IRISH-DUTCH PEATLAND STUDY

GEOHYDROLOGY AND ECOLOGY

- *O. P. W. Wildlife Service, Dublin*
- *Geological Survey of Ireland, Dublin*
- *Department of Nature Conservation, Environmental Protection and Wildlife Management, The Hague*
- *National Forest Service, Utrecht*

The Hydrogeology of Clara and
Raheenmore Raised Bogs, Co. Offaly.

Preliminary Report of Work Undertaken
January 1990 to January 1991

By

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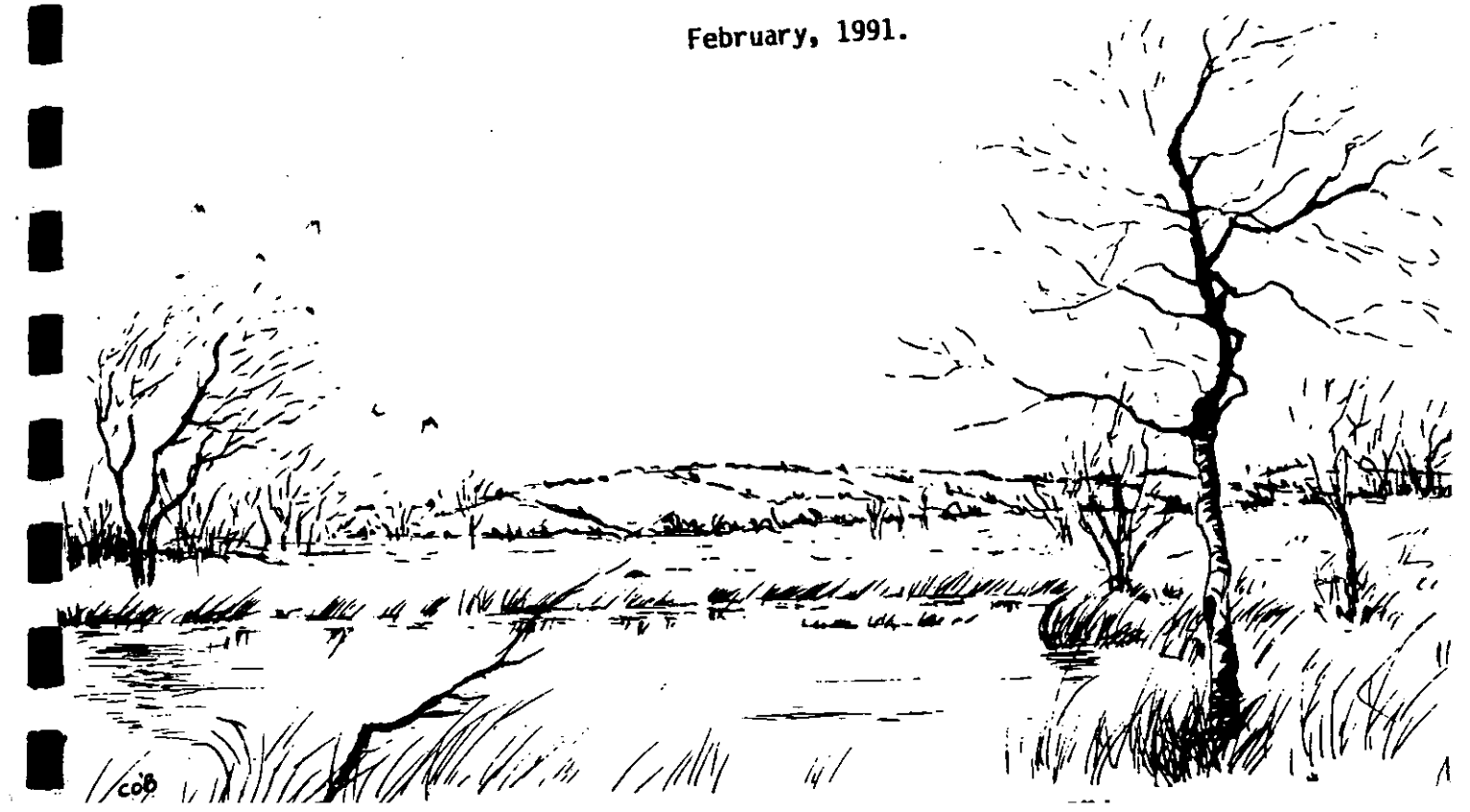
February, 1991.



Jan Streefkerk

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APPENDIX II

APPENDIX III

1 Report Layout.

The report is laid out in a number of sections:

Section 2 contains an introduction and an outline of the overall aims and objectives of the project.

Section 3 gives an overview of raised bog formation and hydrology.

Section 4 describes the project approach.

Section 5 contains a description of the bogs and their general hydrology.

Section 6 describes the pilot study on the north east margin of Clara.

Section 7 describes the drilling, piezometer and well screen installation which took place at both bogs during summer autumn 1990.

Section 8 describes the usefulness of hydrochemistry in helping to understand the hydrogeology of the areas. It also contains an analysis of hydrochemical data collected to date.

Section 9 contains an overview of the computer models which may be employed. It also describes the background theory to two dimensional modelling.

Section 10 describes the study at the old and new facebanks on Clara bog.

Section 11 describes the hydrological study at the intact lagg system on Raheenmore bog.
Section 12 describes the future pilot study in the north west of Clara bog.
Section 13 contains an outline of future work plans till the end of 1991.

2 Project Aims and Background.

2.1 Introduction.

Both Clara and Raheenmore bogs are areas of scientific interest (international and national respectively). They are both wildlife nature reserves and thus are protected by the Wildlife Service.

These bogs are a type that are considered to be extremely rare in western Europe. In fact, both these bogs are two of the few remaining representative raised bogs in Ireland and western Europe.

* The Dutch, much like the Irish, have cutaway ~~most of~~ their raised bogs. The Irish and Dutch government Wildlife Departments have formulated a strategy to conserve both bogs by forming a joint Dutch Irish study group to examine the complex functioning of these two delicate ecosystems and to make recommendations as to the ways they could be managed. A multidisciplinary approach was adopted and three study areas were identified: Hydrology/Hydrogeology, Geology and Botany.

Peat contains in excess of 95% water and therefore the hydrological aspects of the bogs and how they relate to surrounding areas must be understood. Anthropogenic impacts such as drainage and peat cutting have a serious effect on the bog hydrological system (Brocks, K.N. 1988) and therefore these impacts must be quantified in order to effectively formulate useful management strategies.

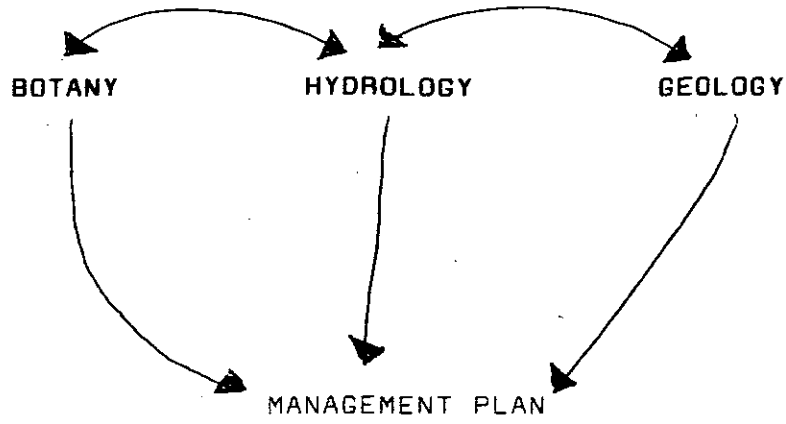
Hydrologists tend to ignore bog systems mainly due to their inaccessability (for equipment etc.) and thus very few detailed studies on raised bog hydrodynamics have been completed thus far (Ingram 1983).

With this in mind it is obvious that the bog hydrology and its relationship with the regional system is the key to formulating suitable management strategies for the bogs. The major study disciplines are interrelated and each feeds into the others. Figure 1 decribes these interrelationships.

It is hoped that the information gathered from the study may be usefully applied to other bog systems in Ireland. Also the results will be used by the Dutch authorities to help regenerate their raised bog systems.

2.2 Aims and Objectives

The overall aim is to develop suitable management programmes for the conservation of the bogs. ~~The objectives of the research are~~: ~~To~~ Investigate the various elements of the water balance;



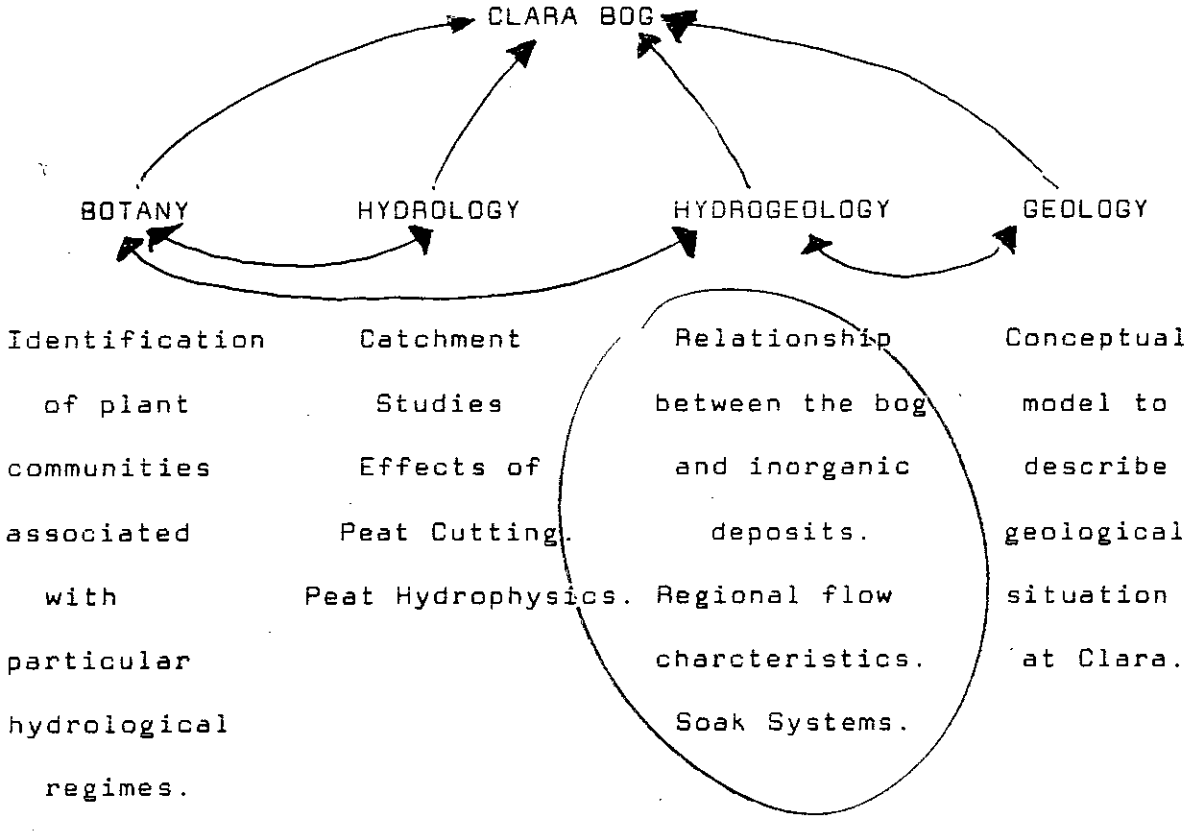


Fig 1 : This diagram decribes the relations between the different disciplines within the project.

why ??

2. To understand the mechanisms and parameters that control the hydrodynamics of the two raised bogs.

At Clara bog the specific objectives of the author's project are as follows:

why ??

1. To understand the relationship both hydrological and hydrogeological, between the peat and the esker deposits on the north of the bog.
2. To descibe the general peat hydrodynamics and to describe the effects of peripheral drainage and peat cutting on the system.
3. To understand the hydrological / hydrogeological nature of the soak systems.
4. To describe the regional hydrology/hydrogeology of the area and explain how the bog contributes to this.

At Raheenmore bog the aims are, at present, less well defined. The hydrology of a relatively intact lagg system is being examined. The effects of deep peripheral drainage and regional aspects may be examined, however, the amount of information pertaining to the latter is small.

At both bogs water balance measurements are being taken by other workers and this information will be available for the final report synthesis.

It is envisaged that both two dimensional and three dimensional computer modelling will be used to describe the systems and thus be a useful predictive aid.

3 Raised Bog Formation and Water Balance.

3.1 Formation

Raised bog formation is well documented in the literature (Streefkerk and Casparie 1989, Bellamy 1986, Mitchell 1975, Hobbs 1986, Gore 1974, Moore and Bellamy 1974).

Peat develops through the accumulation of dead plant remains which do not decompose completely. The conditions for peat development are the presence of a sufficient amount of decaying plant material and a low microbiological activity. The latter is usually a result of very wet conditions and a shortage of oxygen. The acidity of peat bogs also contributes to the depressed microbial activities.

Hammond (1979) used two definitions to describe peatlands:

1. It is land where the depth of organic soil material, excluding the plant layer must be at least 45cm on undrained land and 30cm on drained land.
2. They are organic soil materials that are saturated with water for prolonged periods , or are artificially drained, and have 30% or more organic matter if the mineral fraction is 50% or more

clay, or 20% or more organic matter if the mineral fraction has no clay.

A simplified descripion of raised bog formation is shown in fig.2. Following the last glaciation (8000 b.p.) the existing depressions and basins were filled with glacial meltwater.The surface channnels resulting from this meltwater brought much fine material(silt & clay) which was deposited in these lake basins as lacustrine clay etc.. At first, beds of reeds developed and as their remains accumulated they were succeeded by a greater diversity of minerotrophic plants including tree and shrub species . As this process of terrestrialization proceeded the lake continued to shrink as the fen extended. The fen continued to grow and the fen peat thickened. Because of this the plants on the surface found it increasingly difficult to maintain their necessary supply of inorganic material from the underlying mineral soil. Therefore plants that could thrive on minimal amounts of nutrients (ombrotropic species), colonized the surface of the peat. The main coloniser is these ombrotrophic conditions are Sphagnum species.

The raised bog continues to develop in a manner shown in fig.3 with alternating development of pools and hummocks resulting in the domed topography typical of raised bogs. The bog continues to grow only if the rate of accumulation of plant debris exceeds the rate of decay.

3.2 The water balance of raised bogs.

FIGURE 2

Stages in the development of a raised bog from an open lake.

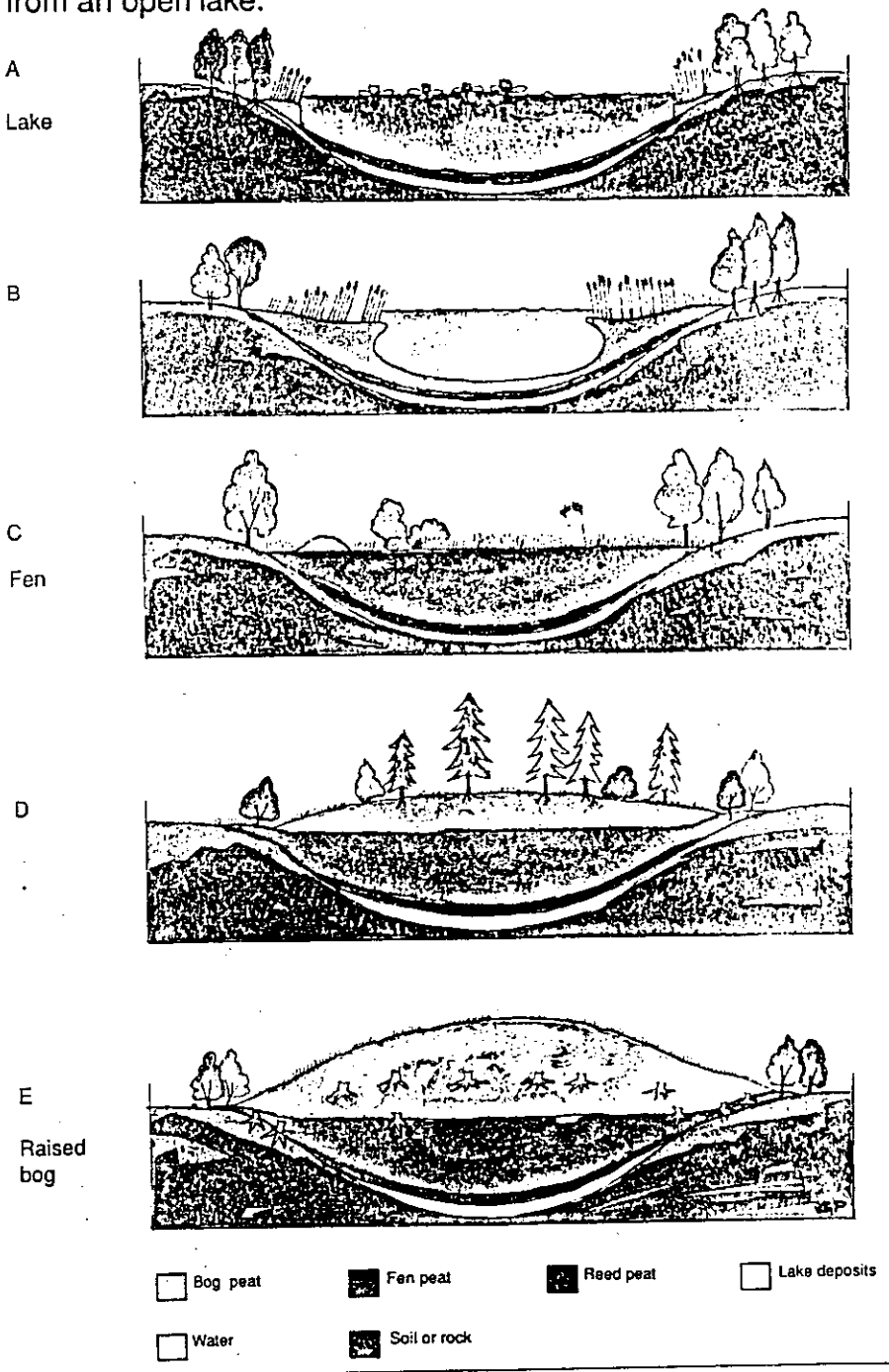
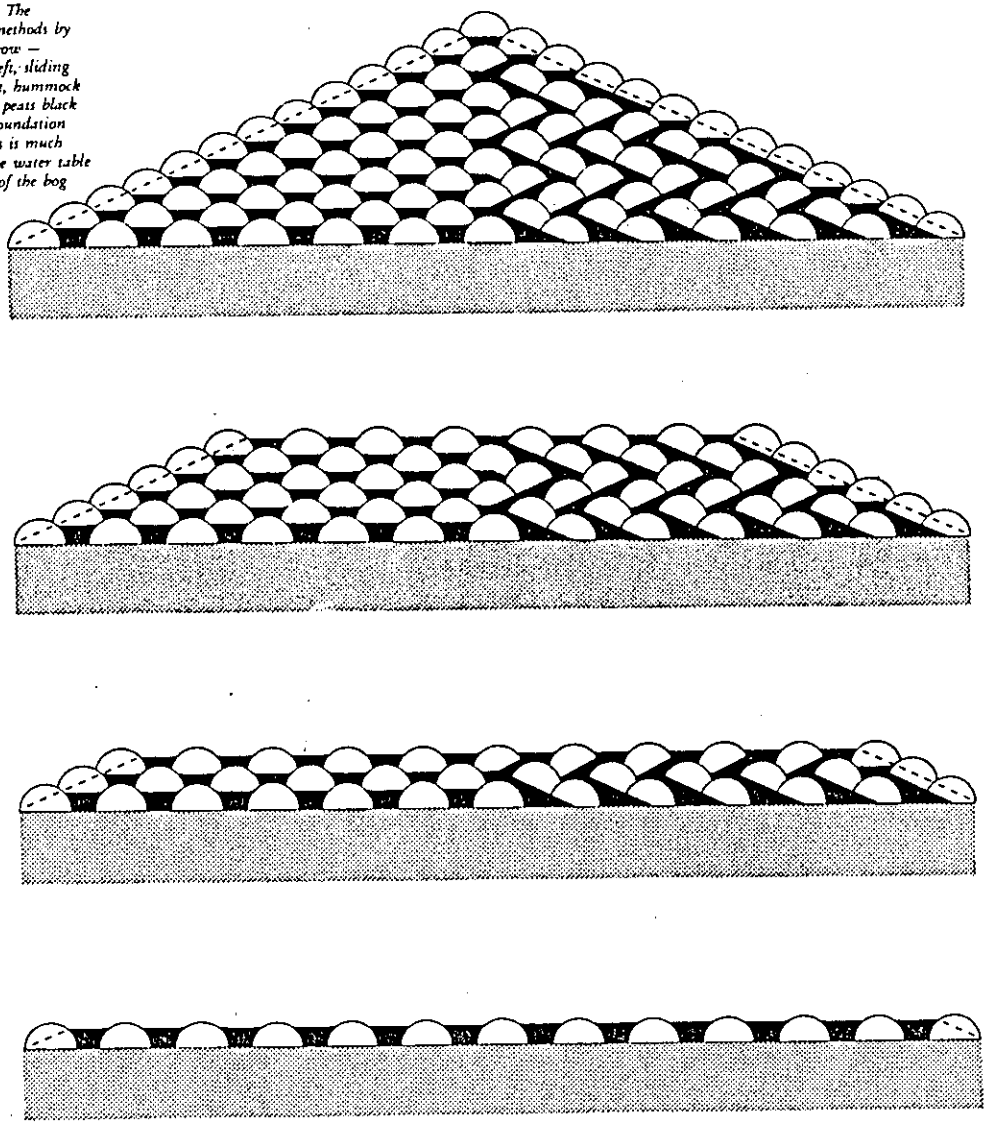


FIGURE 3

How does a raised bog grow? The diagram shows two possible methods by which the peat domes may grow — regular regeneration on the left, sliding or zigzag growth on the right, hummock peats white, hollow and pool peats black and fen and poor fen peats foundation stippled. NB The vertical axis is much exaggerated and in nature the water table (dotted line) and the surface of the bog form an arc, not a pyramid.



DAVID GREENE

The following overview of bog hydrology is taken from an excellant review by Ingram (1983).

An expression of the water balance for raised bog systems can be expressed as:

$$P + U_i + V_i + Q_i + C_i - U_e - V_e - Q_e - C_e - E - W - n = 0$$

where P = precipiation; U = seepage; V = pipe flow; Q = diffuse surface flow; C = open channel flow; W = change in storage; E = evapotranspiration; and n = error.

The first five terms are influxes (recharge) while the next five are effluxes (discharge) distinguished by by the subscripts i and e ,respectively.

3.2.1 Recharge to Raised Bogs.

Two types of recharge are important. Telluric supply (U + Q + C + V) derived from the surrounding area is probably of no great importance to raised bogs because they tend to be isolated from surrounding telluric sources. However, matric forces are capable of raising drainage water (derived from the mineral surroundings) at the bog edge from the eutrophic mire margin onto the mire expanse. Most raised bogs are recharged from precipitation.

3.2.2 Evaporation and Evapotranspiration

A large proportion of the water recharge which mires receive is subsequently discharged by evaporation. The rates of evapotranspiration depend on the vegetation. Ingram (1983) suggests that it is probable that the actual evapotranspiration from bogs is approximately equal to potential evapotranspiration.

3.2.3 Water Storage.

The part of the peat profile in which most storage changes occur contains a living growing layer of plants and a dead layer undergoing diagenesis by humification. With increasing depth, anaerobic conditions prevail and the process of diagenesis becomes imperceptively slow. The anerobic conditions are associated with permanent waterlogging and consequently a constant water content. The upper layer which is periodically aerated is known as the acrotelm. The lower anerobic layer is known as the catotelm.

Most of the water in raised bogs is stored in the catotelm. It seems probable that the water content of the catotelm remains constant over long periods of time. Most of the changes in water storage in bogs accompany water table movements in the acrotelm. The storage changes accompanying the movement of water tables generally amount to no more than 3 - 10% by volume. The thinness of the acrotelm to which the water table movement is confined implies that most bogs have a limited capacity either to store or to release water in the short term.

3.2.4 Seepage.(see section 6.2.3)

The mass transport of liquid through porous media is known as seepage or filtration flow.

The site of most rapid seepage is the acrotelm. Hydraulic conductivity values as high as 2160 m / day have been recorded. Seepage in the catotelm is small and may be in the order 10^{-2} to 10^{-5} m/day.

3.2.5 Overland Flow

The mass movement of water over the land surface without defined channels is termed overland flow or sheet flow. Little quantitative work on overland flow on bogs has been carried out. Saturation of the profile or slow infiltration, which causes ponded water to appear at many points on the surface, will lead to overland flow under intense snow melt or precipitation , when the water in neighbouring hollows overflows to become a continuous network or sheet moving downslope towards the nearest stream.

3.2.6 Open Channel Flow

Open channel flow is probably the greatest source of discharge from the bog system. During the winter period flows are greatest unless unless the bog is snowbound. Hydrographs from raised and blanket bogs usually show rapid responses to precipitation in summer time. The concentration time during which open channel discharge builds up to its peak value is often very short. The most typical feature of summer hydrographs is the tendency for discharge to fall to low values or to cease completely after short dry periods.

4. Project Approach

4.1 Clara Bog

The primary aim of the study is to investigate both regional and local aspects of the hydrodynamics of the bog and surrounding

area. In order to achieve this a north south transect across the bog encompassing the Silver and Brosna rivers (discharge zones) was chosen. Figure A shows an initial conceptual model of the flow mechanisms along the transect based on the available data. Both regional and local scales have been identified. On the large (regional) scale it is envisaged that an estimate of the water balance on the bog may be calculated. This should aid in the conceptualisation of flow mechanisms on and around the bog. It will allow the identification of the relative importance of the different inputs and outputs to the system.

On a smaller (local) scale a number of objectives are identifiable :

1. to investigate the general peat hydrodynamics,
2. to investigate the interface between the esker and peat system and to identify the effects of drainage at the interface,
3. to investigate the origin of the Lough Roe soak system,
4. to investigate the effects of peat cutting at the south of the bog.

Figure B shows the data network as will exist from June 1991. Piezometry, pumping tests, well/stream surveys, hydrochemistry and permeability measurements (on, off and beneath the bog) will allow a detailed equipotential map across the transect to be constructed.

Both local and regional scale situations will be modelled numerically to describe the present situation and the effects of

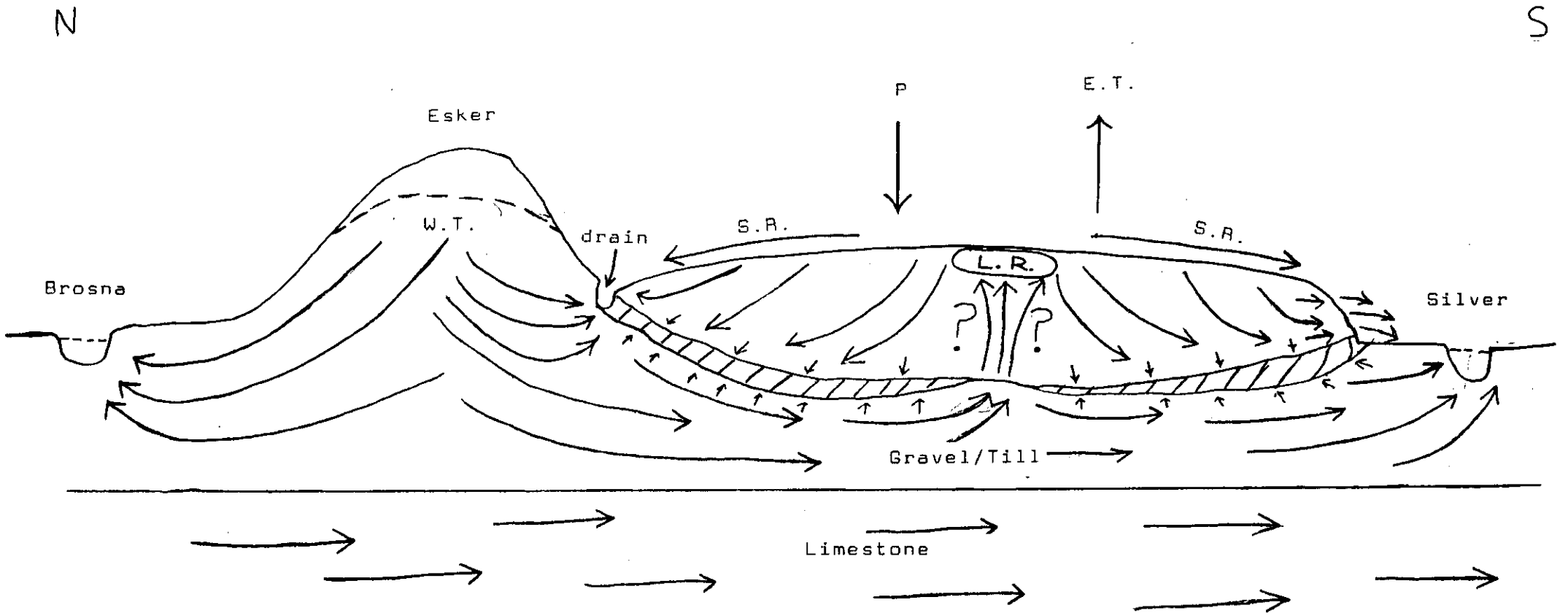


Figure A : This diagram shows the initial conceptual model of the flow mechanisms along a north south transect across Clara Bog.

