to the south by the River Humber and to the west and north by the Cretaceous Chalk of the Yorkshire Wolds (Figure 1), the crests and scrap slope of the Wolds being almost completely free of drift (Catt,1963; Yorkshire Water Authority,1980). Drained by the River Hull and its tributaries, the Holderness till plain exhibits a shallow, saucer-like form, rising almost imperceptibly from the central lowest areas towards the coast and the Wolds.

Since the glacial till rests more or less directly on the underlying Chalk (Catt, 1963), Tertiary deposits being virtually non-existent in this area and since the Chalk surface itself dips eastward beneath the North Sea at an angle of about 5º degree (Catt,1963), it follows that the thickness of the glacial till is greatest in the east, reaching a maximum of about 60 m near the coast, and thinning westwards and northwards to a feather-edge against the Wolds which is found at a high of between 60 m and 90 m.

The Holderness coast is known to be the fastest eroded coastline in the UK and Europe (Furlan, 2008; Quinn et al, 2009 ; Quinn et al, 2010).

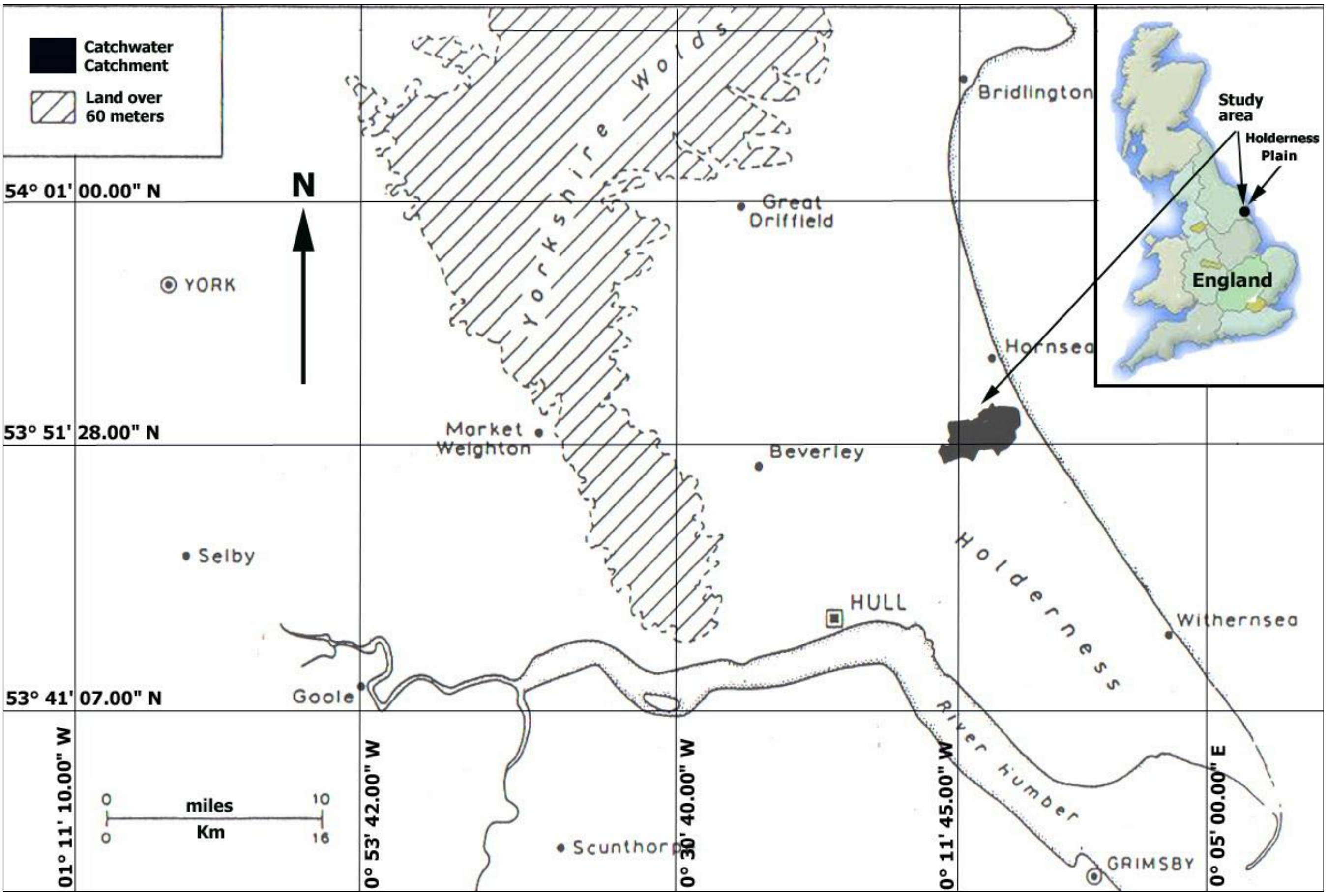

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Figure 1: Location of the Catchwater Drain catchment, Holderness, England.

THE NATURE OF THE GLACIAL TILL IN HOLDERNESS

The stratigraphy of the Holderness till has been the subject of considerable debate over a long period of time and only in recent years has a seemingly authoritative interpretation been advanced by Catt (2007).

The earliest stratigraphical investigations were carried out by Wood and Romes (1868) and but almost a century was to elapse before the next major contributions by Catt (1963), Madgett and Catt (1978). Most of this work was based upon observations on the cliffs of the Holderness Coast. Wood and Romes (1868) recognised three main subdivisions in the glacial deposits which they named, in descending order as the Hessle, Purple and Basement clays.

Similarly, Catt (1963) recognised four boulder tills which they called the Hessle, Purple, Drab and Basement tills subsequently; Madgett and Catt (1978) recognised that only two tills occur above the Basement Till in Holderness, i.e. the widespread Skipsea Till (=Drab Clay) and the Withernsea Till (= Purple Clay) which occurs only in an arc extending a maximum of 10 km inland between Hornsea and Easington.

