Hydrogeological Aspects of Agricultural Drainage in Ireland

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ABSTRACT / Hydrogeological principles and approaches have been applied to the problems of agricultural drainage in Ireland in the hope that such application will contribute to the better solution of the many drainage problems in Ireland. The legal position and a short history of drainage in Ireland are given, as well as a list of the many state bodies involved in arterial and agricultural drainage. The evolution of the present Irish environment is outlined, from the end of the last ice age to the present day, with emphasis on the formation of lands in need of drainage.

Natural conditions indicate that agricultural drainage was required over some 50% (34,450 km^2) of Ireland; the achieved agricultural drainage extends over some 29.3% of the country. Natural conditions affecting drainage are set out under the headings of topographical, geological, hydrogeological, vegetative, and hydrochemical influences as well as man's actions with regard to drainage.

The third portion of the article deals with the ways in which areas now requiring agricultural drainage have been formed. Areas of low or nil infiltration are described, with some emphasis on such occurrences as lacustrine marls, pans of various types, the effects of the Calp and the Namurian in Carboniferous strata, and conditions under which rejected recharge by overfull aquifers produces winter marshes. Then areas afflicted by high, but often diffuse, groundwater discharge are noted. And the effect of bog growth, both raised bogs and blanket bog, are outlined; drainage of bogs is a very specialized operation, mainly undertaken by Bord na Mona.

Some of the harmful affects of drainage are outlined, as reduction of grazing during rare droughts, of lands suitable for waterfowl, as well as some pollution from bog drainage. Drainage does not deplete the groundwater resources of Ireland, which are abundant and little used. The article ends with some general conclusions and a list of some 13 unusual ideas which arise from the application of hydrogeological principles and approaches to problems of agricultural drainage in Ireland.

Drainage is a major means of improving agricultural lands in Ireland and confers many other benefits, such as reduction of floods, improving communications, and better navigation. Two types of drainage are distinguished in Ireland—arterial drainage, concentrating on streams, rivers, and lakes; and field drainage, concentrating on agricultural lands which are too wet for modern farming in one way or another.

In field drainage, there are very close connections between the groundwater and the areas in need of drainage. This has been recognized in a practical way, but there has been only a very limited investigation of the hydrogeological conditions favorable to waterlogging on lands and affecting the proper means of drainage in some situations. This article deals mainly with the hydrogeology of waterlogged agricultural lands and the ways in which an understanding of the hydrogeology and the groundwater can assist in the efficient drainage of the lands. It deals with the drainage of peat, since drained peat is usually converted to agricultural or forest uses.

This presentation also deals with aspects of environmental geology. Any change in the water regime of an area produces changes in the ecology, great or small. Hydrogeology indicates the causes of waterlogged lands needing drainage; it can foretell the changes in water level which will follow drainage. Since these in turn affect the overall environment of the drained and adjacent lands, hydrogeology here forms an important field of the wider science of environmental geology. Drainage has affected large areas of Ireland; some of the causes and effects of such operations are described here.

Scope of Article

This report is concentrated on field or agricultural drainage, and not on arterial drainage. The two are interrelated, as in the statement by Bruton and Convery (1982):

> Two types of drainage—arterial and field—are identified. Arterial drainage involves the artificial widening and deepening of main rivers and important tributaries in order to increase their effectiveness in draining their catchment areas. Field drainage comprises the activities necessary to remove surplus water from fields. The two are

interdependent in the sense that in some areas successful field drainage is contingent upon arterial drainage having been undertaken, and the full benefits of arterial drainage can only be captured if the complementary fieldwork is done.

So some background data is given on arterial drainage, but its interrelationships with hydrogeology are not stressed.

The main body of the report deals with the natural conditions in Ireland affecting our agricultural drainage; the basic fact that our microtopography was molded by ice (solid water) and is not a topography evolving solely under the effects of liquid water is stressed. With regard to the quantity and quality of our drainage waters, emphasis is on the differences between areas of low or nil groundwater infiltration and areas of high and medium groundwater discharge. The report also deals with the drainage of peats, which cover some 17% of the country. Some possible harmful effects of drainage are considered, as it effects groundwater resources and also the environment of farmlands. The 1971 "Land Drainage Problem" map by An Foras Taluntais shows 10 types of drainage problem areas, and covers the whole of Ireland (Galvin, 1971).

