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THE HYDROLOGICAL COMPARISIONS BETWEEN THE CHALK AQUIFER AND THE HOLDERNESS GLACIAL TILL OF SMALL CATCHWATER DRAIN CATCHMENT IN HOLDERNESS, ENGLAND.

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Abstract:

The research programme was about the hydrology of this part of Holderness, particularly in respect of the interactions between superficial and deeper hydrological system, in order that the long term findings from the Catchwater Drain catchment might be more usefully applied to the solution of hydrological problems, including agricultural water supplies, land drainage, flooding and need for irrigation.

There has been no attempt, however, in previous work to quantify the hydrological relationships between the clay and sand/gravel areas of the catchment or even to determine precisely the geographical extent of the sand/gravel layers and lenses.

In the early studies, the assumption made was that the catchment was hydrologically watertight.

This research has resolved a number of outstanding uncertainties which have raisin during the long period of operation of the Catchwater Drain catchment and that it has shed valuable new light on the hydrology, not only of the Catchwater Drain catchment but also of the glacial till of Holderness.

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

Introduction

Catchwater Drain Catchment was one of the few experimental areas in Britain in which glacial till hydrology has been intensively studied which is situated at the east side of the Holderness plain of North Humberside, England (Figure 1). The Catchwater Drain catchment, some 15.5 km sq. in area. The topography of the catchment mirrors that of the wide area of Holderness in which the boulder clay plain rises imperceptibility towards the coast in the east and the Yorkshire Wolds in the west and north. Relief in the catchment ranges from about 25 m O.D. in the north-east to about 7.5 m O.D. at the exit of the Catchwater Drain in the south-west, and consequently the majority of the slopes are quite gentle.

Inevitably the heterogeneous character of the glacial till provides a hydrogeological context which has important repercussions on the storage and movement of water within the catchment. Of these hydrogeological influences the most important are likely to be variations of pore-size and pore-size distribution, especially between the sediment types; the existence of hard pan layers which will impede vertical water movement; and the existence and interconnectivity of lenses or bodies of coarser material within the more widespread clay.

Data Collection and Instrumentations.

The hydrological data from the Catchwater Drain catchment and from the clay and sand/gravel sub-catchment, (Figure 2), are compared with hydrological data for the Chalk aquifer. Particular attention is paid to data on the Chalk piezometric surface and to comparisons of the variation of that surface and variations of ground water level and stream flow which take place in the Catchwater Drain catchment. These comparisons are made over different time-scales and for different data intervals. The research programme is concerned with "conventional" hydrological data such as ground water levels and discharge data. It is important to emphasise, however, that the present study has generated a very large amount of data. Some of this derives from the processing of raw data, e.g. water level, stream flow, and data collected as part of the ongoing catchment experiment, but