In this interpretation the uppermost "till" (the Hessle Clay of Wood and Romes, 1868), was shown by Madgett and Catt (1978) to be merely a Withernsea Till. The Till nomenclature in this region was refined by the work of Madgett and Catt (1978) as a result of particle size distribution, mineralogical, and petrographic analyses. These analyses showed the Drab and Purple Tills to be uniform and distinct, whereas the texture and composition of the Hessle Till varies and reflects that of its subjacent Till. As a consequence of this, the Drab and Purple Tills were renamed as Skipsea and Withernsea Tills, respectively, and the term Hessle Till was discontinued, with this until acknowledged as being the weathered component of whichever Till unit it was observed to be overlying. Evans et al, (2005), believed that the Skipsea and Withernsea Tills date from the Devensian Glaciations and the Basement Till is usually deemed to be Wolstonian in age; however, the age of the Basement Till subject to debate.

Further details relating to the extent, deposition and composition of the Till units present along this coast have been presented by Catt (2007). It is believed to be a consequence of the fact that the difference in strength between each Till type is not especially great (Bell, 2002).

Each of the main till is separated from the next by beds of sands, silts or gravels of varying thickness. Similar sorted and stratified coarser deposits occur locally within each of the tills, and in addition also on the surface of Holderness (Catt, 1963; Furness, 1985; Foster, 1987) especially in the east where arcuate ridges, drumlins, kames and kettle-holes are conspicuous features. Further west the boulder clay is sometimes submerged beneath post glacial deposits of alluvium associated with present and former river courses.

It would be expected that in some cases the sand/gravel deposits will rest directly on the underlying Chalk surface. Certainly this has been found to be the situation in some other Chalk areas, such as southern East Anglia, where Lloyd et al. (1981) showed that sands and gravels in direct contact with the Chalk are an important part of the system of recharge to the Chalk aquifer (Figure 2) a similar direct contact between sand/gravel and Chalk surface is believed to exist in several locations in Holderness.

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The interchange of ground water between coarser deposits in the glacial drift and the underlying Chalk is likely to be accentuated in the Holderness area by the presence of the so-called "rubble Chalk" (Green, 1949). This is a comparatively shallow layer of fragmented Chalk, which is believed to reflect the intensity of cold-climate weathering of the exposed Chalk surface immediately prior to the deposition of the basal layers of till. This layer of "rubble Chalk" has been shown to play a dominating role in the storage and movement of ground water and in the development of water resources in the area, particularly in view of the relatively impermeable nature of the unweathered Chalk in this part eastern England (Green, 1949). Soulsby et al, (2007), suggested that it is critical to characterising groundwater/surface water interchange and in particular baseflow to upland rivers.

The wide stratigraphical variation of glacial till will be apparent from the foregoing account and although the Catchwater Drain catchment may not contain a fully representative sample of all the stratigraphic types, it does nevertheless contain wide variety of till stratigraphy and forms, ranging from stiff, almost toneless chalky clay of variable colour, through lighter sediments which often cap the minor hills of boulder clay, to the lenses and patches of coarser sand and gravel which are often best represented in the higher parts of the catchment (Bonell, 1971).

DATA COLLECTION AND ANALYSES

It was considered essential to undertake a major programme of particle size analysis in order to determine the nature of the near-surface

material in the catchment. However, in the light of the availability of Soil Survey data for the upper soil profile, it was decided to concentrate the sampling for particle size analysis in the subsoil layer which, it was believed, would reflect more accurately the character of the glacial till itself.

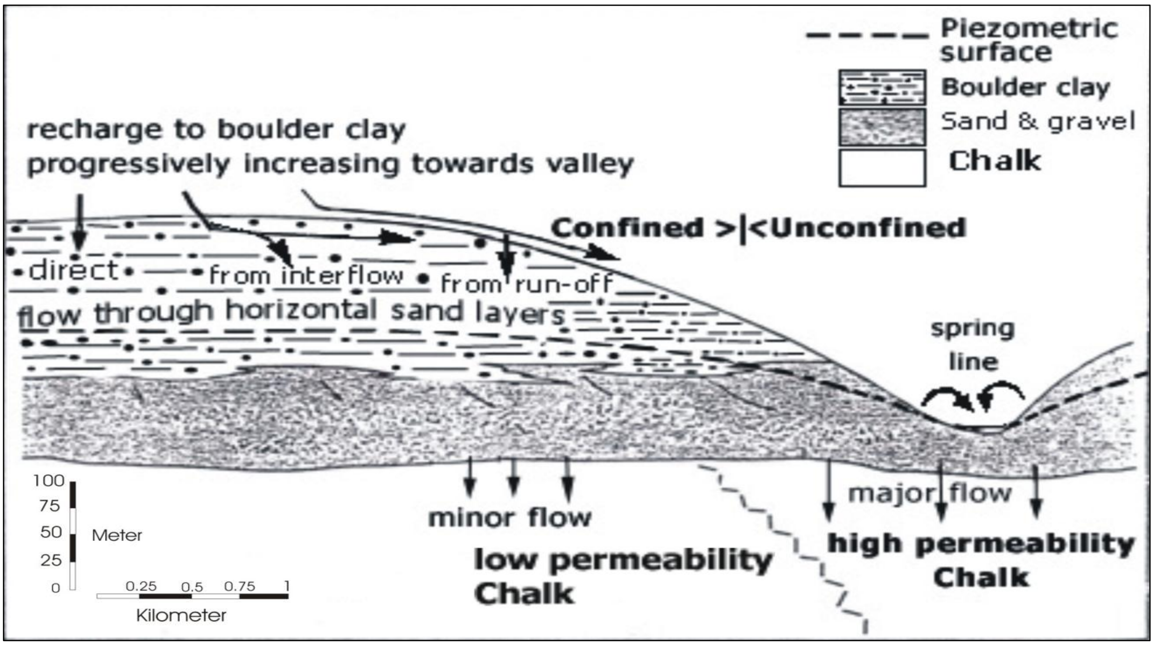

Figure 2 Recharge and flow mechanisms in the chalk and drift deposits of southern East Anglia (Source: Lloyd *et al*, 1981).