This report does not, of course, deal with costs and economics of drainage or of the groundwater component, as Convery (1980) does. From the beginning, the investment of public funds in schemes which eventually benefit private landowners has been a subject of much controversy. Since 1970, the Board of Works has made cost/benefit analyses of all its schemes; that on the Maigue has been published (Steering Group, 1978). These controversies on economic justification and cost/benefit ratios apply mainly to the arterial drainage operations; the field or agricultural drainage has results which are local and can be more readily quantified.

General Drainage Position in Ireland

In general terms, at least half the lands in Ireland were in need of arterial and farm drainage. Of this, some 60% has been done (20,200 km^2), but in places the results have not been satisfactory and additional drainage is required. Thus, in 1949, at least 50% of the farmlands of Ireland were in need of field drainage. Much of the drainage which has been done has not been designed against the actual water flows in the areas, and so is only partly effective. Many of the older schemes have failed for numerous reasons, including improper design, silting, root growth, and (in the case of peat) shrinkage. Moreover, the requirements of modern farming are much more demanding than old low stocking and horse-powered agriculture. With the need to redo unsatisfactory old schemes, and need to drain still more areas to comply with requirements of modern agriculture, it could well be that even in 1984, some 50% of the agricultural lands of Ireland would benefit by field drainage.

As may be seen from the preceeding note, only rough figures can be given as to the total area effectively drained and the total area still awaiting drainage. The river drainage map of the Ordnance Survey (1958) and the Land Drainage Problem Map of An Foras Taluntais (1971) outline the general position. And so, needs for drainage are widespread, and an understanding of the geology and hydrogeology of the areas needing drainage should be of considerable help in solving the drainage problems.

Table 1 sets out the amount of drainage which has been achieved, and the governmental acts under which this work has been carried out. Figure 1 shows the regions and amounts of farmland which have been drained by arterial schemes. Figure 2 shows the regions and amount of farmland which have been drained under the Land Reclamation Act of 1949; over quite a considerable area, more than 25% of the farmland has been drained, and there is almost no area where some field drainage has not taken place. The data have been obtained from different sources, the actual acts, Lynn (1980), Bruton and Convery (1982), and discussions with officers of many of the organizations engaged in drainage.

The accuracy of some of the figures is doubtful. The figures under the 1842 act (101,200 ha), the 1863 act (52,500 ha), and the 1925 act (27,599 ha) are probably accurate, but some lands may be included in more than one total, and so the total of these three may be overestimated. The amount of drainage done on the Owenmore and Barrow is very roughly estimated at 32,400 ha. The figure for arterial drainage is from 1945–1980; the figure for field drainage is from 1949–1978. The starting data is that of the act, but work done over the past five years may not be included in all cases.

The arterial drainage includes some 57,000 ha drained for Bord na Mona. And in 1974–1983, Bord na Mona acquired some 30,700 ha of bog for drainage and peat harvesting.

Another approach to estimating the areas in need of drainage may be based on the wonderful soil maps and reports made by An Foras Taluntais (the Agricultural Institute) county by county. There, soils formed under excess water conditions, and some related soils influenced by too much water, are listed. The total area covered by such soils can be calculated. Tables 2

Table 1. Major acts relative to drainage in Ireland, with approximate figures of the areas drained under each scheme.