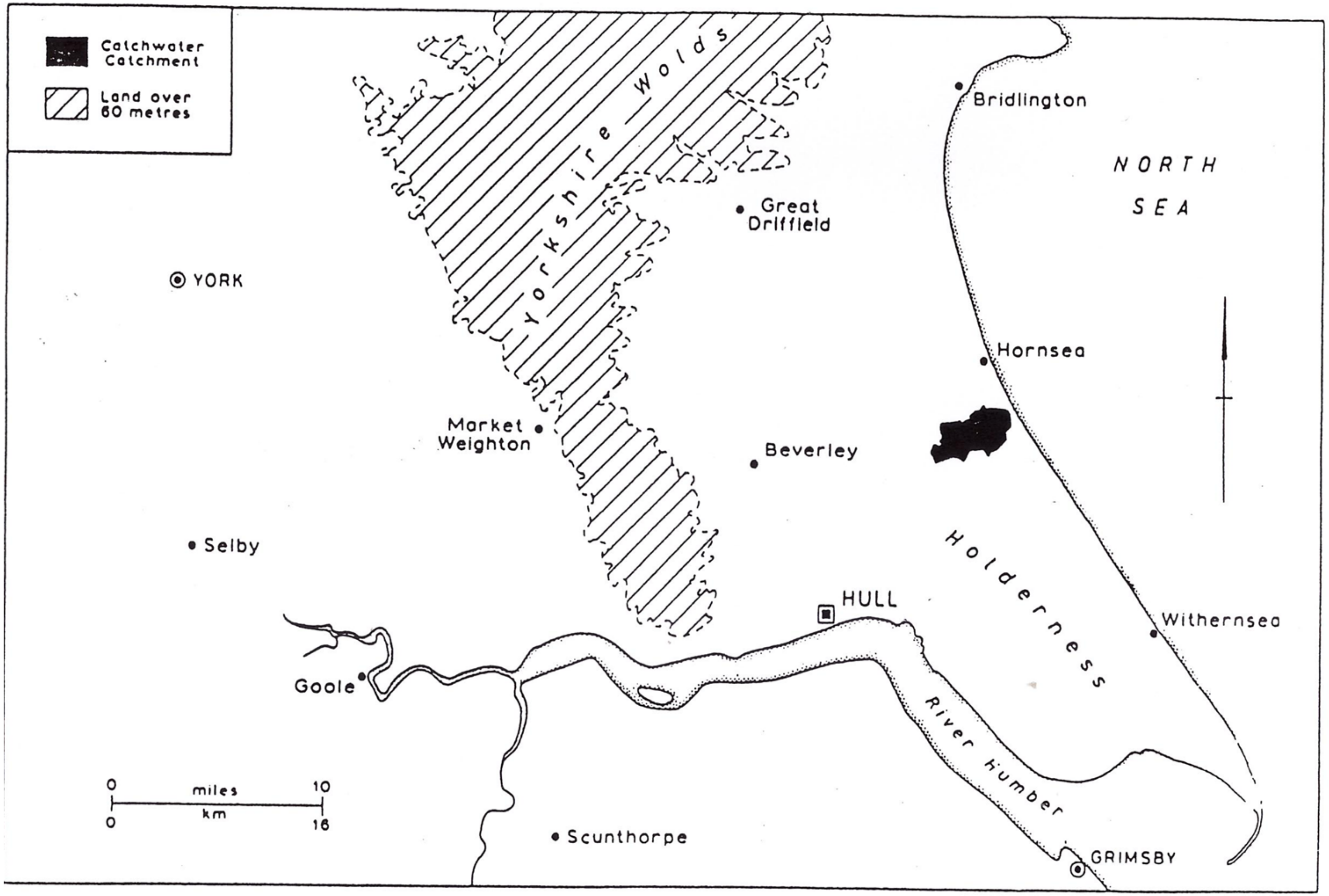


Fig. 1 Location of the Catchwater Drain catchment

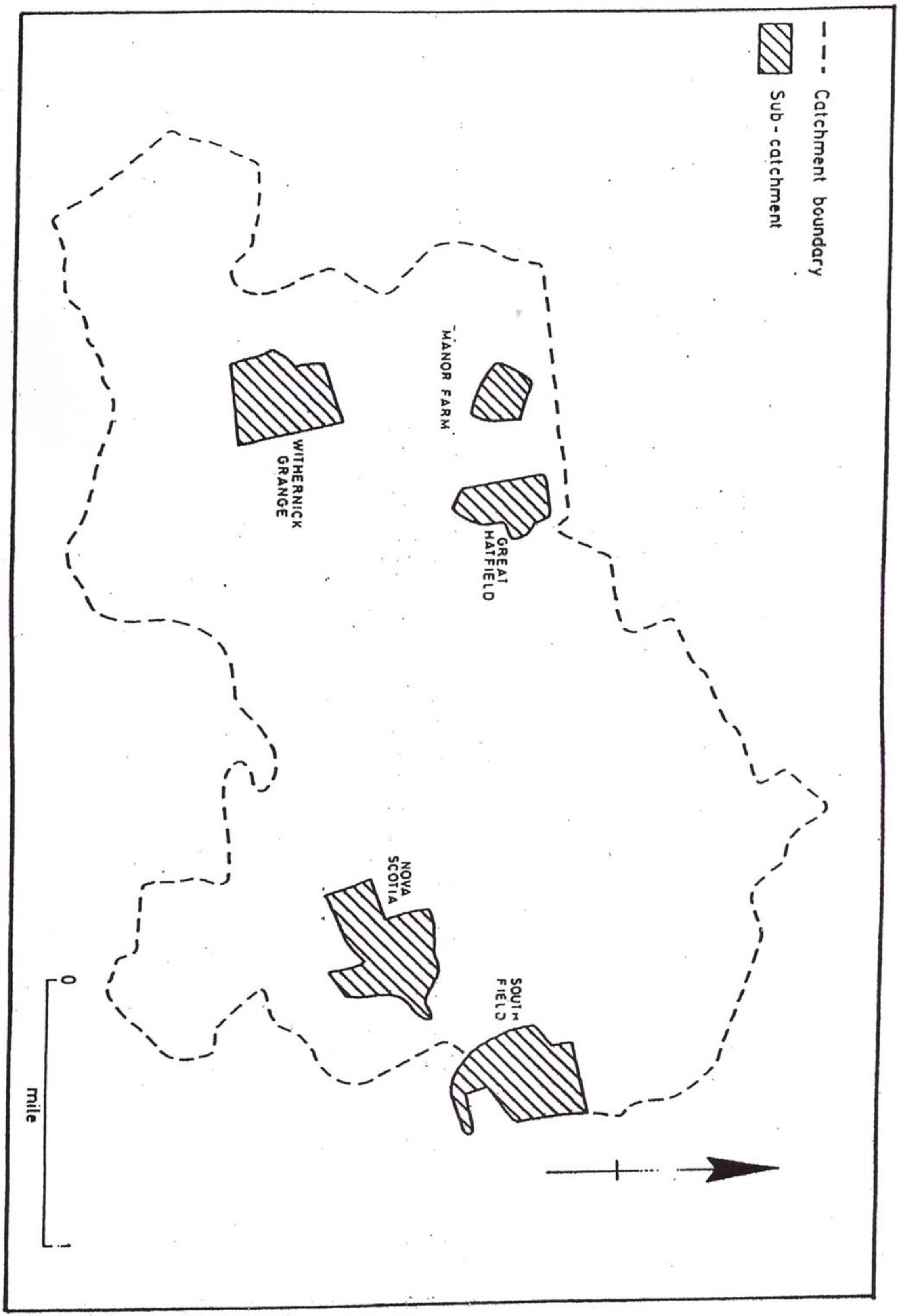


Fig. **2** The sub-catchments.

not processed before the begging of this research programme. This applies to all data collected between 1979 and 1986. Also some important new data has been collected from the other authorities such as the Yorkshire Water Authority, the Soil Survey of England and Wales and the Institute of Hydrology. Finally, entirely new data have been collected and processed as part of this research programme.

In this way it is hoped to compare, interpret and demonstrate the relationship, between the varying hydrological conditions in the underlying Chalk aquifer and hydrological conditions within the till catchment of the Catchwater Drain.

The hydrology of glacial till.

Because glacial till or boulder clay comprises such a heterogeneous collection of morphological features and particle-sizes relatively massive clays on the one hand and lenses and pockets of sand/gravel or even coarser material on the other, its hydrology is equally non-uniform and therefore difficult to characterise. With hydraulic conductivities typically in the range $8.64\text{x}10^{-3}$ to $8.64\text{x}10^{-5}$ cm/day (Freeze and Cherry, 1979), boulder clay forms some of the most extensive shallow aquitards in North America and Europe. In the sand/gravel deposits, however, such as those found in the study area, where hydraulic conductivities may range from 20.41 to 114.62 cm/day (Bonell, 1971) transmission rates are much higher and water storage is much more dynamic . What limited interest there has been in the hydrology of glacial till areas has, therefore, tended to concentrate on the localised potential ground water resources of the coarser materials (c.f. Todd, 1980; Ehler and Grieger, 1983; Kowalski and Janiak, 1986; Michel, 1986; Johnson and Williams, 1987).

Certainly, there has been little attempt to consider glacial drift hydrology on a 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 system in the coarser materials are very small both spatially and in terms of saturated thicknesses.

Hydrologically, these patches of sand and gravel and other lighter material can be regarded, in comparison with the widespread boulder clay, as islands of extremely high permeability where the average of 65.36 cm/day compares with 1.27 cm/day in the clay (Bonell, 1971). These deposits therefore constitute potentially excellent aquifers for ground water storage although severe limitations are likely to be imposed by their limited extent and depth. In this respect particular significance would attach to sand/gravel deposits which rest directly on Chalk. This does occur just outside the catchment at Routh Carr (Chadha, 1988) see (figure 3), and in northern Lincolnshire (Lloyd (1980) see (Figure 4), 1980).

Comparison between ground water levels in the Chalk Aquifer and in the sand and clay areas and Catchwater Drain discharge (1978-1988).

In order to explore the relationships between some aspects of the hydrology of the Chalk and the Catchwater Drain catchment, monthly instantaneous ground water levels for the Chalk and for the sand and clay areas, together with monthly instantaneous values of discharge at the catchment outlet, are examined for the period from 1978 to 1988 (excluding 1979 for which the relevant data are incomplete). The Chalk aquifer ground water levels were recorded by the Yorkshire water Authority (1988) in a well at Hornsea, which is located some 5.0 km to the north of Great Hatfield. Hydrological data, plotted monthly for two contrasting years, are shown in Figure 5 and 6. The summer period of 1987 was drier than the average and as Figure 5 illustrates, there was a steady decline in both ground water and discharge values from April to September. The total April-September runoff from the Catchwater Drain catchment in 1980 was virtually identical (38.5 mm compared with 38.2 mm in 1987). It will be clear from Figure 6, however, that catchment runoff in 1980 was much lower during the early part of the summer and rose to a marked but short-lived peak in August as a result of the occurrence of heavy rainfall. Although this peak is reflected in the graphs of ground water level for both the Chalk and the Great Hatfield sandy area, those ground water responses were very muted. This is to be expected, since the discharge values