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Accordingly, samples were collected from within the stream and drain channels, at lateral spacing of about 150 m (Figure 3) and at a height of 50 cm above the channel bed. It was hoped that this sampling pattern, which yielded a total of 148 samples for analysis, would not only provide a representative coverage of the catchment but would also permit the detailed identification of the sand/gravel areas.

The catchment was divided into grid squares of 1 km on a side (Figure 4). These squares were coded alphanumerically, e.g. 2A1. The letter "A" denotes the square, the number "2" refers to the site number within "A" square, and the number "1" refers to the number of the sample taken from that site. Care was taken to ensure that each sample was dug from the in situ material and not from the superficial covering of washed or weathered material on the channel bank. Each sample was placed in a clean polythene bag and stored at 2^o C until required for analysis.

There are many analytical methods that can be used in a soil particle size investigation and it was therefore necessary to decide which was the most suitable for the analysis of the boulder clay found in the catchment. Brief examination of this material showed that it contains a large proportion of silt and clay. Accordingly, wet sieving was used to enable the measurement of particle size distribution down to the size 63 µm.

Cronican and Gribb (2004); Odong, (2007); Song et al, (2009); Vienken and Dietrich, 2011) developed a method of determining permeability values derived from particle size analysis are different depending upon which formulae are used. While Cheng and Chen (2007) used an empirical equation for predicting permeability of coarse-grained sands.

Beretta et al (2014) the Robinson Pipette is accurate and precise but time consuming. Jarret and Heywood (1954) showed that pipette analysis was more accurate than hydrometer analysis. The chief criticism of this method, however, is that the amount of coarse silt is calculated from the difference between the weight of the sample and the total weight of the other particle size groups. Thus any loss of material during experimentation is recorded within this group. Opportunities for loss to occur exist, particularly during the dispersion stage while the sample is being transferred between utensils. Consequently, the author decided to use two analytical methods. For particles larger than 63 µm wet sieving was used to prevent the structural breakdown of silt to clay which could have resulted from preparing the sample for dry sieving. A Coulter Counter was used for particles less than 63 µm due to the large content of silt and clay.

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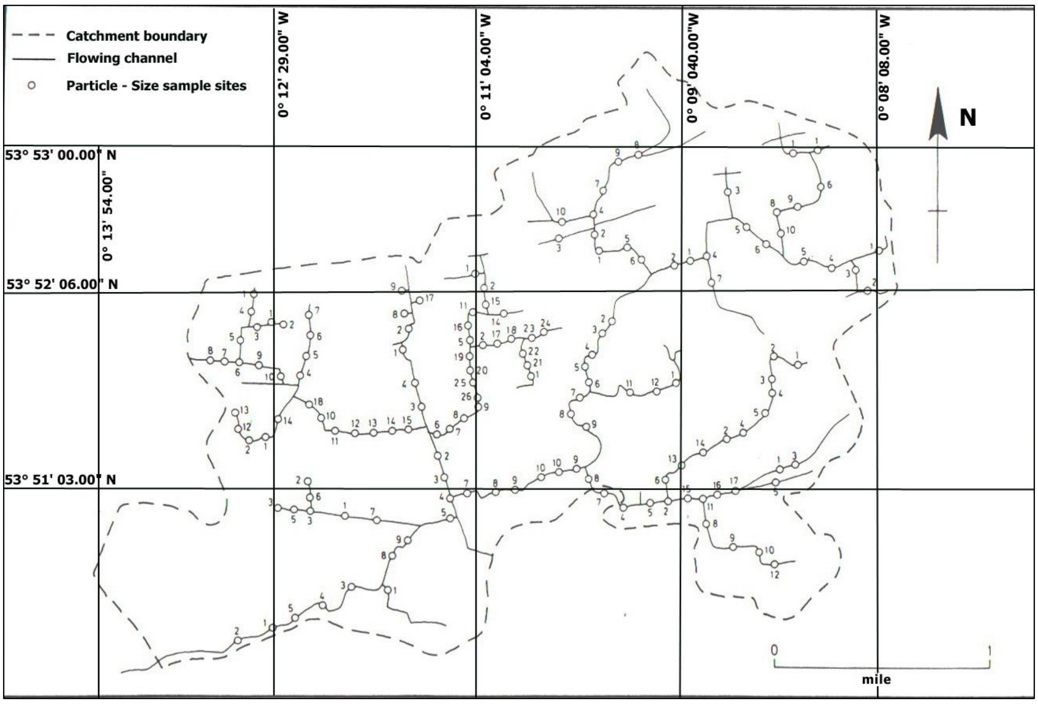
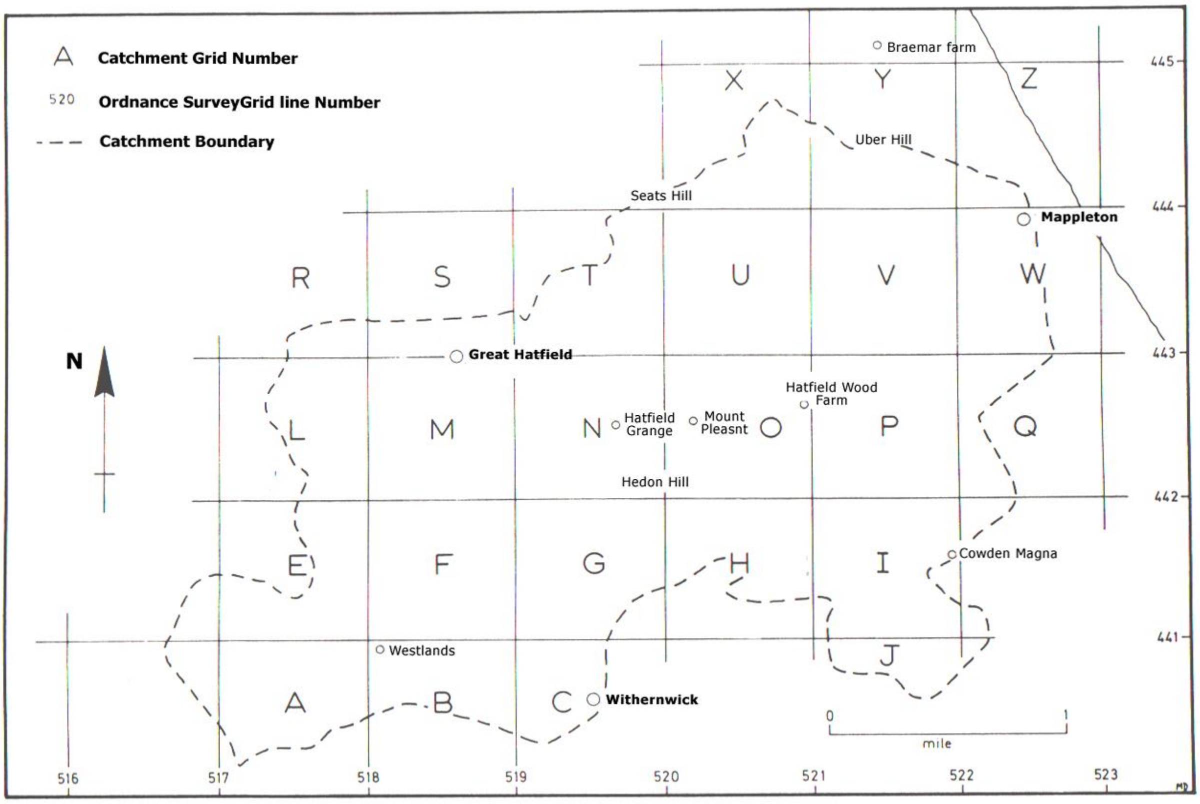


