THE REGIONAL HYDROGEOLOGY OF
RAHEENMORE BOG
CO. OFFALY.

RAY FLYNN

JUNE 1993

TABLE OF CONTENTS.

TABLE OF FIGURES.

ACKNOWLEDGEMENTS

This work was carried out as part of an eleven month contract for the National Parks and Wildlife Service (N.P.W.S.) branch of the Office of Public Works based in the groundwater section of the G.S.I. The project was supervised by Mr. Donal Daly, Head of Groundwater Section, G.S.I. Field hydrochemistry equipment was supplied by the N.P.W.S. Chemical analyses were carried out by the State Laboratory. Pumping test equipment was supplied by the Geological Survey of Ireland. The G.S.I. also supplied vehicles and staff to assist in carrying out field work. The abstract of this report was translated into Dutch by Twan Tiebosch from the Agricultural University of Waginengen, the Netherlands.

CHAPTER 1

INTRODUCTION

1.1 Background

This report describes and discusses the hydrogeological work carried out on and around Raheenmore Bog in the period between August and December 1992. The objective of the work was to examine the position and role of the bog in the regional hydrogeology of Raheenmore bog and its immediate surroundings.

1.2 Former Extent of Raised Bog.

Raheenmore is a raised bog. Raised bogs were once common over large areas of Western Europe and formerly covered 317,000 ha of the land surface of Ireland. A similarly high proportion of the total surface area of other countries such as the Netherlands were also covered by this landform at one time.

The original extent of raised bog all over Western Europe has been greatly reduced by human activity to such an extent that intact examples of this habitat are now extremely rare. Human interference with peatlands was already having a marked effect on the extent of raised bogs in Western Europe as early as the twelfth century when people started to reclaim large areas of bog by drainage and peat cutting (Streefkerk and Casparie, 1989).

Until relatively recently Ireland still had large areas of peatland undamaged by human activity and remained one of the few places left in Western Europe where intact raised bogs were common. This situation has changed greatly in the last 40 years. The mechanisation of turf cutting and the use of peat as a fuel for electricity generation has accelerated peatland reclamation in Ireland to such a level all raised bogs in the country have now been affected by drainage to some degree and most are now irreversibly damaged (Hammond, pers. comm.).

1.3 Conservation of Raised Bog.

A small number of relatively intact raised bogs are still found scattered around the Irish midlands. Some of these sites have been purchased by the Irish Wildlife Service with a view to conserving some of the last remnants of an increasingly rare habitat and an important part of the countries historical, geological and botanical heritage. One of these bogs is Raheenmore Bog.

An understanding of the hydrology and hydrogeology of raised bogs is essential if effective long term conservation plans are to be developed for the reserve.

1.4 Raheenmore Background

Raheenmore Bog is one the best Irish examples of a raised bog in a basinal situation. The site is located in Co. Offaly in the Irish midlands and is 213 ha in area. The area is a good example of a peatland with a well developed hummock-hollow system. The bog has been owned by the Irish Wildlife Servive since 1982 when it received nature reserve status. Active research was initiated on the bog in late 1990 and has been on going there up until the time of writing.

1.5 Irish Dutch Study Research on Raheenmore

Most of the research carried out on Raheenmore Bog was done within the framework of the Irish-Dutch Peatland Geohydrology and Ecology study. This was a multidisciplinary project which examined the geology, hydrology and ecology of raised bogs in Ireland and focused on Raheenmore Bog and a larger peatland, Clara Bog as specific study areas.

1.6 Organisations Involved in Work on Raheenmore

The Irish-Dutch project involved a large number of Irish and Dutch academic and governmental organisations. These are:

Office of Public Works (N.P.W.S.)

Staatsbosbeheer (Dutch State Forestry)

Geological Survey of Ireland

Trinity College Dublin

University College Galway

The University of Amsterdam

Agricultural University of Wageningen

The above organisations have worked in a co-ordinated programme of multi-disciplinary research programme to investigate to nature and operation of raised peat bogs.

1.7 Objectives of Work on Raheenmore

One of the overall objectives of the Irish-Dutch study was to obtain an understanding of the inter-relationship between the hydrological processes operating on the bog and the plant communities growing in particular areas. The information gathered during the study will be used to develop a management strategy for the long term conservation of raised bogs in both Ireland and Holland.

Much work has been carried out on the site by a number of workers in a variety of disciplines including botany, geology, hydrology and hydrogeology. Hydrogeological work carried out prior to this has focused specifically on the bog.

CHAPTER 2

GEOLOGY AND GEOMORPHOLOGY

2.1 Introduction:

This chapter briefly reviews the geology and geomorphology of Raheenmore Bog and the area surrounding it. It is not the objective of this report to review these aspects in any detail. The information outlined here is basically a summary of the work carried out by van Tatenhove in 1990. The reader is referred to the work of Smyth (1993) for a more detailed review of the geology and geomorphology of this area.

2.2 Geomorphology of Area Surrounding Raheenmore Bog.

The topography surrounding Raheenmore bog is very variable (Fig. 2.1). Large areas of flat terrain are found among smaller areas of gently sloping land around the southern and western margins of the bog. This contrasts with the topography on the north and east sides of the reserve which consists of a number of steep sided hills separated from one another by small incised valleys. A typical example of this sort of topography would be Mullagharush hill on the North Eastern side of the bog. The hills found on the southern side of the bog are roughly elliptical in shape and have their long axes trending in an east-west direction. The hills on the northern and eastern side of the bog are approximately conical in shape. Generally speaking the maximum height of the land surrounding the bog is greater than that of the bog itself.

2.3 Geomorphology of Raheenmore Bog

Van Tatenhove(1990) subdivided Raheenmore Bog into two geomorphological units, cut-away bog and uncut bog. The uncut bog has steep sides which rise much more gently to a high point in the centre of the reserve. This is the typical raised bog watch glass topography described in the literature (Ingram, 1980). No pool systems are observed on Raheenmore Bog.