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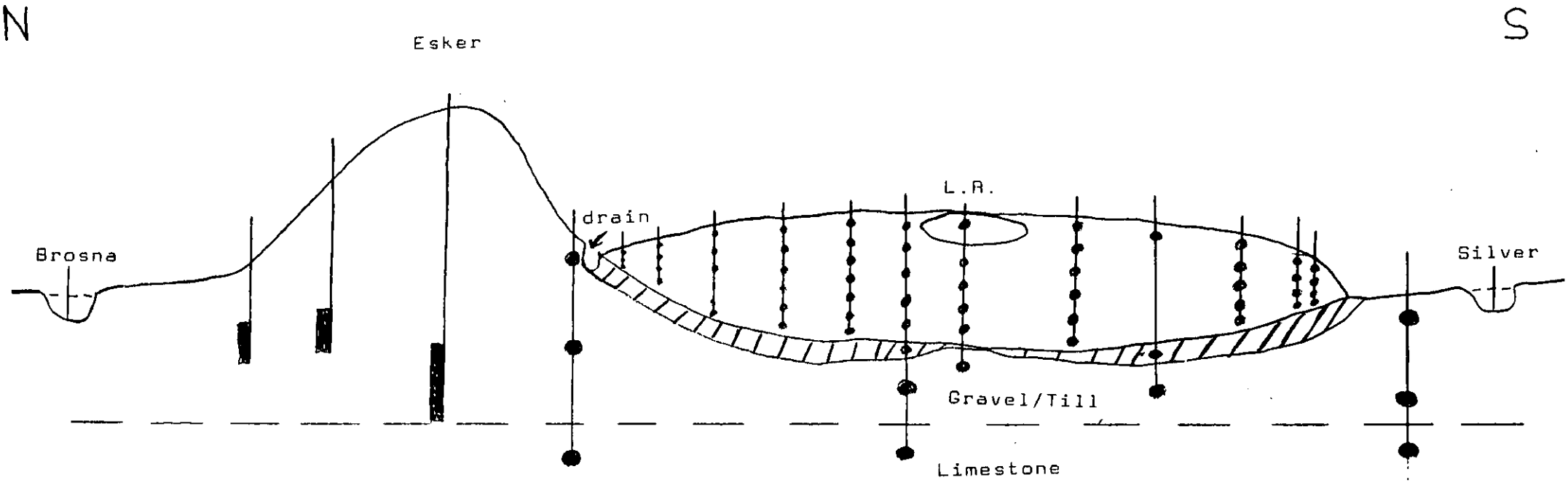


Figure B : This diagram shows the data network along the North-South transect after June 1991. (many of these installations have been completed).

Not to Scale.

future management strategies on the system (e.g. blocking drains, raising water levels etc. - see section).

4.2 Raheenmore Bog.

At Raheenmore bog the hydrology of a realatively intact lagg zone is being investigated.(section 11). This will provide good information on the hydrological functioning of intact lagg. It is currently less clear what form other detailed studies and regional aspects will take at Raheenmore bog. It is likely that a similar approach as explained in secton 4.1 will be taken.

5 Description of bogs under investigation.

5.1 Clara Bog

Clara bog with an area of 665 ha is one of the largest remaining midland raised bogs. It is the only relatively intact raised bog with an intact soak system in Ireland. A soak system is an area of vegetation which is fen like in nature and not characteristic of ombrotrophic conditions. The presence of fen (minerotrophic) vegetation infers an increased availability of nutrients in the area. On Clara two soaks exist, one of which is associated with an open body of water(the western soak). The other, Lough Roe was previously open water but has infilled with plant material.

Clara bog is situated in a depression between an esker complex to the north and glacial till deposits to the south. A quaternary geolgy map has been compiled by van Tatenhove (1990)(fig 4.). The glacial tills to the south are texturally variable ranging from loamy to gravelly till/gravel. The esker sands and gravels are well sorted. At the margins there are greater proportions of finer materials reflecting the less energetic glacial meltwater environment. The bedrock geology is Wulsortian limestone.

5.1.1 Anthropogenic Impacts at Clara.

Prior to acquisition by the Wildlife Service Clara Bog was in the possession of Bord na Mona. It was their intention to develop the bog for economic purposes and so a dense arrangement (20m spacing) of drains were ploughed prior to mining in the east part

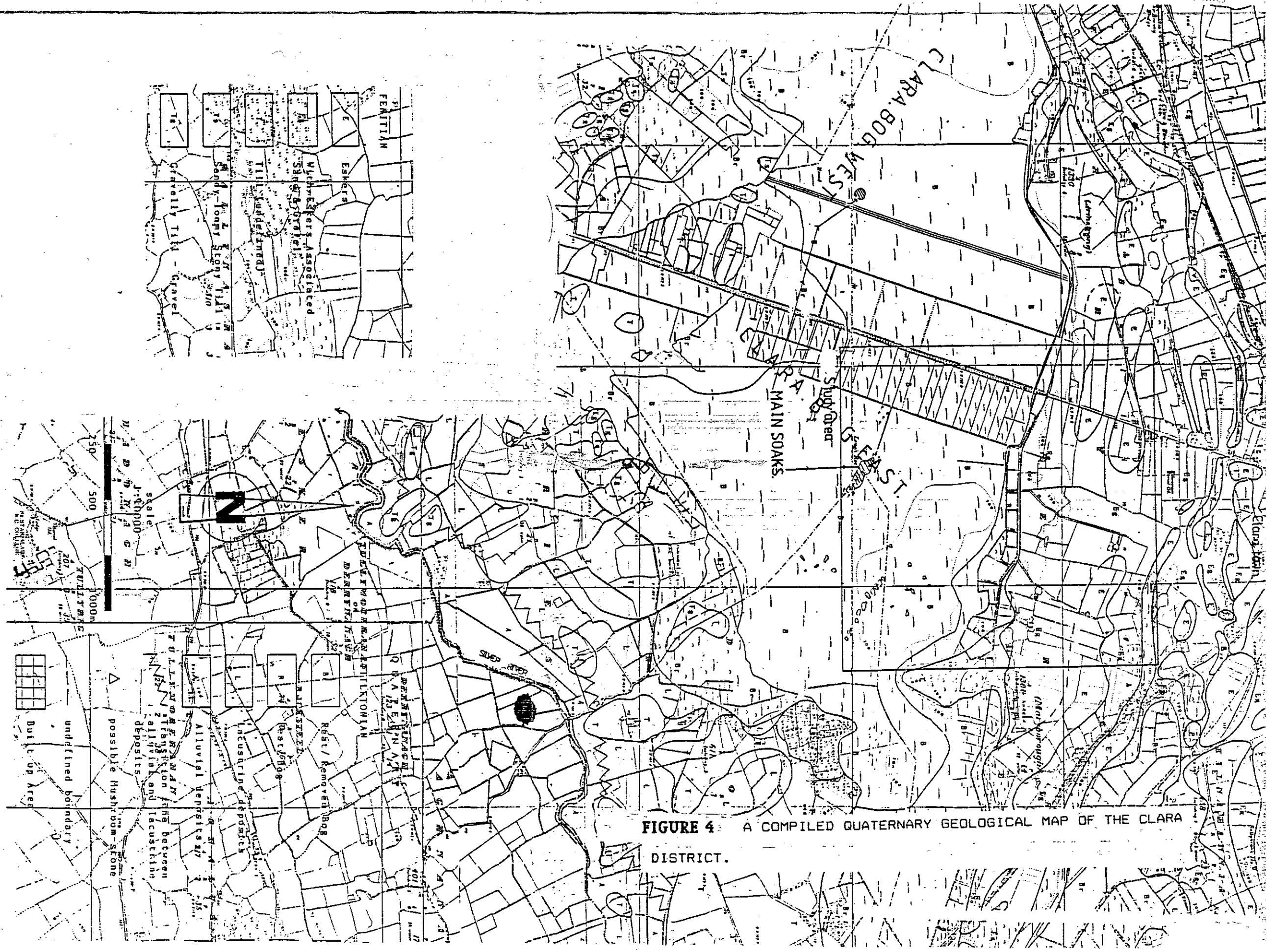


FIGURE 4 A COMPILED QUATERNARY GEOLOGICAL MAP OF THE CLARA DISTRICT.

of the bog.(fig.5). These drains are generally less than 35 cm deep.

The bog has been and is currently mined by individuals for fuel.In particular, the southern end is damaged by periodic cutting. Much of the original bog area has been cut in previous times and this land on the periphery of the bog is used for agricultural purposes. Consequently the periphery of a large part of the bog is surrounded by a drain.

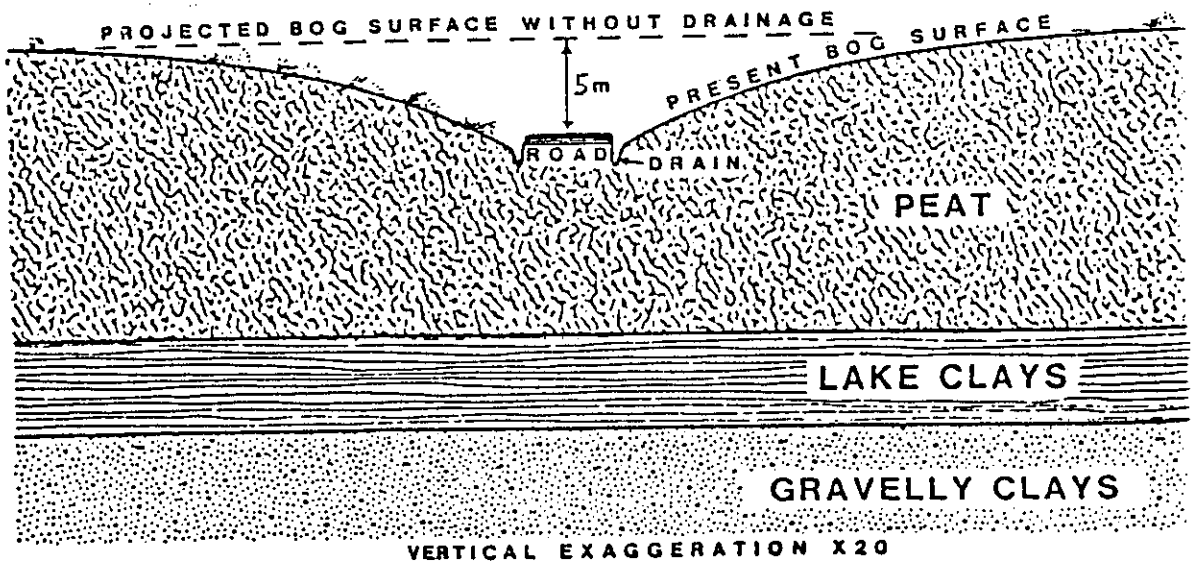
Channelization of rivers in the area may also have indirect effects on the hydrology of the bog. Afforestation of cutover bog to the south east may also have effects on the bog hydrology. Another important consideration is the hydrological effect of the road which bisects the bog. There is a five meter elevational difference between the road and Lough Roe. (see overleaf). Drains on either side of the road collect large quantities of surface run-off from the bog surface.

5.1.2 General Hydrology

Well and stream surveys were initiated around Clara to get an impression of the general hydrology and hydrogeology of the area.

Clara bog is situated between two rivers : the Brosna river to the north and the Silver river to the south.

As mentioned previously drainage and outflow from peat banks is substantial. Fig 5 shows the major drainage channels on and surrounding Clara bog. The major discharge stream flows south east to the Silver river.



East-west cross section at car park showing subsidence due to draina

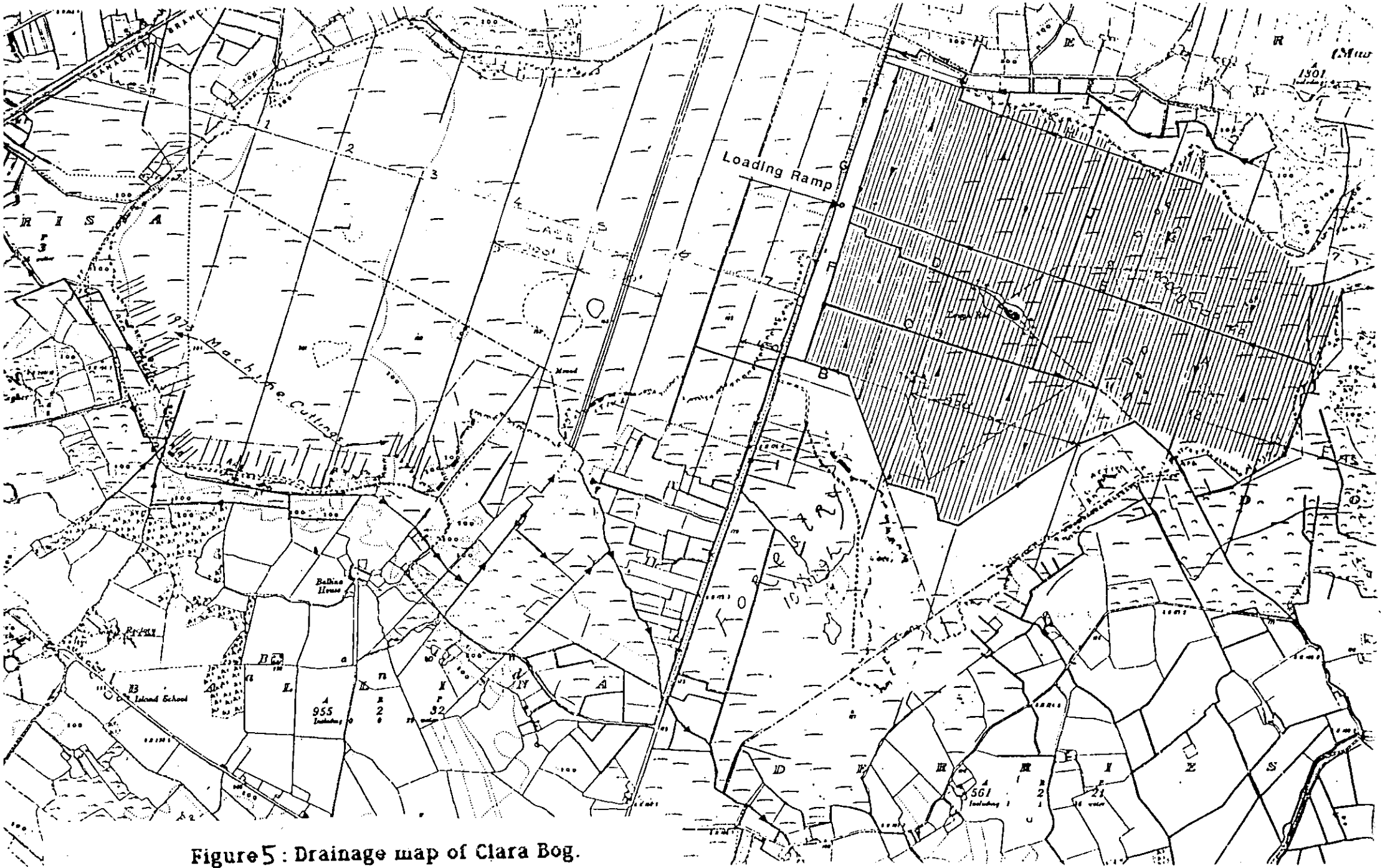
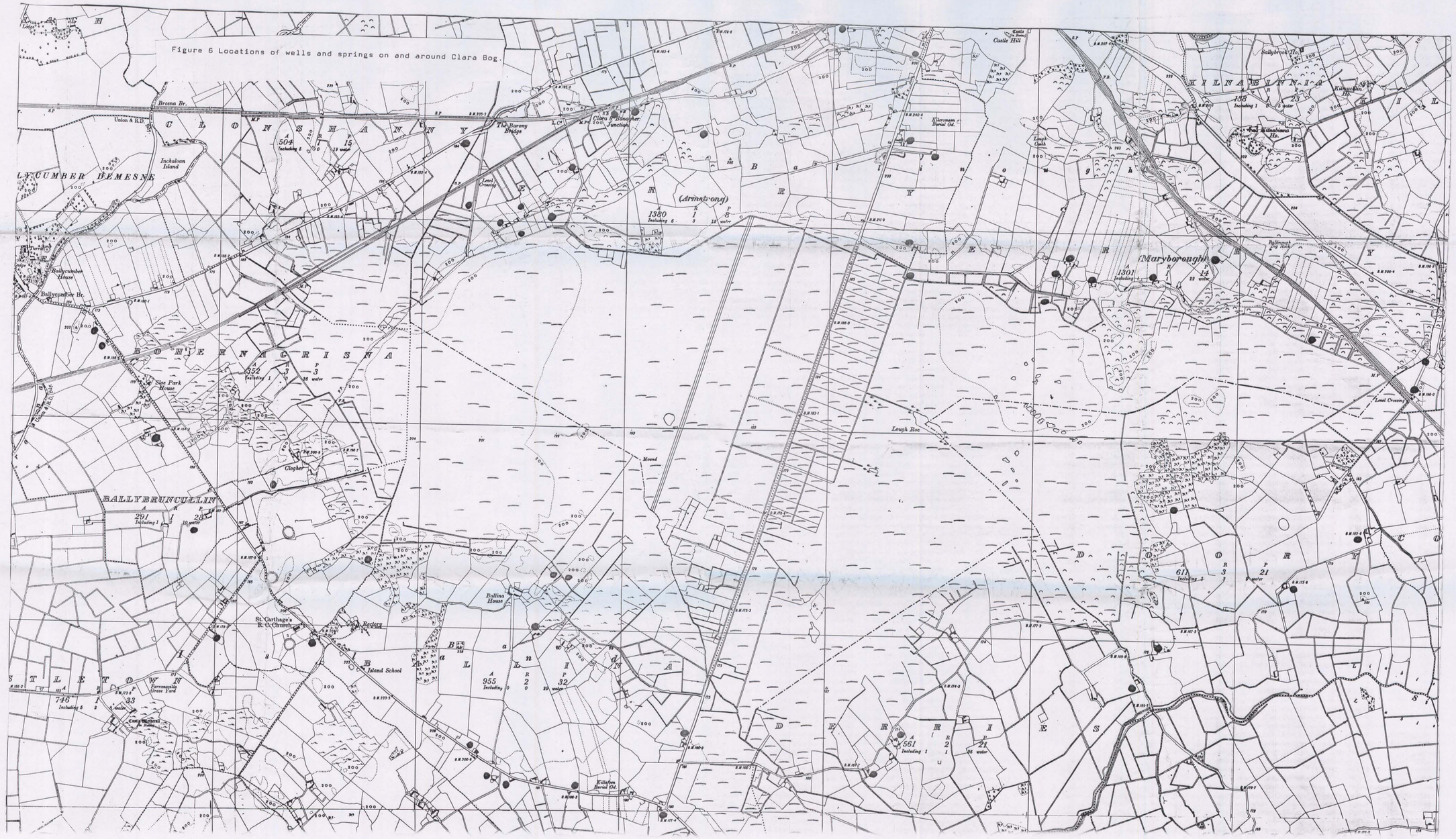


Figure 5 : Drainage map of Clara Bog.

Figure 6 Locations of wells and springs on and around Clara Bog.



A well survey was carried out around Clara. Thirty five wells were identified in a 1.5 km radius (fig.6). The majority were dug wells. Eight springs in the area were identified . Little geological information was available on the wells and many are no longer in use due to the emergence of local authority water schemes. Water levels in these wells are being monitored twice yearly (since Jan. 1991).

5.2 Raheenmore Bog

Raheenmore is a raised bog 213 ha in extent( ). It is one of the best examples of a raised bog in a basin situation. There are well developed hummocks and hollows and the depth of peat is up to 15m in areas.(Source : Bord na Mona)
The bog is situated in a deep depression and is surrounded by glacial till deposits . (see section 7).

5.2.1 Anthropogenic Impacts at Raheenmore Bog.
The major impact is a deep peripheral drain (approx. 3 meters deep). Old drainage systems exist on the bog surface. However these drains have revegetated and probably do not constitute a major impact on the overall bog hydrology.

5.2.2 General Hydrology.
Eighteen wells were identified in the area. As with Clara the wells were mainly dug and three springs were noted. There

are three outlets from the bog(fig. 7). One of these at Tinkers Bridge is currently being guaged with a rectangular plate weir.

6 Hydrogeological Pilot Study at Clara Bog East.

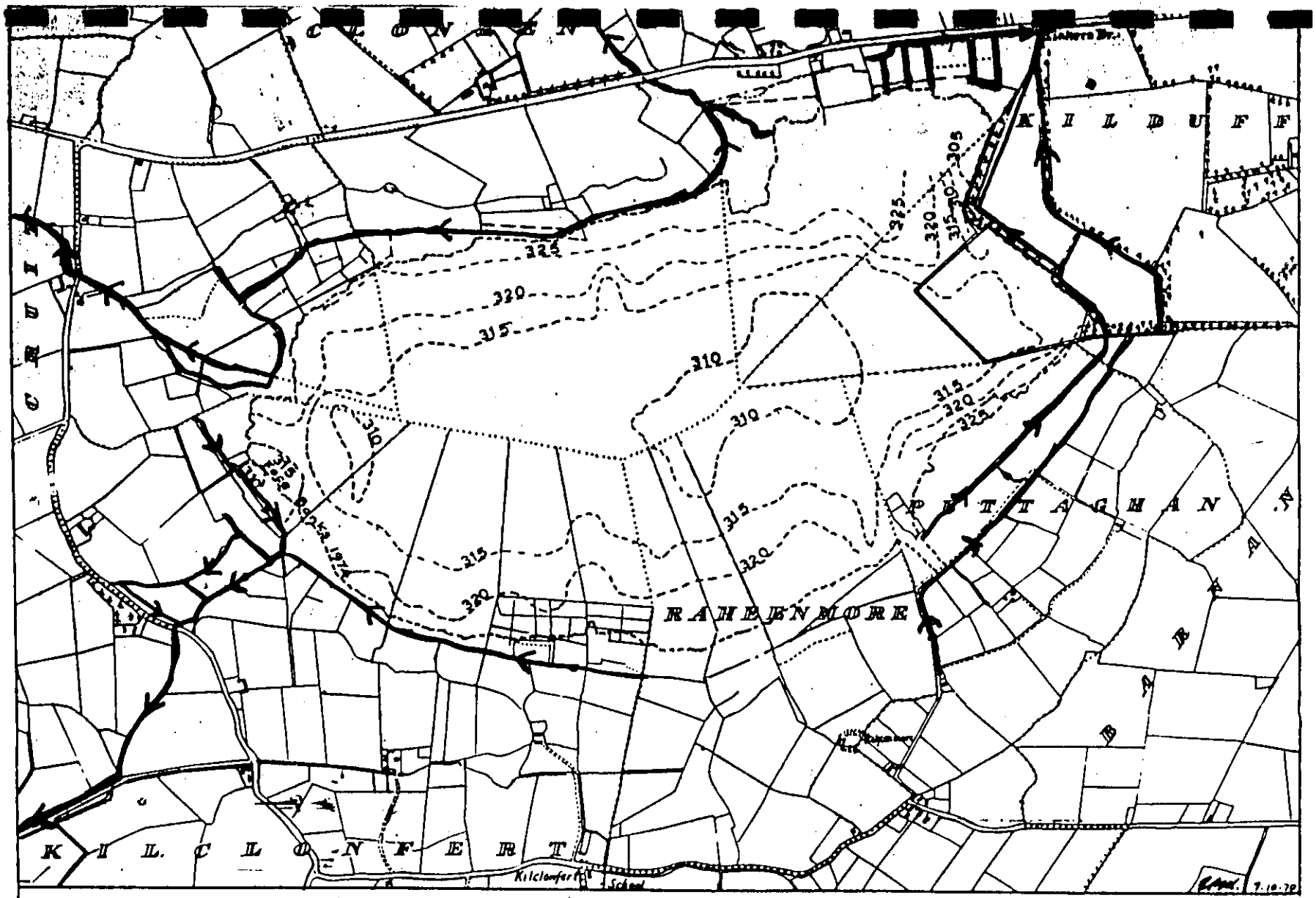
An initial pilot study began on the north east margin of Clara Bog in summer 1990. This area will be referred to as Clara East for the remainder of the report.

The primary aims of this project are :

1. to investigate the peat hydrodynamics,
2. to investigate the likely origin of the soak system,Lough Roe,
3. to investigate the interface between the esker and peat.
4. to describe the functioning of this area with the aid of numerical computer modelling.(see section 9).

6.1 The study area.

The study area is a 1.0 x 1.5 km area in the north east of Clara bog.(fig.8). The area encompasses the Lough Roe soak. A Quaternary geological map of the area has been produced by Flynn (1990) (fig.9). One can see the northern section of the area is dominated by eskers sands and gravels. To the south the peat bog dominates. At the interface there is cutaway peat and a 1 m deep drain. A cross section through the study area (fig.10) by Flynn (1990) describes the geological situation in the area.This was compiled from both geological and geophysical surveys carried out in the area in summer 1990. The bog deposit is underlain by a lacustrine clay deposit.



DERRYGREENAGH ADDITIONAL.
RAHEENMORE BOG.

Figure 7 : Drainage map of Raheenmore Bog.