Date	Title of act	Number of schemes	Approximate ha	Areas drained (acres)
1842	Drainage & Navigation (1842–57)	115	101,200	250,000
1863	Drainage & Land Improvement (1863–92)	63	52,500	130,000
1866	Maintenance of Drainage	—	—	—
1924	Maintenance of Drainage	—	—	—
1925	Arterial Drainage	51	17,500	68,000
1926	Owenmore Drainage	1		
1927	Barrow Drainage	1	32,400	80,000
1928	Arterial Drainage (minor)	—	—	—
1929	Arterial Drainage	—	—	—
1929	Arterial Drainage (amendment)	—	—	—
1945	Arterial Drainage	34	262,800	650,000
1946	Bord na Mona	—	93,080	230,000
1949	Land Reclamation	—	1,168,600	2,887,500
1974	Farm Modernization Scheme	—	202,350	500,000
1977	Water Pollution	—	—	—
1979	Western Drainage Scheme	—	80,940	200,000
Total drained under 10 acts/schemes			2,021,370	4,995,500
Total area of Ireland			6,890,000	17,025,000
% drained under the acts/schemes			29.3%	29.3%

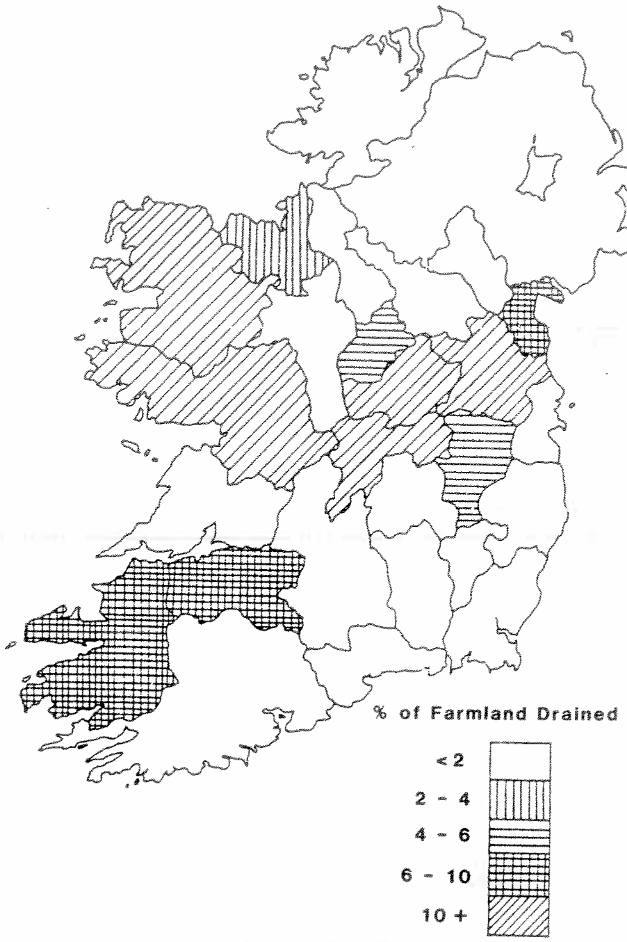


Figure 1. Effects on farmland drainage by arterial drainage in Ireland.