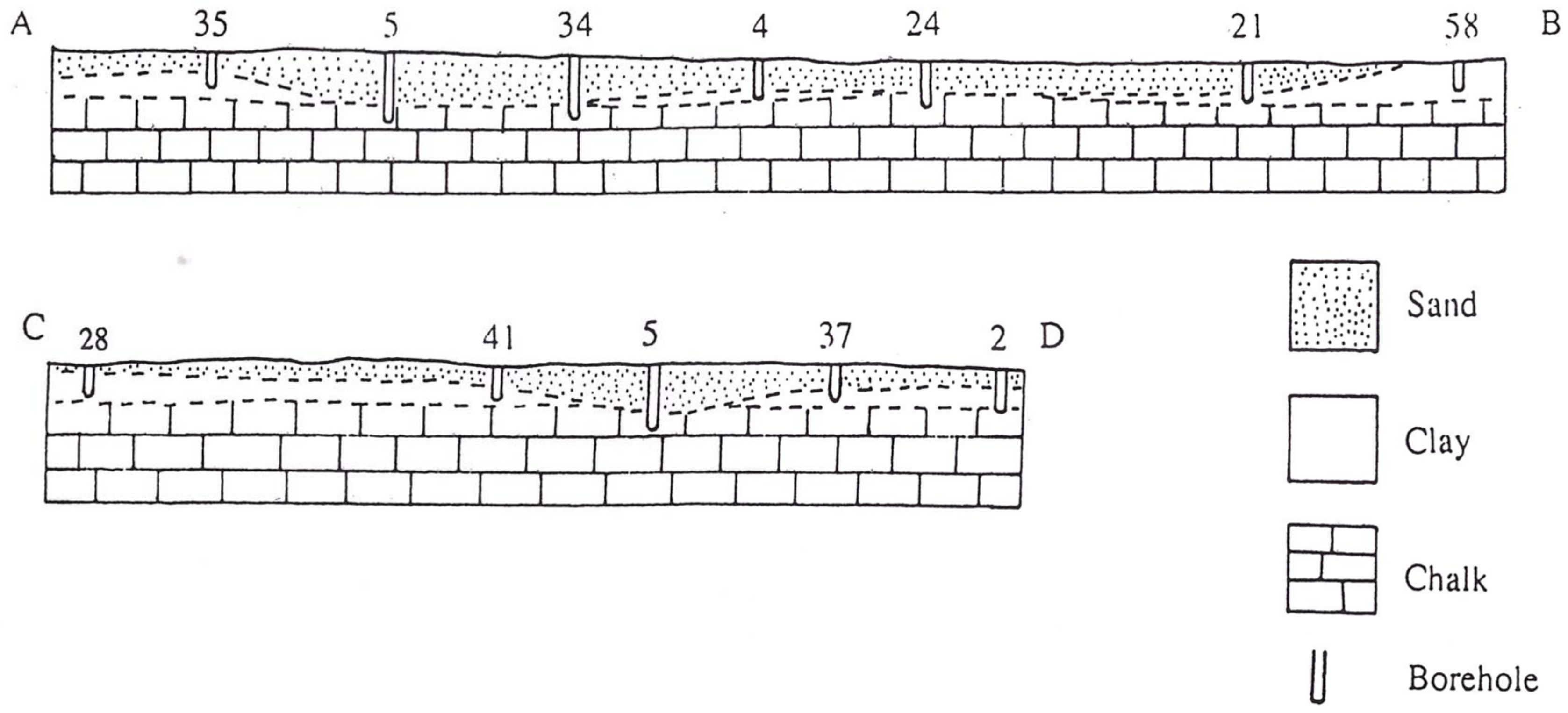


Fig. **3** Cross-sections showing relationships between glacial sand deposits and the underlying Chalk at Routh Carr (Source: Y.W.A., 1988).

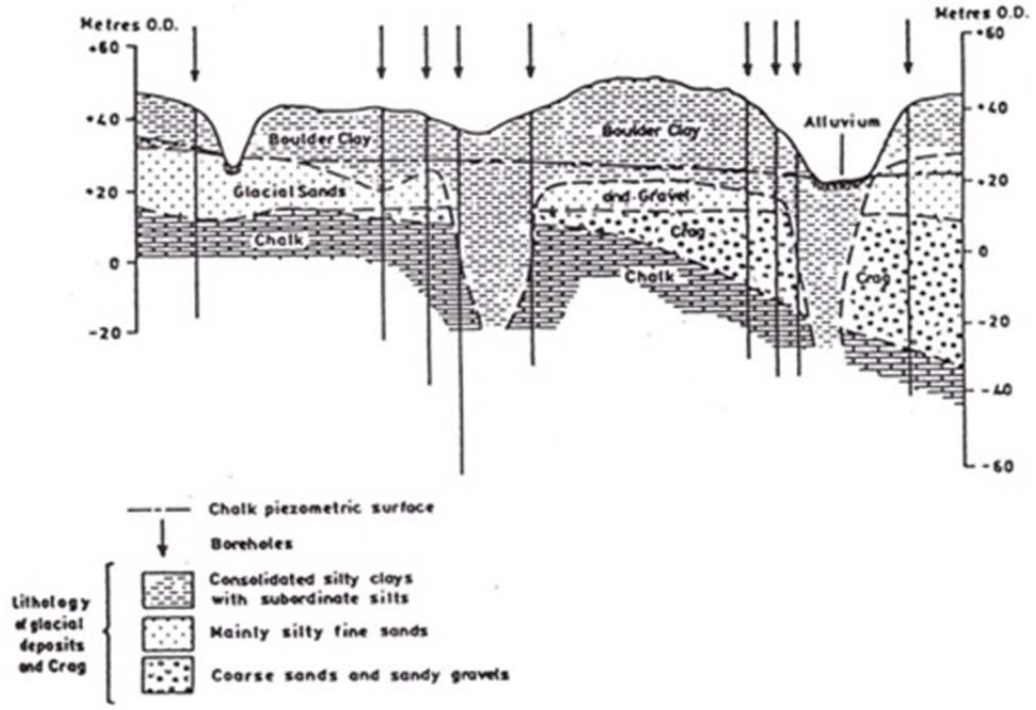


Fig. 4 Hydrogeological section from southern Norfolk showing the relationship between glacial sand deposits and the Chalk aquifer (Source: Foster and Robertson, 1977).