Figure 3 The Particle size samples sites.



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WET SIEVING

Selected sieve mesh sizes were 2.00 mm for gravel, 1.00 mm for coarse sand, 212 µm for medium sand and 63 µm for fine sand. The samples were prepared using the following procedure: a 300 g sample was placed in a beaker and hydrogen peroxide was added to eliminate organic material. After any reaction had ceased, distilled water was added as necessary (e.g. to 250 ml). Then, to avoid flocculation 50 ml of calgon was added to the weighed sample (calgon is a dispersant made up of 7 g of sodium carbonate to 33 g of sodium hexametaphosphate, which is then made up to 1 litre with distilled water).

The sample was left at least 24 hours, and then dispersed ultrasonically for 30 seconds before being poured into and washed through a sieve nest. Then each sieve was washed using tap water and the contents of each sieve were collected in beakers, oven dried at 105º C overnight and weighed. This weight was needed for determining the particles greater than 63 µm.

PARTICLES SMALLER THAN 63 µm

The following methods was used for analysis of the silt and clay fraction (Pethick, 1987). 1.5 g of the field sample was oven dried overnight and then weighed to 4-figures precision using an electronic balance with an accuracy of 0.001 g . Fifty ml of hydrogen peroxide was added to the weighed sample which was then left until reaction ceased. A 1% particle free sodium chloride solution was added to the sample to bring it to 100 ml, and 10 ml of calgon was added. The sample was then left for at least 24 hours and dispersed ultrasonically for 30 seconds before being washed through a 63 µm sieve into a beaker with distilled water. The particle fraction greater than 63 µm, retained on the sieve, was then oven dried overnight at 105º C and weighed to a precision of four figures. Finally, the suspension which passed through the 63 µm sieve was collected in a beaker for subsequent Coulter Counter analysis.

The Coulter Counter Model ZB (Journal of Laboratory Automation, 2003) permits particle-size analysis over the range 0.6-400 µm by number of particles and by volume (and hence weight) of each size of particle. Dual thresholds allow any part of the particle size range to be selected for examination and a range of orifice tubes provide the optimum size of aperture to measure the selected range.

The method is based on electrical conductivity differences between particles and the suspending electrolyte which in this case was 1% NaCl solution. Particles suspended in the electrolyte are made to pass through a small aperture through which an electrical current path has been established. As each particle displaces electrolyte in the aperture, a pulse essentially proportional to the volume of the particle is produced. Thus, a three dimensional particle volume response is the basis for all sizing, regardless of the position or orientation of the particle in the aperture. Particle volume is the most accurate way to measure size.

A suitable amount of the sample in suspension was prepared for analysis, stirred, transferred to a clean beaker and then 1-2 drops of dispersant (Nonidet) were added. The suspension was agitated for about 30 seconds, using an ultrasonic probe and then 1-2 drops of the sample were added to a round bottomed beaker containing 1% particle free solution. Sample concentration was checked before measurement commenced. Triplicate readings were taken in each of 14 set range of particle diameter (Table 1). The particle volumes were converted to diameters then

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to weights using a density of 2600 kg/m^3 for plotting the lognormal distributed frequency curve and a statistical analysis was performed to calculate mean, standard deviation and skewness for each sample.

PATICLE SIZE DISTRIBUTION

Simon and Kenneth (2001) suggested that the grain size analysis is an essential tool for classifying sedimentary environments. The calculation of statistics for many samples can , however, be a laborious process. In this research programme particle size analyses were used directly to determine the distribution of coarser sediments within the experimental catchment. The particle size distribution of a material expresses the proportions of the various sizes of particles which it contains. These proportions are commonly represented by the relative numbers of particles within stated size classes (i.e., by their frequency ratios), or by the relative weight of such classes.

Krumbein (1934) proposed a Phi scale, both to simplify statistical computations and also to avoid negative numbers in the various sand grades and finer materials, whereby the log is multiplied by -1 or in other words,

Phi = - $\log_2$ (diameter mm).

The distribution is described in the form of a cumulative frequency curve and calculation of the particle size statistics, i.e., particle size mean and sorting (Table 2), is normally computerised.