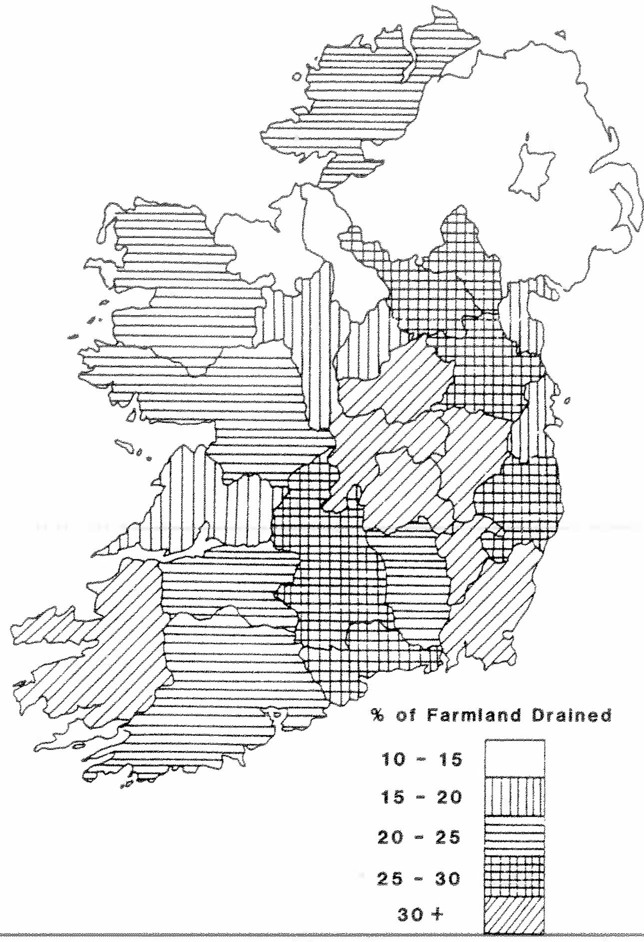


Figure 2. Effects on farmland drainage by field drainage in Ireland.

Table 2. Areas of Co. Leitrim which could benefit to a lesser or greater degree by drainage; from An Foras Taluntais (1973)

Co. Leitrim	Area Ha	Area %
Total area	158,937	100%
Gleys		
Ballinamore series	16,345	10.29
Drumkeeran series	15,215	9.58
Garvagh series	27,277	17.17
Howardstown series	2,494	1.57
Kiltyclogher series	3,622	2.28
Rinnagowne series	6,498	4.09
Total gleys	71,451	44.98
Complexes		
Ballinamore-Allen complex	1,382	0.87
Ballyhaise series	3,236	2.04
Total complexes	4,618	2.91
Peats		
Fen-Ardrum association	15,034	10.10
Raised Bog-Allen series	7,575	4.76
Blanket-Peat-Aughty series	33,792	21.27
Total peats	56,401	36.12
Total area requiring some form of drainage	132,470	84.02

Table 3. Areas of Co. Meath which could benefit to a lesser or greater degree by drainage; from An Foras Taluntais (1983)

Co. Meath	Area Ha	Area %
Total area	232,934	100%
Gleys		
Ashbourne series	40,402	17.46
Ballyshear series	93	0.04
Howardstown series	543	0.23
Mylerstown series	418	0.18
Street series	20,312	8.72
Total gleys	61,768	26.63
Alluvium		
Camoge series	2,686	1.15
Drombanny series	327	0.14
Dunsany series	229	0.10
Feale series	1,494	0.64
Boyne complex	10,346	4.44
Total alluvium	15,082	6.47
Peats		
Raised bog	5,689	2.45
Fens	3,530	1.52
Total peats	9,219	3.97
Total area requiring some form of drainage	86,069	37.07

and 3 give details of the position in Leitrim and Meath. In a bad county they can be very extensive; for Co. Leitrim they extend over 132,470 ha, or 84% of the whole county. In a good county they can be small; for Co. Meath, they extend over 86,070 ha., or only 37% of the county. The Land Drainage Problems map integrates these figures for the whole of Ireland.

These figures indicate the magnitude of the drainage problem in Ireland. Drainage schemes are primarily aimed at bettering the living conditions of those who farm the drained lands, but they give many more beneficial effects, such as local employment on the schemes, the improvement of communications and the betterment of navigation. Their effects on the environment have come into question in the past 20 years or so; there is much to argue on both sides.

Legal Position

The legal position is summarized in Table 1. Official drainage commenced some 140 years ago, and is continuing. Private landlords had done some field or agricultural drainage much earlier, from say 1750; this was either by open drains or by stone-rubble fill covered drains; these are sometimes reopened during modern drainage operations.

The acts are very detailed, much referring to the financing of the works and the ways beneficiaries will, or will not, pay for variable portions of the works. They provide penalties for all who resist the works, or damage them. Thus, "Every person who shall throw or put any weeds, stones, soil or other solid matter . . . into any watercourse . . . shall place or erect any dam, weir or other obstruction . . . shall be guilty of an offence" (Item 29, Arterial Drainage Act, 1925). Item 49 of the Arterial Drainage Act of 1945 sets out the procedure when "the execution of the said (drainage) work is being impeded or prevented solely by reason of the unreasonable withholding by any owner or occupier of land . . . of his consent to the execution of the said works." The procedure was long and complicated; fortunately, drainage brings such benefits that it was very rare for anyone to object to the work of a drainage scheme.