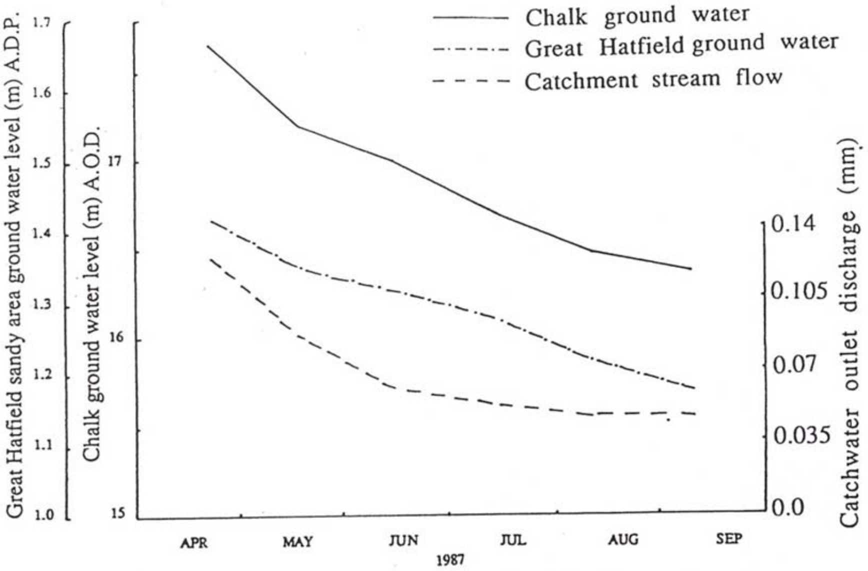


Fig. **5** Ground water level in the Great Hatfield sandy area, stream flow at the outlet of the Catchwater Drain catchment and ground water level in the underlying Chalk, 1987

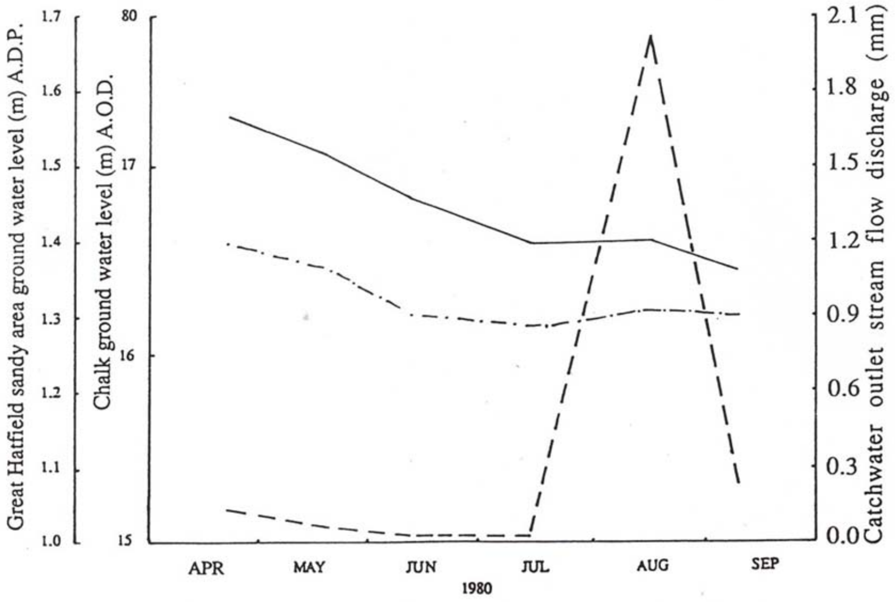


Fig. **6** Ground water level in the Great Hatfield sandy area, stream flow at the outlet of the Catchwater Drain catchment and ground water level in the underlying Chalk, 1980 for the entire catchment would have incorporated a significant quick flow element. The pattern in the remaining years for which data are available was intermediate between these two extremes, showing a close similarity in all years in the variations of ground water level between the Chalk aquifer and the sand area and a less obvious similarity in some years between the catchment discharge variations and the ground water hydrographs. Period averages of the instantaneous values are shown for each month in Figure 7 and these confirm the general relationships outlined above.

Further exploration of the relationships between ground water conditions in the Chalk aquifer and in the sand and clay areas of the Catchwater Drain was carried out using simple regression analysis. The scattergrams in Figure 8 and 9 show the regression relationships between ground water conditions in the Chalk and in the Great Hatfield sandy area and the regression statistics for each year of the data period are set out in Table 1.

Despite contrasting hydrological conditions in 1986 (when total April-September runoff from the Catchwater Drain catchment was 86.3 mm) and 1987 (when total April-September runoff was 38.2 mm), the scattergrams in Figure 8 illustrate a strong and highly significant relationship between Chalk and sand ground water conditions. Indeed, in 7 of the 10 years for which data are presented, R^2 values exceeded 0.85 and in 8 of the years the relationships were significant at the 99% level. This generally significant relationship over data period is reflected in Figure 9 which is a composite scattergram for all 10 years.

Relevant comparative data for the Chalk aquifer and the clay area at Hatfield Wood Farm were only available for six years, i.e. 1982-1988. Data for 1987 were incomplete and have therefore been excluded. Table 2 summarises the statistical data for these years and a composite scattergram is shown in Figure 10. The relationship is clearly weak and indeed in only one year does the R^2 value exceed 0.5 and the level of significance exceed 95%, i.e. in most years there was in fact no identifiable relationship between the Chalk ground water levels and those in the clay areas of the Catchwater Drain catchment.

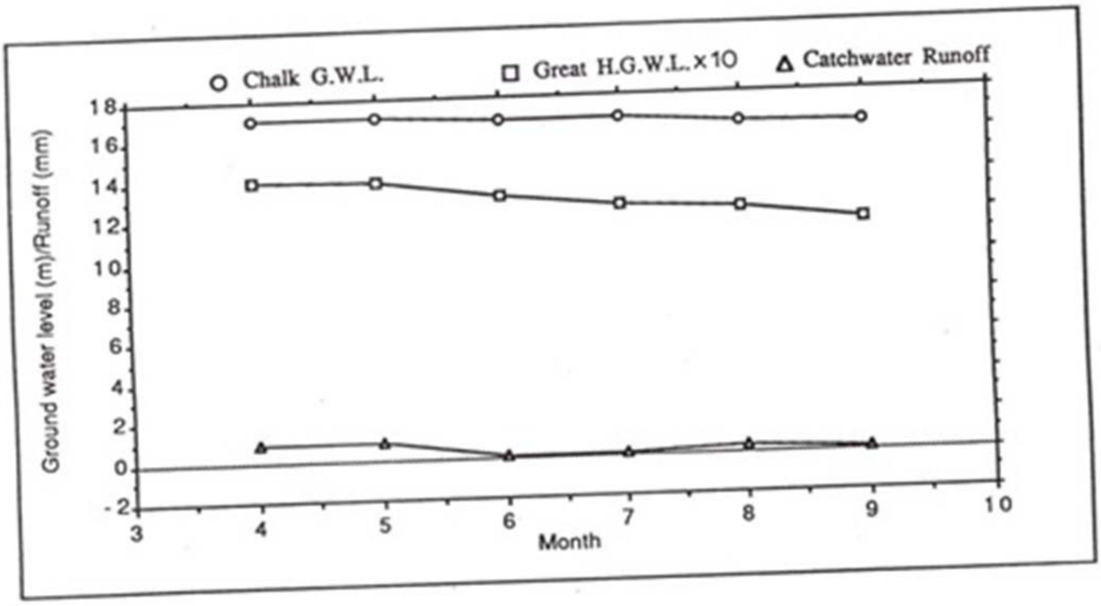
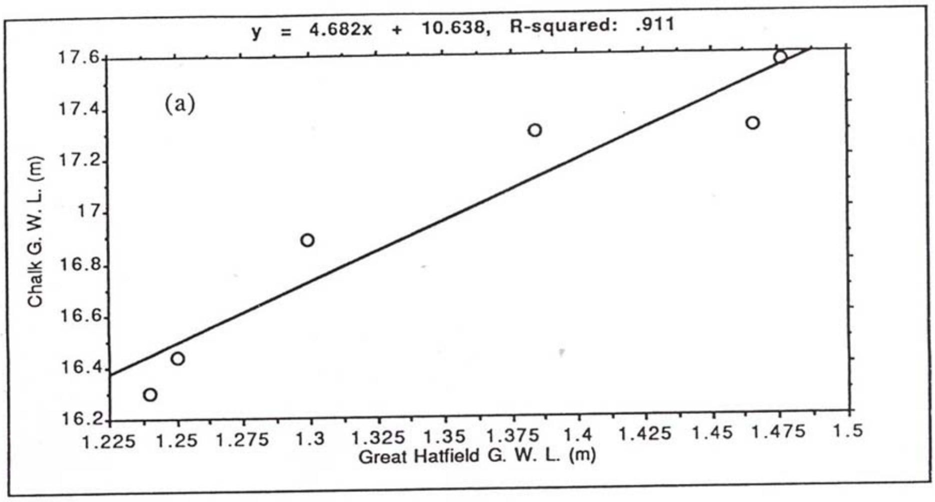