Table 1 Coulter counter volume and diameter settings.

Setting no.	Volume range µm^3	Diameter range µm
1	10240	80.3467
2	10240-5120	80.3467-63.7712
3	5120-2560	63.7712-50.6152
4	2560-1280	50.6152-40.1733
5	1280-640	40.1733-31.8856
6	640-320	30.8856-25.3076
7	320-160	25.3076-20.0866
8	160-80	20.0866-15.9428
9	80-40	15.9428-12.6538
10	40-20	12.6538-10.0433
11	20-10	10.0433-7.9714
12	10-5	7.9714-6.3269
13	5-2.5	6.3269-5.0216
14	2.5-1.25	5.0216-3.9857

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Table 2: Particle size data for representative sites in the Catchwater Drain catchment.

Sample location	Gravel %	Sand %	Silt %	Clay %	Sand/Silt ratio	Mean Phi	sorting Phi	Uniformity coefficient
9M1	0.0	88	10	2	8.8	3.00	1.300	5.667
7M1	0.0	71	21.5	7.5	3.302	3.178	1.320	4.470
6M1	0.0	51	31	18	1.645	3.378	1.350	4.27
5M1	0.0	50	36	14	1.389	3.430	1.370	4.480
4U1	48	18	28	6	0.643	3,.451	1.400	—
9U1	2	19	46	33	0.413	6.190	1.441	2.484
8N1	3.5	20	51.5	25	0.388	6.266	1.523	2.366
25N1	3	16	50	31	0.320	6.232	2.056	2.420
9V1	4	10	36	50	0.278	6.500	2.087	2.090
2W1	4	10	40	46	0.250	6.410	2.150	2.190
1Y1	1	10	40	49	0.250	6.450	3.794	2.055
8L1	3	14	64	19	0.219	6.300	4.144	2.270
1Z1	2	8	38	52	0.210	6.670	4.306	1.900
1W1	3	8	40	49	0.200	6.650	4.543	1.979
7G1	3	10	55	32	0.182	6.400	4.765	2.220

CUMULATIVE CURVES FOR SELECTED SITES

Representative cumulative curves, selected from the 148 such curves originally plotted for the catchment are shown in Figure 5 to 9. These curves show that the percentage of clay ranges from as little as 2% in the great Hatfield sandy areas, where sand attained its greatest concentration (88%), to a very high value of 60% in the central and eastern areas of the catchment at various depths down to 120 cm, reflecting the apparent presence of a clay pan at approximately this depth. It is not certain whether the presence of this clay pan in the till of Holderness and the catchment is the result of a simple process of eluviation or the more complex causes associated with fragipans.

Below the clay pan the effects of weathering appear to end and the remainder of the profile consists of parent boulder clay in most areas of the catchment, and especially in the middle and eastern parts. Apart from the Great Hatfield sandy area and the areas of alluvium and other pocket of coarse particle, most of the catchment yields samples which contain at least 32% silt, suggesting that lenses of sand, silt or gravel can occur at any depth within the glacial till.

A gravel content of 48% was found at the 150 cm level in the area of alluvium, for example, near Seat Hill, with a noticeable decrease in the percentage of clay. In addition relatively high gravel contents are showed in a few other locations.

These results compare very closely with the particle size structure observed by Catt (1963) . Morkland and Powell (1985) found, in their work at Great Cowden, that the clays are interspersed with layers and lenses of sand and gravel of varying extent. Both the predominance of clay tills and the changing depths and thickness of the sand/gravel were confirmed in the Holderness Till.

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The ratio of sand to silt, and the percentages of sand, silt, and clay were calculated for all the catchment samples. however, particle size mean and sorting and uniformity coefficients were calculated for only 15 representative samples. These data are shown in Table 2 and confirmed that the high ratios are for the sand areas, especially at Great Hatfield, the areas of alluvium, and for other specific locations, i.e. pockets of sand or gravel, and that the lower ratios are associated with the areas of clay. One indicator commonly used in the application of particle size distribution to hydrological and hydraulic studies is the effective size, which was defined by Hazen (1893) as that diameter which ensures that 10 percent of the particles are of smaller diameter on the particle size distribution curve. A measure used to indicate the degree of sorting is the uniformity coefficient, which is defined as the ratio of 60 percent finer size to the effective size (10 percent finer size). In this work a large uniformity coefficient, denoted by a steeply sloping particle size curve, indicates a well-sorted mixture, as shown in the sand/gravel curves (Fig. 5 and Table 2) suggesting that these deposits should have high permeability and high hydraulic conductivity, Bonell (1976) confirmed, that because of the greater pore size, the coarser materials in the catchment have a greater hydraulic conductivity (may range 20.41 to 114.62 cm/day) than the finer materials (may range 0.0086 to 0.000086 cm/day). Mash and Denny(1966) studied the influence of grain size distribution on permeability with increasing grain size and with increasing uniformity of grain size.

The effect of grain size distribution on permeability is intuitively obvious (Onur 2014). Coarse-grained soils have larger pores, as well as larger interconnections between the pores, whereas fine-grained soils have smaller pores and narrower interconnections between the pores. Moreover, smaller grains fill the pore spaces between larger grains in well-graded soils thereby reducing the void sizes and the associated interconnections.

A small uniformity coefficient, denoted by a flatter curve as shown in the clay particle size curves (Figures 7, 8, and 9 and Table 2), indicates a poorly sorted mixture which contributes to the lower permeability and hydraulic conductivity of the clay deposits. Therefore, there has been little attempt to consider glacial drift hydrology on a regional scale or even to take it seriously at all in Britain, where till deposits are in any case shallow, and where, from the point of view of water resources, the dynamic hydrological systems in the coarser materials are very small both spatially and in terms of saturated thicknesses.