Lowering of the groundwater level and the drying up of wells and springs have been alleged on several occasions. Since the lowering of the water table will seldom exceed half a meter at any reasonable distance from the drained stream or river, such claims are usually, or almost always, incorrect. But in some cases, special precautions have been taken so as not to disturb existing wells and springs.

Organization of Drainage

There are six state or semistate bodies directly connected with drainage in Ireland. For three of them, drainage is a major operation—for the Office of Public Works, Department of Agriculture, and Bord na Mona. For the other three, drainage is of lesser importance—An Foras Taluntais (Agricultural Institute), An Foras Forbartha (National Institute for Planning and Construction Research), and An Taisce (The Environment).

The Office of Public Works operates mainly under the 1945 Arterial Drainage Act, and so deals mainly with large-scale arterial drainage. It is estimated that from 1945 to 1980, it drained 250,000 ha or 3.75% of Ireland (Bruton and Convery, 1982). The emphasis is on widening and deepening river and stream beds, and removing obstacles to flow, including old bridges and some weirs. At present, the agency is embarking on major drainage in the large basin of the Shannon River, with EEC assistance; progress is slow. The Office of Public Works itself executes these artesian drainage schemes.

The Department of Agriculture operates under the 1949 Land Reclamation Act, the 1974 Farm Modernization Scheme, and from January 1979, under the Western Drainage Scheme; initially, the Land Reclamation projects benefited from some Marshall Aid funds from the USA. When the act was first set up in 1949, it was estimated that some 2,065,000 ha of agricultural land were in need of drainage. Some 1,568,500 ha have now been drained; so there remains some 500,000 ha badly in need of drainage, apart altogether from land where drainage has failed and redrainage is desirable. Work on these agricultural drainage schemes is almost entirely by individual farmers or groups of farmers of agricultural cooperative societies; schemes have to be approved, and when completed, the farmers are compensated. In addition, many farmers drain their land at their own expense; there are no official returns for the amount of land so drained.

Bord na Mona (Peat Development Board) was established under the 1946 Turf Development Act. Up to 1983, it has drained some 93,100 ha of bog; it has plans for drainage of an additional 17,000 ha, and so will deal with 1.6% of the total area of Ireland.

An Foras Taluntais (The Agricultural Institute), and in particular its Soil Survey, have many close links with the technical aspects of drainage. The soil survey always indicated lands in need of drainage of different types in its splendid county reports for Ireland. Research into drainage problems is carried out throughout the country on private farms, where many variations of drainage problems are encountered and analyzed. More intensive research on drainage is carried out at the Agricultural Institute's farms, in particular at Creagh (Co. Mayo), at Ballinamore (Co. Leitrim), and at Kinsealy (Co. Dublin). There has been much work and numerous publications on the findings, as by Mulqueen, Burke, Galvin, MacGrath, Butler, Roche, Lee and many others, to which references are made in this article.

An Foras Forbartha (National Institute for Physical Planning and Construction Research) deals mainly with surface waters, including their quality and pollution; hence it moves into environmental considerations. It does not deal directly with drainage and only marginally with groundwater. McCumiskey (1980) summarizes the manner in which arterial drainage should integrate with present and future water resources and water requirements planning.

An Taisce (The Environment) deals almost entirely with the environment, but touches on drainage in such ways as it reduces the areas suitable for all types of waterfowl—snipe, teal, duck, geese, swans, curlews, and a host of others—either inland or in coastal regions. Merne (1980) lists some 46 species affected by drainage of freshwater wetlands. An Taisce also strives to have implemented in Ireland the many EEC directives regarding the environment.

The Geological Survey of Ireland is the state body responsible for groundwater. And so far as drainage can affect groundwater, it is interested in drainage. Aldwell and others (1983) give something on the interrelationships between groundwater and drainage. The visit to Ireland, in June 1984, of the Commission for Groundwater Protection of the International Association of Hydrogeologists devoted a considerable portion of its time to interrelationships between groundwater and drainage.