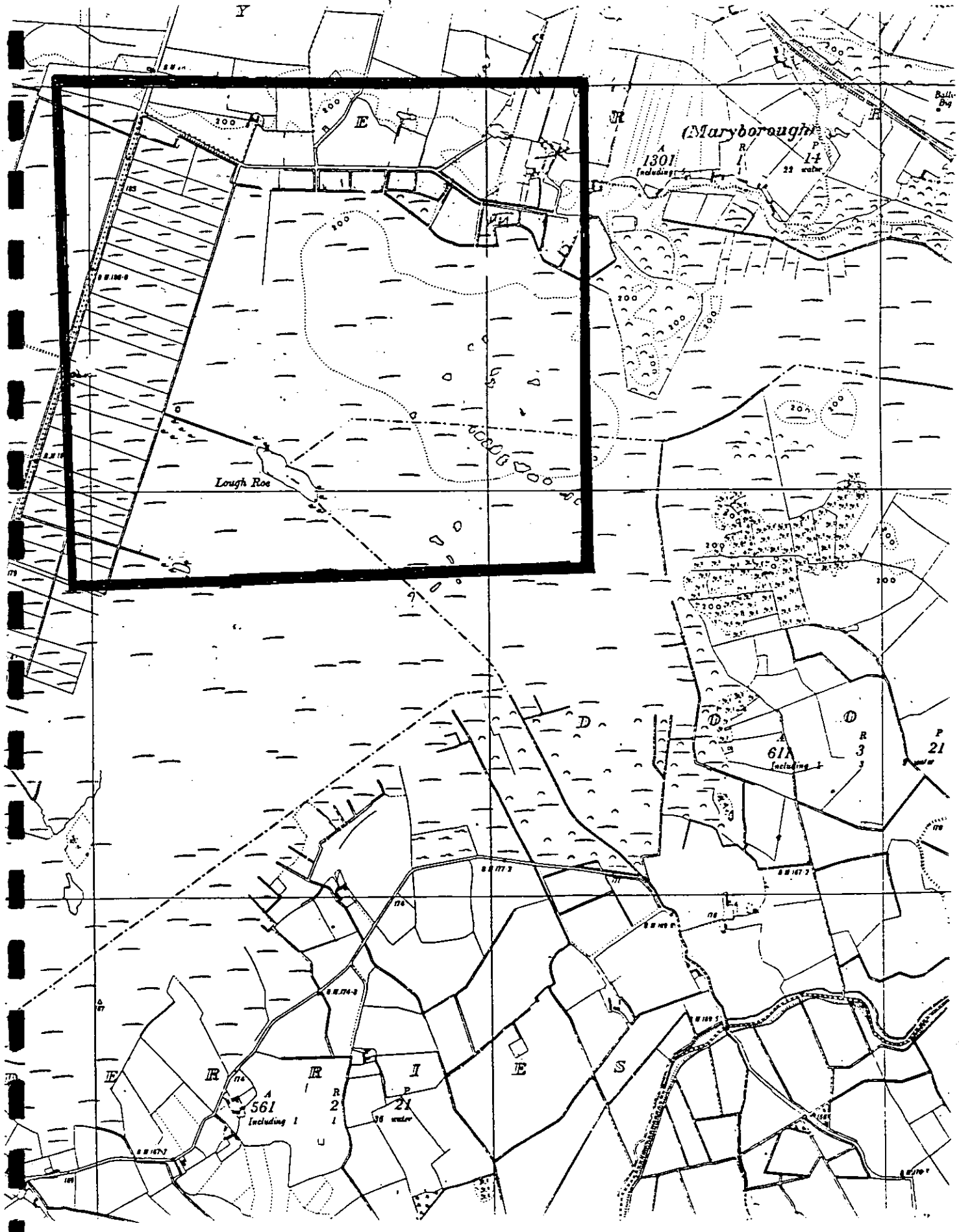


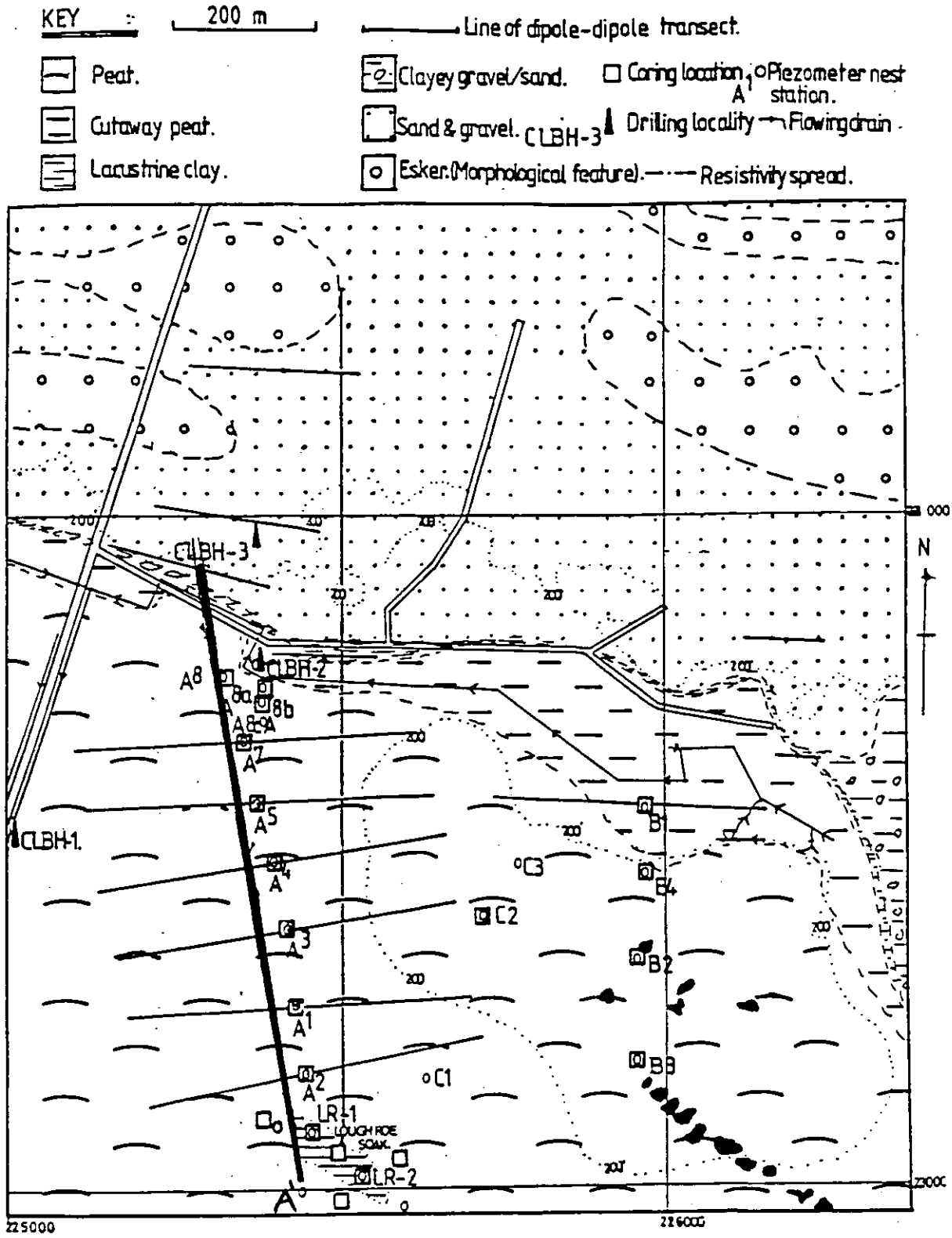
FIGURE 8

The study area at the north east margin of Clara Bog (Clara East).

FIGURE 9

A GEOLOGICAL MAP OF CLARA BOG AND ADJACENT ESKER STUDY AREA.

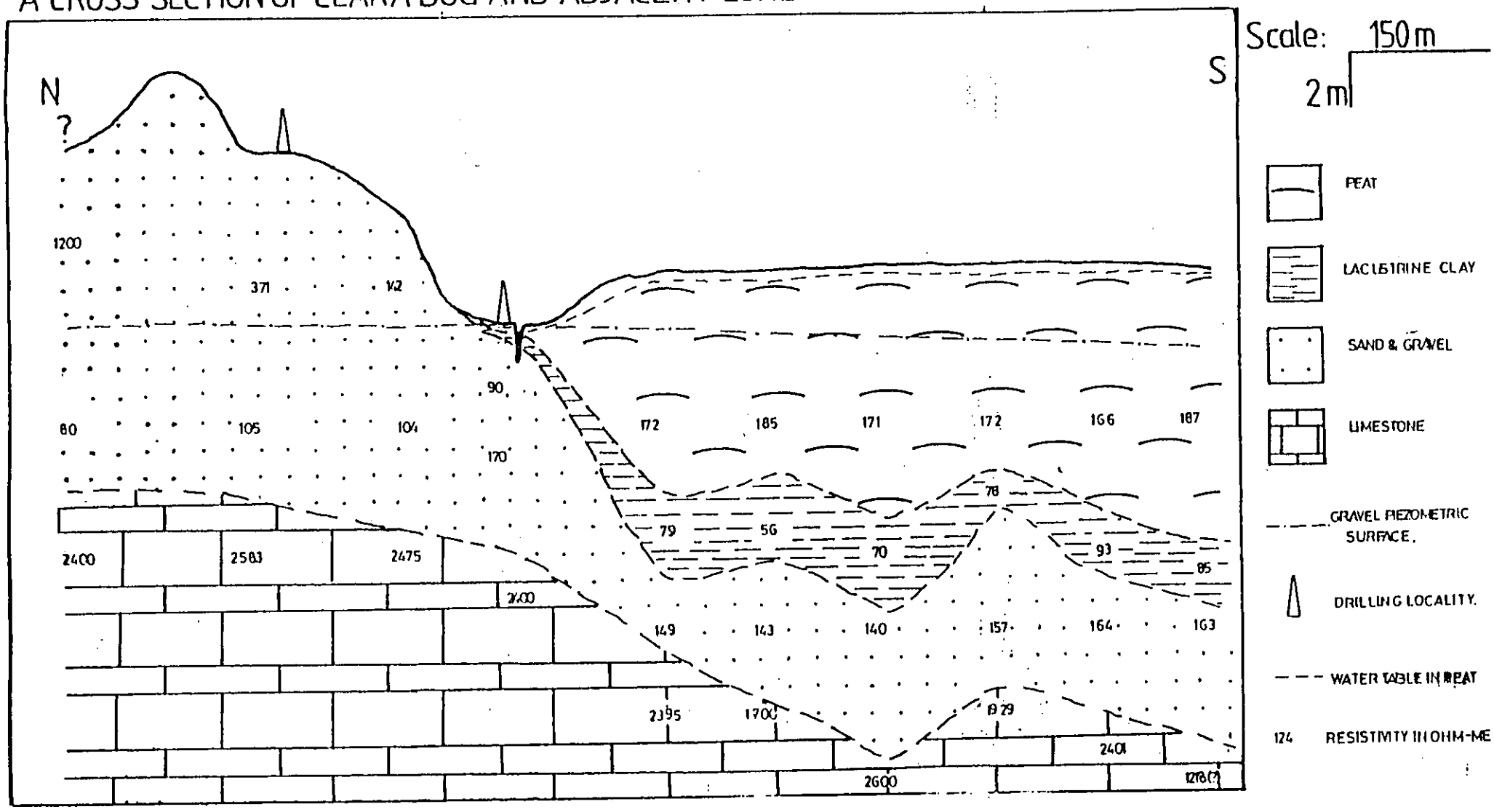
(WITH ADDITIONAL GEOPHYSICAL AND HYDROLOGICAL DATA).



AFTER FLYNN 1990.

FIGURE 10

A CROSS SECTION OF CLARA BOG AND ADJACENT ESKER



SECTION COMPILED FROM BOREHOLE & OFFSET WENNER GEOPHYSICAL DATA.

AFTER FLYNN 1990.

Surface Hydrology

One main perennial drain exists at the interface between the peat and mineral deposits.(see fig.9). This drain is fed by a number of smaller channels which would operate only in the wetter months. The main drain discharges to a larger channel whichs runs along the bog road.

6.2 Methodology

To describe the hydrogeology of the area under investigation a number of methods are being employed which include:

1. coring of the peat ,
2. drilling in the mineral deposits (see section 7 also),
3. permeability tests in the peat and pump tests in the mineral deposits,
4. piezometry, to examine the hydraulic potentials in both the peat layers and the mineral deposits,
5. hydrochemistry (see section 8 also).

Two holes were drilled on the eskers within the study area. Fig. 9 illustrates the locations of these holes . One was at the base of the esker deposit adajacent to the drain and the other was situated on the esker. Section 7 describes the drilling of these holes and figs.21 & 22 show the lithological sequence and the piezometer detail.

On the bog the peat was cored with a Hiller Borer. This allows samples of 50 cm length to be collected. This coring was carried out on transects across the peat as shown in fig.9. The samples

are classified based on their degree of humification which is equivalent to the degree of decomposition of the peat. The degree of humification is quantified using the von Post humification index (von Post & Granlund 1926). The index can be seen in Appendix I. The results of these corings along the transect A - A is shown in fig.10/2.

As may be seen from the diagram the degree of humification generally increases with depth. Close to the peat/clay interface the peat was woody and fibrous . This indicates the presence of fen peat which initially comprises wetlands prior to raised bog development.(Mitchell,1975).

In order to assess the hydrogeology of the peat piezometric head data were required. To collect these data piezometers were installed in the peat at different locations in the study area. These piezometers consisted of 25 mm o.d. PVC tubing with holes at the base for 15 cm . The open area is covered in geotextile. Figure 11 illustrates the construction of the piezometer.

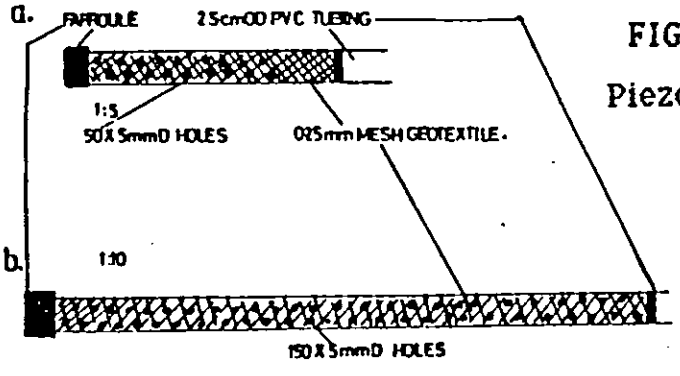
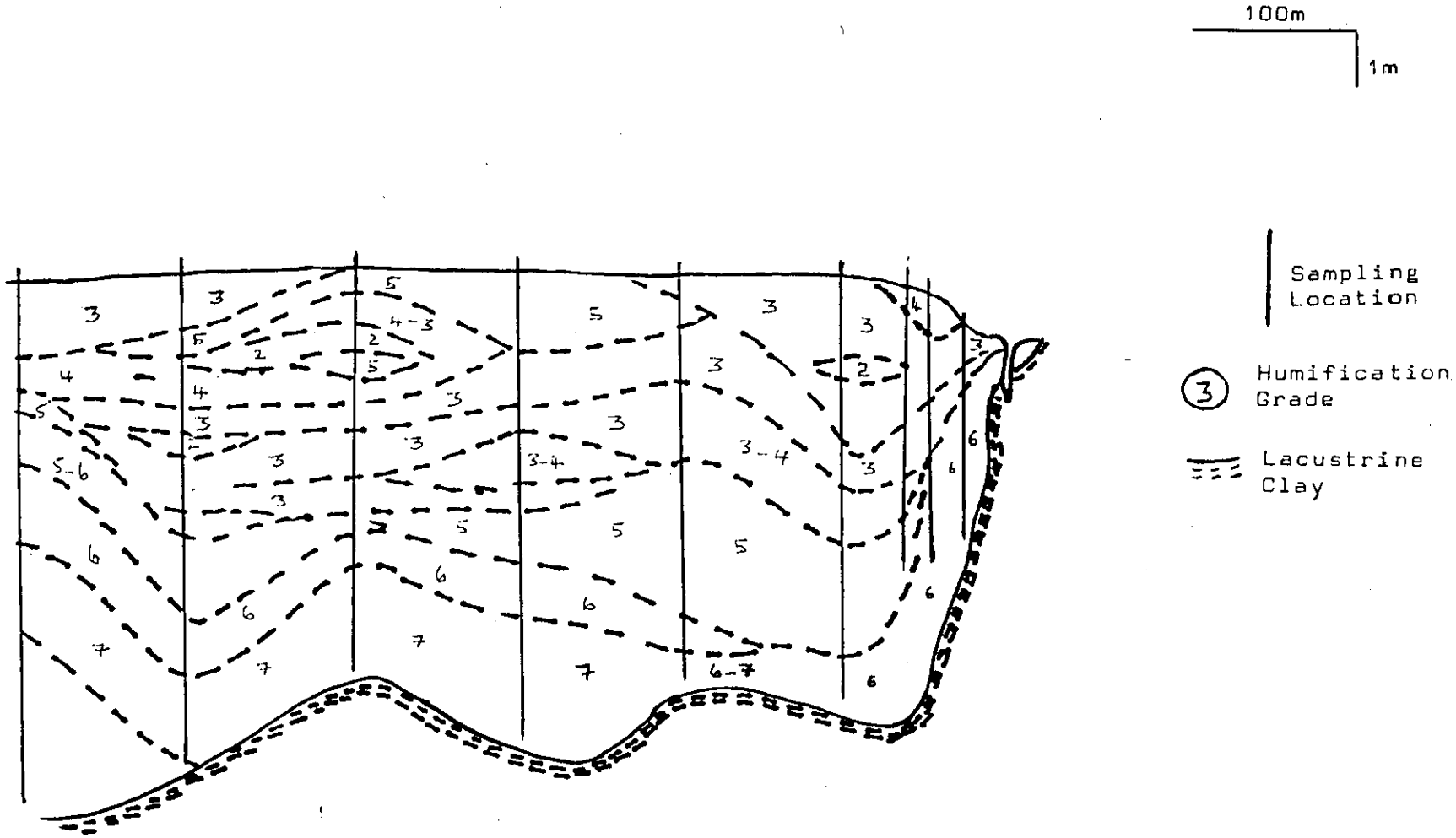


FIGURE 11
Piezometer Detail

Water table or phreatic tubes were 1 m long. Initially piezometers were installed in three transects with two stations placed in Lough Roe. Piezometers were installed at depths of 2,

Figure 10/2 A profile of peat humification along transect A - A.



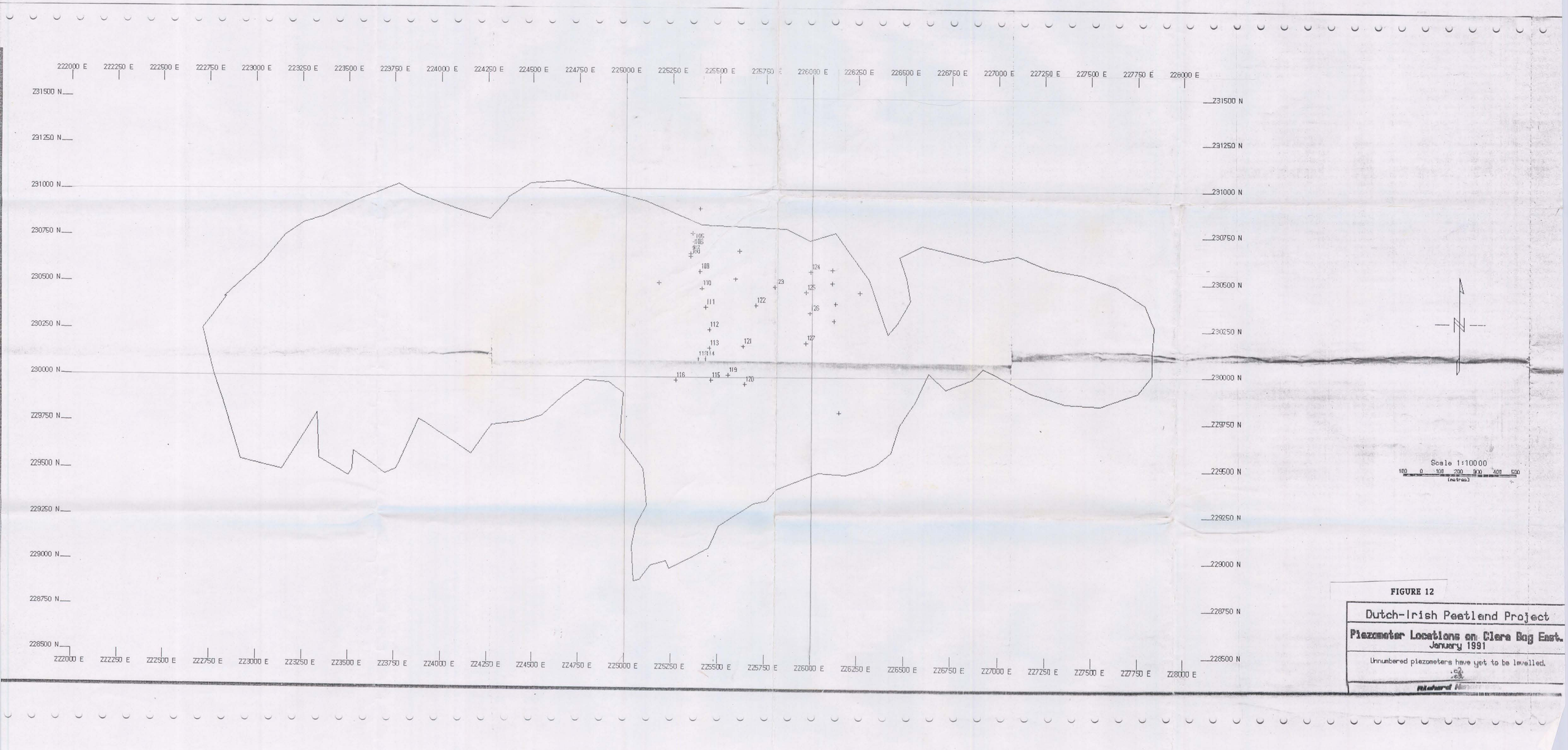


FIGURE 12

Dutch-Irish Peatland Project

Piezometer Locations on Clara Bog East.
January 1991

Unnumbered piezometers have yet to be levelled.

Richard Hart

3, 5, 7 and 9m depending on the peat thickness. The locations of the piezometer stations are shown in fig. 12. The piezometers were pressed into the peat with little difficulty.Phreatic tubes were also installed at each station . Following installation the tubes were filled with filtered bog water and left for one week to equilibrate. The tubes were levelled to ordance datum. This levelling will be repeated as the bog surface rises and falls seasonally. A twice yearly levelling will should be sufficient to maintain accurate head measurements. Hydraulic heads were initially measured on a two weekly basis but are now monitored at monthly intervals.

6.2.1 Permeability Testing in Peat.

In order to assess the movement of water in peat the permeability of the peat must be measured. Permeabilities are needed for calculating flow through peat and are important inputs for models.(see section 9).

6.2.1.1 Methodology.

According to Darcies Law the velocity of water through a medium is directly related to the hydraulic gradient across it by a constant value known as the hydraulic conductivity.

$$V = - K \, dh/dl$$

where V is the velocity through the medium,

dh/dl is the hydraulic gradient,

K is the hydraulic conductivity or permeability.

Two methods were chosen to measure peat hydraulic conductivity : constant head and rising head piezometer tests.

a) Rising and Falling Head Piezometer Tests.

Horslev (1951) has used the above equation to derive the formula :

$$K = [A/S(t2-t1)] \ln(Y2/Y1)$$

where : A = the horizontal cross sectional area of the piezometer,

Y1 & t1 = the head and time measured at time one,

Y2 & t2 = the head and time measured at time 2, values remaining variable,

S = the piezometer shape factor derived by electrical analogue experiments.

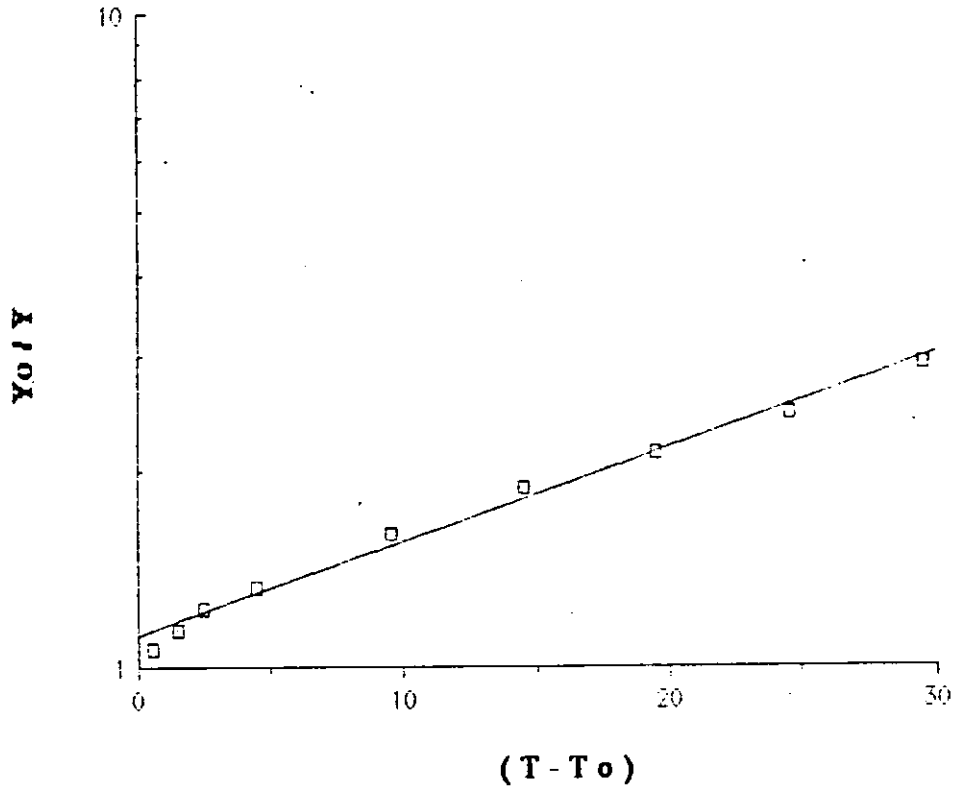
Hydraulic conductivity is determined by plotting $\ln(Y0/Y)$ against $t-t0$.

Fig. 13 shows a worked example of the rising head piezometer test.

The actual method involves removing a quantity of water from a piezometer tube and measuring the head recovery over a fixed time period generally until the original head condition is restored.

b) Constant Head Tests.

Constant head tests involve the use of Marriotte vessels constructed according to BS 3680 (fig.14). This vessel produces a fixed imposed head irrespective of flow from the piezometer. The device also allows variation of the imposed head.



Horslev Rising Head Test

(T-To) mins.	Yo-Y
0.5	1.067
1.5	1.143
2.5	1.231
4,5	1.330
9.5	1.600
14.5	1.880
19.5	2.130
24.5	2.460
29.5	2.910

Yo = 30cm S = 36.85cm A = 3.464 cm^2

K = 7.2 x 10^{-2} m/day.

FIGURE 13 : Example of the Horslev analysis.

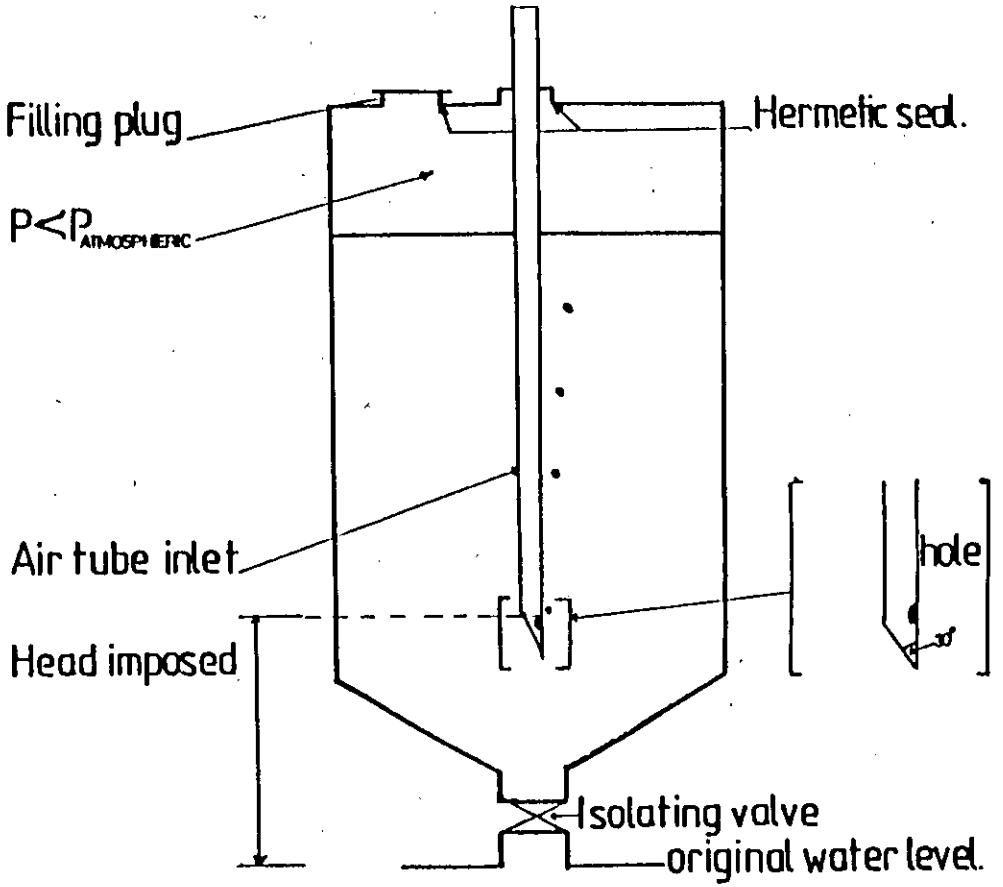


FIGURE 14 Marriote Constant Head Appartus

Rycroft et al (1973) have shown constant head tests to yield more consistent hydraulic conductivities than those obtained by variable head approaches. British Standard 5930 recommends calculation after Gibson(1963) :

$$K = Q_{infin} / (S \times Yo)$$

where Q_{infin} is the steady state flow rate,

Yo is the imposed head ,

S is the shape factor.