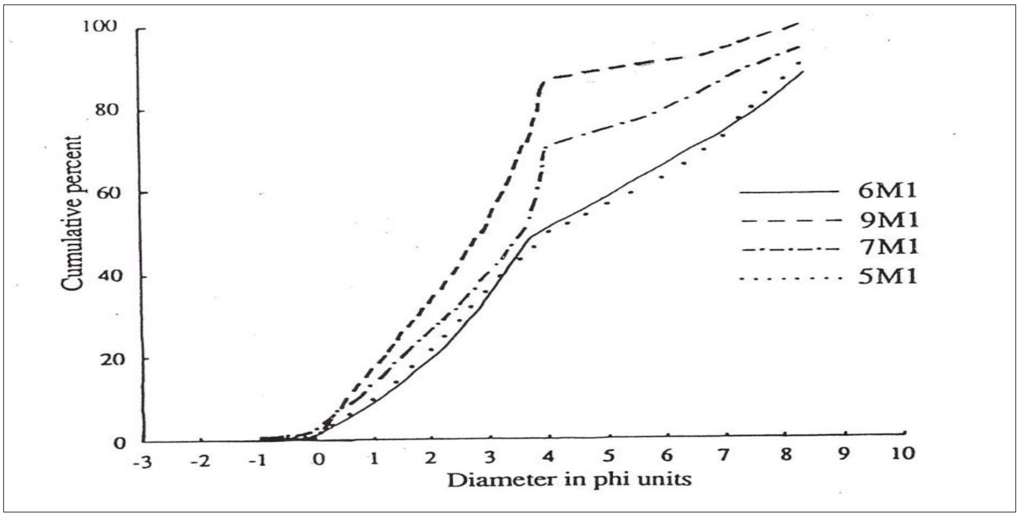

Fig. 5 Cumulative curves for samples 5M1, 6M1, 7M1 and 9M1.

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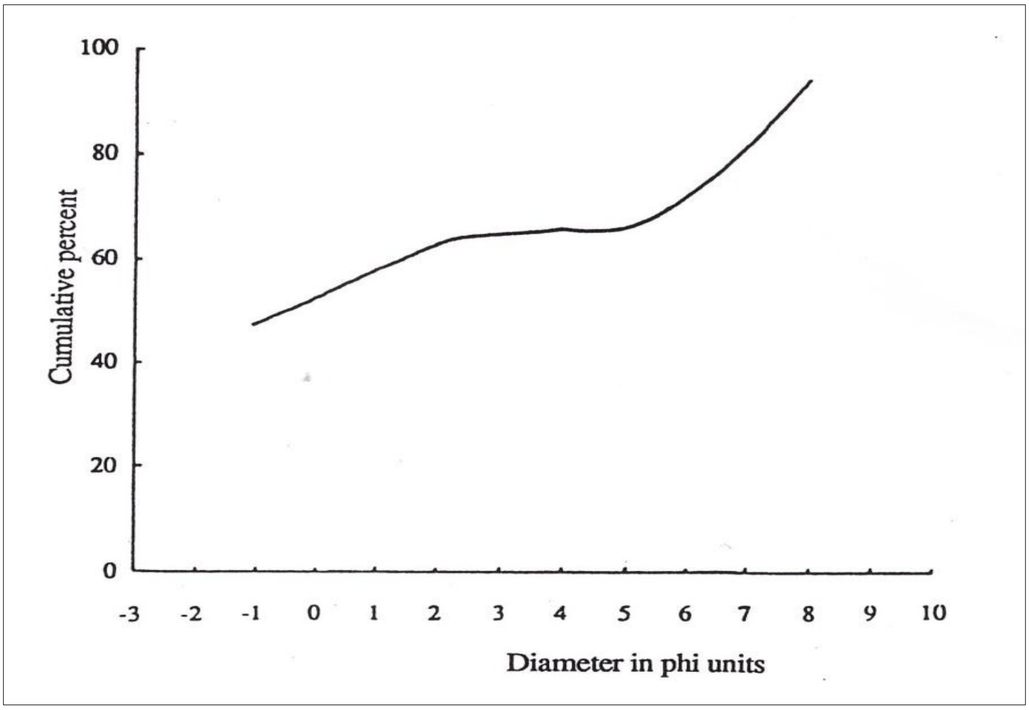

Figure 6 Cumulative curves for sample 4U1.

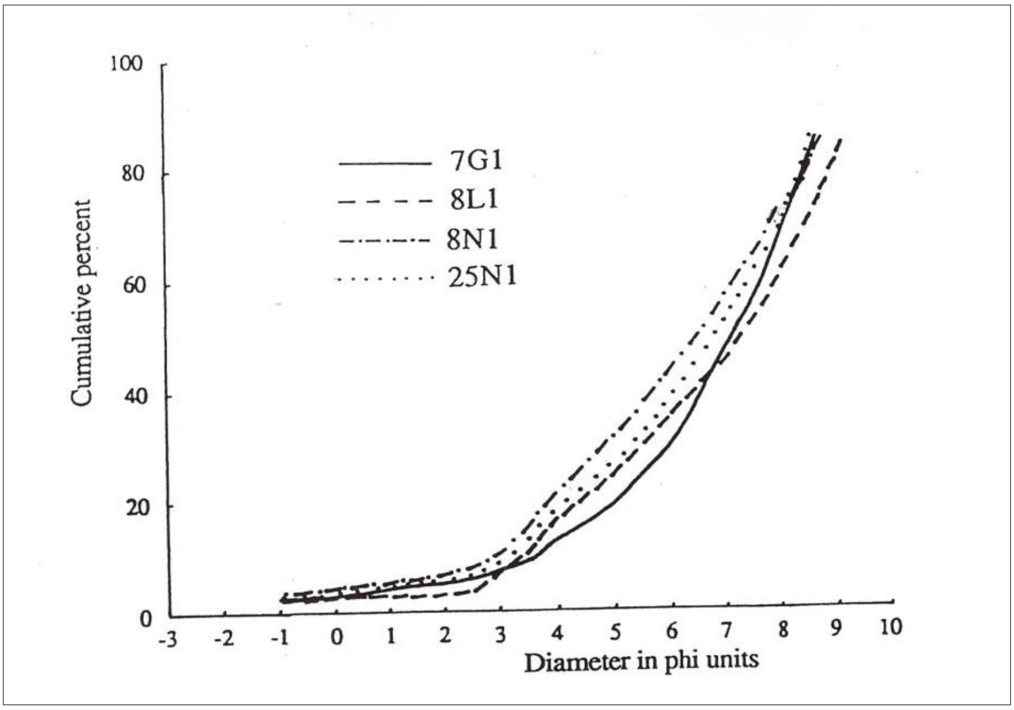

Figure 7 Cumulative curves for sample 7G1, 8L1, 8N1, and 25N1.