Fig. **7** Period monthly averages of ground water level in the Chalk and the Great Hatfield sandy area, and of runoff from the Catchwater Drain catchment, 1978-1988



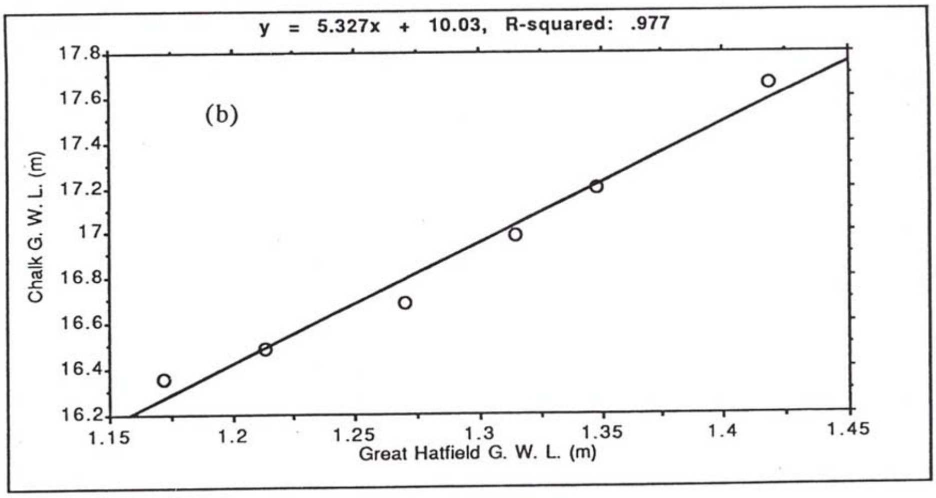


Fig. **8** Relation between Chalk and Great Hatfield ground water levels: a) 1986; b) 1987

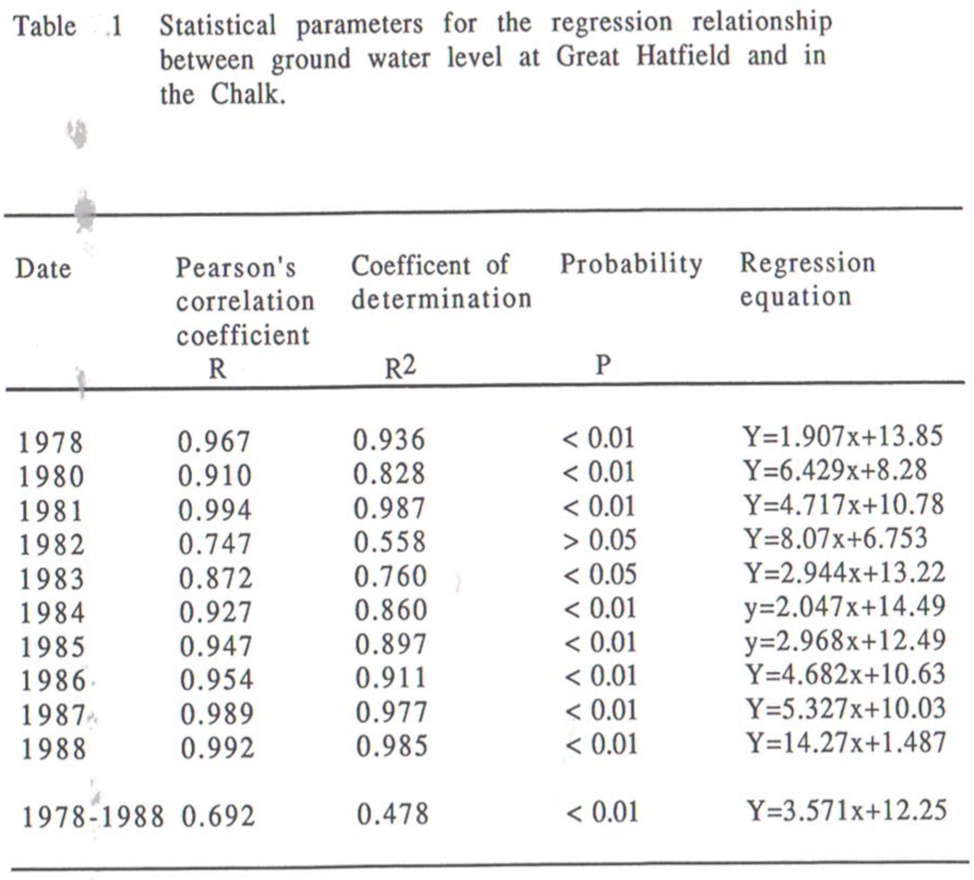


Table 1 Statistical parameters for the regression relationship between ground water level at Great Hatfield and in the Chalk.

