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Some relationships of drainage problems in Ireland to solid and glacial geology, geomorphology and soil types

J MULQUEEN
Agricultural Institute, Ballinrobe, Co.Mayo, Ireland

T N GLEESON
Agricultural Institute, Kinsealy, Dublin, Ireland

ABSTRACT

An experimental study into the relationship between geology, geomorphology and soils and land drainage problems is reported. Site investigations were carried out to diagnose the cause of drainage problems and to relate the problem to geology, geomorphology and soils. Test pits and bores were sunk, drains installed and notes made of soil profiles, groundwater and piezometric levels. Investigations were confined mostly to problems with an element of groundwater seepage.

The results indicated that it is possible to generalise the occurrence of drainage problems. Heavy soils with impervious layers are associated with shales and some sandstones. Stratified impervious layers such as iron pans are associated with granites, schists and some sandstones. Groundwater seepage is a major drainage problem in the Irish lowlands. Seepage is associated with rolling landscape of glacial origin in which layers of gravels and sands are commonly found at depth. Groundwater seepage is also commonly associated with mountains and hills with permeable rocks. Groundwater seepage is widespread along the end moraines of the last general and local glaciations. Theory and experiment show that drains on or near the aquifer are required in order to intercept successfully the flow of water and control the water table.

INTRODUCTION

Experience gained from the investigation of unsatisfactory drainage systems over a number of years indicated that the designs did not consider sufficiently the hydrology of deep underground layers. While most of the drainage problems were complex, many were associated with seepage from higher ground through deep permeable strata. As investigations proceeded, it became apparent that many drainage problems could be correlated with solid and glacial geology and certain soil types.

Practically all geological periods are represented in the solid geology of Ireland (Geological Survey of Ireland, 1962). The Carboniferous formations predominate as its limestones, shales and sandstones cover all the central lowlands. Devonian Old Red Sandstone (ORS) formations occur mainly in the south (Kerry, Cork, Waterford), in Tyrone and in a few inliers in the

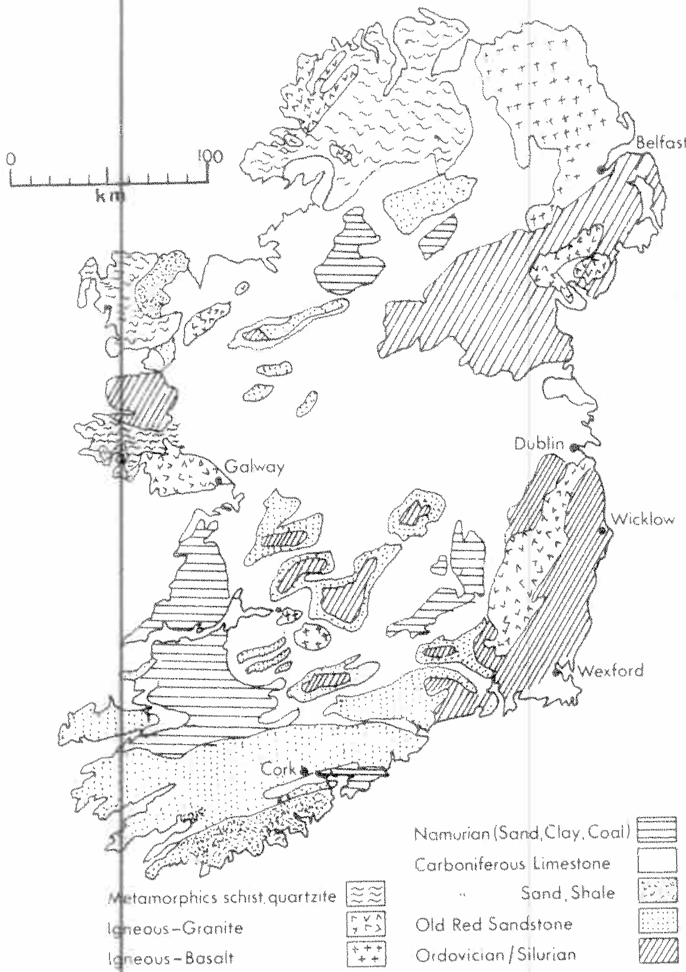

Fig. 1. A simplified geological map of Ireland.

limestone central plain. Ordovician/Silurian account for most of the remainder of the sedimentary rocks (Figure 1). Granites are locally important in Donegal, Connemara and in the Mourne and Wicklow mountains and basalts in Antrim and Derry. Metamorphic schists and gneisses cover extensive tracts in Tyrone/Donegal and in Mayo.

Practically all of Ireland was glaciated. The last or Midlandian glaciation gave to Ireland its distinctive features of drumlins, moraines, eskers and kames (Figure 2). The central lowlands, often thought of as a flat plain, are rolling and undulating with profound influence on the groundwater hydrology.