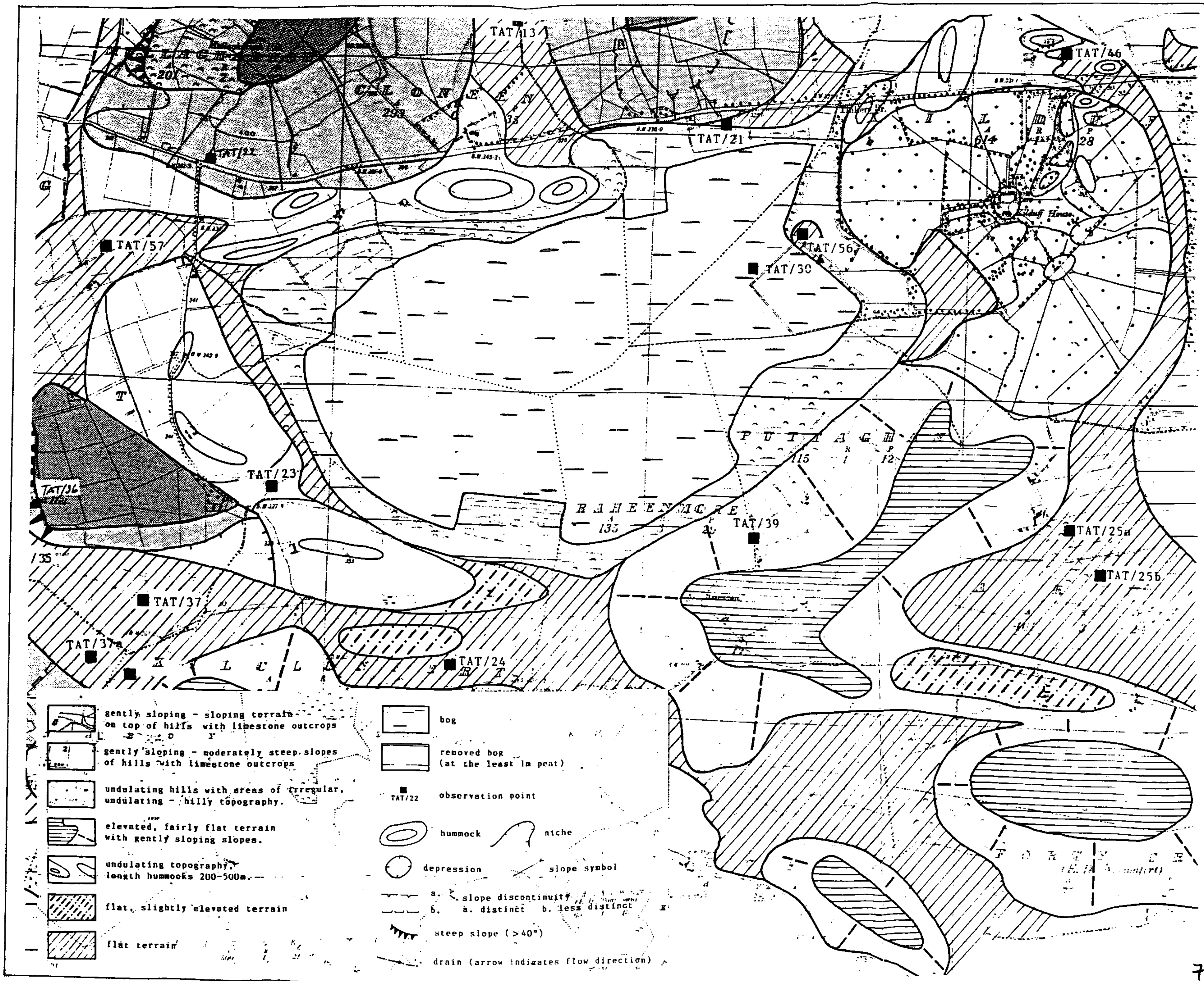
Raheenmore Bog has a well developed hummock and hollow microtopography in its centre. This topography is absent in areas strongly affected by drainage, particularly around the bog margins. The steep sides currently observed around the bog margins are a result of subsidence due to cutting and drainage. The natural margin of the bog has been removed by cutting on all sides.

Areas were peat has been removed by cutting have been classified by van Tatenhove as removed bog. The extent of removed bog is very variable. The thinnest zone is found on the northern side of the bog and the thickest on the south-east. Removed bog has a generally flat topography crossed by numerous small drains.

2.4 Drainage

The main drains in the area around Raheenmore Bog are found in the area immediately surrounding the bog. A survey of the drains in the area was carried out

Fig. 2.1 : Geomorphological Map of Raheenmore Bog and the Surrounding Area (, After van Tatenhove, 1990).



by the author in September 1992 in which the distribution and flow direction of drains was noted. The results of the survey are shown in figure 4.1, where it can be seen that the drains form an approximately circular shape around the bog margins which is only broken on the north western and south eastern sides of the bog where topographic high points correspond to surface water catchment divides. Drainage in the area has an approximately radial pattern flowing from around the bog margins. Most of the drainage discharges through three principal drains, two of which flow to the north and one to the south west. A number of smaller drains flow from the high ground surrounding the bog margins into the marginal bog drains. A large number of water logged ditches associated with former turf cutting are found in the removed bog area.

2.5 Geology of Raheenmore Bog.

Both the bedrock and subsoils in the area surrounding Raheenmore bog are varied. This section will very briefly review the various units encountered in the area. Descriptions and interpretations of the different units are based largely on the logs of four G.S.I. boreholes drilled on the bog.

The bedrock immediately surrounding and underlying Raheenmore Bog is a blue-grey Carboniferous limestone. Examination of the lithology at the outcrop in the North Eastern part of the area showed the unit to be blocky and moderately jointed suggesting reasonable permeabilities. However, further examination of the cores taken from the two boreholes below the bog in which bedrock was encountered revealed a massive lithology with few joints.

Most of the information concerning the deposits overlying the bedrock is derived from G.S.I. boreholes drilled on the bog. In all localities Glacial till was seen to overlie the bedrock. The deposit is lithologically very variable and contains abundant lenses of clayey gravel in an otherwise fine grained diamictic deposit. Grading curves taken in all the boreholes show the deposit to be poorly sorted.

A blue-grey lacustrine clay overlies the till in which two of the four GSI boreholes were drilled, RHBH1 and RHBH4. The clay is overlain by fen peat. Peat rests directly on top of glacial till in the other two boreholes. Both situations are also inferred on van Tatenhoves' map.