Date	Pearson's correlation coefficient R	Coefficent of determination R^2	Probability P	Regression equation
1978	0.967	0.936	< 0.01	$Y=1.907x+13.85$
1980	0.910	0.828	< 0.01	$Y=6.429x+8.28$
1981	0.994	0.987	< 0.01	$Y=4.717x+10.78$
1982	0.747	0.558	> 0.05	$Y=8.07x+6.753$
1983	0.872	0.760	< 0.05	$Y=2.944x+13.22$
1984	0.927	0.860	< 0.01	$y=2.047x+14.49$
1985	0.947	0.897	< 0.01	$y=2.968x+12.49$
1986	0.954	0.911	< 0.01	$Y=4.682x+10.63$
1987	0.989	0.977	< 0.01	$Y=5.327x+10.03$
1988	0.992	0.985	< 0.01	$Y=14.27x+1.487$
1978-1988	0.692	0.478	< 0.01	$Y=3.571x+12.25$

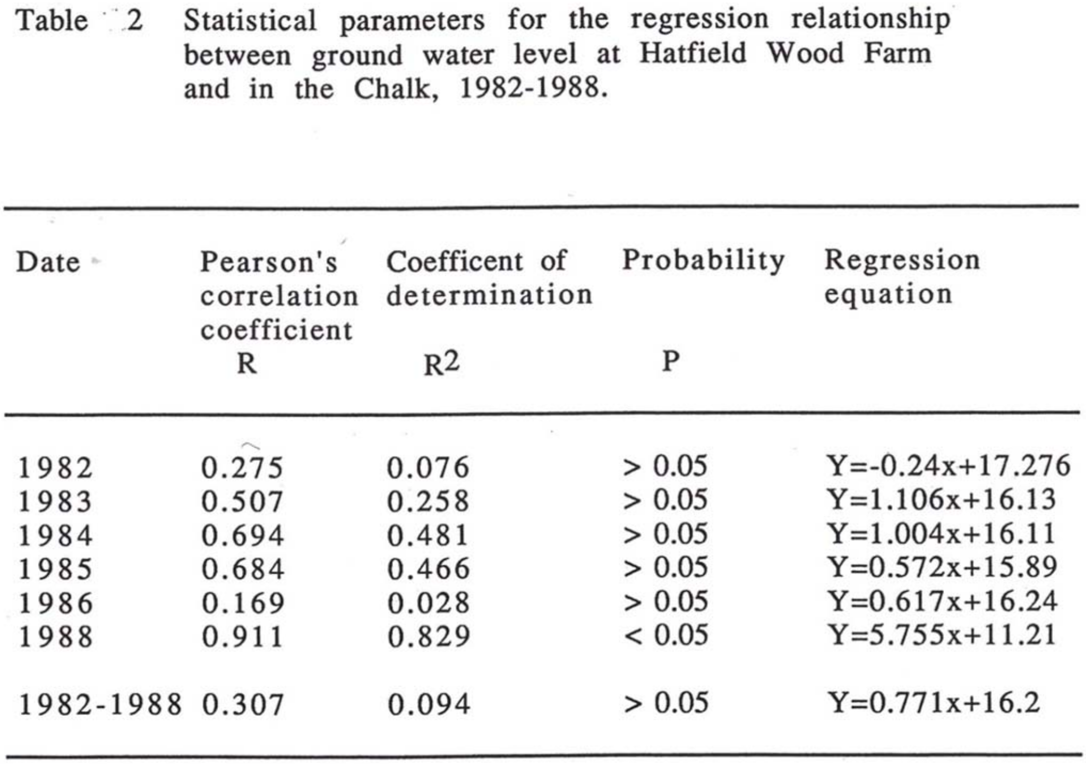


Table 2 Statistical parameters for the regression relationship between ground water level at Hatfield Wood Farm and in the Chalk, 1982-1988.

Date	Pearson's correlation coefficient R	Coefficent of determination R^2	Probability P	Regression equation
1982	0.275	0.076	> 0.05	$Y=-0.24x+17.276$
1983	0.507	0.258	> 0.05	$Y=1.106x+16.13$
1984	0.694	0.481	> 0.05	$Y=1.004x+16.11$
1985	0.684	0.466	> 0.05	$Y=0.572x+15.89$
1986	0.169	0.028	> 0.05	$Y=0.617x+16.24$
1988	0.911	0.829	< 0.05	$Y=5.755x+11.21$
1982-1988	0.307	0.094	> 0.05	$Y=0.771x+16.2$

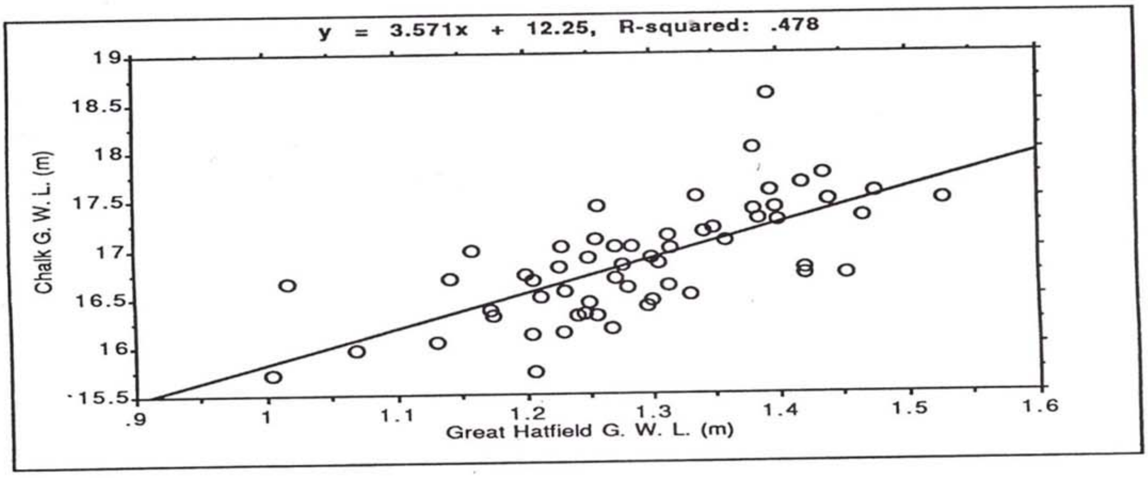


Fig. **9** Relation between Chalk and Great Hatfield ground water levels, 1978-1988

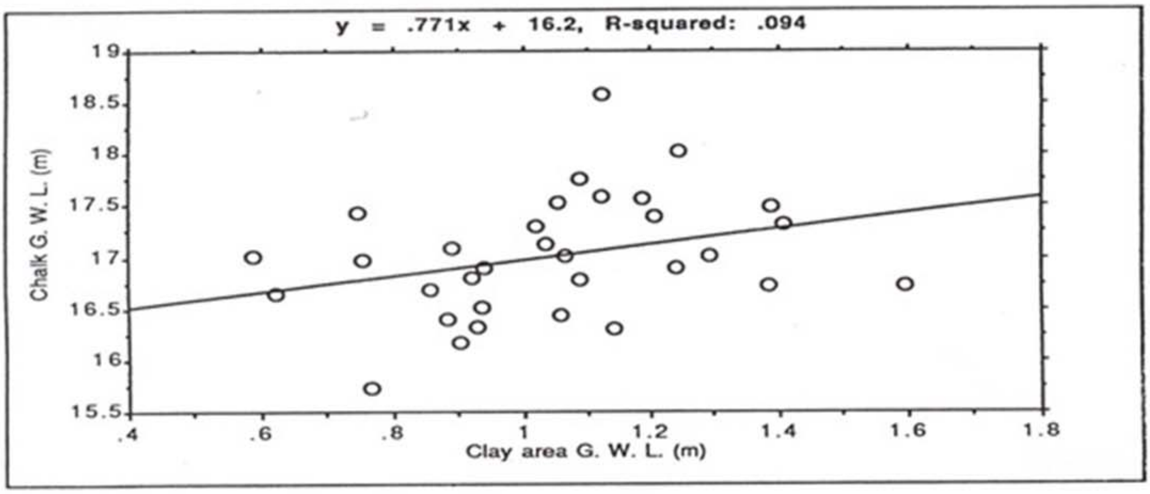


Fig. **10** Relation between Chalk and clay area ground water levels, 1982-1988

Comparision between hydrological conditions in the Chalk Aquifer and in the Catchwater Drain catchment during the study period (1987-1988).