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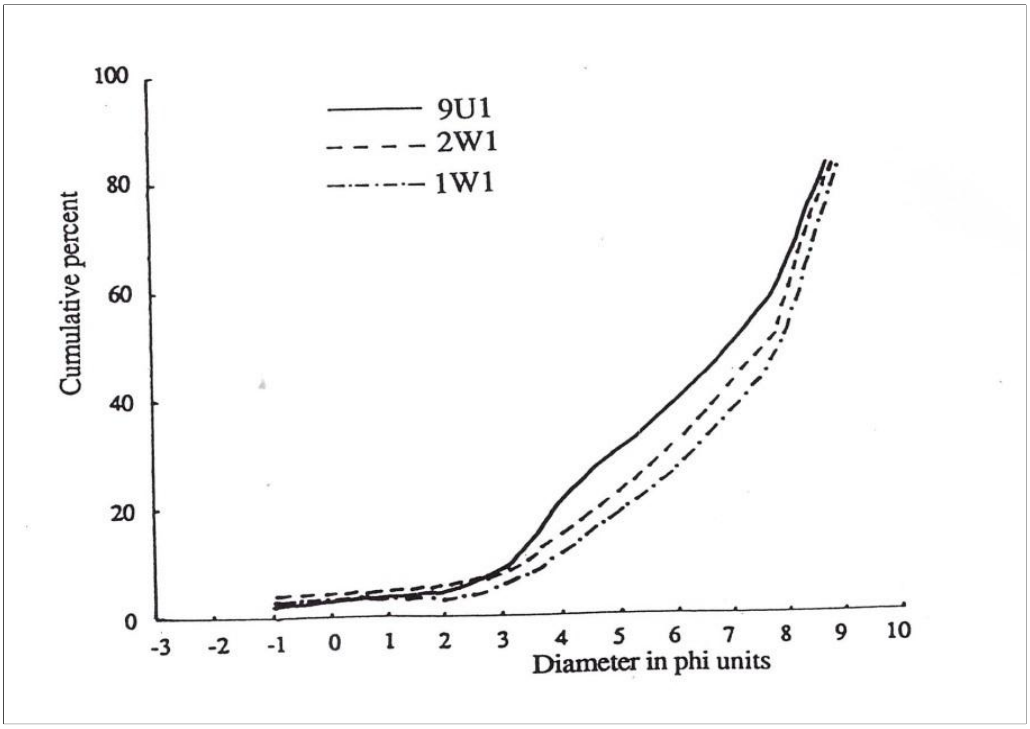

Figure 8 Cumulative curves for samples 9U1, 1W1, and 2W1.

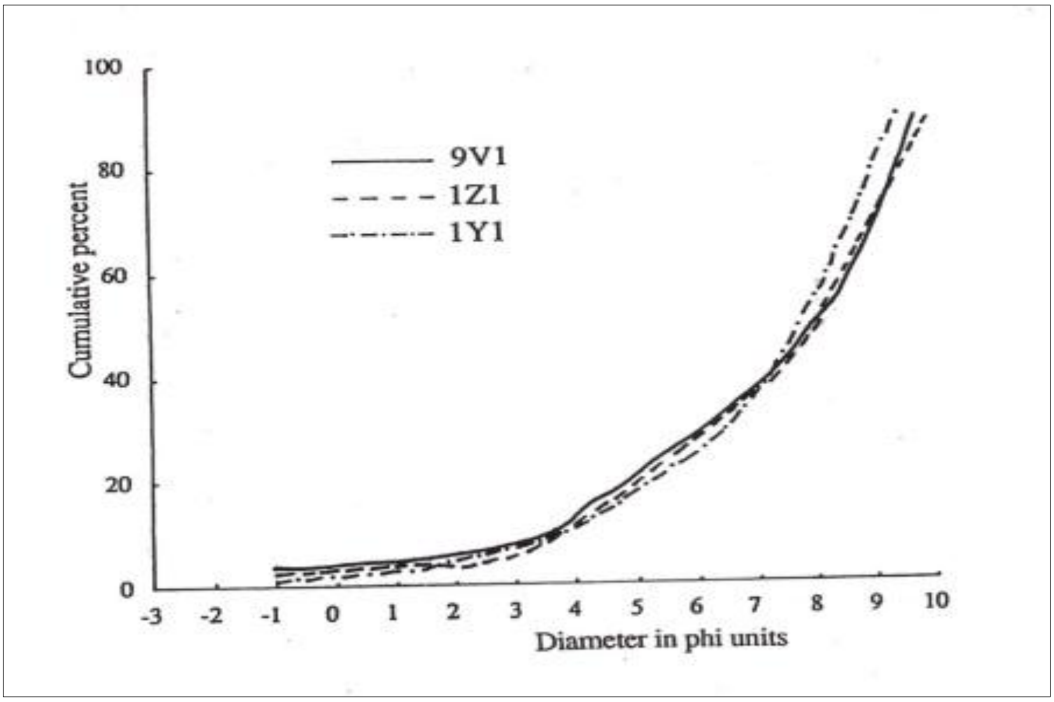

Figure 9 Cumulative curves for samples 9V1, 1Y1 and 1Z1.