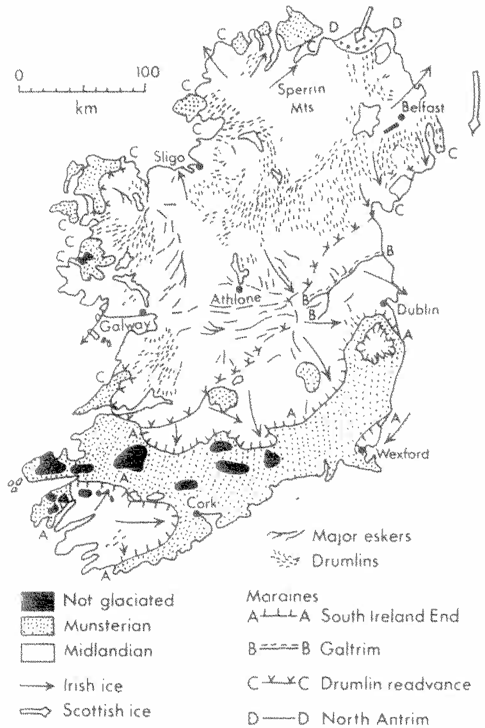

Fig. 2. Glacial geology of Ireland, redrawn after Herries Davies and Stephens (1978).

There is a close relationship between the soils and the solid and glacial geology. Impervious layer problem soils are associated with Carboniferous shales, sandstones and some limestones and some ORS formations (Gardiner and Radford, 1980). Stratified impervious layer problem soils (iron and silica pans) are associated with ORS, Silurian, schist/gneiss and granite formations in situations with deep groundwater.

In Ireland, rocks have been classified as porous, fissured and impervious in relation to aquifers for wells (Aldwell et al., 1976). Only Bunter sandstone (Triassic) is classified in the porous category and this is of limited extent (near Kingscourt, Dungannon and Cookstown). Carboniferous limestone is the major example of fissured rock. In addition, there are numerous local aquifers especially in the Carboniferous limestone and in some volcanic rocks (Aldwell et al., 1976). Rocks such as granites, ORS and conglomerates and Upper Carboniferous shales and sandstones have been classified as impervious (Aldwell et al., 1976). While these rocks may be unproductive for high yielding wells, they can be the cause of significant seepage and spring problems in the upper soil layers. This seepage is transmitted through the upper weathered zone and cavities in the rock.

Glaciation has had a major influence on groundwater conditions. Apart from the formation of rolling and undulating landscapes, glaciers also gave rise to unsorted and sorted deposits which are often interlayered and buried under glacial till. In undulating landscapes, buried layers, lenses and infill deposits of gravels and sands promote the flow of water from high ground into low ground where it often leaks up under pressure to the surface layers causing high water tables and waterlogging. As early as 1907, Kilroe drew attention to the potential of gravels and sands in drift deposits for farm wells. In general, it appears that glacial features have a strong influence on drainage patterns (Herries Davies and Stephens, 1978) and groundwater hydrology in Ireland.

Weathering can also have pronounced effects on the flow of drainage water. The iron pan which develops as a result of downwards leaching and deposition of iron compounds as a cement can effectively act as a barrier. Weathering can also result

in reduction of permeability through a reduction in grain size and/or an increase in compaction.

The solution of drainage problems in the situations outlined requires a knowledge of the flow of water in plain and sloping lands with single and multilayer soils. Analyses of the flow of water into drains and wells in plain land with single layer soils are available for a great variety of geometries (Van Schilfgaarde, 1974; Wesseling, 1973). Analyses of the flow of water through single layer sloping land (Selim and Kirkham, 1972) and multilayer sloping land (Selim et al., 1975) have also been made. The drainage of plain multilayered soils has been analysed and solved by Wesseling (1973) and Toksöz and Kirkham (1971a, 1971b). The occurrence of groundwater seepage additional to rainfall complicates the analyses of drainage. Some solutions for restricted conditions are available (Hinesley and Kirkham, 1966; Najamii et al., 1978). The geometry of the problem must be known before any of the solutions can be applied.

METHODS

A programme of field investigations of drainage problems was set up to discover the type and extent of drainage problems in Ireland and the nature of their geometries. This took the form of site investigations to diagnose the cause of the drainage problem and to relate the problem to the local geological and topographic features. Test pits were excavated by hydraulic digger and some test holes were bored. Soil profiles, water table levels and piezometric heads were recorded. Drains were also installed in a number of locations. Investigations were mostly confined to seepage and high groundwater table problems. Descriptions of representative sites of some typical drainage problems encountered is shown in the results. These are from a preliminary survey and more detailed investigations are continuing.