The classical ecological succession of lacustrine peat grading into fen peat before passing into the more ombotrophic raised bog peat is observed in all the cores taken on the bog (Westein and Veldkamp, 1993). Peat thicknesses greater than 15 metres are observed at some sites (Smyth, 1993).

CHAPTER 3

PERMEABILITY INVESTIGATIONS

3.1 Introduction:

This chapter describes the methods and tests used to determine the permeability of the inorganic units surrounding or underlying Raheenmore Bog. The tests were carried out to determine the ability of the inorganic deposits to transmit water and thus help to establish the nature of the hydrogeological relationship between the bog and older geological units. An assessment of the permeability of these units is vital if the behaviour of groundwater in and around the reserve is to be determined. Grain size analyses of subsoil samples taken during drilling and a series of short duration pumping tests were carried out with a view to achieving this aim. The following sections deal initially with the details and results of the pumping tests followed by a similar discussion about the results of the grain size analyses before integrating the two data sets.

3.2 Background to pumping tests :

Two pumping tests were carried out by the author on the G.S.I. boreholes on the Raheenmore Bog. The tests were carried out in December 1992 and the resulting data has been used to determine the permeability of some of the deposits surrounding and underlying the bog.

Pumping tests involve removing water from an aquifer via a well using a pump thus upsetting the naturally prevailing hydraulic conditions. The response of the water level in the well allows a number of aquifer and well parameters to be determined. If the well is pumped at a constant discharge for a long period of time the aquifer parameter transmissivity (permeability x saturated aquifer thickness) can be determined. The analytical formulae used to calculate aquifer parameters assume a number of hydrogeologically ideal conditions which are frequently not met in reality. Despite this complication pumping test techniques are a very useful hydrogeological tool for investigating the permeability of geological deposits.

Testing over a long period of time results in a large volume of aquifer being sampled. Smaller scale hydrogeological techniques such as piezometer testing do not sample such a large volume of rock or soil (although they do provide greater resolution of data on a smaller scale). A transmissivity value obtained from long duration pumping test therefore gives a more representative indication of a geological units bulk permeability.

3.3 Pumping Test Methodology:

This section briefly outlines the techniques and equipment used to carry out the pumping tests.

3.3.1 Pumps

The pump used in a pumping test must be selected to suit the geological units to be investigated as well as for practical reasons such as portability and ease of use. The objective of a pumping test is to stress an aquifer in order to produce a hydraulic response measured as drawdown in a well. This must be done without causing the water level in the abstraction borehole to drop below the level of the pump inlet. Different pump types are used to obtain the maximum aquifer response to pumping in different deposits. High permeability deposits need to be pumped at a higher discharge rate than lower permeability units. Lower permeability deposits need to be pumped a pump capable of discharging at a lower discharge rate.

It was initially attempted to pump the boreholes with a surface mounted belt driven diesel pump. Unfortunately the minimum discharge that this pump could operate at was above the maximum discharge rate which the boreholes could discharge water. A pump with a lower discharge was therefore necessary.

A compressed air driven pump was used for both tests. The apparatus is a specialist pump originally developed for chemical sampling. However the pump operated at the low discharges required and was therefore ideally suited to pumping tests in low transmissivity boreholes, e.g. between 0.1 and 1 m2/day. The pump was submersible and had a 48mm external diameter. It could therefore fit inside 2"(50mm)ID piezometers. The pump and associated apparatus were also light and portable and could be easily used at all piezometers that needed to be tested. However, the apparatus is however easily damaged when pumping fines so holes which needed to be tested using this pump were first pumped at a high discharge using the surface mounted pump.

3.3.2 Test Procedure

The following section describes the procedures used during the pumping tests.

It was attempted to pump piezometers in three of the four G.S.I. boreholes. The fourth hole, RHBH-4, was located in the centre of the bog and was inaccessible. One of the pumped holes, RHBH-3 was pumped for two minutes before drying out. It was concluded that the piezometer was surrounded by low permeability material at its filter and that it may in fact be blocked.

The two holes, RHBH 1a and RHBH 2a were pumped at a constant discharge rate for 240 mins. Pump discharge was monitored by measuring the time taken to fill a five gallon drum. Water levels were monitored over logarithmic time intervals of between 30 sec at the start of the test and 40 mins at the end. The rate of rise of the water level in the well was monitored over similar time intervals for one hundred minutes.

Well head hydrochemistry was measured at regular intervals in all tests carried out by the author on GSI piezometers. The parameters measured were temperature, conductivity and pH. A sample was taken for laboratory analysis at 200 min after the start of pumping in both tests.

3.4 Analysis:

All pumping test data were analyzed using straight line semi logarithmic plots. If the slope of the plot changed with time the transmissivity values used were those taken from the later part of the pumping tests where the influence of local conditions immediately around the pumping well were minimised. The most representative aquifer volume could therefore be obtained from later pumping data.

Two sets of semi-logarithmic plots were plotted for each hole that was pumped. The pumping well data set were analyzed using time vs drawdown plots. The recovery of the water level in the well was measured at the end of the test and a residual drawdown vs dimensionless time graph was plotted.

The transmissivity of each borehole was determined from the slope of the plot using the standard Jacob plot method of analysis(Jacob, 1949) which states that on a semilogarithmic graph of drawdown against time transmissivity can be calculated from the graph using the formula

$$T=2.3\ Q\ /\ 4\ \text{pi}\ As \quad (1) \qquad \text{where}$$

T is Transmissivity (m2/day).
Q is Discharge (m3/day).
As is the change in drawdown for a log cycle of time.

A second Transmissivity value can be obtained from the water level recovery data using a standard Theis recovery plot. The Theis recovery method involves plotting residual drawdown vs log dimensionless time(time since pumping started/time since pumping stopped) and calculating transmissivity from the following:

$$T=2.3\ Q/\ 4\ \text{pi}\ As' \quad (2) \qquad \text{where}$$

T and Q have the same meaning as in (1) and As' is the change in residual drawdown for one log cycle of time.