Several of the other state bodies have marginal interests in drainage. The Department of Fisheries monitors the effects of drainage on inland fisheries. The Electricity Supply Board has an extensive network of gauging stations mainly in relation to hydropower potential. The Land Commission has an interest in agricultural drainage, as in the reallocation of lands. The National Board of Science and Technology held a meeting on drainage on 20 November, 1980.

Environmental Considerations

Drainage is but one of man's activities under which the forest-covered Ireland of some 10,000 years ago has been converted into a highly productive land, yielding food for all its people and with great surpluses, in particular of milk, milk products, and meat from cattle, sheep, and pigs, for export. In making these changes, the environment has been almost completely changed, not once, but in stage after stage.

Each change has produced subsidiary changes, and the ecology strives to suit itself to the new environment.

The cutting of the forests was the most dramatic and starting with the ringing of elm stands in the forests to allow better grazing and primitive tillage among the leafless dead trees (Mitchell, 1976, p. 114). To 1600, McCracken (1971) estimated that 12% of Ireland was still tree-covered; but during the succeeding 200 years, forests were almost entirely wiped out. Another major environmental change was the coming in and spread of bogs from say 7000 BP. Raised bogs and mountain peat now cover some 17% of Ireland (Hammond, 1981); yet these peats have formed and spread after man's earlier efforts at agriculture and stonewalling of fields. The bogs also encroached on, and ousted the forests (see in Fig. 6). Of course, bog growth was due to small but significant climatic changes, not to man's activities; but it in turn had to be dealt with by man, initially for fuel supply, later for reclamation for agriculture. And the development of the varied soils of Ireland from scoured fresh rock, from weathered rock, and above all from glacial deposits of so many types, all are environmental changes made in Ireland since the melting of the ice sheets and glaciers some 13,000 to 15,000 BP. Environmental changes have always occurred, are now occurring, and will occur in the foreseeable future.

And for the past 400 years or so, the environment is being changed by drainage. The need for drainage is stated in the earliest scientific paper on Ireland—King's "Of the Bogs and Loughs of Ireland," published in 1685. In 1698, an act of William and Mary ordered estates to be bordered by a fence of quickset bushes and a ditch "five feet deep and four feet broad"; William was Dutch and accustomed to drainage problems. And from then on, drainage proceeded apace. Up to 1798, many of the landlords, big and small, invested heavily in drainage. Traces of these drains are often unearthed when modern drains are being lain; many of them still function. During the nineteenth century, drainage was installed only when prices for agriculture production were high. And from 1842, government took an increasing part in drainage.

The environmental changes produced by drainage are great. They may be considered from many viewpoints; the agricultural viewpoint is certainly the most important and well defined. But drainage can also be considered from the hydrogeological, and indeed the overall geological viewpoints. And it is with such that this article is primarily concerned—with the hydrogeological aspects of agricultural drainage in Ireland.

In dealing with agricultural drainage, this article moves into a field little studied by most hydrogeologists. There, much has been learned from the many scientists, technicians, and practical farmers who have researched, studied, and published on all aspects of agricultural drainage. As a result, the list of references is long, and shows the wide range of disciplines studied and used in solving the drainage problems of Ireland. It is hoped that this long reference list will adequately acknowledge the author's debt to the many workers who have published on many aspects of the subject.

Natural Conditions

Natural conditions calling for land amelioration have been known for very long. An early scientific paper by King (1685), "Of the Bogs and Loughs in Ireland," was Volume XV of the publications of the Royal Society of London; it can still be read and even applied to current drainage problems. Today it is possible to identify the main influences which have contributed to areas requiring agricultural drainage. They fall under six main headings in this section of the article: (1) topographical influences, (2) geological influences, (3) hydrogeological influences, (4) vegetative influences, (5) hydrochemical influences, and (6) man's influence. Of these, hydrogeological influences are the most important, since the water to be drained is groundwater, which includes soil water, and some stagnant surface water, often rejected recharge.