RESULTS

Solid geology and drainage problems

In general, the underlying rocks were found to affect soil drainage through their influence on the groundwater. For example, soils on highly fissured cavernous limestone are free of drainage problems except where the ground surface intercepts the water table as in hollows or where percolation to groundwater is impeded by layers or pans of low permeability. Rocks of low permeability result in perched or high groundwater tables. This effect was especially noted where the soil cover is thin. Granites and some ORS are good examples of this. In hilly and mountainous areas, the permeability and stratigraphy of the rocks determine the hydrology of the adjacent low lying land in that they determine the nature and amount of surface run-off and deep seepage.

Thin soil on Silurian sandstone near Griggins Bridge, Galway Sheet 25* and Figure 3

The site is located on the lower slopes of the Maumtrasna mountains which rise to 430 m (Figure 3). The solid geology is mostly sandstone. Rock dips vary from 25° to 80°. About the 40 m contour, the ground changes from dry on the upper to wet on the lower slopes. Above the 40 m contour, the soil consists mostly of free draining brown podzolics and semi-pervious podzols. There are peat deposits on the crest. In the valley there is variable thickness of semi-pervious tight fine sand which is overlain by up to 3 m of peat. Below the surface fibrous layer, the peat is very soft and wet. Rainfall is about 2 800 mm/year.

A test trench was cut to the bedrock across the hillside near the 40 m contour. This trench varied from 1 to 2 m deep. Large boulders stopped access to the bedrock in places. More or less parallel trenches were cut down-slope and in the deep peat area. Seepage water was found to issue through joints and cracks in the rock giving rise to surface run-off and hillside seepage on the slope. In the valley, seepage through the rock appeared to be widespread and this was deduced from point and line outbreaks of water rich in iron ochre. This may account for the very liquid state of the peat. The trenches had only

* All Map Sheets referred to are those of the six-inch to one mile series.

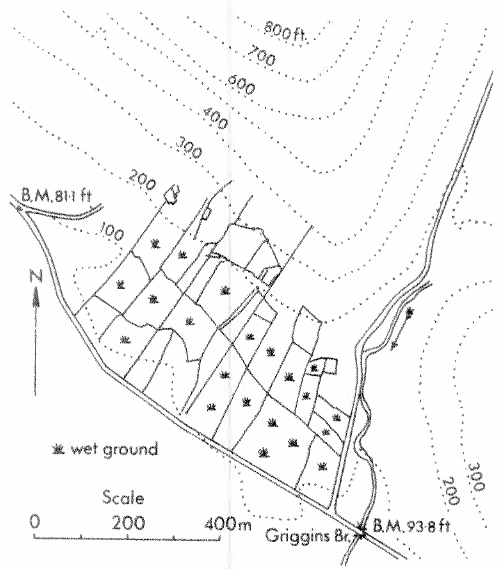

Fig. 3. Location of site at Griggins Bridge showing wet ground subject to seepage and contours in hundreds of feet.

very limited effect in reducing groundwater seepage down-slope of them. Much of the seepage water underflowed the trenches, only to burst out through joints and cracks down-slope. Seepage of this kind appears to be common along the lower slopes and valleys of these mountains.

Springs from ORS at Gallarus, OS Sheet Kerry 42 and Figure 4

Two springs were found flowing from joints at the base of a bench of sandstone rock on the 60 m contour. The rock is a 'Dingle Beds' ORS formation (Geological Survey of Ireland, 1962). The springs are within otherwise dry rocky land. A plant, *Iris pseudacorus* (yellow flag), which was found to be associated with groundwater seepage throughout the country, was growing at the springs. This flow through joints spilled over lower ground. There was a layer of glacial drift increasing in thickness down-slope.

Further down-slope, there is intensive seepage with numerous springs in the glacial drifts. A typical profile in this section was:-

0 - 0.3 m	-	Peaty topsoil.
0.3 - 1.2 m	-	Compacted gravelly light grey loam with flags, gleyed, highly weathered, very slowly permeable.
1.2 - 2.1 m	-	Compacted pinkish loam with many flags and some large boulders, slowly permeable.
2.1 - 2.7 m +	-	Aquifer layer, cobble stones and flags, highly permeable, massive water break-through.
2.7 m	-	Digging stopped.

The cobblestone aquifer appeared to be recharged from large flows through the strongly jointed sandstone bedrock. This gives rise to high heads which were confirmed in piezometers. Three previous attempts to drain this land were not successful because of drain spacing and depth. Drains installed in the aquifer at 2 - 3 m depth on an experimental basis gave control of the water table and indicated the possibility of successful drainage at economic spacings.