Graphs were completed for all pumping wells. Some plots were also produced for observation piezometers in the same borehole although no analytical technique for quantifying aquifer parameters in this situation is known. Many additional techniques exist for plotting and analyzing pumping test data although it was felt that the possibility of obtaining additional information using these methods is slim as the ideal analytical solutions under which the formulae were derived are not met in either of the tests carried out.

3.5 Results

Table 3.1 : Results of constant discharge tests on GSI boreholes CLBH 2, CLBH 3, CLBH 4 & CLBH 5.

Borehole Tested	Aquifer	Method of Analysis	Transmissivity (m^2/day)
RHBH 1	Gravelly Till	Theis Recovery	7.67
RHBH 2	Limestone Bedrock.	Theis Recovery	31

Large fluctuations in water level during the pumping tests did not allow transmissivity values to be calculated from pumping borehole data.

3.6 Grading Curve Analysis

The inorganic subsoil units which surround and underlie Raheenmore Bog vary widely in their texture. Most of the deposits contain variable amounts of sand, silt and clay although deposits lacking coarser or finer fractions also exist. It is hydrogeologically important to know the relative abundances of the various grain size fractions in each unit in order to assess the permeability of particular horizons and thus the ease with which groundwater can flow through them. The relative abundances of the different grain size fractions in a deposit can be assessed using a grading curve.

3.7 Background to Grading Curve Analysis.

A grading curve is produced when a subsoil sample is passed through a number of increasingly finer sieves. The relative proportions of the fractions retained by each sieve are weighed and plotted on a semi-logarithmic graph of cumulative weight retained with increasing grain size against sieve mesh diameter. The curve produced from this plot is called a grading curve.

Grading curves can be of considerable use when examining the properties of unconsolidated deposits. The curves can be used to qualitatively and quantitatively investigate the geological, geotechnical and hydrogeological properties of subsoils. One of the most important applications of grading curves is the approximate quantitative determination of the permeability of a subsoil. The approach is a cheap and useful method of getting a value for this important geotechnical parameter.

Grading curves provide a useful approach for obtaining the relative contributions of particular horizons to a transmissivity value obtained from a pumping test provided representative samples are taken of the various horizons encountered during drilling. A better idea of the permeability variation of the water bearing deposits can thus be obtained from the pumped borehole. This technique is particularly valuable in the highly variable subsoil sequences which are common in Irish Quaternary deposits.

3.8 Theory

The hydraulic conductivity of a subsoil is calculated from a grading curve using the Hazen equation. The Hazen equation states that:

$$K = Cd_{10}^2 \qquad (1)$$

where

K is the hydraulic conductivity of a medium (cm/sec.)
d_{10} is the grain size at which 10% of grains in the sample are finer (mm)
C is an empirical constant relating the two variables and has a value between 0.46 and 1.41.

Much work has been carried out on the use of the Hazen equation which questioned the validity of the empirical range and the power relationships. The results of this research have shown the equation to be valid in its original form. The equation was used in its original form to determine the permeability of samples taken during this project.

3.9 Analysis

The d_{10} of all grain size distribution curves was measured and permeabilities calculated for the upper and lower limits of the empirical factor, C. (See equation. 1)

The permeability values obtained from a number of samples in a particular soil unit were averaged for each representative horizon and multiplied by its saturated thickness. This process was repeated for all samples taken from a particular borehole, the resulting values summed and a transmissivity value obtained. The transmissivity values calculated using the grading curves were compared with those obtained from the pumping tests.

The comparison between the transmissivity values obtained from pumping tests and those calculated from grading curves provided a useful check on the representativeness of the samples taken. The variation of permeability in particular unconsolidated geological formations can be assessed with greater confidence by combining grading curve and pumping test data.

The relative quantities of water contributing to the overall transmissivity from each geological horizon were determined using the Hazen technique. The permeability of the different horizons was obtained by multiplying the proportion of the transmissivity calculated by the Hazen rule by the value obtained from the pumping test data. The resulting value is divided by the saturated thickness of the sample horizon and a permeability value thus obtained.

3.10 Results:

The permeabilities calculated from grain size distribution curves using the Hazen rule are shown in Table 3.2. Uniformity co-efficients have also been included to reflect the range of sorting in the deposits encountered. The permeability values have been converted to m/day for convenience.

In two cases the d10 value cannot be determined as the grain size at this interval is too small to be measured. The permeability in these cases therefore remains indeterminate from grading curves. The permeability of the fine grained units were assumed to be approximately zero in comparison to the determinate values in these cases.

Table 3.2 Grading Curve Results for RHBH-1

SAMPLE DEPTH(M)	D10 (mm)	Uc	K (0.41)	K (1.46)	PROPORTION . OF TOT.TRANS.
4.00	0.0028	1000	0.00	0.00	0.000
5.00	N/D	N/D	0.00	0.00	0.000
6.00	1.2	35	510	1816	0.994
6.80	0.06	400	1.27	4.54	0.003
7.50	N/D	N/D	0.00	0.00	0.000
8.00	0.06	283	1.27	4.54	0.003

Transmissivity range from grading curve data : 868 - 3088

3.11 Discussion.

The Transmissivity values obtained from the pumping tests are low as would be expected from clay rich subsoils and lightly fissured bedrock. The permeability of the units examined is discussed in more detail below.

3.11.1 Permeability of the Bedrock.

A rough indication of the permeability of the bedrock in RHBH 2 can be obtained by dividing the transmissivity value by saturated thickness of the bedrock (5m). A bulk permeability of 6.2 m/day is obtained. This value is, in some repects, misleading. The permeability of the bedrock mass itself is effectively zero. The abstracted water is transmitted through the fissures in the rock. Fissures have a finite permeability which increases with increasing width. A geotechnical log of the bedrock core taken during drilling, stating the size of the fissures, would allow the permeability of the bedrock to be determined in greater detail.

3.11.2 Permeability of the Till.

The permeability of the glacial till in RHBH 1 was determined by integrating the permeability values obtained from the Hazen rule with the transmissivity value calculated from the pumping test. The permeability of particular horizons in the deposit could thus be determined. It is notable that the transmissivity obtained from the pumping test is believed to be more accurate. Calculation of transmissivity values by integrating grading curve data yields values that are two to three orders of magnitude greater than those obtained from pumping. A loss of much of the clay and silt fractions during sampling could possibly explain the discrepancy between the two values.