Some 45% of Ireland is underlain by Lower Carboniferous limestones, often karstified (Figure 3); these are the main rock aquifers. Of the overlying drift, fluvioglacial deposits cover 19%, and other unconsolidated aquifers cover some 6%. Bogs of all types cover 17% of the country. For the rest, impermeable or semi-impermeable formations persist, and give rise to difficult drainage conditions.

Topographical Influences

The impedence of open drainage by residual forms of glacial topography plays an important role in formation of areas requiring agricultural drainage. Eustatic and isostatic rises and falls of the coast have also had much influences in the evolution of the surface drainage. Such drainage is the topographical factor most emphasized here, as directly affecting areas of marsh and bog and lands in need of agricultural drainage.

Glacial Topography

Glacial topography was evolved under the action of solid, not liquid, water. While there were rivers and lakes on the great glacial ice sheets, and streams under

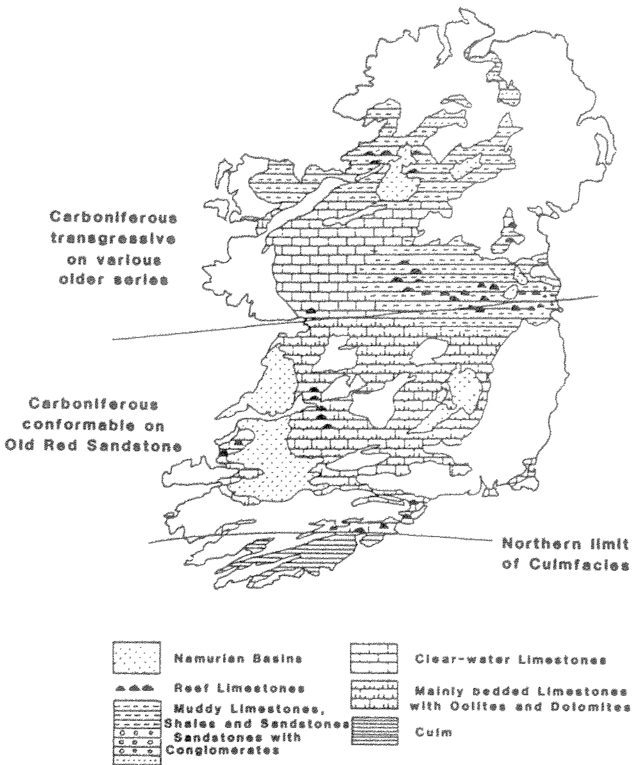


Figure 3. Extent of the Lower Carboniferous formations in Ireland.

the ice, their location was unrelated to the topography of the underlying solid rock with its glacial debris cover in places. When the ice melted some 10,000 years ago—and took a considerable long time in so doing—there was an adjustment in the drainage pattern from flow on ice to flow on rock and glacial debris.

On the large scale, the old mountains and hills, some of which had projected above the ice cap, controlled the main drainage. There may be a few exceptions, but in general our main streams and rivers are correctly aligned with the topography. While in late glacial times, overflow streams cut what are now known as dry valleys in the sides of our hills, streams now flow where they should, at the bottom of the valley. However, on a small scale, such as will affect an individual farm or group of farms (from 50 to 200 ha), the position is different. The evolving surface drainage has, for a number of reasons, not cut back and drained the many small areas which are marshes, bogs, and wet patches, all in need of man's drainage efforts.

The permafrost will have sealed off groundwater flow across the outcrops of many of the aquifers. These aquifers are mainly the fluvioglacial outwash, a widespread but shallow aquifer today, and also to some extent the karstified limestones and the deeper portion of the eskers and moraines. These formations will then have acted as aquicludes, and on them lakes will have formed, some water flowing in summer and warmer periods, all ice at other times. In these lakes, clays and lacustrine marls will have formed; these are aquicludes, so that even after the permafrost had melted, the bottoms of the lakes would be lying on their own, new, aquiclude. The precipitation of soluble calcium bicarbonate as calcium carbonate (calcite and related minor species) was due to a number of changes, such as pressure reduction, water temperature increase, and evaporation from the free surface of the water body. In some cases, the groundwater below the lake would be under sufficient pressure to rupture the impermeable cover of clay and lacustrine marl, and break out as springs from below the marl, like the major springs at Ballinagard, Co. Roscommon.