A worked example is given below:

Volume released per 1cm drop in Marriotte vessel = 350 cm3.

Using Gibsons formula:

If Q is the flow rate then a level drop of 1.3 cm is =

455cm3/30mins = 9.1×10^{-4} m3/hour.

$$S = 2 \pi l / \ln [l/d + \{1 + (l/d)^2\}^{1/2}]$$

where l = length of open section(m),

d = internal diameter(m).

Then if l = .16m & d = .021m => S = 0.365.

If the head imposed was 0.225m then :

$K = 9.1 \times 10^{-4}/0.365 \times 0.225 = 2.63 \times 10^{-1}$m/day.

6.2.1.2 Results and Discussion

The results of piezometer permeability tests carried out by the author and Flynn(1990) are summarised overleaf. They have been plotted against the humification index. Some authors have demonstrated a negative relationship between humification and permeability. As humification increases the permeability decreases.(Rycroft et al 1974,Ingram 1983). Firstly the hydraulic

conductivity results agree with much of the literature (Aycroft et al 1974, Chason and Siegel 1986).

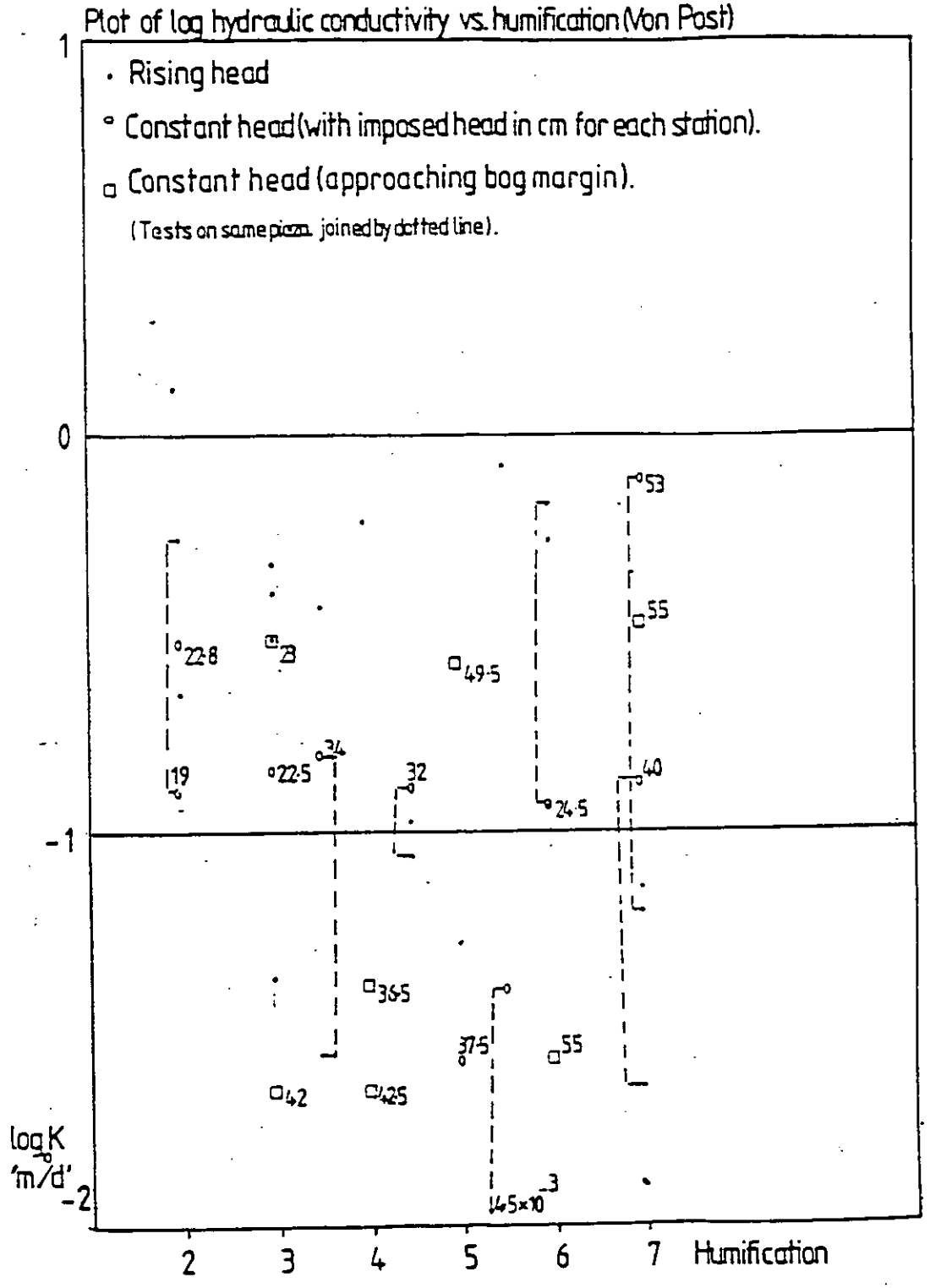
However, there appears to be no relationship between conductivity and humification.

The hydraulic conductivity of peat is an extensively reviewed and disputed subject Hemond and Goldman(1985),Hobbs(1986),Ingram(1974),Chason and Siegel (1986),Aycroft et al(I)(1974),Boelter (1964).

Ingram et al 1974 have suggested that flow through peat is non-Darcian. They noticed that flow into or out of a seepage tube installed in humified peat varies in a non linear manner with the artificial hydraulic gradient created. They suggested that this was the result of the variation of hydrulic conductivity in peat. However, Hemmond and Goldman (1985) suggest that these results are a consequence of the effective stress applied during the course of the test which would not be applicable under normal conditions. Flynn (1990) after analysing the data in fig. 15 concluded that the data agreed more with Hemmonds hypothesis than Ingrams. Flynn concluded that rising and falling head tests were not suitable as the peat is disturbed excessively. Constant head tests are the best method for obtaining comparative permeabilities and an approximate method of acquiring natural hydraulic conductivities under low imposed heads.(<30cm).

Therefore, it may be more applicable to use constant head tests during the wet period so as to minimise the heads imposed on the peat.

FIGURE 15



AFTER FLYNN 1990.

6.2.2 Equipotential Contour Maps

On the basis of piezometer nest data a water table contour map is illustrated in fig. 16. The equipotentials show a recharge mounding in the centre of the study area flowing radially outwards towards the bog margins and the bog road.
Fig.17 shows the equipotentials at 5 m below the peat. The flow pattern is somewhat similar with a similar mounding in the center but the flow is less radial in nature.

6.2.3 Flow Through the Peat

In order to assess the flow of water through the peat in a 2-D section a flowline was chosen based on the water table map (fig. 16). Unfortunately the piezometer station arrangement did not reflect the nature of the water table contours and a less than ideal flowline was necessarily chosen. The flow line extends from the central recharge mound to the clay lined drain at the north margin.The sections (figs.18 & 19) show the equipotentials along the flowline during the summer and winter periods respectively. At the discharge point, the drain, the equipotentials are more densely arranged reflecting the relatively low permeability lacustrine barrier and possibly lower conductivities due to peat compaction close to the drain. However it also appears that all the water is not discharged to the drain and some is flowing through the clay interface. This suggests that the clay may be more permeable than had been realised and an estimate of clay permeability will be necessary.

222000 E 222250 E 222500 E 222750 E 223000 E 223250 E 223500 E 223750 E 224000 E 224250 E 224500 E 224750 E 225000 E 225250 E 225500 E 225750 E 226000 E 226250 E 226500 E 226750 E 227000 E 227250 E 227500 E 227750 E 228000 E

231500 N

231250 N

231000 N

230750 N

230500 N

230250 N

230000 N

229750 N

229500 N

229250 N

229000 N

228750 N

228500 N

ZZ2000 E ZZ2250 E ZZ2500 E ZZ2750 E ZZ3000 E ZZ3250 E ZZ3500 E ZZ3750 E ZZ4000 E ZZ4250 E ZZ4500 E ZZ4750 E ZZ5000 E ZZ5250 E ZZ5500 E ZZ5750 E ZZ6000 E ZZ6250 E ZZ6500 E ZZ6750 E ZZ7000 E ZZ7250 E ZZ7500 E ZZ7750 E ZZ8000 E

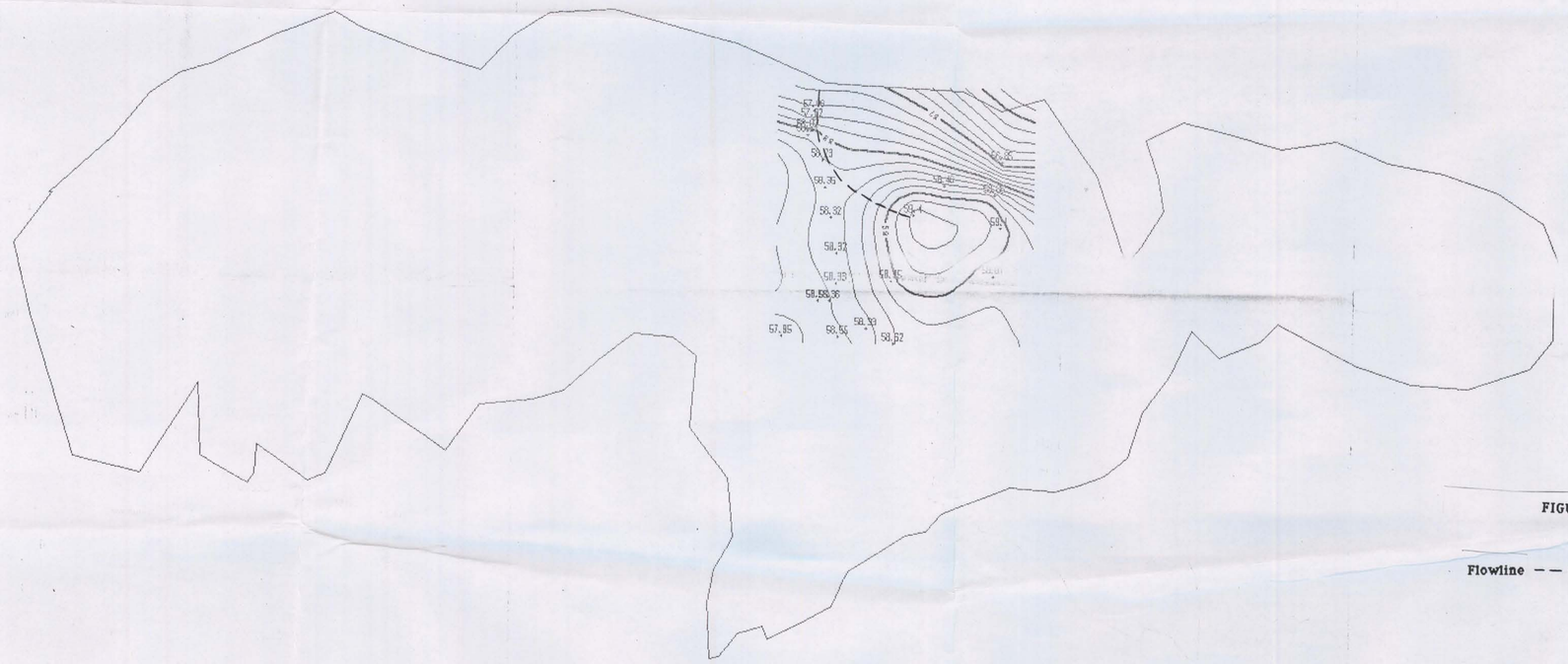


FIGURE 16

Flowline – – –

Scale 1:10000

100 0 100 200 300 400 500 (metres)

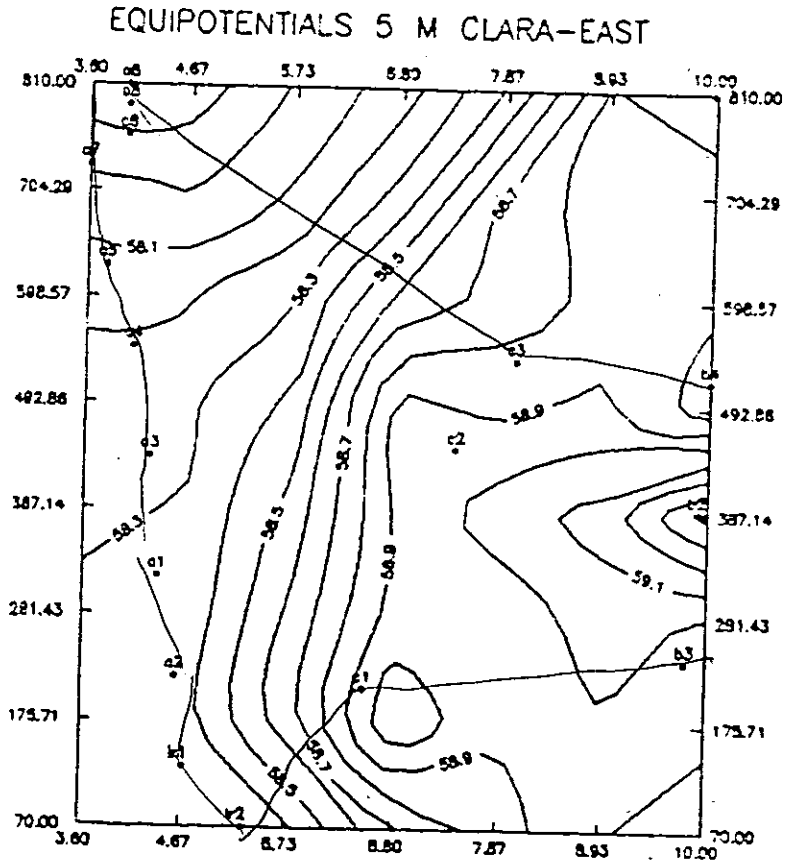
IRISH - DUTCH PEATLAND PROJECT

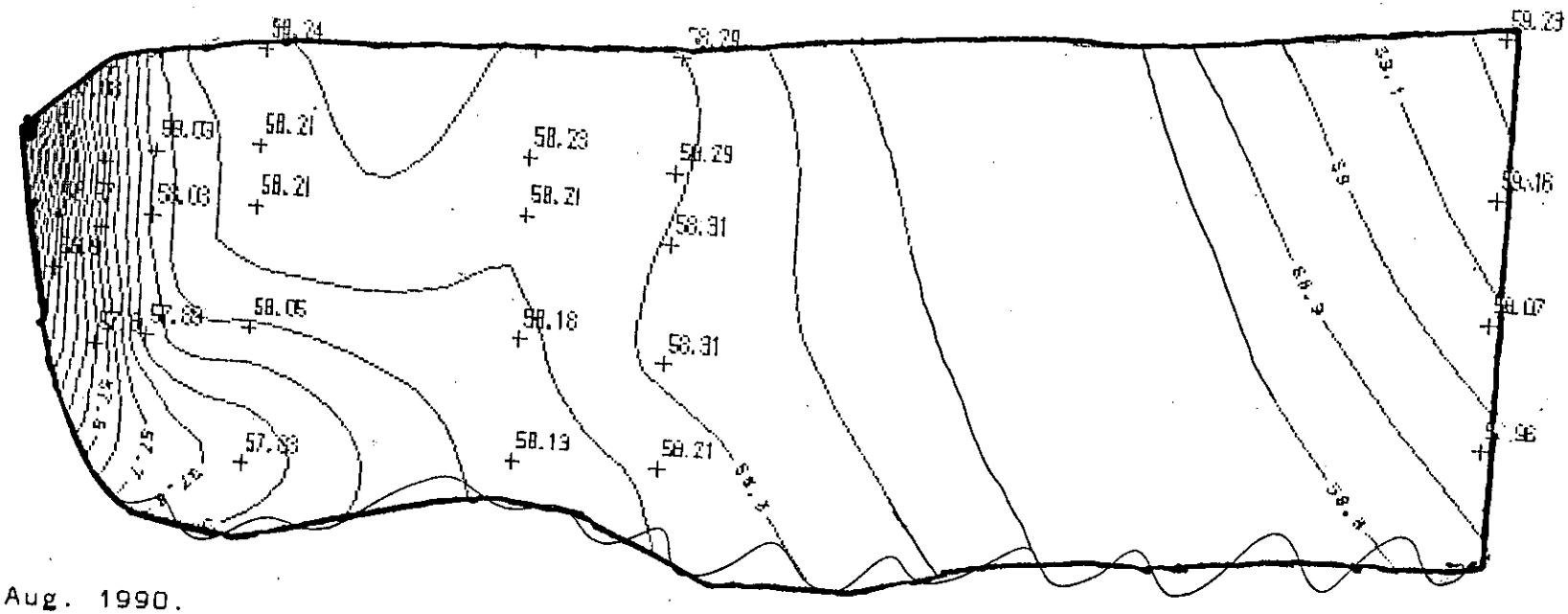
PIEZOMETER LOCATIONS ON CLARA BOG EAST
HYDROLOGY

Piezometers locations on Clara east - January 1991.
SCALE 1:10000
.c3.

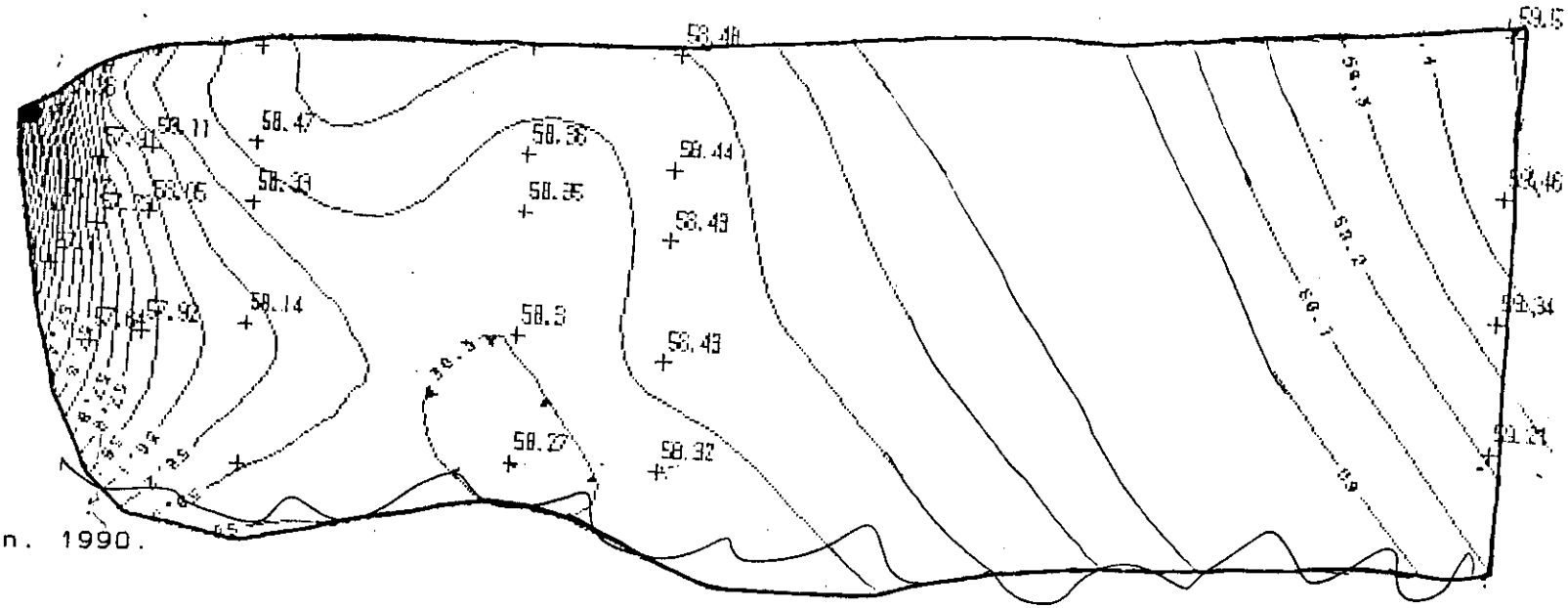
RICHARD HENDERSON

Figure 17 A contour map of equipotentials at five meters in the peat . The area contoured is the same as illustrated in figure 16.





Summer 8 Aug. 1990.



Winter 22 Jan. 1990.

Figures 18+: A plot of equipotentials along the flow line at Clara East 19

Numerical modelling of this flow line has been attempted by Flynn(1990) and is described in section 9.

6.2.4 Hydrogeology of the Mineral Deposits.

Pump tests were carried out on the lithologies revealed in the drilling using a surface belt driven discharge diesel pump. Where possible recirculation of water into the unconfined esker gravels was minimised by directihg the outflow to the margins of the lacustrine clay. The pump did not allow step tests to be carried out. Discharge was measured periodically using a 5 gallon drum. The mathemathical analysis of the pump test data is described by Flynn(1990). At Clara Borehole No. 2 (CLBH 2- situated close to the drain) the aquifer is probably transitional between confined and unconfined. It was considered that Walton's 'leaky analysis' gave the best approximation of the transmissivities in gravel, clayey gravel and limestone lithologies at CL BH2. The respective transmissivities were 16.1 ,7.35 and 6.8 m2 /day. At CL BH 3 Jacob and Theis recovery analysis gave figures of 1542 and 1136 m2/day respectively for the esker gravels.

The head values in the boreholes indicate :

1. Regional flow in the direction of the Silver River. However no lateral control exists at present to indicate the exact flow direction.

2. Vertical flows present in the piezometers at CLBH2 indicate upwelling of water through the clay deposits into the drain. This has been confirmed by hydrochemistry (section 8.5).

6.2.5 The Soak System - Lough Roe

A number of explainations have been suggested for the anomalous fen vegetation that constitutes the soak areas:

1. these areas may be areas of greater surface water flow on the bog thus causing a greater movement of nutrients through the area enabling a different botanical regime to dominate. They may effectively be operating like funnels,channeling large quantities of water through the area.

2. It also has been suggested that these areas are/were being fed by small springs. This could occur if mounds of glacial till/gravel were exposed above the lacustrine clay deposits thus allowing mineral rich water to reach these areas. The eskers could conceivably be acting as recharge mechanisms for the soaks. (see fig.20). A preliminary borehole drilled along the road during winter 1989 revealed artesian pressure in the deposits under the lacustrine clay. However, the hydraulic head was not sufficient to explain the soak.

Two piezometer nests have been placed in the L. Roe soak. No vertical hydraulic gradients operate in the soak. Whilst piezometery does not indicate any upwelling of water preliminary hydrochemical profiling (see section 8.5) may indicate higher electrical conductivities at depth in comparison to other

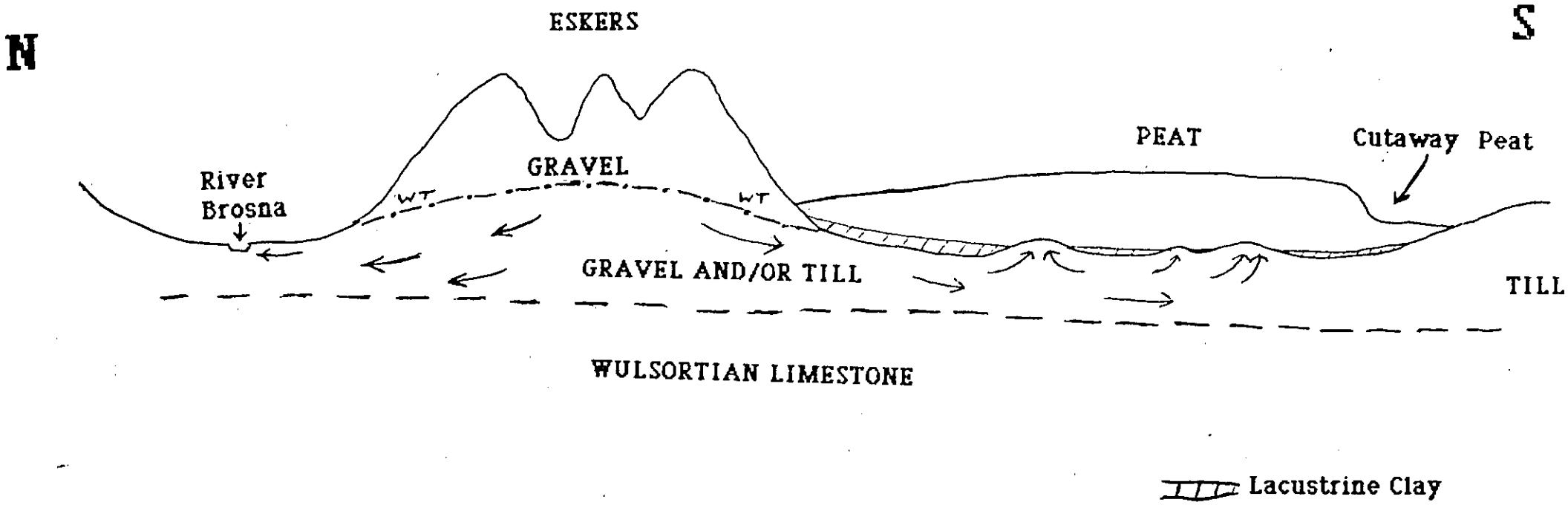


Figure 20: Hypothetical geological cross section along the bog road showing the possible Esker - Soak relationship.

stations. This however has to be investigated much more thoroughly.

The western soak also will be investigated in a similar manner.

6.2.6 Future Work Plans

A number of weaknesses have been identified in the data set for Clara East.

1. Increased piezometer coverage on the bog to gain a more accurate impression of water movement on the bog. These piezometers have been installed and their locations are shown in fig.12.

An increased density close to the drain is required to describe in more detail what is occuring in this area . Permeability tests will be needed on these new 'nests'.

2.Flow measurement in the drain at the northern margin . During the winter period flows in this drain assume greater importance and may be a useful input for the numerical models (see section 9). Flows are measured using the dye dilution method as described in Appendix II.

3. Another borehole in the area (along the road) will be a lateral control and aid in describing the flow in the mineral deposits and the hydrogeological situation in the deposits beneath the peat. This will be drilled in summer 1991.

4. It is important that permeability values for the lacustrine clay be obtained.

It is envisaged at the end of May 1991 a report will be produced that describes this study area. This will include a north/south cross section from the River Brosna to the Silver River to describe the hydrological situation in the area.

7 Drilling, Piezometer and Well Screen Installation in Boreholes at Clara and Raheenmore Bogs.

7.1 Introduction

A number of boreholes were drilled in the vicinity of both bogs during the summer and autumn of 1990. These were drilled by the Geological Survey of Ireland drilling rigs.

Both rotary and shell and auger methods were employed mainly using the light percussion rig. Although this method is slow in nature it has two important advantages :

a) it allows more efficient recovery of unconsolidated deposits and,

b) it allows greater accessibility to areas otherwise unavailable for drilling.

7.2 Clara Boreholes

Two holes were drilled on the north east side of Clara bog(see Fig 9).

CL BH2 is situated on cutaway peat at the interface between the peat and esker deposits. This hole was positioned approx. 3 m from a marginal drain. A brief lithological log is shown below (also see fig. 21):

0 - 0.3 m Peat.

0.3 -1.1 m Gritty Clay.

1.1 - 4.3 m Clayey gravel(a thin confining layer of clay may be present at 4.3m.)