Despite the difference between the two transmissivity values, an attempt to calculate the permeability of various horizons in the till was carried out in the manner described in section 3.6.3.

The most permeable horizon in the till was the clayey gravel which is found between 5.0m and 6.75m depth below the surface. A permeability of approximately 4.1 m/day was calculated for this unit. The permeability of the adjacent horizons is significantly lower. Permeabilities of 0.005 m/day were calculated for the bouldery clay below the gravel. In all cases, when the permeability could not be calculated from grading curves and it taken to be effectively zero. Based on this information it appears that groundwater in the till below Raheenmore Bog flows mainly in coarse clayey gravel lenses surrounded by lower permeability material. The lateral extent of these units are not known.

3.11.3 Hydraulic Connection Between Units

The absence of a measurable response in the bedrock in RHBH 2 to pumping in the gravelly till above it indicated that little hydraulic connection exists between the two units. This was felt to reflect the low permeability deposits separating the two lithologies.

CHAPTER 4

HYDROCHEMISTRY

4.1 Introduction

Little detailed hydrogeologically-based hydrochemical investigations were carried out on Raheenmore Bog since the start of the Irish-Dutch raised bog study. Most hydrochemical work to date has focused on the chemistry of bog waters with a view to explaining the distribution of various plant species. A brief hydrochemical survey of the waters under and surrounding Raheenmore bog was carried out between August and December 1992. The following chapter describes this work and the significance of its results.

The hydrochemical investigations carried out consisted of a field hydrochemical survey of the drains surrounding the bog, field hydrochemical monitoring during pumping tests and sampling for laboratory analysis during the same tests. The reader is referred to the work of Kelly(1993) for more detailed work on the hydrochemistry of the bog waters on Raheenmore Bog.

4.2 Field Hydrochemical Survey of Drains.

A field hydrochemistry survey of the drains surrounding Raheenmore bog was carried out on the 9th and 10th of September 1992. The objective of the survey was to distinguish the different water types flowing in the drains. Field hydrochemistry can frequently be a useful tool in distinguishing between water flowing from peatlands and that flowing from the surrounding area. Similar surveys carried out on Clara Bog proved useful in distinguishing water flowing from adjacent inorganic deposits from peatland waters based on the temperature and electrical conductivity of the water.

An EC survey was undertaken in the drains surrounding Raheenmore Bog in an attempt to distinguish different water types found in the area and thereby gain a more detailed insight into the hydrogeological processes operating around the bog margins.

Based on the information outlined above a Conductivity survey of the drains in the immediate surroundings of Raheenmore bog was carried out. The parameter was measured at regular intervals in all drains around the bog margins and in those drains flowing into and out of the bog.

4.3 Results

The results of the survey are shown in table 4.1 and the associated location map is shown in figure 4.1. The numbers shown in the figure correspond to the site numbers in the table.

Fig. 4.1 : A Map of Hydrochemical Sampling Sites On and Surrounding Raheenmore Bog, Co. Offaly.

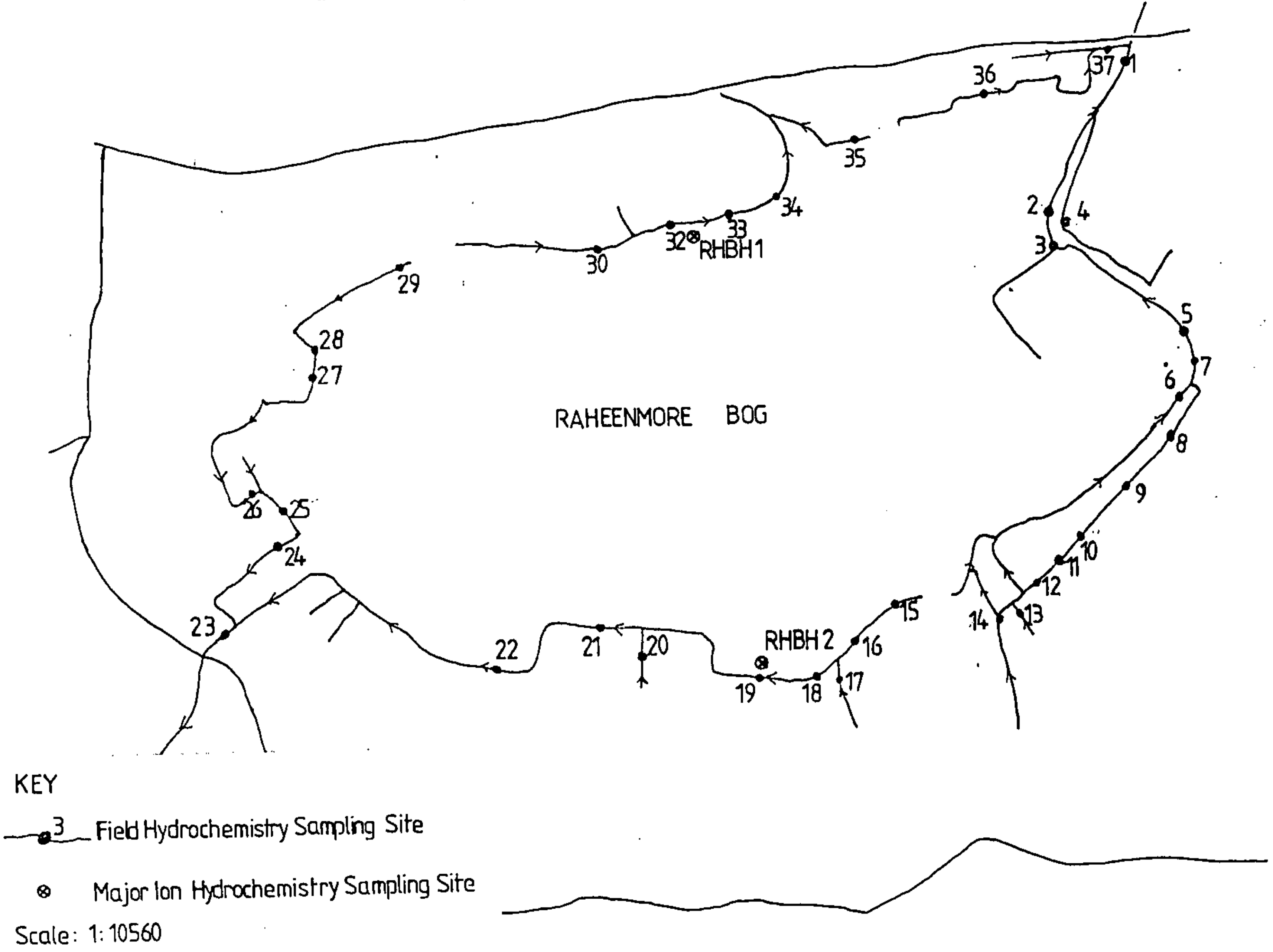


Table 4.1 : Results of Conductivity Around the Margins of Raheenmore Bog.