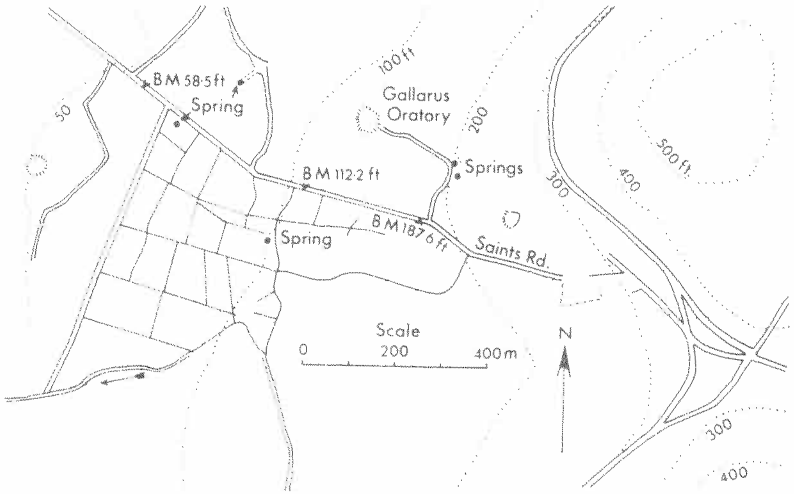

Fig. 4. Location of site at Gallarus showing contours and springs.

Seepage from Devonian shale at Gortroe, OS Sheet Limerick 17

The fields examined lie at the base of the Devonian ridge where it abuts on a dry valley. The valley contains glacial sand and gravel mounds. Test pits were excavated in wet ground just down-slope of the water breakthrough line. A typical profile was:-

0 - 150 mm	-	Peaty topsoil.
150 - 450 mm	-	Very soft light grey gleyed silty loam - very low permeability, the thickness of this layer varied up to 750 mm deep.
450 - 1 500 mm	-	Red flesh-coloured brittle shale - no water breakthrough.
1 500 - 2 100 mm	-	Red flesh-coloured brittle shale, water breakthrough and permeable.
2 100 mm	-	Digging stopped.

Upward gradients were detected in piezometers driven into the ground. Drains were located in the Devonian shale at 1.6 m and spaced according to the gradient i.e. the next drain down-slope was placed where the invert intersected the ground. These successfully dried the ground. This ground had been drained with stone and pipe drains three times previously.

Seepage through Carboniferous limestone

The greater part of the central lowlands of Ireland is composed of Carboniferous formations. As a result of erosion to a relatively flat plain, only the lower synclinal basins remain (Geological Survey of Ireland, 1962). These are mainly Carboniferous limestones and Namurian shales. These strata are covered by thick deposits of glacial drift which dominate the drainage. However, in west Galway, Mayo and Clare there are extensive areas where only a thin layer of soil covers the limestone and indeed the limestone itself is exposed over wide areas as in the Burren and south Galway.

A number of these sites with high groundwater tables and rock exposures were examined. They exhibit classical characteristics of karstic limestone such as underground streams and swallow holes. In general, higher ground in these areas is dry because rainfall percolates freely to the groundwater table. The wet ground appeared to be caused mainly by dipping of the surface below the groundwater table and in a few areas by the occurrence of perched water tables on impervious beds of limestone.

Test bores and a trench were made at the Agricultural Institute farm, Creagh, Ballinrobe where dry land on karstic and wet land on impervious limestone occurred side by side. The bores confirmed that the perched water table was due to very slowly permeable limestone. The wet area was successfully drained into the karstic area by blasting a trench through the rocks. This trench allowed drainage water from the wet area to flow into the karstic area where it soaked away.

Seepage through Carboniferous shale at Rooska near Lisdoonvarna, Clare OS Sheet 8

In general, Upper Carboniferous shales give rise to fine textured soils of very low permeability. The drainage of these soils requires very close spacing combined with improvements in permeability (Mulqueen, 1974). But scattered throughout otherwise uniform wet land on Carboniferous shales are occasional dry areas and hillocks. These hillocks are frequently surrounded at the base by very wet ground. In Co. Clare, the dry land has been classified Kilfergus series (Finch, 1971). It also occurs in Cos. Leitrim, Cavan and Sligo. On examination, the dry areas were found to consist of shallow soils overlying highly fissured, brittle and sometimes loose shale bedrocks. This brittle shale was found to continue into the wet low ground. Clearly, the permeable shale was transmitting the water from higher into lower ground where it gave rise to strong seepage. A typical profile at a site at Rooska was:-

0 - 225 mm	-	Topsoil.
225 - 700 mm	-	Weathered greyish clay loam, with much silt.
700 - 1 350 mm	-	Black shaly soil, soft and slow draining.
1 350 mm +	-	Brittle shale rock, loose with water breakthrough, the depth to brittle shale varied up to 1.8 m.

It appears that deep drainage would successfully solve this drainage problem.