Figure 11 illustrates, for the 1987-1988 period, further aspects of the relationship between ground water levels in the Chalk aquifer and stream flow and ground water levels in the sand and clay areas in the Great Hatfield and South Field sub-catchments. Although the cessation of stream flow and the drying out of the tube-wells with increasing desiccation at the clay transect severely restricts the usefulness of such comparisons, it is clear from Figure 11 and Table 3 that there was in both years, but especially in 1987, a close similarity between the recession of Chalk ground water levels and the recessions of stream flow and ground water level plotted for the Great Hatfield sub-catchment. In 1988 it will be noted that, although the Chalk and sand ground water levels peaked in May and declined steadily thereafter, stream flow from the sand area peaked in June. A substantially different relationship appeared to exist in the clay area since, in the earlier part of the 1988 dry season, i.e. April to June, when ground water levels and stream flows were recorded in the clay area, their variations with time did not resemble very closely the ground water variations within the Chalk aquifer.

Conclusion

The data interpreted as indicating a direct hydrological relationship between the Chalk aquifer and the Great Hatfield sandy area. Certainly, their pattern of ground water fluctuations was similar. In the much larger clay area of the catchment, however, the pattern of ground water fluctuations did not resemble closely those in the underlying Chalk aquifer during the early part of the summer. In addition, later in the summer, falling ground water levels

in the clay areas led to drying-up of the open ditches. Clearly these apparent hydrological relationships would be expected if the Great Hatfield, and perhaps other, bodies of sand and gravel are indeed in hydraulic continuity with the Chalk aquifer providing strong evidence that there is an upward movement of ground water from the Chalk into the sand area at great Hatfield, either because they rest directly upon the Chalk aquifer, similar situations occur also in northern Lincolnshire (Lloyd, 1980), and in Norfolk, as shown in Figure 4, where permeable crag deposits glacial sand rest directly on the underlying Chalk aquifer, or because of the presence of very localized permeable drift materials which permit hydraulic continuity through the till to the surface.

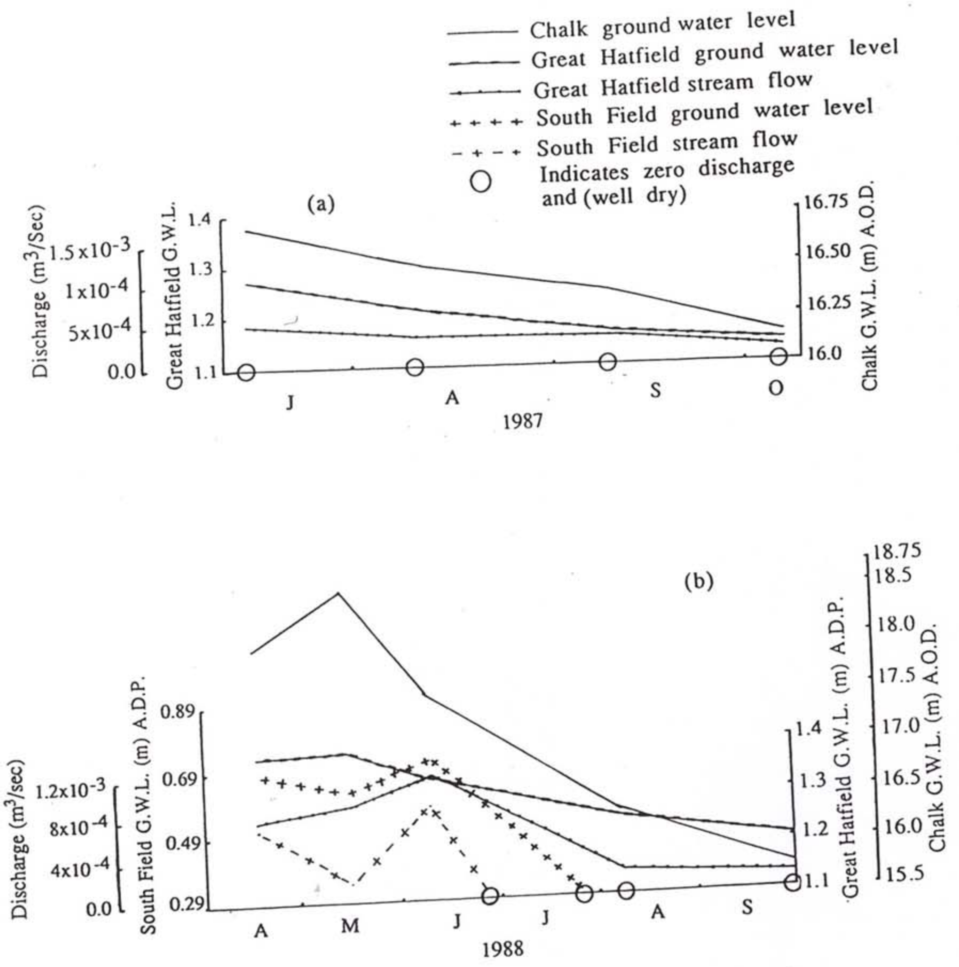


Fig. **11** Ground water levels and stream flow in the sand and clay areas, and ground water levels in the Chalk: a) July-October, 1987; b) April-September, 1988