Site No.	Conductivity (uS/cm)	Site No.	Conductivity (uS/cm)
1	374	20	475
2	342	21	272
3	71	22	244
4	478	23	244
5	496	24	180
6	94	26	246
7	745	27	227
8	744	28	107
9	780	29	159
10	764	30	70
11	725	32	59
12	779	33	95
13	284	34	124
14	69	35	63
15	145	36	350
16	522	37	388
17	749	38	394
18	319	RHBH 2-1	720
19	273	RHBH 3-1	720

4.4 Discussion of Field Hydrochemistry

The conductivity measurements taken around the bog margins show a continuous range of values starting at around 60 Us/cm and ranging up to a maximum of 780 Us/cm. The lower end of the range is occupied by waters which are believed to be derived from peat and have very low concentrations of total dissolved solids(Shotyk, 1987). The upper end of the EC range is occupied by waters contained in the deposits below the bog and found in drains flowing from the adjacent inorganic deposits. Waters found in the intermediate range between these two values are thought to be mixtures of the two water types. Electrical conductivity measurements therefore proved to be very useful technique for discriminating between bog water and regional groundwater.

Examination of the results of the survey show that the drains flowing along the eastern, southern and western margins of the bog have electrical conductivities substantially greater than bog water. The highest conductivities measured were observed in the drain which flows around the south eastern margins of the bog. Most of the water observed in this area is derived from water flowing in from the surrounding mineral soils. The quantity of water flowing to the drain from the bog is minimal as most of the peatland waters are channelled away in an outer drain before reaching the bog margins. The low conductivities of the outer drain waters reflect this situation.

Waters along the southern and western margins of the bog have lower conductivities reflecting a greater input of bog water than that along the south eastern edge. In certain areas the proportion of bog water is felt to be quite high and EC values measured approached those for pure bog water. This may reflect the residual effects of rainfall from the previous day which has resulted in surface runoff flowing into slow flowing drains. Local increases in drain water conductivity are most frequently associated with minor inputs of regional groundwater flowing from drains in the adjacent mineral soils.

Hydraulic heads in RHBH 2 on the southern side of the bog adjacent to the boundary drain indicate no vertical component in the hydraulic gradient at that site. An upward groundwater flow component is typically observed in deposits discharging to hydraulically connected drains. This situation is not observed at this locality. It is therefore concluded that the underlying groundwater is not in hydraulic continuity with the marginal drain in the area adjacent to RHBH 2.

The drain along the northern margin of the bog contrasts with other drains in the area as it consists almost solely of low conductivity water which is thought to reflect the overwhelming dominance of bog water. Conductivities in other marginal drains are higher than those of bog water but are lower than those observed in the deposits below the peat.

Hydraulic head data from RHBH 2 which is adjacent to the southern drain indicates that regional groundwater flow does not have a significant upward flow component at this point. Based on this information, it is suggested that minor groundwater seepage and surface runoff flowing in from the surrounding area are mixing with low conductivity bog water on the southern, eastern and western marginal drains.

4.5 Major Ion Hydrochemistry.

Major ion hydrochemical investigations on Raheenmore Bog were mainly carried out by Kelly(1993) and focused on the waters of the upper metres of the peat with a view to investigating the availability of various plant nutrients. Little information existed on the major ion hydrochemistry of the regional groundwater underneath and surrounding the bog prior to this investigation.

Two hydrochemical samples were taken from the deposits below the peat to determine the hydrochemical characteristics of the regional groundwater in the area under and immediately around Raheenmore Bog. Both samples were taken while carrying out pumping tests on the G.S.I. boreholes RHBH 1 and RHBH 2. The sample taken from RHBH 1 was taken from the till deposits which underlie the peat in many areas. The sample taken from RHBH 2 was taken from the upper five metres of bedrock on the southern side of the bog. Both waters were refrigerated immediately after sampling and analyzed in the State Laboratory, Abbotstown the following day.