Glacial geology and drainage problems

Glacial geology appears to have widespread influence on drainage problems. The predominant features were produced by the Midlandian glaciation (Figure 2), the Irish equivalent of the North European Weichsel and the British Devensian. The remainder of the country was covered by local glaciers and the earlier Munsterian (Saale, Wolstonian) glaciation. As the glaciers melted, they gave rise to moraines, kames, eskers, drumlins and plains and valleys of till and outwash deposits. These glacial features often contain layers and lenses of sands and gravels. These layers promote the flow of water from high to low ground in undulating and rolling landscapes.

Moraines, kames, eskers and associated plains and valleys are common in the central lowlands of Ireland and near the extremities of the Midlandian glaciation. The drumlins are almost entirely confined to the last glacial re-advance (Figure 2). While some drumlins are free draining and even contain melt water gravel and sand layers e.g. at Creagh, Ballinrobe, they are mostly covered by soils of low permeability.

Some hydrological characteristics of glacial features relevant to drainage are illustrated in the following three examples drawn from a large number of investigations.

Deep blanket peat at Muingmore, Mayo OS Sheet 25 and at Glenamoy, Mayo OS Sheet 12

This area of north-west Mayo has gently rolling topography. It does not appear to have been glaciated in Midlandian times (Figure 2). At Muingmore the ground slopes from the Hill of Tristia (129 m OD) to the low ground in Muingmore (about 10 m OD); slopes are generally about 3%. Two sandpits were examined high on the side of Tristia hill. Sandpit 1 shows sandy glacial drift with some boulders varying from 900 to 2 400 mm thick resting on gneiss bedrock. Sandpit 2 shows a 7.5 m thick sand deposit. The top sections of both pits had podzolised iron pans which give rise to perched water tables. Below the iron pan the sand is permeable. The peat varies up to about 1.8 m except where it is cut-over.

On the lower flats the peat is about 4.6 m deep. Over most of the area it rests on a grey silty sand with micaceous coarse sand in places. There was a slow but steady inflow of water into test pits and a strong flow from the micaceous sand. At depth the peat was strongly decomposed and tended to collapse into the test pits. These peats have extremely low permeabilities.

Some piezometric results are shown in Table 1. High sites were located on high ground with iron pans. Results indicate a perched but falling water table over the iron pan while the groundwater was deeper than 3.35 m. On the low ground results indicate falling or nearly static groundwater levels.

TABLE 1

PIEZOMETRIC LEVELS (BELOW GROUND SURFACE) AT A HIGH (H) AND A LOW (L) ELEVATION AT MUINGMORE IN WINTER

1) High: peat depth - 1 668 mm					
Piezometer depth (mm)	900	1 118	2 100	3 350	
Piezometer water level (mm)	254	406	dry	dry	
2) Low: peat depth - 3 759 mm					
Piezometer depth (mm)	900	2 100	3 350	3 530	4 570
Piezometer water level (mm)	343	279	483	635	1 245

At Glenamoy the topographic and soil conditions are somewhat similar to those at Muingmore. On the high ground there is about 1.2 m of peat resting on podzolised shattered mica schist. There, all leakage through the iron pan percolates to the groundwater through the permeable shattered mica schist. On the low ground the peat is generally 3 m deep but may be up to 5 m in depressions. The subsoil is silty sand with slow permeability. However, in some test pits there was a rapid inflow of water suggesting that the subsoil conditions are not homogeneous. Piezometers were installed at 5 depths at 4 elevations along a transect downhill in the low ground. Results from one elevation are shown in Table 2.

TABLE 2

PIEZOMETRIC HEIGHTS AT ONE ELEVATION WITH 2 730 mm PEAT ON 13/2/81. (WATER TABLE WAS AT SURFACE OF GROUND)

Piezometer depth (mm)	800	1 900	2 900	3 900	5 900
Water level (mm) below surface	10	30	90	190	1 210

There was a very small downward hydraulic gradient in the peat and a strong downward hydraulic gradient in the subsoil. The piezometers behaved similarly at the other elevations. A piezometer was driven through the bed of the outfall stream at the base of the slope to a depth of 2.9 m. This stream is an erosion channel with all the peat washed away. The bed of the stream was on the mineral subsoil 5 m below the level of the bog. The piezometric height was 1.5 m above the bed of the stream which had 100 mm water depth.

The occurrence of blanket peat over mineral soils with pans is well known (Crompton, 1956). This was found on hillocks and high ground. Down-slope on the lower ground there was no evidence of a pan. The presence of a falling water table at all elevations suggests deep percolation and flow of water downhill from the high to the low ground. The piezometers also suggest the presence of permeable layers at depth. The occurrence of seepage in low ground where the peat has been mostly cut away, the occurrence of hillside seepage and the absence of pans at Geesala and Glenamoy on low ground with deep peat and the occurrence of positive piezometric heads above the mineral soil/peat interface raises the possibility that these peats may have developed in the early stages under the influence of seepage. Similar hydrological conditons have been found over much of west Mayo, in Donegal and west Kerry.