4.3 - 5.95 m Clean Gravel.

5.95 - 8.35 m Hard Stony Till.

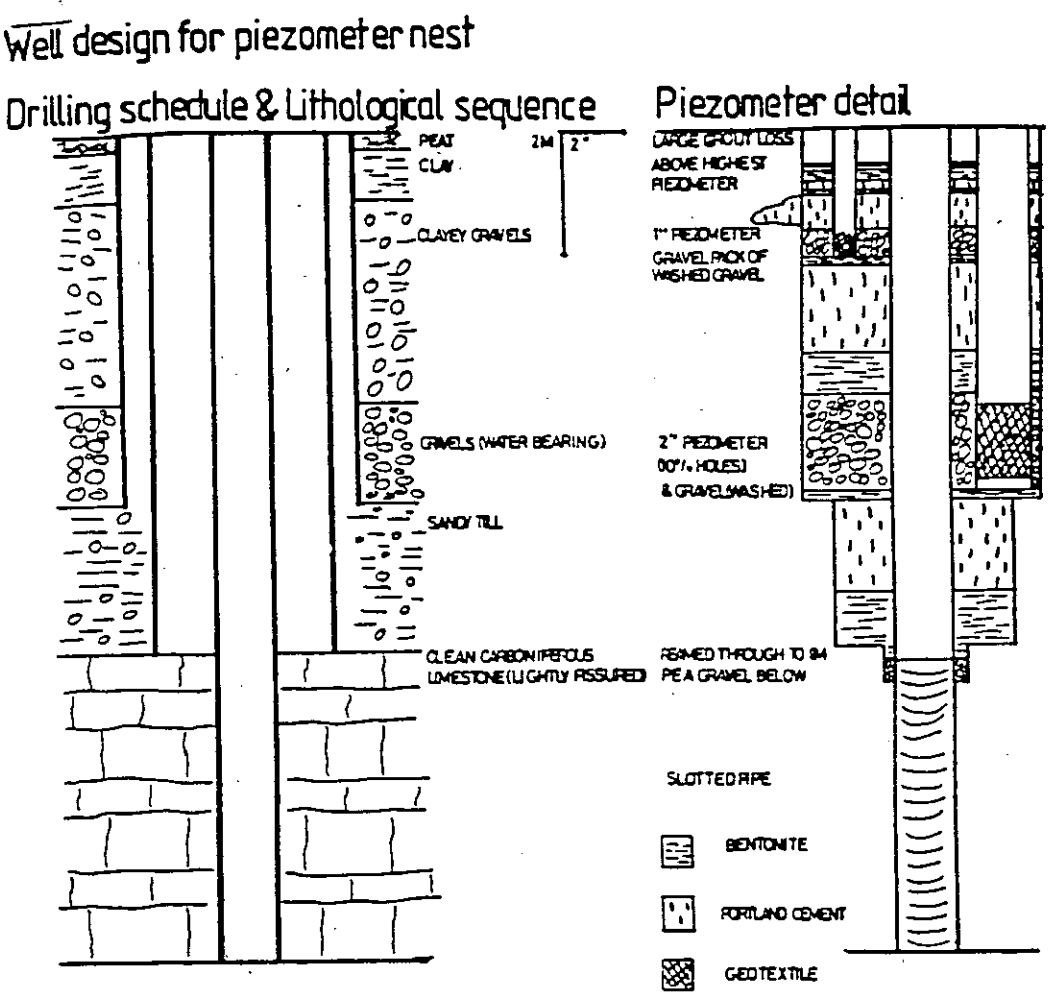
8.35 - 13.35 m Carboniferous Limestone.

CL BH2 was completed as a piezometer nest. Piezometers were installed in the limestone,the clean water bearing gravels and the clayey gravel (see fig.21).The limestone piezometer was 60mm o.d.PVC rigid tubing which was slotted from 8.65 to 13.35 m. The piezometer in the clean gravel was 60mm o.d. rigid PVC,had a geotextile filter and was slotted from 5.7 to 4.5 m . The clayey gravel piezometer was 25mm o.d. PVC , had a geotextile filter and was slotted from 2 m to 1.8m.

Pea gravel was used as a packer around the piezometers.Seals between the piezometer were affected using concrete and bentonite as illustrated.(fig. 21).

Below the clay lithology it was obvious that the hole was enlarged due to the action of the bailer. Large amounts of concrete were required to backfill this cavity.

FIGURE 21


Well design for piezometer nest
Drilling schedule & Lithological sequence
Piezometer detail
PEAT
CLAY
CLAYEY GRAVELS
GRAVELS (WATER BEARING)
SANDY TILL
CLEAN CARBONIFEROUS LIMESTONE (LIGHTLY FISSURED)
2M
2"
LARGE GROUT LOSS ABOVE HIGHEST PIEZOMETER
1" PIEZOMETER
GRAVEL PACK OF WASHED GRAVEL
2" PIEZOMETER
(0.7% HOLES)
& GRAVEL WASHED)
REAMED THROUGH TO 84
PEA GRAVEL BELOW
SLOTTED PIPE
BENTONITE
PORTLAND CEMENT
GEOTEXTILE

CL BH3 is situated on the esker 180m north of CL BH2 and is elevated 6.15m above CL BH2.A brief lithological log is described below(also see fig 22):

0 - 0.5 m Brown Earth Topsoil.

0.5 - 1 m Clayey Sand.

1 - 2.5 m Sand and Gravel.

2.5 - 5.25 m Sand,Silt and Fine Gravel.

5.25 - 8.0 m Sand and Silt(with clay lenses).

8.0 - 12.7 m Sand and Gravel(with some silt).

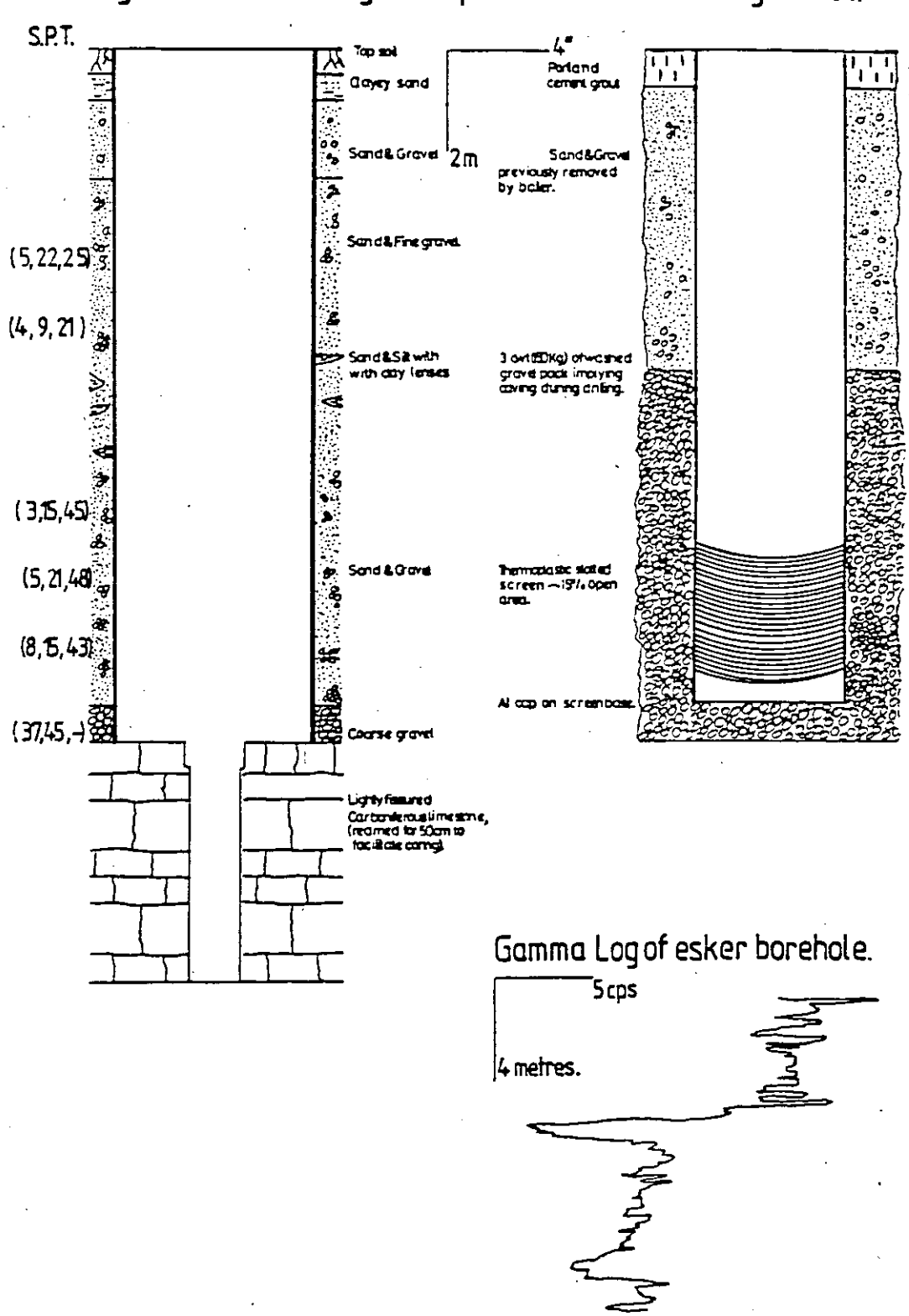
12.7 - 13.4 m Coarse Gravel.

13.4 - 18.0 m Carboniferous Limestone.

Because of hydrogeological continuity between the lithologies a well screen was installed rather than piezometers. Due to the presence of clay lenses within the sands and gravels a gamma log of the hole was taken to decide the best situation for the screen (see fig 22). The screen was positioned between 9.76 and 12.21 m. The screen itself was 155mm o.d.thermoplastic with 2mm slots and 15% open area. An aluminium cap was placed on the base of the screen.The well screen was heat welded to 155mm o.d.wavin pipe .

The screen was backfilled to 6.2 m with a washed pea gravel pack.From 6.2 m to 0.6 m the backfill used was sand and gravel previously removed by the bailer.

FIGURE 22


Well design for abstraction borehole on esker.
Drilling schedule & Lithological sequence
Well design detail.
S.P.T.
(5,22,25)
(4,9,21)
(3,15,45)
(5,21,48)
(8,15,43)
(37,45,-)
Top soil
Clayey sand
Sand & Gravel
Sand & Fine gravel
Sand & Silt with with clay lenses
Sand & Gravel
Coarse gravel
Lightly fissured Carboniferous limestone, (reamed for 50cm to facilitate coring)
2m
4"
Portland cement grout
Sand & Gravel previously removed by boiler.
3 cwt (150Kg) of washed gravel pack implying caving during drilling.
Thermoplastic slotted screen ~15% Open area.
Al cap on screen base.
Gamma Log of esker borehole.
5cps
4 metres.

Both holes were completed with a concrete base and fences were erected around the holes to prevent livestock damage.

7.3 Raheenmore Boreholes.

At Raheenmore the main aim of the drilling (from the hydrogeological point of view) was to identify the effects of the deep(>= 3.0m) peripheral drain which surround s the bog .The regional flow in the mineral deposits which underlie the peat will also be determined.

Three holes were drilled at Raheenmore bog. Two(RH BH1 and RH BH 3) were situated close to the drain on the northern side and one(RH BH2) was situated on the southern side (see fig 23). All holes were situated at either end of a piezometer transect crossing north south over the bog.

Access to drill sites RH BH1 and RH BH2, which are situated on the bog, was facilitated using the "swamp shoes" tractor and sleigh arrangement supplied by Bord na Mona.

RH BH1 had a lithological sequence as follows(see fig 24):

0 - 3.5 m Peat.

3.5 - 5.0 m Clay with angular pebbles.

5.0 - 6.75 m Gravel.

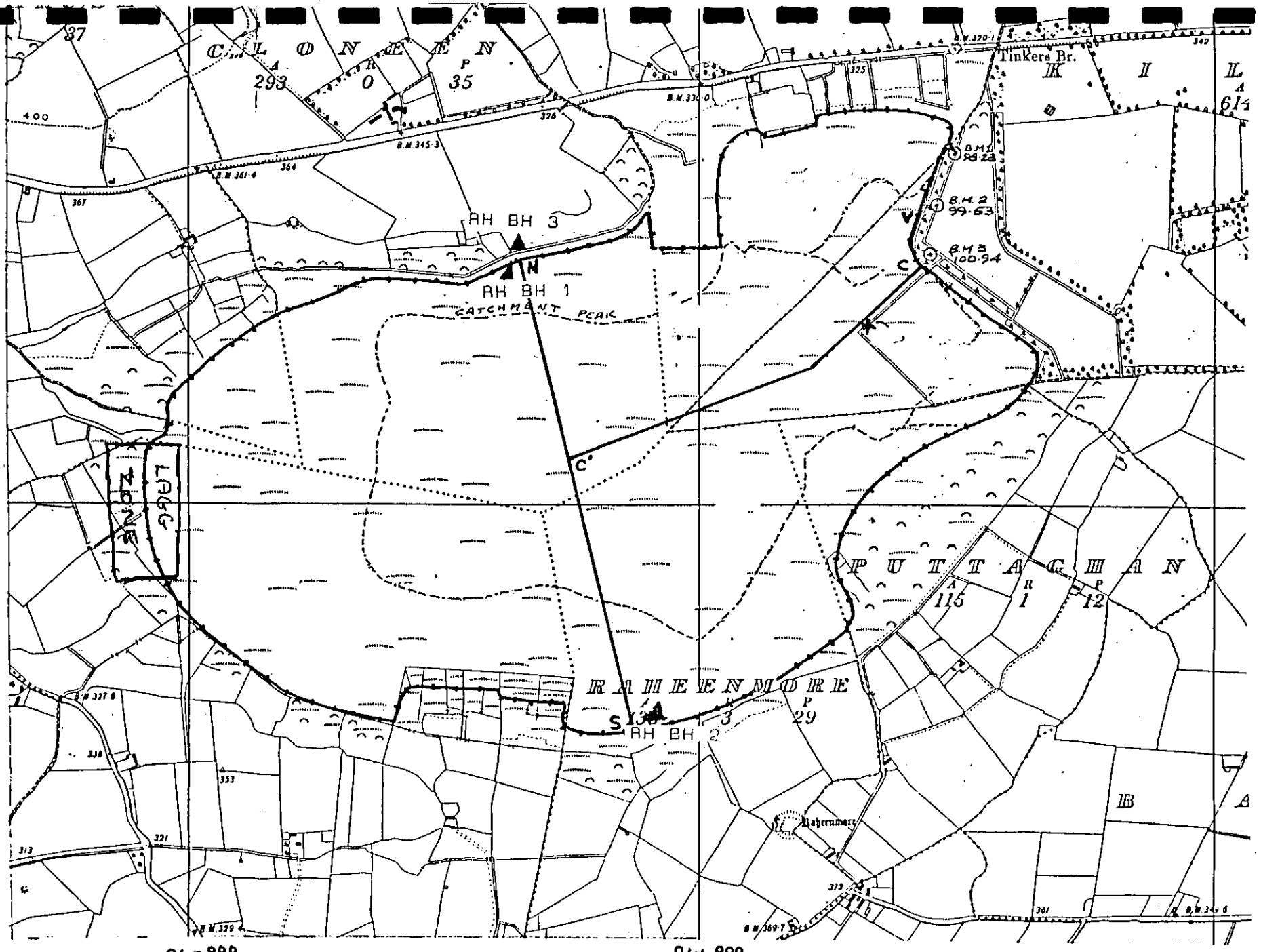
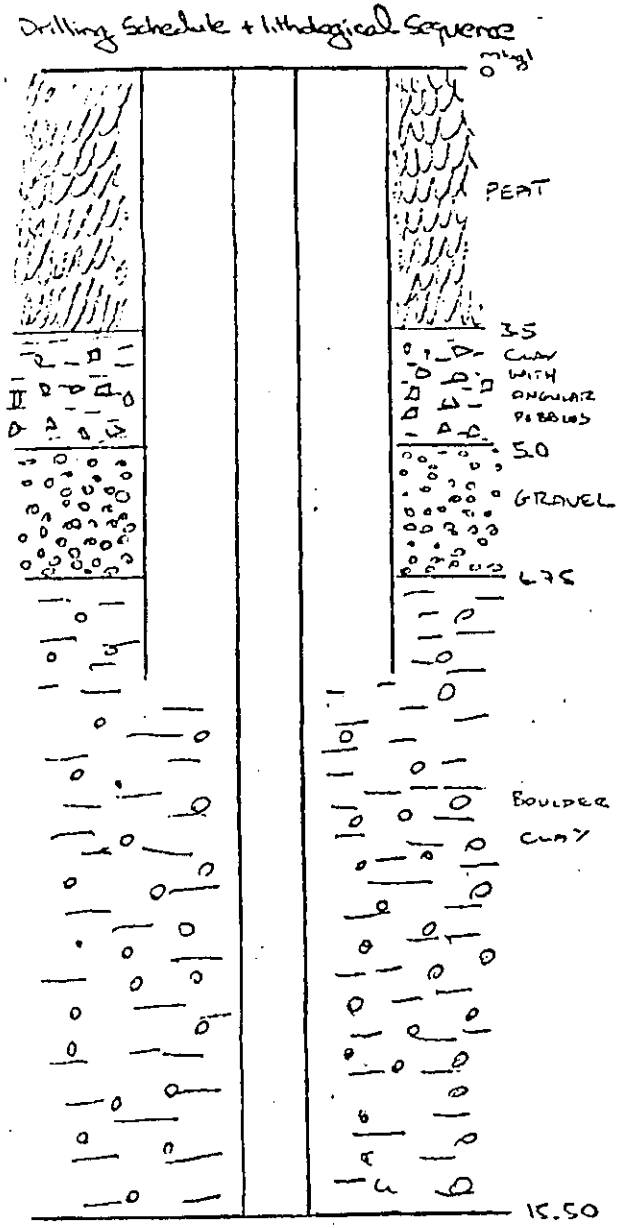


Figure 23 The locations of the boreholes on Raheenmore Bog.



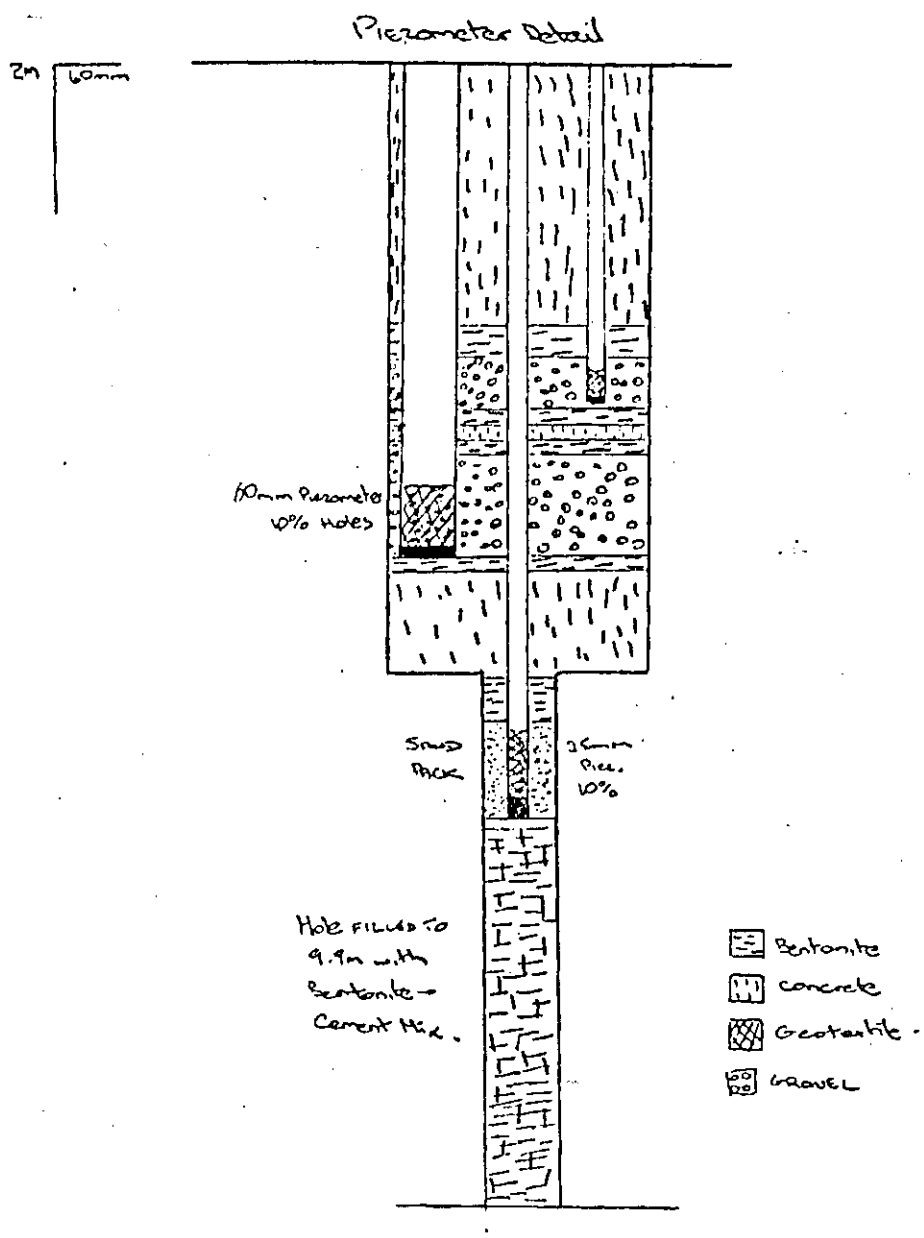


FIGURE 24 RHBH1

6.75 - 15.50 m Boulder Clay.

Piezometers were installed in the three lithologies below the peat layer(see fig. 24). The hole was backfilled with a bentonite/concrete mix to 9.9 m. A 25mm o.d. PVC piezometer was slotted for 1 m between 9.7 m and 8.7 m. The piezometer had a 10% opening and had a geotextile filter.A 60mm o.d. PVC piezometer was situated in the gravel lithology between 6.65 m and 5.55 m.The piezometer was slotted for 1 m (10% opening), had a geotextile filter and a 10cm sump. A 25mm o.d.PVC piezometer with 50cm slots,as described previously, was positioned between 4.6 m and 4.1 m.
Sand and gravel packs were used around the piezometers and bentonite/concrete sealants were used between the piezometers(see fig.24).

RH BH2 had a lithological sequence as follows(see fig.25):

0 - 3.2 m Peat.

3.2 - 3.9 m Boulder Clay.

3.9 - 4.1 m Clean loose gravel.

4.1 - 5.0 m Stiff grey clay with angular pebbles.

5.0 - 5.6 m Stony plastic clay.

5.6 - 8.3 m Carboniferous Limestone.

A 60mm o.d. PVC piezometer was installed in the bedrock between 5.7 m and 8.3 m .It was slotted for 2.5 m and had a 10 cm sump.

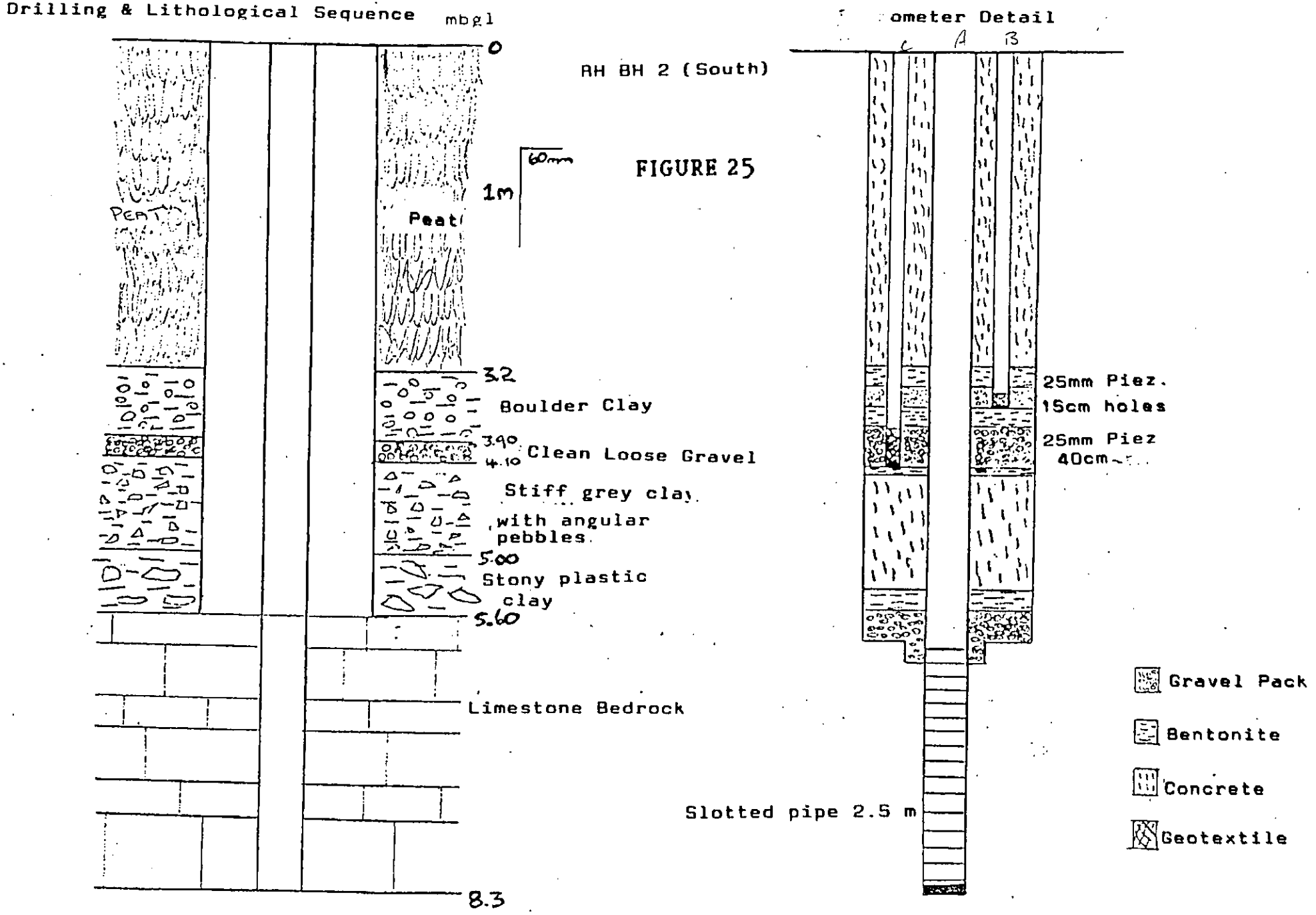

Drilling & Lithological Sequence
mbgl
0
1m
60mm
Peat
3.2
Boulder Clay
3.90
4.10
Clean Loose Gravel
Stiff grey clay
with angular pebbles
5.00
Stony plastic clay
5.60
Limestone Bedrock
8.3
BH BH 2 (South)
ometer Detail
C
A
B
25mm Piez.
15cm holes
25mm Piez
40cm
Slotted pipe 2.5 m
Gravel Pack
Bentonite
Concrete
Geotextile

FIGURE 25

A 25 mm o.d. piezometer was installed between 4.2 m and 3.8 m in the clean gravel lithology. It was slotted for 40cm and had a geotextile filter.
A 25mm o.d. piezometer was also situated between 3.6 m and 3.45 m in the boulder clay.This piezometer had a geotextile filter and was slotted for 15cm.

As before gravel packs were used around the piezometer slots and concrete/bentonite sealants were used to seal between the piezometers(see fig.25).

RH BH3 had a lithological sequence as follows:

0 - 2.2 m Peat.
2.2 - 3.2 m Boulder Clay.
3.2 - 3.6 m Gravel.
3.6 - 15.0 m Stiff grey dry boulder clay.
15.0 - 19.0 m Red to brown boulder clay(iron present).
19.0 - 23.0 m Highly fissured limestone bedrock.