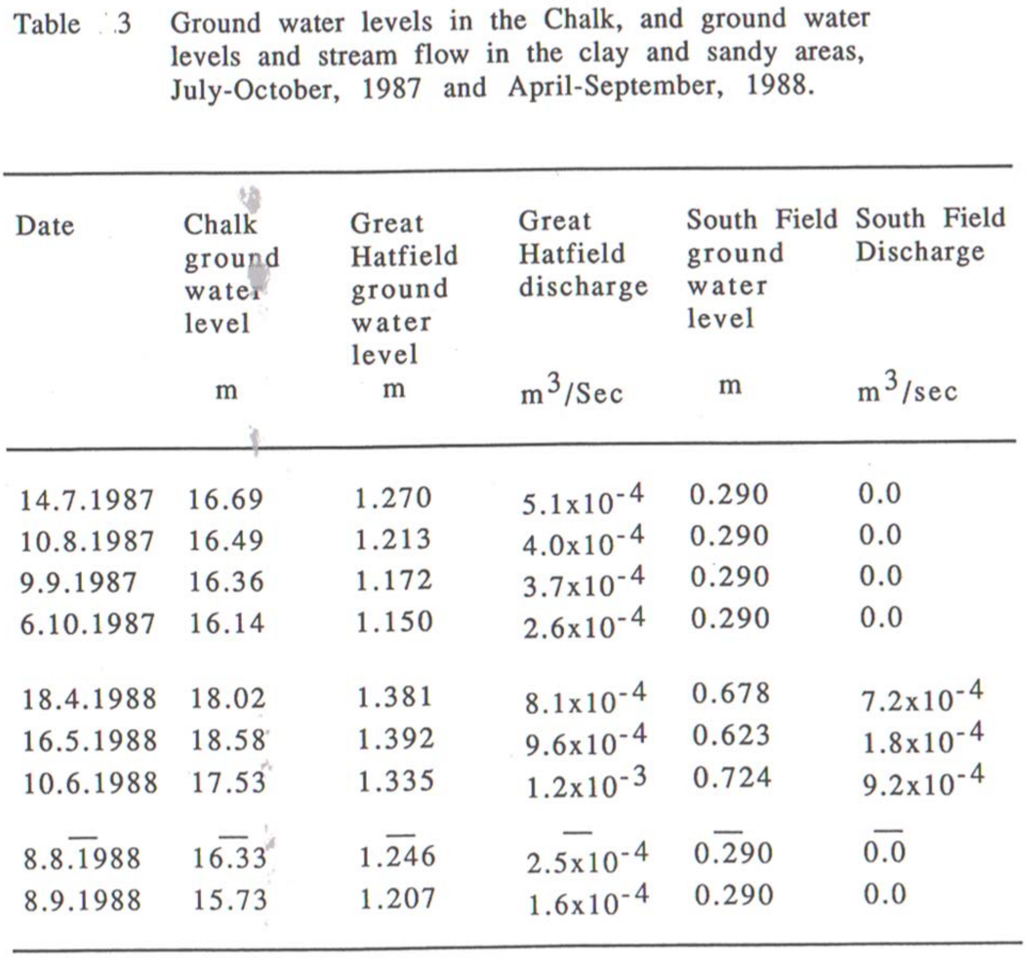


Table 3 Ground water levels in the Chalk, and ground water levels and stream flow in the clay and sandy areas, July-October, 1987 and April-September, 1988.

Date	Chalk ground water level m	Great Hatfield ground water level m	Great Hatfield discharge m^3/Sec	South Field ground water level m	South Field Discharge m^3/sec
14.7.1987	16.69	1.270	5.1×10^{-4}	0.290	0.0
10.8.1987	16.49	1.213	4.0×10^{-4}	0.290	0.0
9.9.1987	16.36	1.172	3.7×10^{-4}	0.290	0.0
6.10.1987	16.14	1.150	2.6×10^{-4}	0.290	0.0
18.4.1988	18.02	1.381	8.1×10^{-4}	0.678	7.2×10^{-4}
16.5.1988	18.58	1.392	9.6×10^{-4}	0.623	1.8×10^{-4}
10.6.1988	17.53	1.335	1.2×10^{-3}	0.724	9.2×10^{-4}
8.8.1988	16.33	1.246	2.5×10^{-4}	0.290	0.0
8.9.1988	15.73	1.207	1.6×10^{-4}	0.290	0.0

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جیاوازییێن هایدرولوجی دناڤبەرا عەمبارێن ئاڤێ تەباشیری و بەر رەخێ گێچێ هولدرینس یێ چوونا ئاڤ گرتی ل كومكەرەك بچیك ل هولدرینسی / انگلترا

پوختە:

پروگرامێ ڤەكولینێ ل سەر هایدرولوجیا ئەڤێ پارچا هولدرینسی بتایبەتی ژلایێ كارتێكرنێن ناڤبەرا سیستەمێ هایدرولوجی یێن كیروسەرڤە . ژبەر كو دیتنێن دیر ژ گرتنا چوونا ئاڤێ ژ ئاڤا كومكری باشتر بهێتە بكارهینان بو شروڤەكرنا ئاریشێن هایدرولوجی یێن بخوڤە گریدیت وەكو دابینكرنا ئاڤا رووەكی , رەواندنا عەردی لافاو , و پێتڤێن بو ئاڤدانێ.

ل كارێ بەرێ چ هەول نەهاتەدان بو ڤەبارەكرنا پەیوەندیێن هایدرولوجی ناڤبەرا جهێن ڤور (تەڤن) و جهێن خیز / بەرخشك یێ كومكەرێن ئاڤێ یانكو حەتابهیری دیاركرنا پێڤەچونا جوگرافی یا تەخەوچینێن خیز/ بەرخشكا.

ل خواندنێن زی هاتینەكرن , وا دانا هاتیە دانان ئەو بو كو ئەو كومكەرنا ژلایێ هایدرولوجی ئاڤ گرتی بو . ئەڤێ ڤەكولینێ ژمارەك ژ گومانێ دیار ئەوێن دوركەفتین ل كردارێن دەم درێژ یا چوونا ئاڤا گرتی ل كومكەری و ئەڤێ روناهی یەكی ببن دا رێژا ل سەر زانینا ئاڤێ (هایدرولوجی) نەك بتنێ یا چوونا ئاڤا گرتی ل كومكەری بەلێ هەروەسا یا بەر رەخێ گێچێ هولدرینسی.

ئومێد ئەوەی كو تێگەهشتنێن باش یێن هاتین ئەنجام دا دێ ببهابن ل لێكدانا رەفتارێ هایدرولوجی لجهێن وەكی ڤی جهێ ل هەر دەڤەرەكێ هەبیت .

المقارنات الهيدرولوجية بين خزان مكون الكلس وترسبات هولدرنيس الجليدية لتصاريف المياه المحصوره لمستجمع صغير فى منطقة هولدرنيس ، انكلترا.

الملخص:

برنامج البحث كان حول هيدرولوجية هذه المنطقة من هولدرنيس ، وتحديدا فى التداخلات المعتبرة بين النظام الهيدرولوجي السطحي والعميق منه، حيث ان تصريف المياه المستجمعه ذات المدى الطويل اوجدت تطبيقات اكثر فائدة لحل المشاكل الهيدرولوجية، متظمنة تجهيزات مياه الرئ وتصاريف المياه الارضية وكذلك الفياضانات وتوضيفها فى مجالات الارواء.

لم يكن هنالك محاولات فى الدراسات والاعمال السابقة لتحديد وقياس العلاقات الهيدرولوجية بين مناطق الطين والرمل /الحصى لهذا المستجمع او حتى تحديد الامتداد الجغرافي بشكل دقيق لطبقات الرمل /الحصى وعدساته

كان الافتراض فى الدراسات السابقة مبنية على ان المياه المستجمعه كانت عبارة عن مياه محكمة(watertight) متجمعة بطريقة هيدرولوجية.

هذا البحث قد حل عددا من الشبهات الكبيرة والتى قد تصاعدت خلال الفترات الطويل لعمليات تصريف المياه المستجمعه والتى ادت الى تصليط مزيدا من الضوء فى الدراسة الهيدرولوجية ليس فقط فى كيفية تصريف المياه المستجمعه ولكن ايضا فى الترسبات الجليدية لمنطقة هولدرنيس .

من المؤمل ان الفهم المعزز فى نتائج هذا البحث سيكون ذو قيمة فى تفسير السلوك الهيدرولوجي لمناطق اخرى كثيرة متشابهة لمنطقة هولدرنيس