Artesian seepage at Kilcorney near Enfield, OS Sheet Meath 48

This site lies in an area of extensive deposits of moraines and eskers at the south western extremity of the Galtrim moraine (Figure 2). The topography is shown in Figure 5. A

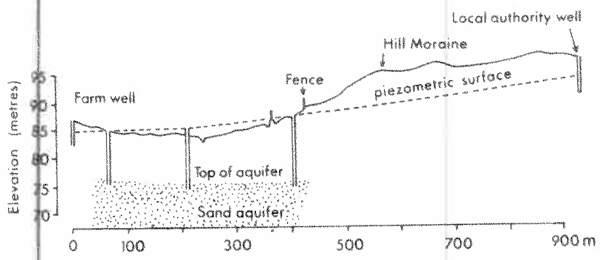

Fig. 5. Transect of an artesian seepage at Kilcorney.

survey showed the occurrence of springs, water weeds and positive upward gradients and that the matrix of the soil is very tight and of very low permeability. Three test bores were drilled across the low lying ground (Figure 5). Water levels were recorded in these and in two adjoining wells.

Test bore 1 showed bluish silt loam with a 300 mm layer of gravel at 5 m and a coarse sand with a 600 mm thick gravel aquifer at 11.4 m. Test bore 2 showed that the aquifer began at 9 m and coarse sand and gravel occurred at 11.4 m. In test bore 3 some seepage occurred at 4.2 m and a sand with gravel aquifer at 8.1 m. The sand and gravel was 0.9 m thick. In test bores 2 and 3 the layer immediately above the gravelly sand contained layers of sand. The static water level in test bore 2 was 1.5 m overground. A fourth test bore was put down near test bore 2 and developed for pumping. However, it went dry indicating that the aquifer is not continuous. Test bore 2 continued to yield water under artesian pressure.

A 7 m deep ditch was cut at the intersection of the wet and dry ground. This showed the occurrence of discontinuous layers, lenses and deposits of gravels and sands surrounded by glacial till. At one point an infill of rounded boulders and cobblestones with some gravel and sand was found. This was 5 m at the widest point and about 5 m deep and probably the site of a glacial braided stream. Only small seepages were met along the invert of the ditch and no spring was encountered. This ditch had little effect on the piezometric heads but it did

collect water flowing through the sand layers above the level of the bed. After two days of heavy rainfall in September, test bore 1 rose from 2.05 to 0.85 m below ground level despite being only 8 m downhill of the ditch.

Test bore 2 yielded 2 700 l/h at 4.5 m drawdown. The level of test bore 1 fell from 660 to 813 mm below ground level and test bore 3 fell from 700 to 940 mm as a result of pumping test bore 2. All these values were steady state. On cessation of pumping after 44 h, well bore 2 recovered 90% of its drawdown within 0.5 h.

This artesian drainage problem is caused by a leaky aquifer. The rapid response to rainfall suggests that the aquifer is connected to permeable layers in the morainic till. Moreover, other layers of sand and gravel shallower than the main aquifer aided the transfer of water into the low ground. The possibility of discontinuities in the aquifer calls for the location of relief wells in the best situations.

This type of drainage problem was the most common found in the central lowlands. It was found for example at Ballinasloe, Castleboy, Kiltulla, Roscommon and Tulsk, in the Howardstown soil (Co. Limerick and Westmeath) and very frequently in Co. Mayo. Unlike Kilcorney the confining layer was soft loose and non-cohesive and was semi-liquid. Springs were found less frequently than at Kilcorney.

Groundwater seepage at Sevenacres, Clonlahy, OS Tipperary Sheet 71

This site lies on the lower slopes of Slievenamon mountain (Figure 6). The upper half approximately corresponding to the 60 - 90 m (200 - 300 ft) contour band is underlain by Devonian shale and conglomerate while the lower half (below the 60 m contour line) is underlain by Carboniferous black earthy shales with flaggy limestones. Glacial drift from the Midlandian glaciation covers the whole farm.

The farm coincided with the end moraine of the Midlandian glaciation (Figure 2). Test pits in the wet upland area showed that the soil consists of sandy to clay loam boulder clay with numerous sand and gravel lenses and layers to about 2.5 m deep.