The hole was backfilled with boulder clay material to 9.3m.From 9.3 to 9.0m the hole was sealed with bentonite.
A 25mm o.d.piezometer(30cm slots and a geotextile filter) was installed between 8.6 m and 8.2 m in the boulder clay.
A 60mm o.d.piezometer with 7 cm sump and 25 cm slots(10 % opening with a geotextile filter)was positioned between 3.60m and 3.35m in the gravel layer.

Pea gravel was used for packing ,boulder clay previously removed by the bailer was used for backfill and bentonite/concrete sealants were used as before(see fig 26).

7.4 Conclusions

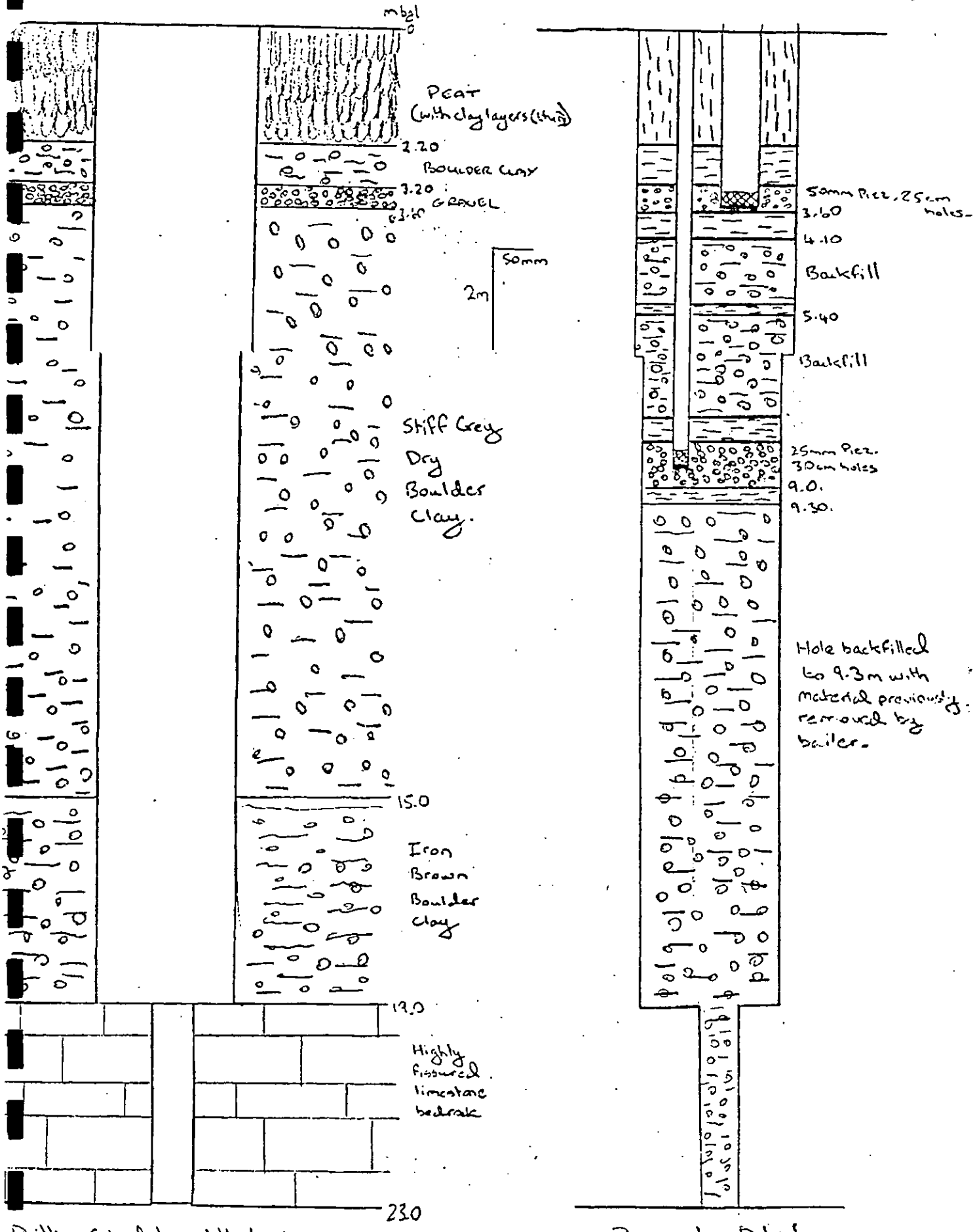
Drilling, although slow at times due to the complex nature of the lithologies, was successful . At CL BH2 and RH BH3 the initial holes were aborted due to a particularly hard diamiction which prevented drilling.

However,access using other methods would not have been possible due to the soft wet nature of the terrain.
Sampling of the lithologies could not have been carried out more accurately using other methods which were available at the time.

8 Hydrochemistry.

8.1 Hydrochemistry as a tool for describing hydrogeology.
Various research workers have demonstrated that hydrochemical surveys are useful tools for assessing the hydrogeology of an area.(Lloyd 1969,Marsh 1977). Marsh(1977) demonstrated the usefullness of chloride distribution in showing the influences of geological structural control in the Lincolnshire limestone aquifer. Hydrochemical distribution maps can provide independent checks on piezometry and can reveal hyrogeological conditions which are not necessarily apparent from piezometry.(Lloyd and

Figure 26 Raheenmore Borehole No. 3 (RH BH 3).



Drilling Schedule + lithologies

Piezometer Detail.

Note: 1½ metre phreatic installed in Peat adjacent to borehole.

Geotextile
Gravel Pack
Bentonite
Concrete
Boulder Clay Backfill

Heathcote 1985). Collins(1987) has demonstrated the use of hydrochemisry in typing groundwaters as a means of describing the major sources of groundwater to two fens in Norfolk.

In this study it is envisaged that identification of hydrochemical facies will allow a characterisation of water types and consequently permit identification of the lithological sequence(s) from which the water originated. This should help in describing the hydrogeological conditions which pertain to the investigation area.

Analysis of anion evolution and the electrochemical evolution sequence may be used as these sequences, when combined with other hydrochemical analysis and hydrogeological data, can provide considerable information on the flow in aquifer systems.(Daly 1989).

Siegel (1989) investigated the recharge-discharge function of bogs in Alaska by comparing concentrations of solutes and measurements of electrical conductivity in bog groundwater and surface water.

The aims of hydrochemical surveys in this study are as follows:

1. To describe the the general hydrochemistry of the peat and surrounding geological deposits.
2. To describe the hydrological processes operating at the peat-mineral deposit interface.For example, it may allow the identification of upwelling water from concealed springs in drains .

3.The identification of polluted wells in the area may be important as polluted groundwater may have serious impacts on the delicate lagg vegetation zones through eutrophication.
4.The most important use of hydrochemistry may be in the vicinity of the soaks where the minerotrophic vegetation indicate a mineral rich water supply in comparison to bog type water which has a chemistry comparable to rainwater. The vegetation associated with the soak areas is comparable to a fen plant community.

8.2 The Chemistry of Bog Waters.(Raised and Fen Peats).
As the soaks have been identified as an important hydrological area it is appropriate to review the differences between fen waters and raised bog waters .
Raised peatlands contain water which has a low pH and dissolved constituents. Ombrotrophic peatlands contain abundant dissolved acids from the decomposition of plant materials. These peatlands are generally precipitation fed and since they recieve no significant inputs of solid bases from groundwaters ,the H+ ion produced via decomposition is not neutrolised(unlike fen peatlands which are primarily groundwater fed). Therefore raised bog waters are acidic and low in ionic strength.(Shotyk 1987).

Gorham(1955) has classified peatlands based on the total concentration of the based cations (K,Mg,Ca,+Na).

Peatland Type	Total concentration of Ca,Mg,Na+K. mg/l
Raised Bog	3.3
Extremely Poor Fen	4.4
Poor fen	6.4
Transitional fen	9.7
Rich Fen	10.9
Very Rich Fen	28.8
Extremely Rich Fen	53.4

Tolonen and Seppanen(1976) found that combining Ca+Mg+Na+K and plotting against pH grouped bogs and fens well.
Clausen et al (1980) also showed that fen runoff was higher in pH,conductivity,alkalinity,calcium,magnesium,iron,sodium and manganese than raised bog runoff. However, raised bog waters were higher in colour, mercury and acidity. Shotyk (1987) states that due to the acidic, reducing nature and abundant dissolved organic matter in bog waters they are enriched with iron manganese and aluminium relative to normal freshwaters. Robinson (1930) has shown some bog waters in Virginia to contain up to 2ppm Al, 1-7ppm Mn and 1-40ppm Fe. In typical freshwaters their concentrations are .06ppm Al, .008ppm Mn and .04ppm Fe. (Drever 1982). Verry (1975) has shown that concentrations of organically derived nutrients are highest in the streamflow from water sheds containing ombrotrophic peatlands. Schwintzer and Tomberlin (1982) have shown that total silica is up to 0.3ppm in raised bogs as opposed to 7ppm in fens. Total dissolved boron is

generally greater in peat waters than in freshwaters.(Tolonen & Seppanen,1976).

An important consideration with the interpretation of hydrochemical data are the the anthropogenic impacts on systems.

8.3 Anthropogenic Impacts - their importance.

Comparisons of the quality of run off from natural and disturbed (by peat mining) Minnesota peatlands indicate that disturbed peatlands have higher concentrations of colour, suspended sediment, acidity, potassium, iron, aluminium and sodium. Grootjans et al (1982) point to the importance of recognising polluted groundwater as a possible threat to the delicate lagg zone system. Polluted systems could also confuse interpretation of data.

8.4 Methods

A number of preliminary hydrochemical surveys have been carried out to date on Clara Bog in April and June 1990. Figure 27 shows the location of sampling sites. Samples of water were taken from piezometers at different depths on the bog,drainage water was sampled and ground water samples were taken from wells and springs situated in the surrounding mineral deposits. pH , conductivity and temperature were measured on site whilst other analytes were determined in the laboratory using standard procedures. All samples were maintained at less than 4°C to prevent chemical decomposition.

222000 E 222250 E 222500 E 222750 E 223000 E 223250 E 223500 E 223750 E 224000 E 224250 E 224500 E 224750 E 225000 E 225250 E 225500 E 225750 E 226000 E 226250 E 226500 E 226750 E 227000 E 227250 E 227500 E 227750 E 228000 E

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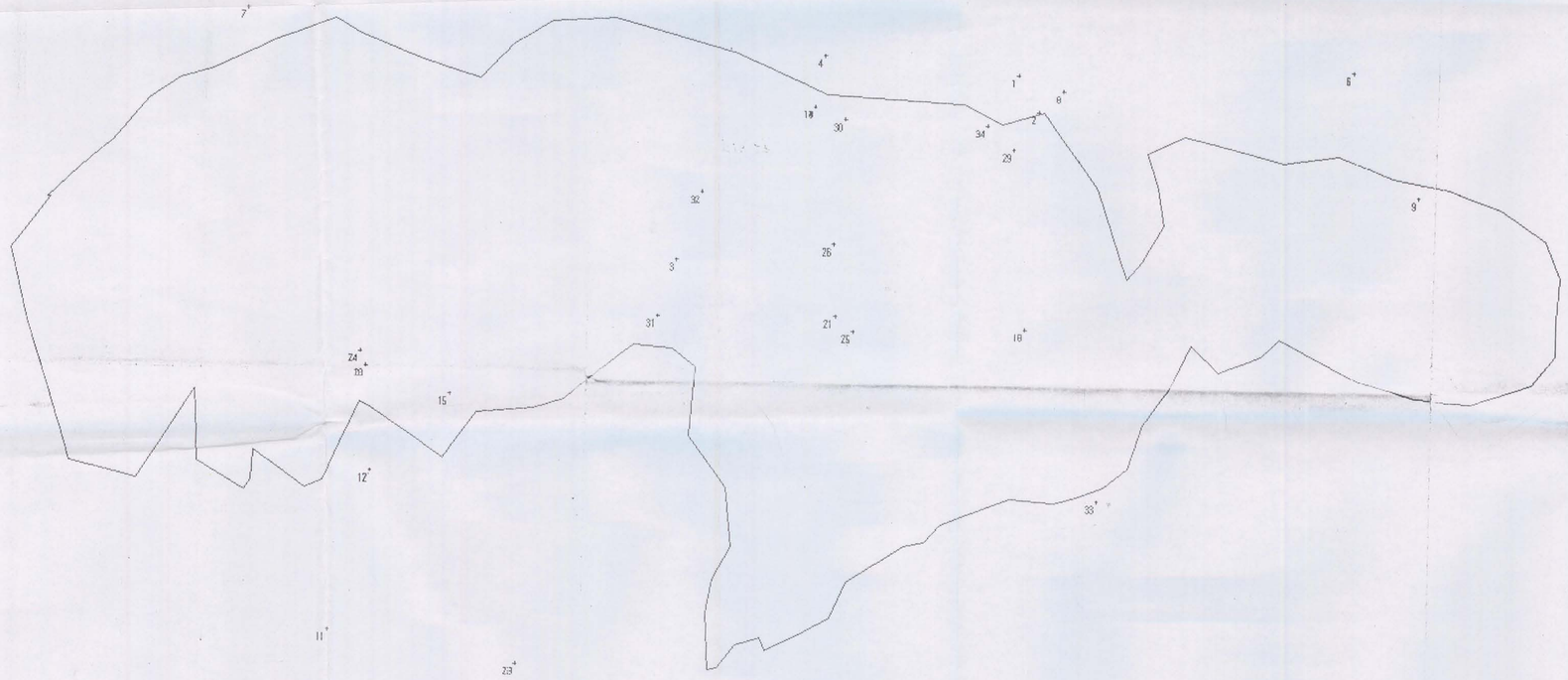
ZZ2000 E ZZ2250 E ZZ2500 E ZZ2750 E ZZ3000 E ZZ3250 E ZZ3500 E ZZ3750 E ZZ4000 E ZZ4250 E ZZ4500 E ZZ4750 E ZZ5000 E ZZ5250 E ZZ5500 E ZZ5750 E ZZ6000 E ZZ6250 E ZZ6500 E ZZ6750 E ZZ7000 E ZZ7250 E ZZ7500 E ZZ7750 E ZZ8000 E



Scale 1:10000

100 0 100 200 300 400 500 (metres)

FIGURE 27

Dutch-Irish Peatland Project
Hydrochemical sampling locations. .bz.
.c1. .c2. .c3.
Richard Anderson

8.5 Results and Discussion

The results of the surveys are shown in Appendix III. The CHEMPROC computer package was used to analyse the data. All concentrations are in ppm.The code refers to the sample number. The ion balance error, ionic ratio is computed and each sample is given a classification code (eg F3-Ca HCO3+) based on its chemistry. The key to this classification system is shown overleaf.

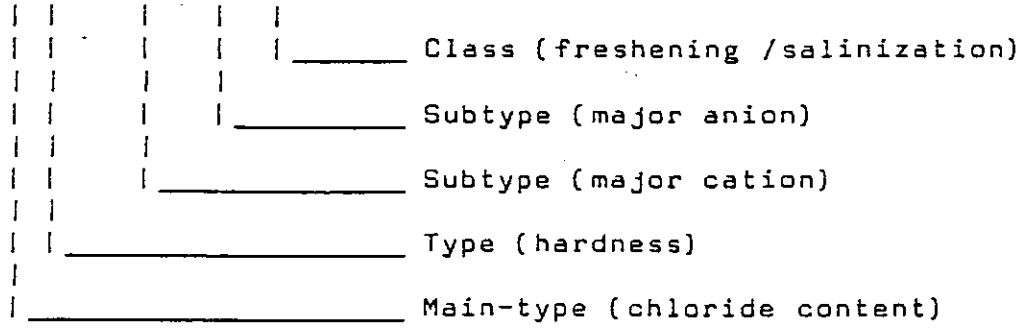
It can be noticed from the results that the bog waters have high ion balance errors indicating an imbalance of cations and anions. These unknowns are probably organic acids (Lamar & Goerlitz 1966 and Puustjarvi 1968). Such ion imbalances are common in coloured ,low pH waters (Hem 1970). Malmer (1963) states that other sources of error may include cations measured analytically that were bound to colloids in the undisturbed water.

The results show the peat waters to be acidic and low in conductivity. The results agree well with the literature discussed above. The samples from the mineral deposits are of near neutrol pH and calcium bicarbonate rich. Samples from drains on the periphery of the bog are also similar to the latter possibly indicating upwelling water to the drain. This will be discussed later.

Hydrochemical profiling was performed at sites on the bog to examine the chemical status of water at different depths in the peat. Figures 28 & 29 allow a comparison of pH and conductivity

Explanation of Stuyfzand Classification

Example : F 1 - Ca HCO3 +



Main-type :

Chloride content (mg/l)	Code	Meaning
0 - 150	F	Fresh
150 - 300	Fb	Fresh-Brackish
300 - 1000	B	Brackish
1000 - 10000	Bs	Brackish-saline
100000 - 20000	S	Saline
> 20000	H	Hyperhaline

Type:

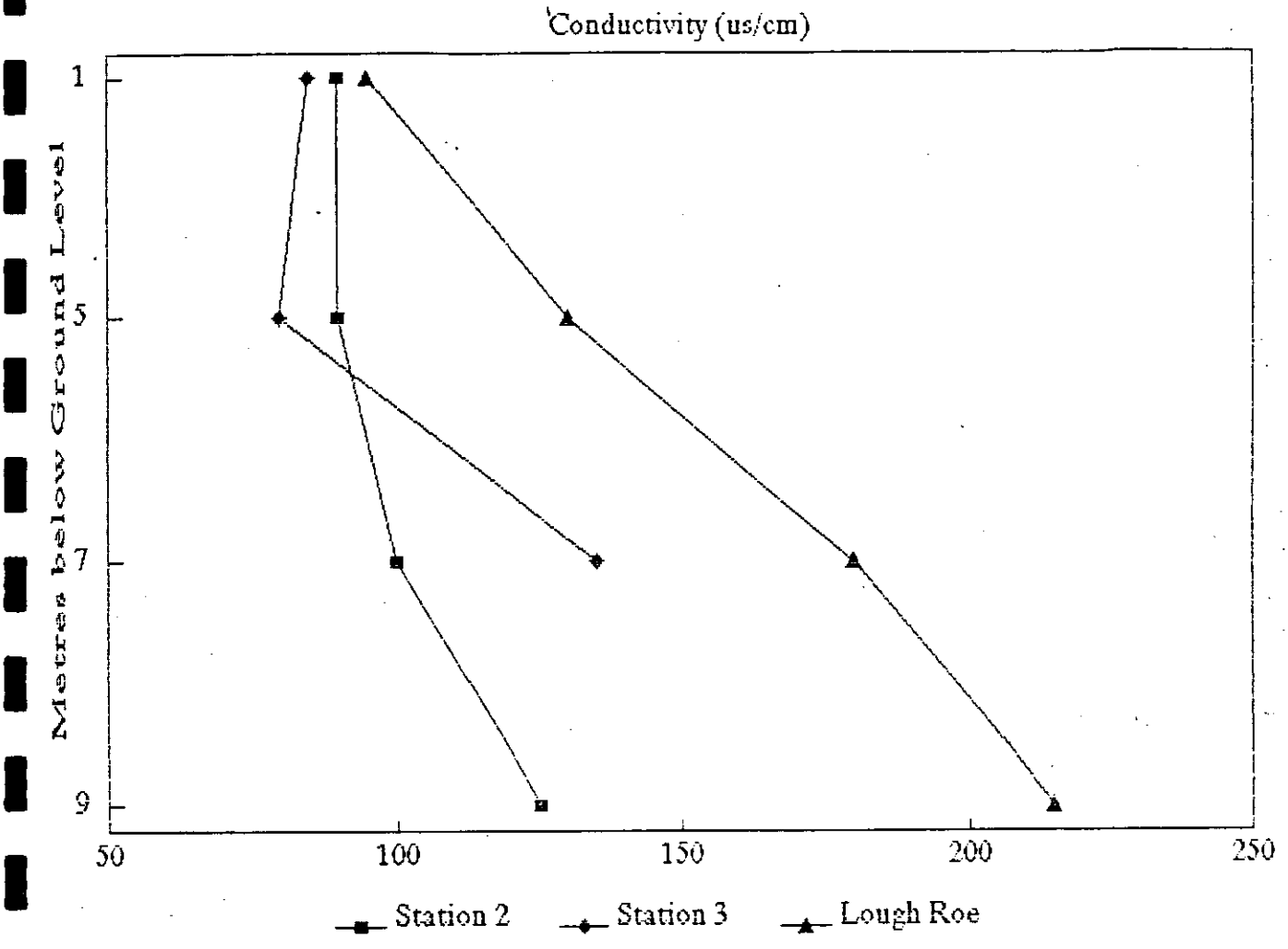
HCO3 / Tot. hardness(mmol/l)	Code	Meaning
0 - 0.5	*	very soft
0.5 - 1	0	soft
1 - 2	1	moderately hard
2 - 4	2	hard
4 - 8	3	very hard
8 - 16	4	extremely hard
16 - 32	5	extremely hard
32 - 64	6	extremely hard
64 - 128	7	extremely hard
128 - 256	8	extremely hard
> 256	9	extremely hard

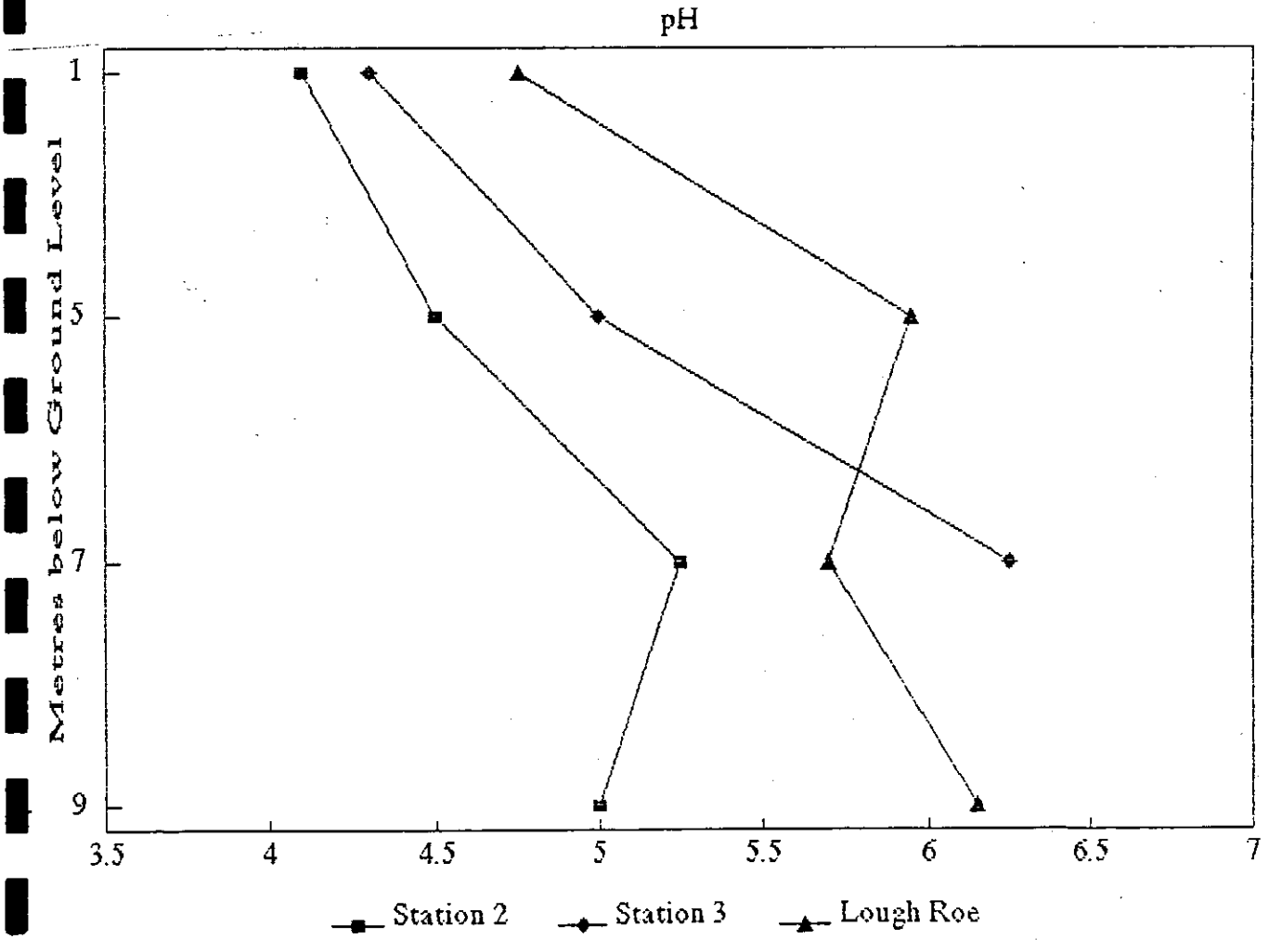
Na + K + Mg)calculated = 1.061 * Cl (meq/l)

Class :

Na + K + mg) calc.	Code	Meaning
	-	(Na + K + Mg) deficit
	o	(Na + K + Mg) balance
	+	(Na + K + Mg) surplus

Figures 28+29: The diagrams illustrate the results of hydrochemical profiling at Lough Roe and other stations on the bog.