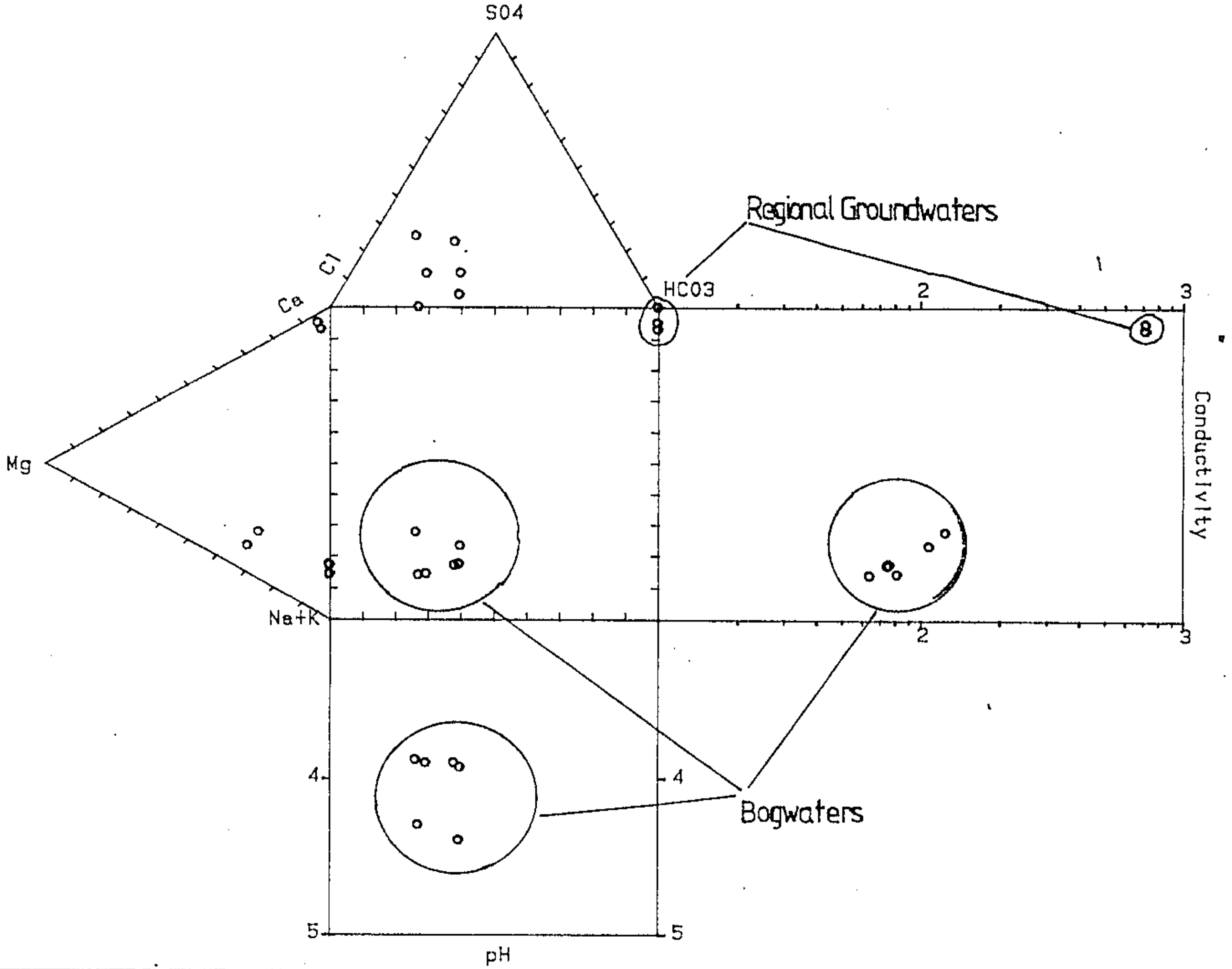


Fig. 4.2 : A Durov Hydrochemical Plot Displaying the Contrast Between the Hydrochemistry of Bog and Regional Groundwaters.

PLOTTED: Jun 09 1993

4.6 Results of Major Ion Hydrochemical Analyses

The results of the major ion hydrochemical investigations carried out on Raheenmore Bog are shown in Appendix 2. Both analyses are plotted on a Durov plot and are shown in Fig. 4.2 below and compared to typical bog water samples.

4.7 Discussion of Major Ion Hydrochemistry.

The Durov plot shows that hyrochemistry of the regional groundwater in both the till and the bedrock contrasts remarkably with that of the waters in the bog. The regional groundwater plots in the $CaCO_3$ field whereas the bogwater plots in the NaCl field. A clear distinction between the two water types can thus be discerned using the Durov plot.

The high conductivity of the till and bedrock waters is a direct reflection of the abundant dissolved solids in the water. The total hardness to total alkalinity ratio has been used by E.P. Daly in hydrochemical studies in the Nore Basin to determine whether ion exchange has taken place. Ion exchange is thought to have taken place in a water if the ratio is less than one. Neither of the samples taken had ratios less than one and it was therefore concluded that ion exchange was not an important hydrochemical process below the bog despite the presence of abundant clay in the sampled boreholes.

CHAPTER 5

REGIONAL HYDROGEOLOGY

5.1 Introduction:

This chapter discusses the construction and interpretation of the potentiometric surface map of the deposits which underlie and surround Raheenmore Bog. The map integrates hydraulic head information from a number of wells and boreholes with the results of other aspects of the hydrological investigation of the area already outlined in previous chapters.

5.2 Domestic Well Survey.

Four boreholes have been drilled by the G.S.I. on Raheenmore Bog between 1990 and 1992. No G.S.I. boreholes exist in the area immediately outside the reserve. However, a number of wells and boreholes are found in this area where they are used as domestic / farm water supplies. It was believed that these sources could be used to gain further insight into the regional hydrogeology of the Raheenmore area. A comprehensive well survey of all the holes around the bog was undertaken to achieve this aim.

All residences in the area immediately surrounding Raheenmore Bog were visited and a brief questionnaire survey concerning the house / farm water supply carried out. Permission was sought to measure the water levels in those houses which utilised groundwater and was granted in all cases. Unfortunately many of the supplies were inaccessible or were pumping thus giving a dynamic water level rather than a static value. In both these situations the data for these sources could not be used. Those sites where static water levels could be measured were levelled relative to Ordnance datum.

The results of the survey were combined with hydrochemical data, topographical data and G.S.I. borehole information. Only those domestic wells which had water levels believed not to be affected by pumping were used to construct the potentiomentric contours. It is believed that except for the time interval immediately after pumping had stopped the groundwater levels of the various sources were representative of the regional situation. The water levels in non pumping boreholes were dipped and then checked five minutes later to see if they had changed significantly. A hole in which a measurable change in water level was observed over this time period was disregarded.

Chapter 4 describes how hydrochemistry was used to determine those areas where groundwater may be upwelling into the marginal drains and those areas where the two systems are isolated.

The recharge mounds on the northern side of the bog are based largely on topographic data and have been entered, albeit questionably, due to the absence of data, to show the main recharge zones outside the bog.

It must be noted that in many areas the water-level data is either sparse or of poor quality. In short, the map is a rough approximation of the natural situation and is based mainly on poor data. The potentiometric surface contours are felt to be most accurate on the bog where G.S.I. water level data is used and the geological control of the data is best.

5.3 Results.

The potentiometric surface map for the inorganic deposits surrounding and beneath Raheenmore Bog is shown in Fig. 5.1. All groundwater sources in the area are shown on the map but only those with hydraulic head values beside them have been used to construct potentiometric surface contours.