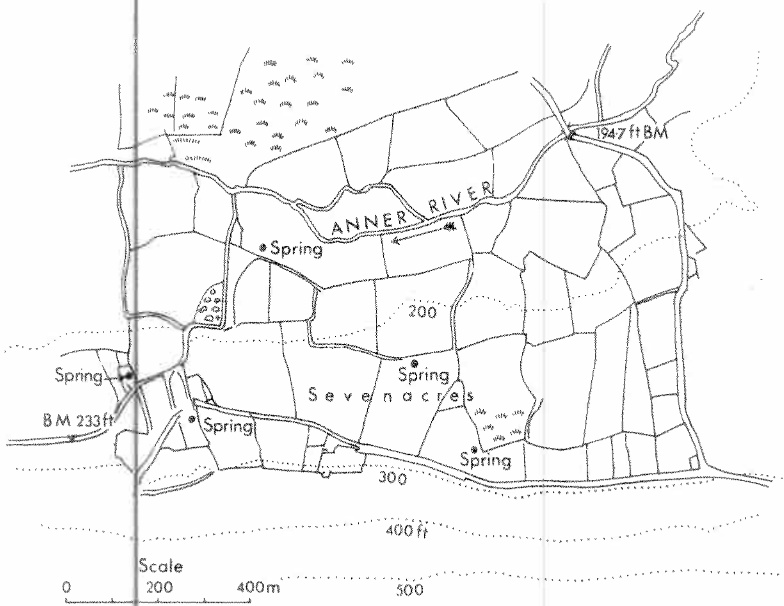

Fig. 6. Contours (ft) and springs on Sevenacres Farm.

This rested on stiff black boulder clay. There was strong to massive breakthrough of water through the gravel and sand. There are five springs shown in Figure 6. One of these near the southern boundary is used as a farm gravity water supply. Yellow flag *(Iris pseudacorus)* is locally abundant. Test pits in the wet lowland area (backswamp region of the River Anner) showed that the top metre or so is alluvium of a silty loam texture underlain by a 1 - 1.3 m layer of coarse gravel with some coarse sand on stiff dark grey boulder clay. In one test pit the boulder clay was underlain by a 450 mm thick layer of lake clays. A very strong spring was associated with the gravel underlayer.

Almost 70% of the farm is wet and the other 30% is free draining. The free draining soil consists of a deep well drained loam of about 1.5 m deep, the bottom layers consisting of gravelly loam. Side by side with this and at the same elevation is a very wet area characterised by strong springs.

This suggests that the springs arise from permeable layers in the underlying sandstone, breaking through the rock and stiff overlying boulder clay into the very permeable gravels and sands. In these gravels the spring spreads out to affect large areas of ground because of the very low head loss. Peat depths of about one metre and more developed in areas subject to strong seepage.

This problem of groundwater seepage from higher ground appears to be widespread along the boundary of the last glaciation. It has been found at Dunlavin (Co. Wicklow), Solohead (Co. Tipperary) and extensively in Co. Limerick. It has also been associated with local glaciations in Co. Wicklow at Brittas and is widespread in Co. Kerry.

Soil types and weathering in relation to drainage

Impervious layer problems

Soils with thick structureless plastic impervious layers and with high fine sand, silt or clay contents are often associated with Namurian shales and limestones in Clare, Limerick, Kerry, Kilkenny, Leitrim and Sligo (Gardiner and Radford, 1980). They are also associated with drumlins as in Monaghan, Cavan, Leitrim and Clare. Impervious layer soils are also associated with ORS formations in Clare and Tipperary (Slieve Felim). Generally soils derived from ORS formations do not have the extremes of low permeability associated with the Namurian shales. These impervious layered soils are characterised by a thin topsoil (80 - 400 mm) resting on a tight very slow draining clay, silt or fine sand. Measured permeability is as low as 1.10^{-5} m/day. The drainage of these soils was discussed by Mulqueen (1974).

Stratified impervious layers and weathering

Soils derived from many rocks are intrinsically permeable when located in suitable topography. These include ORS and Silurian sandstone and shales, most Carboniferous limestones, schists, gneisses and granites (Aldwell, 1980). But in these, weathering can result in the formation of pans. These include iron and silica pans and calcrete pans on limestone derived sands and gravels.

Glaciation often resulted in a transfer of drift from one rock type over another. This has produced drainage anomalies when for example iron pans develop on ORS drift over Carboniferous karstic limestone or over a gravel moraine with a tight fine sand pan. Examples are found near Killorglin (Kerry) and Creggs and Castlecoote (Roscommon).

Iron and silica pans

While the thin iron pan is well known (Crompton, 1956), unusual examples of iron pans have been found near Pollatomish (Mayo) and near Killorglin (Kerry). In both areas, pans are deep and thick. They vary in depth from 0.5 to 2 m below the peat-mineral interface. They vary from clearly defined iron pans to thick cemented layers up to 0.5 m thick. This pan consists of fine sands in some areas and gravels in other areas cemented together by iron, organic matter and other compounds. The Pollatomish pan adjoins a block of land with artesian seepage breaking through gneiss bedrock. Yet another unusual occurrence has been found at Beaghmore (Tyrone) (Dardis, 1980). Here a variable depth of cut-over peat, commonly 600 mm, overlies an iron pan which in turn in some places overlies a silica pan on a deposit of gravel. Kilroe (1907) has noted calcrete and iron cemented gravels and sands forming a hard conglomerate near Moneyneany close to Draperstown (Derry). Calcrete pans are also known from Mayo and Galway on sands and gravel deposits (Kilroe, 1907).