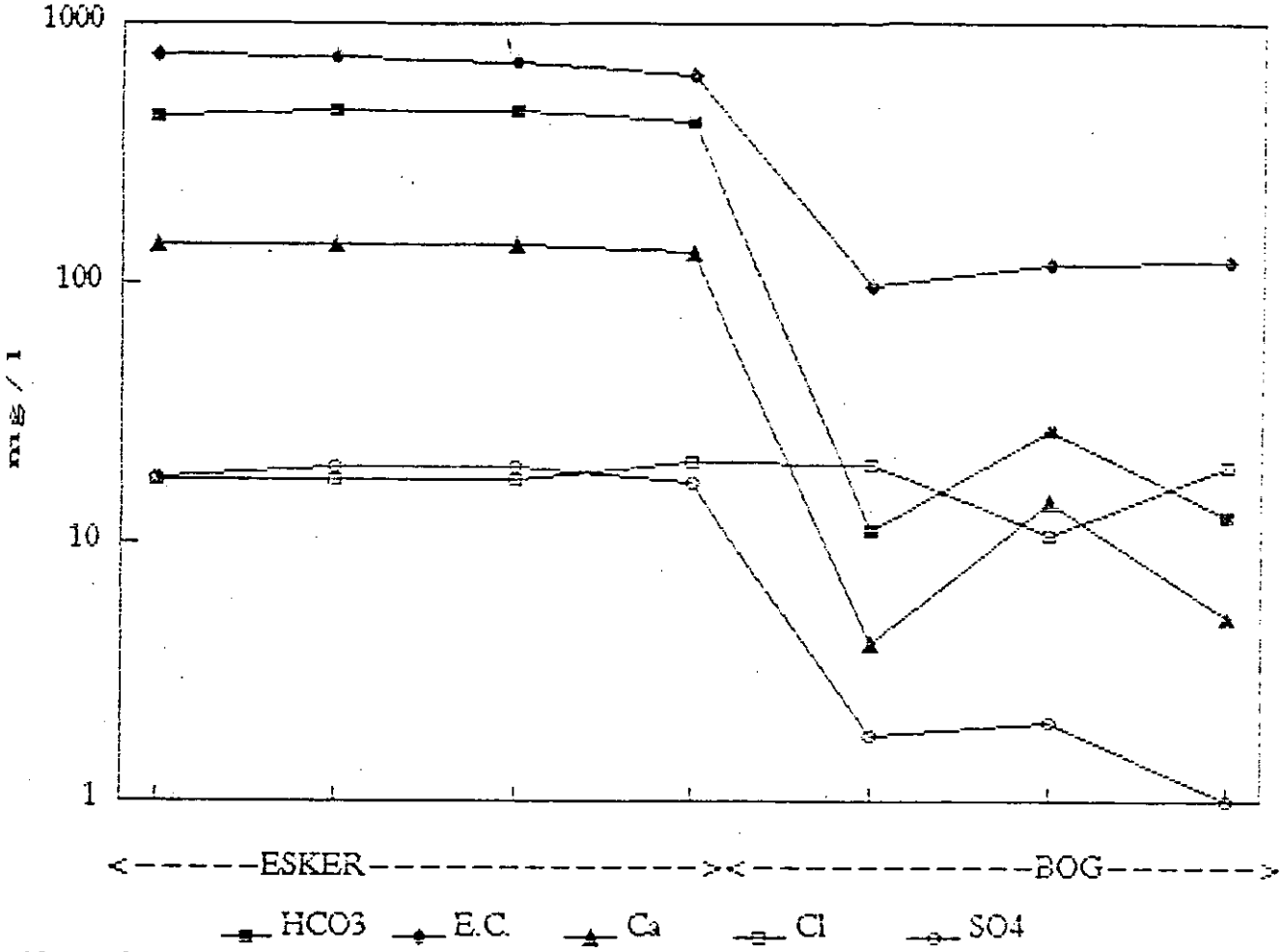




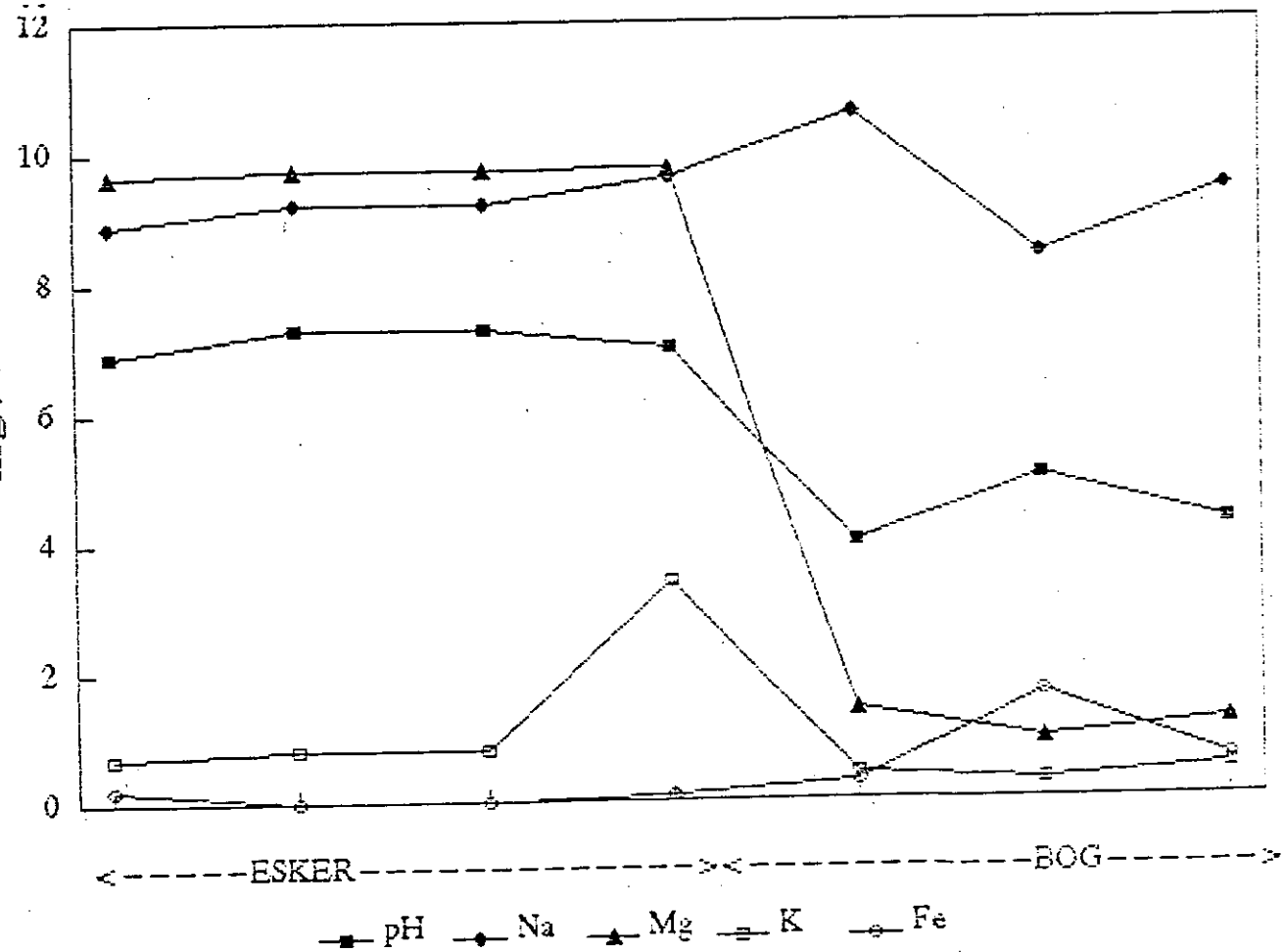
at three stations on Clara East. They clearly show an increase in conductivity with depth , the greatest at Lough Roe.
The situation with pH is more complicated but the trend is increasing with depth. These results probably indicate the former fen like situation which occurs prior to the development of a raised bog. This fen peat would have been predominantly fed by mineral groundwater thus the increasing values with depth. An interesting result is that at Lough Roe. Conductivity is greater than at the other sites - a possible upwelling spring may be suggested. This of course is speculative and a more rigourous hydrochemical profiling will be necessary.

Groundwater was sampled on the A - A transect across the esker and the bog (fig.9). The results of this transect are simplistically illustrated in figure 30. Groundwater samples were taken from the boreholes CLBH2 and CLBH3 ,the drain and piezometers along the bog transect. One can see there is a large decrease in most parameter concentrations at the bog esker interface and on the bog. Exceptions to this would be sodium, chlorine and iron which do not change or increase slightly in peat waters. As raised bogs are predominantly rain fed one would expect sodium and chloride to be high. The slightly higher values of iron are in agreement with the literature.
A method developed by van Wirdum(1980) and later used by Grootjans et al (1982) which was employed to explain the sources of groundwater to wetland situations in The Netherlands was used. By plotting ionic ratio against the natural log of corrected conductivity values one can see where the water is situated on

Figure 30 : The results of hydrochemical analysis on waters on a transect across the Esker and Bog.



Note : E.C. is expressed as us/cm.



Note : pH is expressed as pH units.

the athmocline - lithocline gradient. Ionic ratio is the ratio between calcium and chlorine in waters. It is calculated as follows :

$$\text{Ionic Ratio} = \frac{Ca(meq/l)}{Ca(meq/l) + Cl\ (meq/l)}$$

Low conductivity and mineral poor water (atmocline) is rainwater like.This water would have low calcium. High conductivity ,mineral rich water is lithoclinic in nature. This water has high calcium and relatively low chlorine concentrations. Thassoclinic water is approaching the composition of sea water. This water would be high in chlorine and conductivity. Figure 31 is a plot of the water samples using this technique.

It is clear a number of water types are grouped on the plot. Bog water is situated in the region of the athmocline.(Type I). Groundwater from the surrounding eskers are in the lithocline sector .(TypeII). Between the athmocline and the lithocline a number of samples are grouped. These are mainly water samples from the drains at the interface between the esker and the bog.(Type III). This probably indicates a situation where mixing is occuring of the bog derived water and upwelling water from the underlying gravels in the drain. Two of the samples were not included because they were polluted with organic wastes.

8.6 Future Work.

An extensive hydrochemical survey, particularly in the soak areas will be undertaken in March 1991. The analytical techniques applied will be similar to those described above.It is hoped that

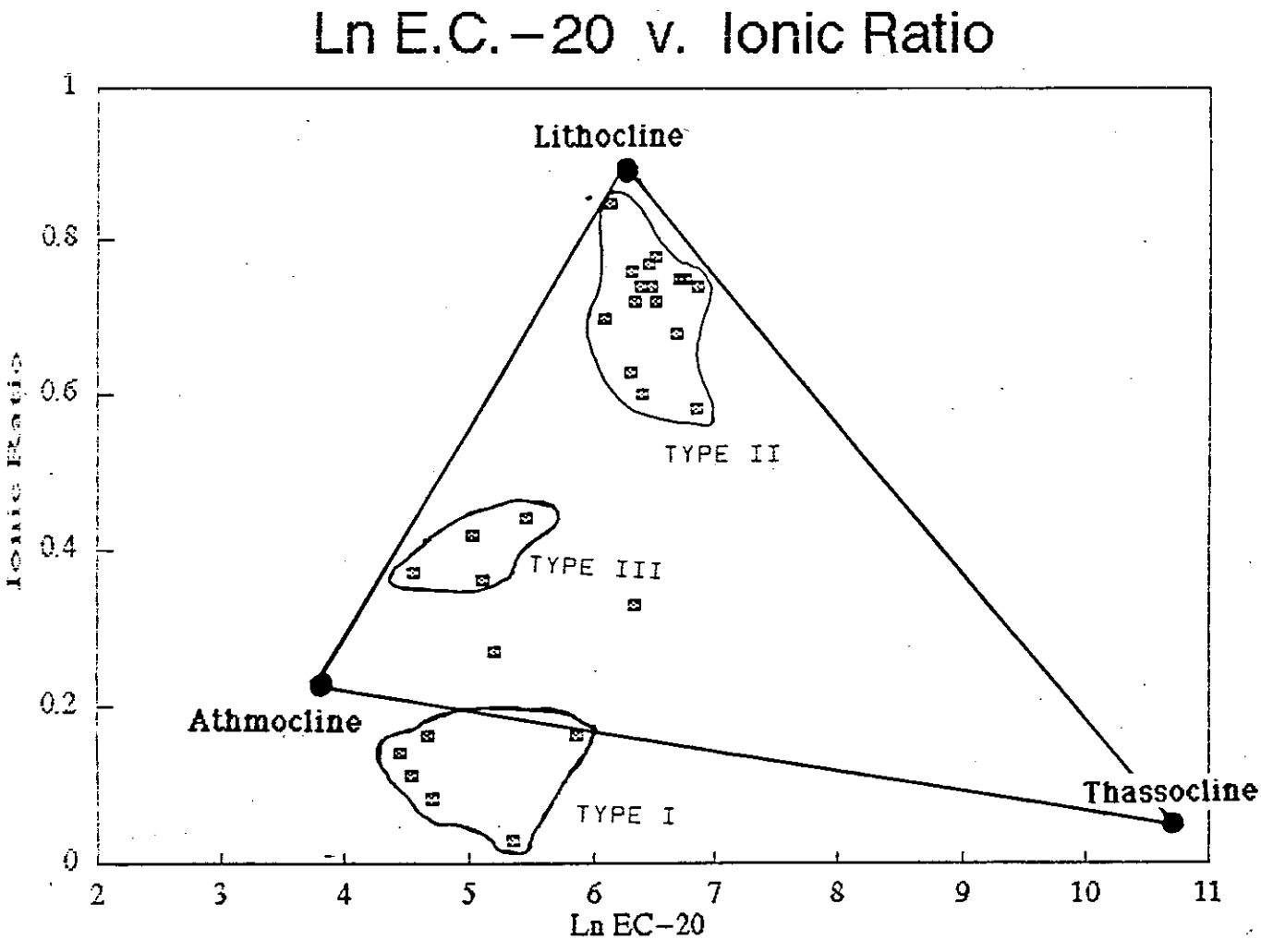


Figure31: Diagram showing a plot of ionic ratio verus the Ln Electrical Conductivity. The three water types are illustrated.

the results of this survey will lead to a better understanding of the hydrological processes operating around and on the bog.

9 Computer Modelling of Data.

9.1 Overview

A major aim of the project is to develop predictive models to describe the dynamics of water movement in and around both bogs . Models may be useful in describing :

1. General peat hydrodynamics,
2. The effects of drainage on the periphery of the bog,
3. The likely effects of peat cutting on the bog system over time, (e.g. subsidence, compaction).
4. Seepage (if any) through the 'confining' clay layer under the peat.
5. The regional flow patterns in the area ,
6. The eskers as a recharge - discharge mechanism for Clara bog and the likely effect (if any) of continued sand and gravel extractions from the eskers on the bog.
7. The effectiveness of removing/blocking drains etc. on the hydrology of both systems.

The above modelling aims are preliminary and may be modified at a later stage.

There are 3 basic types of models which have been used in hydrogeology: scale models, analog models and computer-numerical

models. It is envisaged that numerical models will only be considered in this study. Initially, two dimensional modelling will be attempted on the data sets for the experimental study on Clara East.

9.2 Backround Theory to 2 - D Computer Modelling.

The two dimensional transient flow of groundwater in a confined isotrophic aquifer is governed by the partial differential equation (Fetter 1980) :

$$\frac{\partial}{\partial x}\left\{T\,\frac{\partial h}{\partial x}\right\} + \frac{\partial}{\partial y}\left\{T\,\frac{\partial h}{\partial y}\right\} = S\,\frac{\partial h}{\partial t} + Q$$

where T = Transmissivity,

h = Head,

t = Time,

S = Storativity,

Q = Net Groundwater discharge or recharge,

x,y = Rectilinear Co-ordinates.

This equation is valid for a continuous aquifer for which there are values of T, S, and h everywhere. The continuous aquifer can be replaced by a network of points. If the points are small but a finite difference apart and the spatial changes in h are approximately linear between adajacent points a finite difference model can be applied. The points form a regular grid pattern and the partial differential flow equations are replaced by a set of finite difference equations.

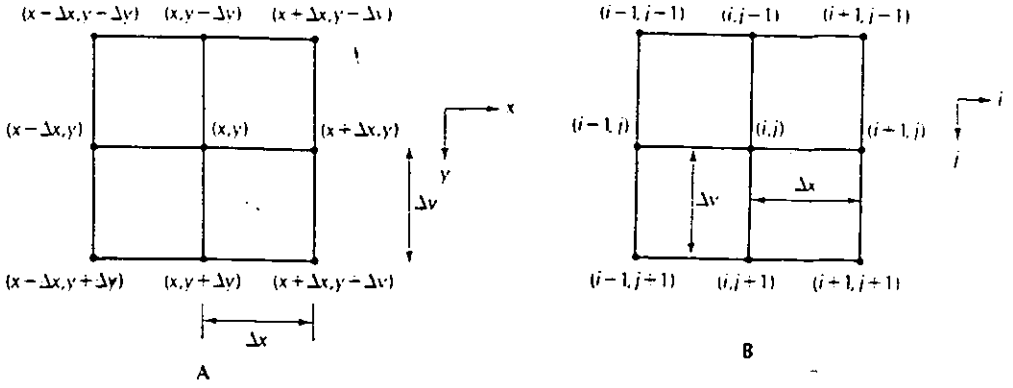


FIGURE 12.24. A. Finite-difference grid; B. Computer notation for finite-difference grid.

The finite-difference form of Equation is given by (40):

$$h_{i,j}(T_{i-1,j,2} + T_{i,j,2} + T_{i,j,1} + T_{i,j-1,1} + S\Delta x^2/\Delta t) \qquad \textbf{(12-16)}$$
$$- T_{i-1,j,2}h_{i-1,j} - T_{i,j,2}h_{i+1,j} - T_{i,j,1}h_{i,j+1}$$
$$- T_{i,j-1,1}h_{i,j-1} = (S\Delta x^2/\Delta t)h\phi_{i,j} - Q_{i,j} + Q_n$$

where

T is the aquifer transmissivity of a volume of the aquifer close to node i, j

$h_{i,j}$ is the head calculated at node i, j

$h\phi_{ij}$ is the head calculated at node i, j at the end of the previous time increment, Δt

$Q_{i,j}$ is the net withdrawal rate at node i, j

Q_n is the leakage or recharge rate into the aquifer

There is a difference equation of the form of 12-16 for each node in the finite difference grid. Generally a large set of equations must be solved simultaneously for h at each node. A solution is obtained by solving the sets of equations for nodes along the rows or columns of the grid starting at one boundary of the model and progressing sideways or downwards to another boundary. For steady flow conditions ($\Delta t=0$), the finite difference equations may be solved to find values of h at all points in the interior of the boundaries. If the problem is time dependent then the initial values of head must be known or assumed. The model then solves for the change of head with time.

9.3 Data Requirements for 2 - D models.

The data requirements for 2-D models are head values, permeability values and discharge and recharge from the system. The description of boundary conditions for the model is also vital for producing a representative model. Generally, modelling data sets are far from complete and less accurate models can be formulated with less data. Comprehensive head data are probabaly the most important and provide a good degree of control in calibration. The calibration of the model to fit observed data is the key to developing a valid model.

The final procedure in validating the calibrated model would be a sensitivity analysis to examine the factors which most affect the model.(e.g. recharge , constant head etc.).

Separate simulations are carried out using the mathemathical model which individual parameters varied in turn over the tolerance to which they are known.

For example the transmissivity may be varied by +/- 40%, the storage co-efficient by +/- 400%, the recharge by +/- 20%, and the condition of an uncertain boundary changed from a fixed groundwater potential to a no flow condition. In each case the sensitivity of the aquifer response in terms of changing groundwater potentials and flows is noted. This will show the sensitivity of the aquifer response to each parameter and may suggest that further field work should be carried out to define certain of the parameters more accurately. It will also indicate the degree of accuracy that can be anticipated from the model.

9.4 Modelling of the Data

Modelling of two systems at different scales is envisaged :

1. The bog system(i.e. the hydrodynamics of the peat) with particular interest in the drains - small scale,

2. The regional system between the Brosna and Silver rivers (discharge areas during the winter period) encompassing the bog and eskers (at Clara) - large scale.

The results from model 1 will be integrated into model 2 to gain an appreciation of the bog system in the regional context.

On Clara East modelling can be performed along the flowline (see section 6.2.5). Flynn (1990) has modelled this line using a finite element model. He showed the model to be most sensitive to recharge, the constant head value in the drain and the permeabilities of the marginal units. A much more extensive model is required to describe the system in more detail. The results of Flynns work suggested a greater density of piezometers was needed closer to the drain and the inclusion of the high permeability acrotelm layer, which was not included, in the model was important. Because of the high water table present in peat during the winter time the acrotelm assumes more importance in describing the movement of water at this time and thus must be included in future models. The AQUA computer package used by Flynn (1990) utilises a finite element method. These methods reproduce accurate heads but associated flows tend to be incorrect(Rushton and Redshaw 1979). With increased piezometer coverage on Clara East a no. of other flow lines may be identified on the bog and modelled in a similar fashion. It is hoped that a progession from two to three dimensional models will be made on the bog since sufficient piezometer nests exist to allow a 3-D grid to be formulated

Flynn (1990) also produced a preliminary model of the esker - drain - bog interface. He found that the presence of the drain distorted the regional flow pattern in the esker deposits producing upwelling through the clay layer into the drain.This has been confirmed through the use of hydrochemistry.The regional flow in the limestone was not affected. The model also suggested downward seepage of bog water through the low permeability clay.

9.5 Regional Modelling

Regional modelling is performed on a much larger scale . Initially a 2-D model will be used to describe the situation on a transect linking the two rivers in the area. Head data from abstraction wells in the Clara area are being collected within a 1.5 km radius for use in the model. Again it is hoped that a progression to 3-D modelling will be possible.

9.6 Available Groundwater Model Packages .

A number of computer packages are available to the author. The simplest is FLOWNET (van Elburg et al, 1989). It models two dimensional steady state saturated groundwater flow in a rectangular inhomogenous anisotropic section of the subsoil. The pattern of flowlines and equipotential lines is obtained by using the finite difference method and a regular grid.

The model SWAMP (Soil Water Modelling in Peat) (Fahner and Schouwenaars 1990) was developed to simulate groundwater fluctuations in peat. In this model the different terms of the water balance are determined using meterological data

(precipitation,evaporation), characteristics of the vegetation (pot.transpiration, depth of root zone) and hydrological characteristics of the peat layers and the underlying geological strata. Following calibration the model is used to predict groundwater levels under different hydrological,meterological and vegetational regimes.

The MICROFEM package is a 3-D development of FLOWNET (Hemker and van Elburg 1988). This package was developed to create and analyze a wide range of multi-layer steady state groundwater flow models with a maximum of 4 aquifers .

Apart from the above models others are described in the literature .Guertin D.P. et al (1987) describe the development and testing of the Peatland Hydrologic Impact Model (PHIM). It is a generalised , deterministic,continuous simulation model. Three independant landtype submodels were created to represent watershed conditions common in the region. These were natural peatland , mined peatland and mineral soil upland. The model is used to predict changes in stormflow,low flow and water yield caused by changes in water sheds such as peatland drainage, peat extraction,timber harvesting or a combination of these land use within a catchment. The model can be used to formulate land management plans that minimise adverse impacts on the quantity and timing of streamflow.

Kemmers and Jansen (1978) used a simple analytical model to calculate stationary changes in water levels in the

Korenburgerveen bog remnant (The Netherlands), resulting from the lowering of the level in adjacent suface water. Because of the large transmissivity of the fluvial glacial sands underneath the bog,even small changes in the surface water level resulted in lowering of the water level in the bog.

Ernst(1979) calculated stationery changes in the water level of the Fochteloerveen bog area as a result of lower water levels in the agricultural surroundings by way of a 2-D analytical six layer model.

Ganzevles and Janmaat(1987) used the computer model STATRECT, based upon the finite element method on the assumptions of a stationary situation and a maximum of 2 aquifers to study the hydrological relations between the Engbertsdijksvenen bog and its surroundings.

Poelman and Joosten (1990) used the FEMSATP model in an ecohydrological study on the Groote Peel bog (The Netherlands). This model consists of the following sub-models :

1. A model of the saturated groundwater system ,made up of a finite element network.
2. A model of the unsaturated zone and the plant/atmosphere system. They divided the bog reserve into 9 sub regions and the surrounding agricultural area was modelled in 5 sub regions : 4 concentric zones of each 500m width around the bog reserve, 600, 800, 900 and 1500 ha, and the remaining part of the

model area, 7000 ha.. For each sub-region a 1-D model of the unsaturated zone was coupled with the saturated zone.
3.A model of the surface water system. For each sub region the water courses were modelled as a single resevoir. The water balance of the surface water consisted of surface run off, inter flow with the saturated system, water supply via inlet structures and outflow over an adjustable weir.

10.0 *Investgations at the old and new peat banks.*

10.1 Introduction

As mentioned in the introduction peat cutting by individuals on the south west part of Clara Bog is prevalent. The resulting face banks may constitute a major impact on the bog hydrology.
The loss of water at the banks will cause the peat at the edge to dry out and in doing so the peat may subside and permeabilities may be altered. Permeability changes and subsidence are the major results of cutting peat. Subsidence may occur in peat due to:
1. Shrinkage due to drying,
2. Contraction by capillary force,
3. Biochemical oxidation. Daly(1980).
When peat is cut the water level will be lowered. This causes oxidation of organic matter (3.) and this results in the peat becoming more decomposed. Boelter(1972) has shown that permeability in peat decreases with increased decomposition. He measured decomposition by using the fibre content and bulk desity as indicators. Therefore, the decomposition of peat due to

facebank drainage will lead to a lowering of the peat primary permeability over time. However, peat shrinkage and contraction at the face banks may lead to crack formation and a large increase in secondary permeability may result.(Anon. 1974 reported in Daly 1980).

A number of projects were initiated at old and new face banks to :

1. investigate the hydrological situation at a new face bank and thus to quantify the immediate effects of peat cutting on the bog hydrological system.

2. to investigate the change in the hydrological situation at a face bank over time and thus quantify the long term effects of cutting on the system.

10.2 Site Selection

It was of paramount importance to select representative sites. Locating the fresh site was relatively easy as cutting at the edges of the bog during the spring and summer months is prevalent in some areas. The selection of the old face bank was more difficult as small drains parallel to face on the bog or cracks in the peat would cause problems with analyses of data later. After extensive reconnaissance of the bog edges a site on the west side was chosen. This site was aged by a botanist (pers. comms. Jan van Dijk) based on vegetation recolonisation. It is considered approximately five to six years old.

10.3 Methods and Techniques

Both piezometry and permeability measurements are the principal techniques which will be employed. Also,the hydrophysical characteristics of the peat may be determined in order to describe the hydrological situation in the peat. Standard 25mm piezometers were installed at different depths on short transects across each bank. The precise locations of the piezometers relative to the banks are illustrated in figure 32.

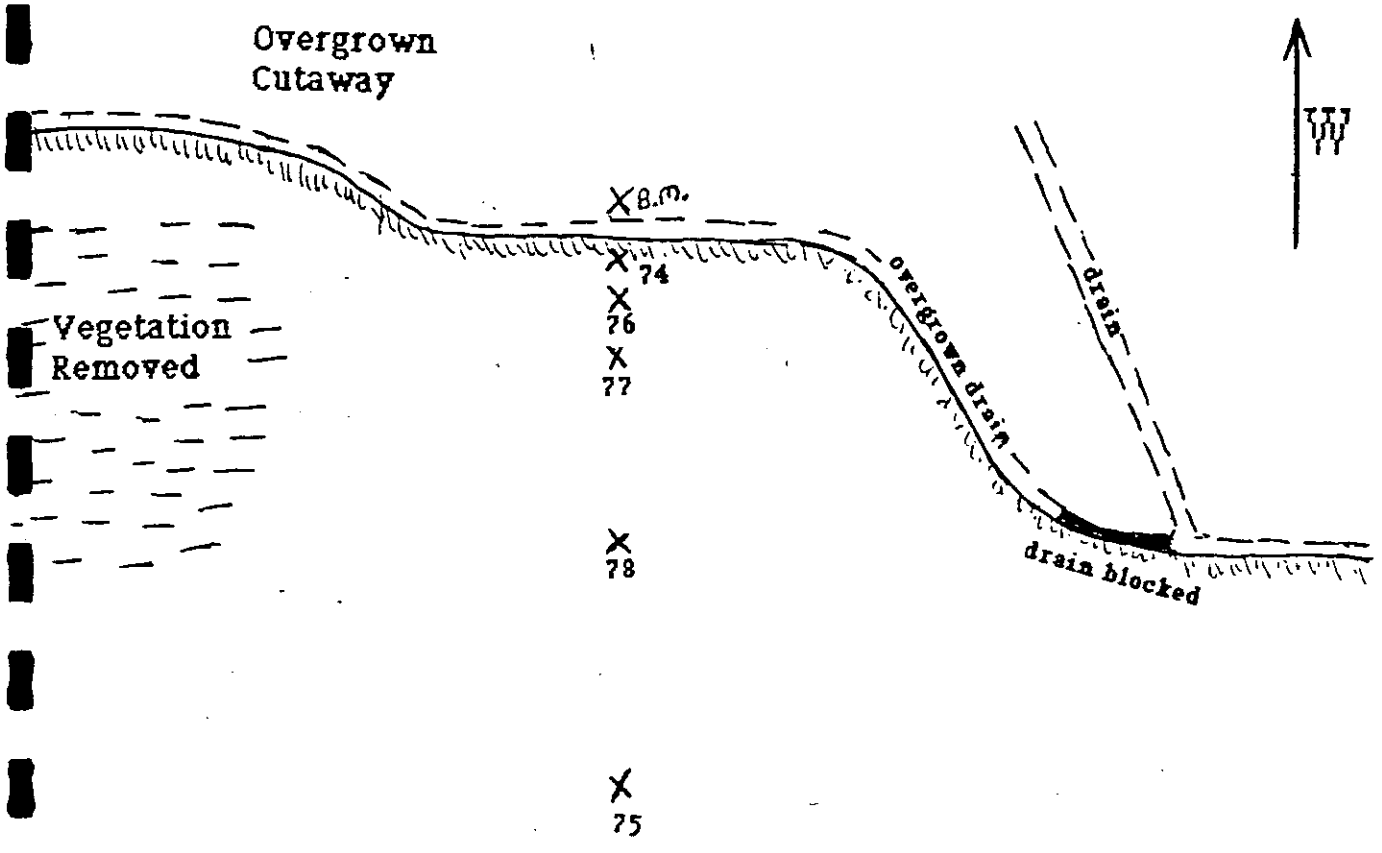
The piezometer heads are monitored on a two weekly basis and constant head permeability tests are currently being employed.