5.4 Water Table Data for Raheenmore Bog.

No water table map exists for Raheenmore Bog although in most cases the water table is thought to be at or very close to the surface. A surface contour map of the bog is therefore thought to be a good reflection of the potentiometric surface in most areas of the bog except around the margins of the reserve where drainage had a significant impact.

5.5 Discussion of Potentiometric Surface Map.

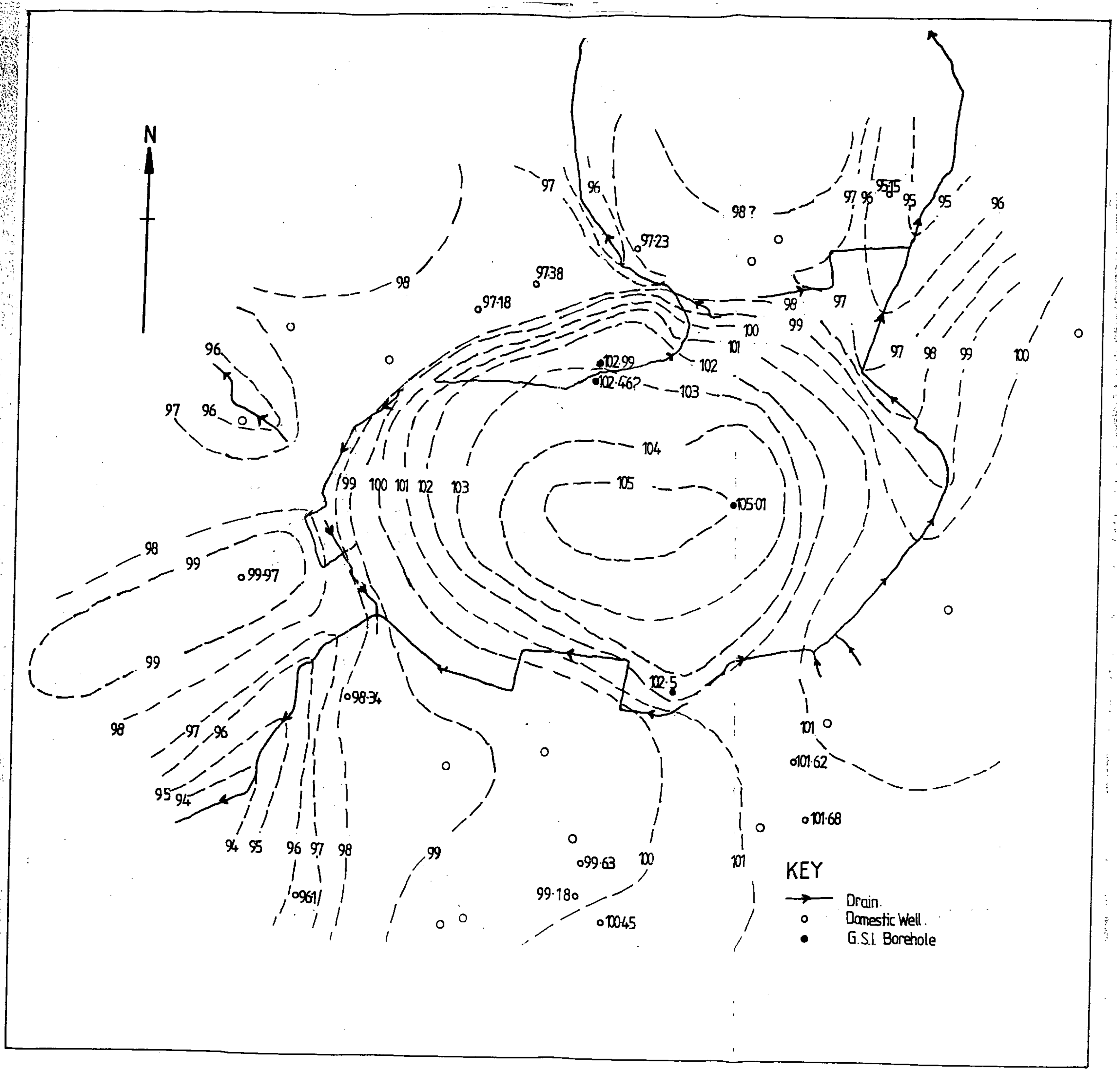
A number of interesting features are apparent from the potentiometric surface map of Raheenmore Bog from which a reasonable picture of the hydrogeology can be obtained. These are dealt with in point form below:

(1) Potentiometric contours show that all the streams draining the bog have regional groundwater upwelling into them at some point. This data is based largely on conductivity measurements obtained during the drain survey. It is possible that this information is incorrect and that the high conductivity values observed in the marginal drains are a consequence of substantial inflows of high conductivity water from drains in the area surrounding the bog.

(2) The highest topography in the area is on the south eastern side of the bog. A groundwater catchment divide between groundwater flowing to the south west and water flowing to the north is found here. The area is represented as a saddle dividing the two zones.

(3) The highest groundwater heads are those observed below the centre of the bog. Water levels in this area are substantially higher than those in the surrounding deposits. Most of the peat under the bog is underlain by low permeability clay which is thought to act as an aquitard separating the peat from the underlying till deposits. Water levels in the topographically higher areas surrounding the bog are lower than those below the bog. This may reflect a higher permeability in these deposits compared to those below the peat.

Fig. 5.1 : A Potentiometric Surface Map of the Inorganic Deposits Surrounding and Beneath Raheenmore Bog, Co. Offaly.



5.6 Conclusions

The high water levels beneath the peat can be interpreted as a consequence of limited recharge seeping through the clay into the underlying deposits. The recharge occurs, despite the low permeability of the clay, as a result of the one to four metre head difference which exists between the peat and the till. Downward seepage from the peat to the till thereby occurs, although the proportion of the total groundwater flow in the peat which flows through the clay remains indeterminate.

Many of the drains around the edge of the bog appear to have very little influence on the regional groundwater regime. The low permeabilities of the inorganic deposits below and immediately surrounding the bog hinder the discharge of groundwater to those drains along its margins which cut below the peat.