Impervious layer and seepage problems on ORS drift

Many soils on ORS drift are wet (Gortaclareen and Puckane series) in Clare (Finch, 1971) and similar soils on the Slieve Felim/Keeper Hills near Newport (Tipperary) and Doon (Limerick). These soils are characterised by tight upper layers with bulk densities up to 1 620 kg/m^3. Permeabilities are very low and if drains are to be effective in this horizon, the soil must be loosened. The layers deeper than 1 000 to 1 500 mm are less

tight and more permeable with slow inflow through small cracks. Sometimes, there is groundwater seepage present as springs or diffuse seepage. Where springs or clearly defined seepage are present, they must be intercepted with deep drains into or near the aquifer. It appears that gravel mole drainage, together with interceptor drains where required, offer the best prospects for drainage of these problem soils.

DISCUSSION OF DRAINAGE

Rock types influence drainage mainly because of the grain size which results from weathering. Namurian shales give rise to soft and stiff plastic soils of very low permeability. Where these soils are deep, they can only be drained by mole or gravel mole drainage. Limestones, sandstones, granites and metamorphic rocks mainly give rise to loamy and sandy soils. Weathering on the more sandy soils can give rise to stratified pans. These can be broken with rippers and ploughs. Where they are overlain by more than 600 mm of peat, the pans can be broken by digging and trenching.

The Irish landscape is mountainous along the coastal belts and hilly inland. The hills are mostly of glacial origin but with significant ORS hills. Mountainous and undulating topography gives rise to differential water tables inducing seepage from higher to lower ground. Seepage water problems in turn merge with high groundwater tables as in the basins of some rivers. Seepage water flows through rocks, glacial tills and meltwater deposits. Seepage breakthrough from solid rocks is difficult and uncertain to resolve. While springs can be piped away, seepage through the joints and fissures is difficult to control. Moreover, recharge is often large because of high rainfall and extensive catchments.

Most seepage of agricultural importance comes through glacial tills and meltwater deposits. Flow takes place through layers depending on their permeability and topography (Selim et al., 1975). Successful drainage can be accomplished by using the theory for the drainage of layered soils. This theory shows that for realistic drain spacings the drains must be on or near a permeable layer (Table 3).

TABLE 3

DRAIN SPACING (METRES) FOR 2-LAYERED SOIL FOR K_1 (OF UPPER LAYER) = 100 mm/d, AND K_2 (OF LOWER LAYER) = 25 m/d WHERE THICKNESS OF UPPER AND LOWER LAYERS AND 2.0 AND 1.0 m RESPECTIVELY AND RAINFALLS OF 10 AND 20mm/day. STEADY STATE ARCH IS 300 mm BELOW GROUND SURFACE. CALCULATED FROM NOMOGRAPHS BY TOKSÖZ AND KIRKHAM (1971b)

Drain depth (m)	R = 0.01 m/day	R_2 = 0.02 m/day
0.5	2	1
1.0	6	3
1.5	14	9
1.7	25	11
1.8	34	14
1.9	45	16
2.5*	77*	52*

* Drain in permeable layer; design water table crest at interface of lower/upper layer.

Before the theory can be applied, the geometry of the problem must be known. The investigations have shown that the geometries are complex. Not alone does the soil vary from area to area, but at any one site there can be continuous and discontinuous layering. This layering gives rise to great differences in permeability. Moreover, the drainage of the surface layers can be considerably influenced by the nature and hydrology of the underlying layers. This has already been emphasised by Van Hoorn (1972) in relation to the drainage of river flood plains. A thorough knowledge of the soil and hydrological properties at depth is essential to determine the feasibility and design of drainage.

These investigations have also shown that it is possible to generalise the occurrence of drainage problems in relation to solid and glacial geology and topography. Heavy soils with impervious layers are associated with shales, iron pans with granites, schists and some sandstones. Mountains and glacial features such as kames and ridges induce seepage into the lower ground. This is greatly facilitated by the occurrence of stratified sands and gravels. When the geology and topography are known, the drainage problems are known too in a general way

(De Ridder, 1972). Anomalies do exist as a result of translocation by ice of debris of one rock type over another but this can be anticipated from a knowledge of the solid and glacial geology. This information can be obtained from geological and soil surveys and can be used as a basis for drainage investigations.

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