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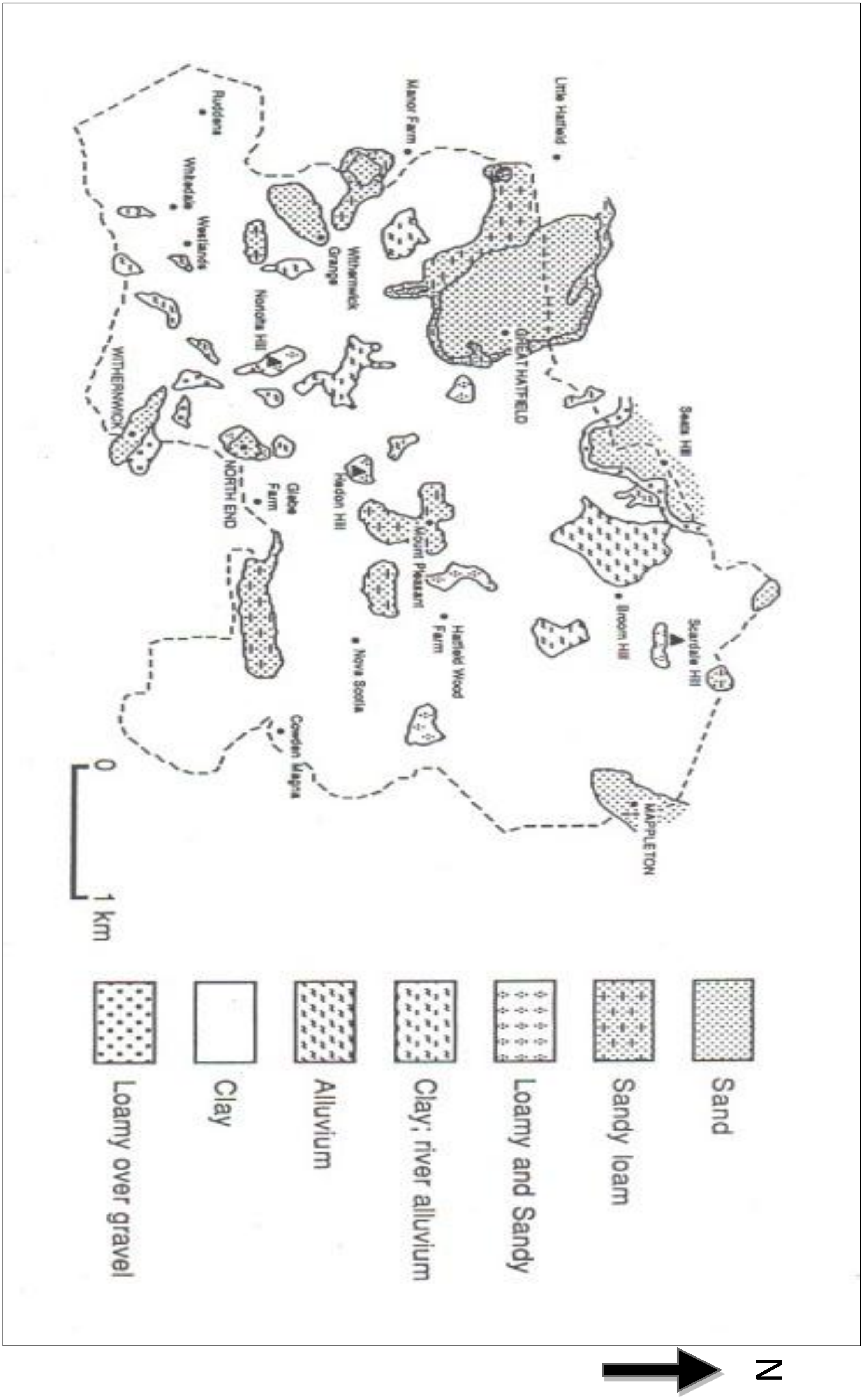

Figure 10 Map defining the location of sand and gravel deposits in the Catchwater Drain catchment (Based on field source data and Soil Survey of England and Wales, 1983).

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CONCLUSION

It is believed that the detailed distribution of the sand and gravel areas within the Holderness glacial till summarised in (Figure 10) represents the most complete picture yet obtained of the location and extent of these coarser, more permeable materials.

Furthermore, the particle size analysis showed that the percentage of clay ranges from as little as 2% in the Great Hatfield sandy area to a very high value of 60% in the central and eastern of the catchment at various depths down to 120 cm. The presence of high values of clay at various depths in the profile appears to reflect various processes (it has been suggested that fragipan may be due to the weight of the original ice sheet or that they may be due to pressure built up as the fine particles washed into summer suncracks are compressed by subsequent swelling in the wetter part of the year and such pans were due to eluviations of fines from the upper part of the horizon by the infiltration of rainwater during the post-glacial period, Bonne l, 1971) of clay pan and fragipan formation. The amount of sand attained its greatest concentration in the Great Hatfield area 88% where the clay content was at its lowest value.

Most of the samples outside the Great Hatfield sandy area contain at least 32% silt, and a gravel content of 48% was found at the 150 cm level in the alluvium area and in a few other locations. A simple and direct relation appears to exist between permeability and the uniformity coefficient of the samples.

From the above results and interpretations of particle size analyses, provide support for the postulated hydrological relationship between the superficial glacial till (sand and gravel areas) of the catchment and the underlying Chalk aquifer, due to their high permeability and hydraulic conductivity, and that this results in an upward movement of ground water from the underlying Chalk into the large sand and gravel areas, which led to the channel flow of the catchment emanated only from some of these large sand and gravel areas of the catchment, during dry period between July and September. This indicates that, indeed, these gravel and sand areas in hydraulic continuity with the underlying Chalk aquifer, either these sand and gravel areas rest directly upon the underlying Chalk aquifer or because of their high permeability and hydraulic conductivity. While in the much larger clay area of the catchment, however, the lower permeability and lower hydraulic conductivity led to the drying-up of the open ditches during dry period between July and September.

It is to be hoped that improved understanding which has thereby resulted will be of value in the interpretation of the hydrological behaviour of extensive, similar areas elsewhere.

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