An analysis of the data collected thus far will be initiated in the latter part of March 1991.

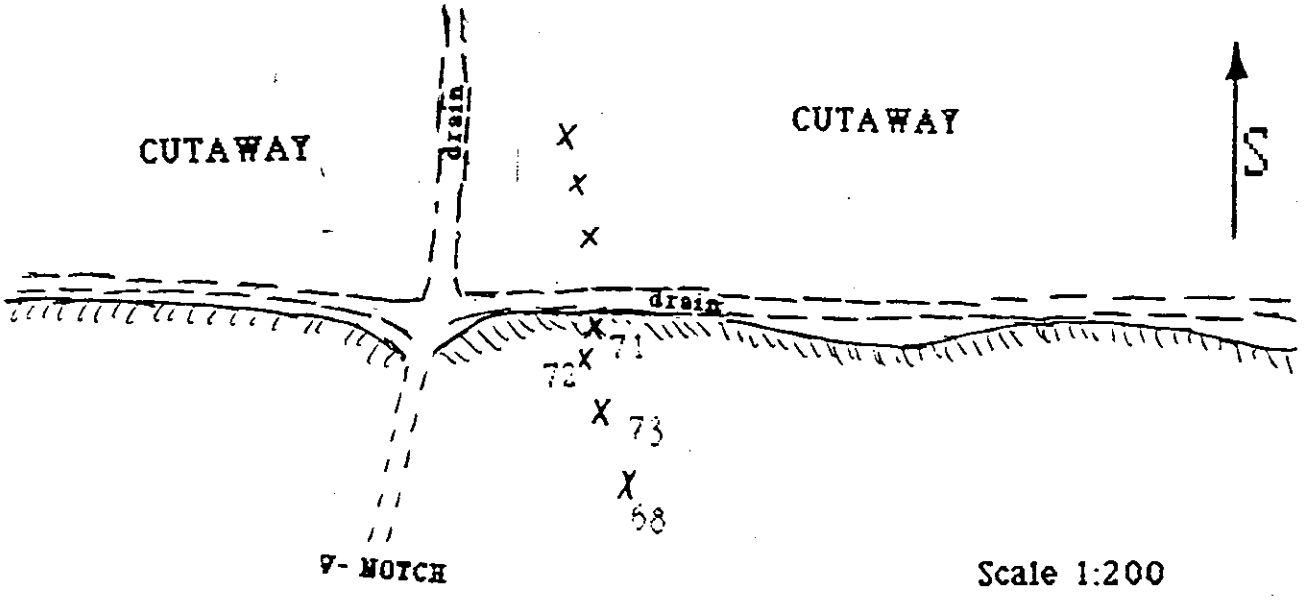
11.0 Lagg Vegetation Zone Hydrology.

The lagg vegetation zone is the marginal area of a raised bog with a characteristic poor fen vegetation indicating the junction of mineral rich and mineral poor waters. On a great many bogs in Ireland this zone is destroyed through peat cutting and drainage. At the east end of Raheenmore Bog a particularly intact lagg zone exists.(pers.comms. Lara Kelly). The succession of plant species across this zone is strongly associated with the hydrological situation within the area. To identify a relationship between the vegetation and hydrology a grid of phreatic tubes was installed across the area of interest. Figure 33 shows a sketch of the grid arrangement. As may be seen a number of drains exist within the area. This may lead to problems relating vegetation structure to

FIGURE 32 OLD FACEBANK CLARA SOUTH WEST



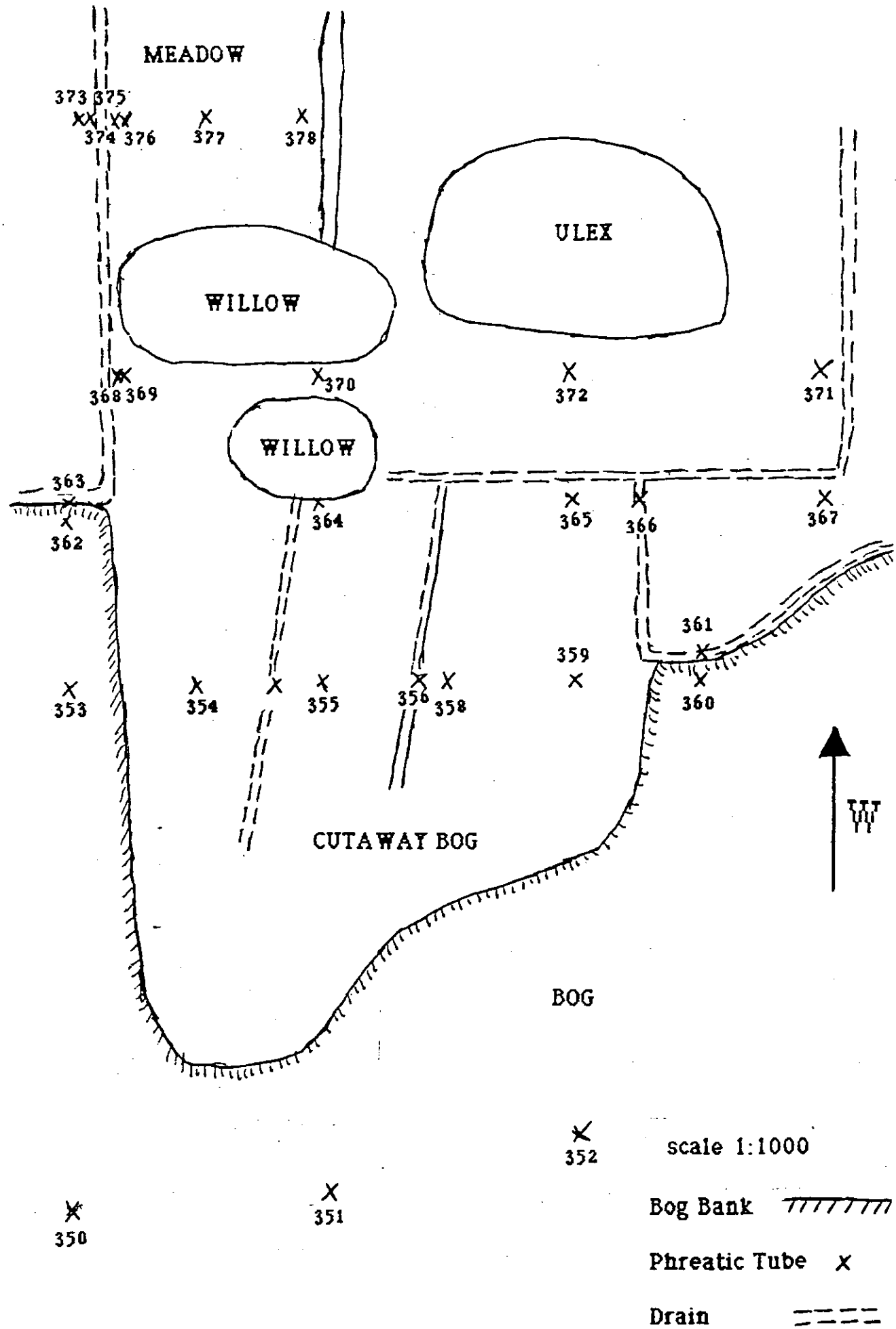
NEW FACEBANK CLARA SOUTH WEST



Scale 1:200

Piezometer 1. Phreatic
depths at 2. 1.50 m
all stations. 3. 3.00 m

FIGURE 33 SKETCH OF PHREATIC LOCATIONS AT RAHEENMORE LAGG ZONE



hydrology. This is because there would be a lag reaction in the response of the vegetation to the new hydrological situation posed by the drains.

The tubes are monitored monthly. At the end of March 1991 a water table contour map for the area will be produced and a decision to continue with this study will be taken.

12.0 Pilot hydrogeological study at Clara North West.

A pilot study to examine the relationship between the esker and the bog in the north west area will begin in June 1991. Figure 34 shows the hypothetical situation in this area. On the north side of the esker there is cutaway peat bog. Clara bog is situated on the southern side of the esker. Its seems likely that the peat was removed prior to the 1900's . (Source : Local farmers). This peat would probably have constituted a part of Clara bog. The lowering of the topographic level may have altered the present bogs hydrology. Since the peat was removed the esker may be acting as a conduit for water flow from the bog. It is proposed that a similar pilot study as on Clara East be instigated to examine the situation. An extensive piezometer transect to the western soak will be installed and holes will be drilled on the esker and close to the soak.

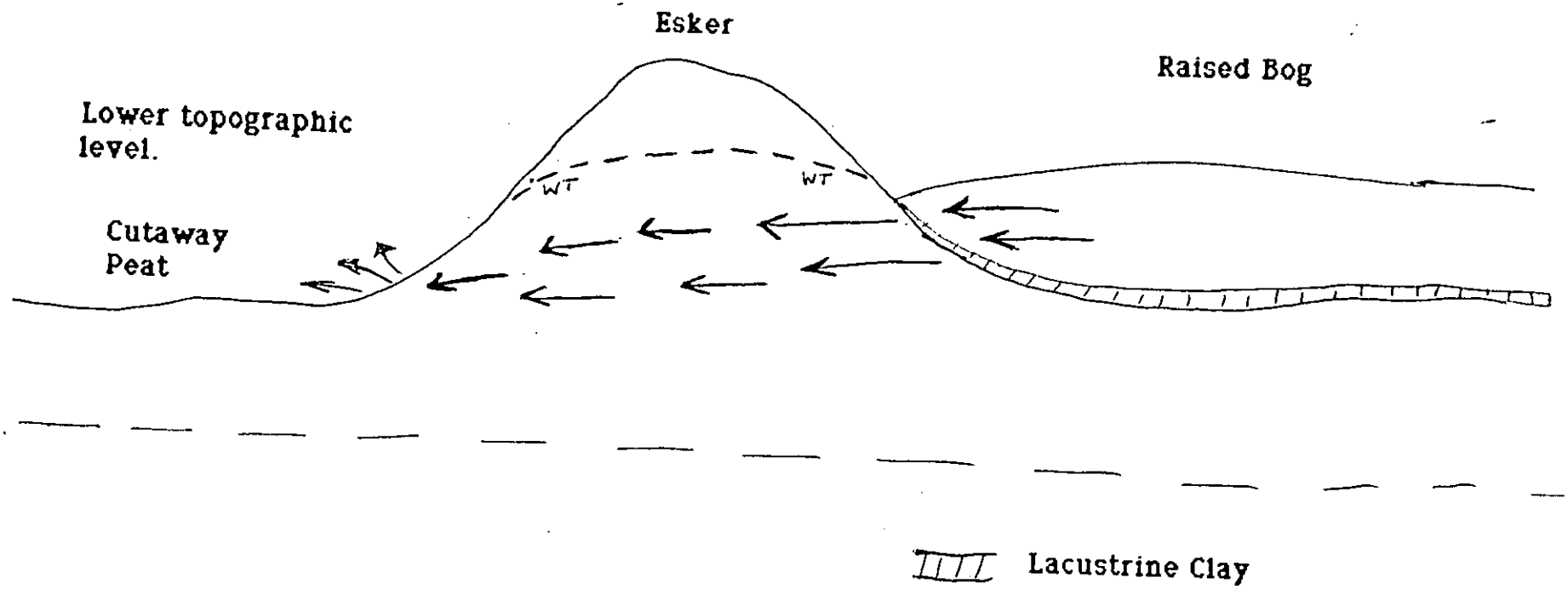


Figure 34: A sketch drawing of the possible situation at the Esker - Bog interface at Clara North West showing the Esker acting as a conduit for flow from the bog.

13.0 Work Programme for 1991.

The work schedule for the period March to December 1991 is shown below:

March

1. Reports on the old/new facebanks and the lagg zone hydrology will be produced for the end of March 1991.
2. Hydrochemical sampling particularly around soaks.

April - May

1. More detailed analysis of Clara East transects.
2. Examine the hydrological situation on a north-south cross section from the River Brosna to the Silver River.
3. Assessment of hydrochemical data from the survey in March.

June, July, August

1. Pilot study at Clara North-West.

September-October

1. A second hydrochemical survey will be performed.
2. Analysis of data from the Clara North-West pilot study.

November-December

1. Assessment of regional data for Clara.
2. Further analysis of data for the Clara North-West transect.

A more detailed work programme can be seen in Appendix **IV** .

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APPENDIX I

Degrees of humification following Von Post and Granlund (so-called degrees of squeeze)

H 1 Completely unhumified plant remains, from which by hand only almost colourless water can be squeezed.

H 2 Almost unhumified plant remains; the squeeze water is light brown and almost clear.

H 3 Very poorly humified plant remains; the squeeze water is cloudy and brown.

H 4 Poorly humified plant remains; peaty substance does not escape from between the fingers by squeezing.

H 5 Moderately humified plant remains; the structure is however still clearly visible; the squeeze water is dark brown and very cloudy, while some peat escapes between the fingers.

H 6 Fairly highly humified plant remains; the structure (texture) is unclear. About a third part of the peat escapes through the fingers. The part remaining in the hand has a more clear plant structure than the part that was squeezed out.

H 7 Highly humified plant remains; about half of the material escapes when squeezed. The water which may escape is dark brown in colour.

H 8 Very highly humified plant remains; two-thirths escapes through the fingers. The remainder consists mainly of resistant bits of roots, wood etc.

H 9 Almost completely humified plant remains; almost all the peat escapes through the fingers. Structure is almost absent.

H10 Totally humified plant remains; amorphous peat; all the peat escapes the fingers without any water being squeezed out.

APPENDIX II

DISCHARGE MEASUREMENT BY CONTINUOUS SALT INJECTION

Principle

A known concentration of salt (C1) is added to a stream at a known discharge (q1). The increase in the concentration of salt downstream (C2) is measured (e.g. by increase in conductivity) once steady state has been achieved. The total mass of salt put in must equal the total mass of salt passing the point downstream so the input concentration multiplied by the input discharge must equal the concentration in the stream multiplied by the stream discharge (q2) i.e.

$$C1\ q1 = C2\ q2$$

Strictly, because the discharge of the stream has been increased by the discharge of the salt solution the equation should be

$$C1\ q1 = C2\ (q2 + q1)$$

However because the discharge of salt solution is small compared to the discharge of the stream it can be ignored. If the stream contains a background concentration of the tracer then C2 is the increase in concentration upon input of the tracer.

Method

Dissolve the salt in bucket.
Measure the conductivity of the solution.
Find a point far enough downstream from the input point to make sure that the solution will have been fully dispersed in the stream. Use a dye if necessary.
Measure the conductivity of the stream.
Add the salt solution at a constant rate by siphoning the solution from a graduated container at a constant head. The rate will have been determined beforehand.
Measure the conductivity downstream - it should rise, reach a plateau and then decline. Input should be for long enough for the plateau to be clearly distinguished. The increase in conductivity over background is C2 in the equation.

Sample Calculation

A litre of salt solution enters in 10 seconds so q1 is 0.1 l/s. The conductivity of the salt solution is 50,000 µS/cm (C1). The increase in conductivity downstream (C2) is 150 µS/cm.
The stream discharge is

$$q2 = \frac{q1 \times C1}{C2}$$

which is

$$\frac{0.1 \times 50,000}{150}$$

$$= 33.3 \text{ l/s}$$

If the salt solution discharge had been taken into account the answer would have been 33.23 l/s.

APPENDIX III

Name	CL BH2 G	CL BH2 L	4M Piez W	Bog Drain	CL BH2 G3	Spring SW
City	Clara	Clara	Clara	Clara	Clara	Clara
Map	1	1	1	1	1	1
Date	1990.0807	1990.0807	1990.0515	1990.0515	1990.0807	1990.0515
Unit	3	3	3	3	3	3
Code	14	13	24	17	12	5
Depth						
Altitude						
Filter1						
X-Coord.						
Y-Coord.						
Type						
EC	748	711	160	512	760	731
pH	7.3	7.6	5.9	6.7	6.9	6.7
Temp.	10.001	10.001	10.001	10.001	10.001	10.001
Na	9.2	9.8	6.8	9.2	8.9	10.7
K	.8	1	1.1	1.3	.7	4.2
Mg	9.73	9.44	1.1	5.5	9.64	7.1
Ca	140	128.5	14.8	128.3	141.77	209.1
NH4	1	0			.58	
Cl	17.5	16.5	17.6	33.3	17.3	31.3
HCO3	456.5	417.41		204.96	439.37	366
SO4	19.6	18.5	20.7	30.5	18	40
NO3	.8	9.4	2.27	7.44	3.5	7.76
Fe	.025	.116	1.03	.38	.189	.052
Mn	.221	.017			0	
Al						
SiO2						
o.PO4	0	0			0	
Calcite	0.35	0.58		-0.61	-0.06	-0.19
Dolomit	-0.29	0.20		-2.41	-1.11	-1.69
Siderit	-10.95	-10.68		-11.88	-11.37	-11.67
Rhodoch	-10.98	-10.71		-11.89	-14.40	-11.70
Gypsum	-1.79	-1.84		-1.60	-1.82	-1.37
OH-Apat	-40.72	-39.46		-34.95	-42.74	-34.23
Chalced	-12.08	-12.08		-12.08	-12.08	-12.08
Quartz	-11.53	-11.53		-11.53	-11.53	-11.53
Gibbsit	-9.12	-9.13		-9.16	-9.14	-9.16
Kaolini	-41.09	-41.11		-41.16	-41.12	-41.17
pe						
Viviani	-61.27	-60.51		-56.92	-62.37	-57.12
P CO2	-1.76	-2.10		-1.50	-1.38	-1.26
Sum +	8.01	7.42		7.10	8.05	11.24
Sum -	-8.15	-7.62		-4.87	-7.91	-7.49
error %	-0.87	-1.34		18.67	0.85	20.04
TIC mg/l	100.48	86.76		59.99	112.68	106.15
Ion.rat	0.78	0.77		0.63	0.78	0.75
Na*	-0.53	0.63		-9.31	-0.72	-6.70
K*	-0.35	0.67		0.64	-0.34	3.58
Mg*	8.55	8.33		3.26	8.48	5.00
SO4*	17.13	16.18		25.81	15.56	35.59
Ca*	139.62	128.15		127.58	141.40	208.43
Na+K+Mgm	1.20	1.23		0.89	1.18	1.16
Na+K+Mgc	0.52	0.49		1.00	0.52	0.94
K-20	671.83	635.61		542.30	667.62	817.41
EC-20	661.98	629.24		453.12	672.60	646.93
error %	0.74	0.50		8.96	-0.37	11.64
ANC	7.46E0	6.82E0		3.35E0	7.18E0	5.99E0
Buf.CO2	5.75E-7	9.75E-7		5.75E-7	4.73E-7	5.75E-7
Buf.tot	2.10E-3	9.82E-4		3.78E-3	5.05E-3	6.56E-3
HCO3H	F3-CaHCO3+	F3-CaHCO3+		F2-CaHCO3	F3-CaHCO3+	F3-CaHCO3
Tot H	F2-CaHCO3+	F2-CaHCO3+		F2-CaHCO3	F2-CaHCO3+	F3-CaHCO3

Name	WELL CLARA	Well Clara	Spring Clara	CL BH 1 CLARA	CL BH 3 CLARA	V-NOTCH CLARA
City						
Map	1	1	1	1	1	1
Date	1990.0615	1990.0615	1990.0615	1989.1127	1990.0807	1990.0504
Unit	3	3	3	3	3	3
Code	2	8	9	3	4	15
Depth						
Altitude						
Filter1						
X-Coord.						
Y-Coord.						
Type						
EC	1008	841	743	534	933	99
pH	6.8	6.9	7	7.1	7.5	4.3
Temp.	20	10.001	10.001	10.001	10.001	10.001
Na	25.9	17.8	9.7	8.6	14.1	9
K	42.9	9.7	1.9	.8	1.4	.3
Mg	15.83	17.09	12.58	4.77	10.68	1.12
Ca	162	108.6	99.33	112.9	177.7	7.78
NH4	.17	.02	0	4.6	.09	.02
Cl	52.6	18.4	17.3	15.8	26.1	17.9
HCO3	451.54	375.88	366.12	402.73	478.43	26.3
SO4	42.6	55.7	20.8	1	71	1
NO3	118.5	21.3	9.9	.1	31.8	.3
Fe	.1	0	0	.01	1.2	.15
Mn	.01	.07	0	.171	.142	.004
Al						
SiO2						
o.PO4			0	0	0	0
Calcite	0.03	-0.24	-0.17	0.03	0.64	-4.92
Dolomit	-0.69	-1.12	-1.07	-1.14	0.22	-10.50
Siderit	-11.26	-14.44	-14.32	-11.18	0.31	-14.98
Rhodoch	-11.38	-11.46	-14.35	-11.21	-10.80	-14.98
Gypsum	-1.47	-1.44	-1.86	-3.13	-1.19	-3.99
OH-Apat	-33.32	-34.31	-42.81	-41.98	-39.55	-65.49
Chalced	-12.20	-12.08	-12.08	-12.08	-12.08	-12.08
Quartz	-11.70	-11.53	-11.53	-11.53	-11.53	-11.53
Gibbsit	-8.62	-9.14	-9.13	-9.13	-9.13	-12.37
Kaolini	-40.25	-41.12	-41.11	-41.10	-41.10	-47.59
pe						
Viviani	-56.64	-65.36	-70.98	-61.68	-27.71	-71.69
P CO2	-1.21	-1.44	-1.55	-1.61	-1.95	0.09
Sum +	11.20	7.53	6.29	6.56	9.91	0.92
Sum -	-11.28	-7.86	-6.91	-6.97	-10.03	-1.01
error %	-0.32	-2.17	-4.68	-3.04	-0.65	-4.41
TIC mg/l	117.77	96.48	89.60	94.55	100.83	769.08
Ion.rat	0.58	0.72	0.72	0.76	0.75	0.16
Na*	-3.33	7.57	0.08	-0.18	-0.41	-0.95
K*	41.86	9.33	1.56	-0.31	0.88	-0.36
Mg*	12.30	15.85	11.42	3.71	8.93	-0.08
SO4*	35.19	53.11	18.36	-1.23	67.32	-1.52
Ca*	160.87	108.20	98.96	112.56	177.14	7.40
Na+K+Mgm	3.53	2.43	1.51	0.77	1.53	0.48
Na+K+Mgc	1.57	0.55	0.52	0.47	0.78	0.54
K-20	937.16	668.84	560.10	547.88	858.95	106.24
EC-20	892.08	744.29	657.55	472.59	825.71	87.61
error %	2.46	-5.34	-8.00	7.38	1.97	9.61
ANC	7.37E0	6.13E0	5.98E0	6.59E0	7.82E0	4.31E-1
Buf.CO2	5.10E-7	4.73E-7	4.61E-7	4.73E-7	8.01E-7	1.15E-4
Buf.tot	5.57E-3	4.33E-3	3.38E-3	2.96E-3	1.38E-3	1.47E-1
HCO3H	F3-CaHCO3+	F3-CaHCO3+	F3-CaHCO3+	F3-CaHCO3	F3-CaHCO3+	F*-CaClo
Tot H	F3-CaHCO3+	F2-CaHCO3+	F2-CaHCO3+	F2-CaHCO3	F3-CaHCO3+	F*-CaClo

Name	LR DeePiez	Road Drain	Borehole NE	Drain CPark	Drain NEast	DUG WELL NW
City	Clara	Clara	Clara	Clara	Clara	CLARA
Map	1	1	1	1	1	1
Date	1990.0615	1990.0615	1990.0515	1990.0515	1990.0615	1990.0515
Unit	3	3	3	3	3	3
Code	21	32	6	31	34	1
Depth						
Altitude						
Filterl						
X-Coord.						
Y-Coord.						
Type						
EC	120	151	844	262	640	1028
pH	4.3	3	6.3	6.5	6.7	6.9
Temp.	10.001	10.001	10.001	10.001	10.001	10.001
Na	9.4	15.4	10	11.2	9.4	40.3
K	.5	.8	1	1.4	2.7	41
Mg	1.218	2.96	22.4	3.1	9.14	1.766

Name	Tinker Weir	TinkerSprin
City	Raheenmore	Raheenmore
Map	1	1
Date	1990.0504	1990.0504
Unit	3	3
Code	28	10
Depth		
Altitude		
Filterl		
X-Coord.		
Y-Coord.		
Type		
EC	500	519
pH	7.5	7.4
Temp.	10.001	10.001
Na	9.6	10.6
K	4.4	1.3
Mg	5.48	13.19
Ca	95	107.13
NH4	2.3	2.3
Cl	18.2	8.4
HCO3	293	422.26
SO4	21.7	1
NO3	21.7	.3
Fe	3.8	2.9
Mn	.099	.101
Al		
SiO2		
o.PO4	0	0
Calcite	0.23	0.32
Dolomit	-0.62	-0.10
Siderit	0.67	0.60
Rhodoch	-10.93	-10.90
Gypsum	-1.84	-3.16
OH-Apat	-40.40	-40.73
Chalced	-12.08	-12.08
Quartz	-11.53	-11.53
Gibbsit	-9.13	-9.12
Kaolini	-41.09	-41.09
pe		
Viviani	-25.91	-26.58
P CO2	-2.15	-1.89
Sum +	5.84	7.03
Sum -	-5.97	-7.05
error %	-1.12	-0.15
TIC mg/l	61.96	90.92
Ion.rat	0.70	0.85
Na*	-0.52	5.93
K*	4.04	1.13
Mg*	4.26	12.63
SO4*	19.14	-0.18
Ca*	94.61	106.95
Na+K+Mgm	0.98	1.58
Na+K+Mgc	0.54	0.25
K-20	505.15	565.71
EC-20	442.50	459.31
error %	6.61	10.38
ANC	4.79E0	6.89E0
Buf.CO2	8.01E-7	6.70E-7
Buf.tot	8.75E-4	1.56E-3
HCO3H	F3-CaHCO3	F3-CaHCO3+
Tot H	F2-CaHCO3	F2-CaHCO3+

APPENDIX IV

IRISH DUTCH PEATLAND GEOHYDROLOGY AND ECOLOGY STUDY

PROPOSED WORK PROGRAMME FOR RICHARD HENDERSON

January:	Installation of extra piezometer sets on Clara East. Preparation of report on 1990 drilling [Report]. Preparation of preliminary report for external examiner [Report].
February:	Constant lead permeability tests on old and new facebanks. Analysis of hydrochemistry data compiled to date [Report]. Monitoring of winter flows in drain at Clara East. Monitoring of water levels in wells in Clara region. Preparation of maps using Geosoft computer package. Appraisal of Hydrocom computer package. Augering with "cobra" drill and Minuteman power anger, in conjunction with Mary Smyth, on Clare Bog.
March:	Water sampling for chemical analyses, particularly near the soak areas. Analysis of all data (head and permeability) from the old and new face bank [Report]. Analysis of phreatic data from the lagg zone at Raheenmore west [Report]. Course to local people.
April-May:	Further analysis of Clara East transects [Reports]. North-south cross-section from River Brosna to Silver River. Assessment of hydrochemical data [Report].
June, July August	Drilling supervision. Six boreholes will be drilled - (i) Raheenmore (ii) Car park on Clara Bog (iii) Clara north-west, (iv) near soak on Clara West (v) The Island, south west of Clara Bog and (vi) south of Clara Bog near Silver River. Detailed pilot study at Clara north-west, including piezometer installation, drilling, permeability tests, pumping tests, hydrochemistry. Pumping tests and permeability determinations in piezometers and boreholes installed in 1990.
September - October:	Hydrochemical Survey [Report] Final report on Clara west Transect. Preliminary analysis of flows at Tinkers bridge, Raheenmore.
November-December:	Analysis of data for Clara north-west [Report]. Assessment of regional data for Clara [Report].

COMMENTS:

1. Monitoring of water levels will continue throughout the year.
2. [Report] indicates that a report will be completed and circulated at this stage.
3. This is a draft work programme which will be finalised in March following discussions with Jan Streefkerk.
4. This work programme was prepared in consultation with Richard Henderson and Richard Thorn.

Donal Daly,
28th February, 1991.