The drainage of the innumerable lakes which formed on the land surfaces newly freed of ice cover and at the edge of the ice caps and glaciers was complex, and in places has not been completed. Ideas on the size of postglacial lakes, and areas of swamp, are shown on Figure 4. Their drainage is complicated by the growth of vegetation and formation of bogs, often raised bogs. Where the glacial lake was small, and its drainage basin comparatively large, the water from precipitation and snow-icemelt filled the lake and raised it to a level where it could overflow. The overflowing stream tended to cut a drainage channel and lower the level of the lake either entirely or to an extent where water inflow/outflow were again in balance. The lake was drained. Where the size of the lake was large in relation to its drainage basin, inflowing water was transpired and evaporated, and levels did not rise to that height at which significant overflow would take place. The lake was not drained. It would appear that this failure to drain applied mainly to the small lakes, lakelets, and ponds (including kettle holes) on the lands bordering the retreating ice sheets. But it is possible that this applied also to larger lakes, giving rise to extensive bogs; their drainage is both arterial and agricultural. Charlesworth (1957, vol. 1, pp. 456–461) gives much on the formation and drainage of these lakes.

The solifluction and movement of vast masses of glacial debris, mainly boulder clay and to a lesser extent fluvioglacial deposits, has in many places blocked the emerging, postglacial, surface drainage. Such movement is basically due to the moistening of the drift by snowmelt or precipitation, and then its freezing in winter or longer periods of cold; there is

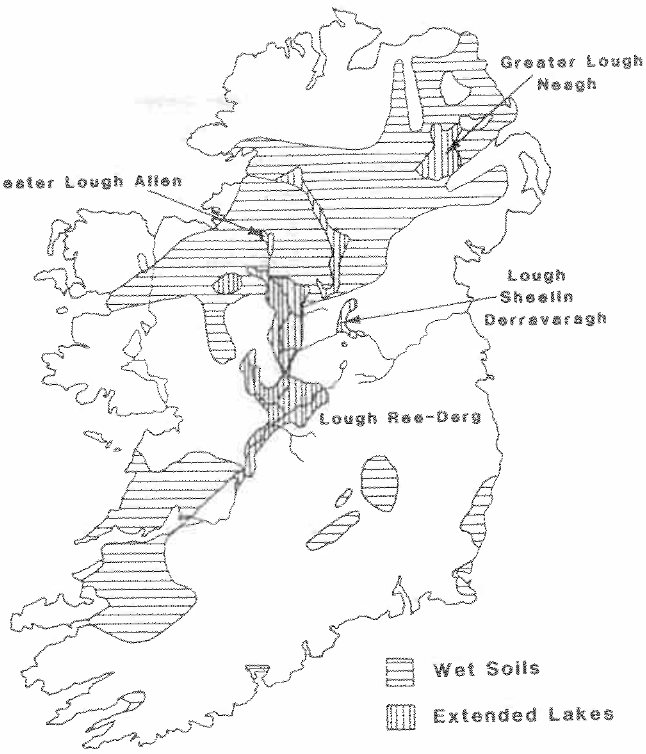


Figure 4. Extent of lakes and wet soils at the end of the last glaciation in Ireland.

an alteration of water and ice in the drift. Under such, the drift may flow and block the drainage. This action also gives rise to strange orientation of boulders and cobbles in the drift; such do not normally affect the drainage of lands thus blocked by solifluction and movement downhill of drift, mainly boulder clay. Kettle holes, pingos, and other abnormal topographic forms created in late and postglacial times may also result in areas, often small, which are in need of drainage.

The Quaternary of Ireland, including its topographical ramifications, is a vast subject (Synge, 1950, 1979; Mitchell, 1976, 1980). It is not possible to go into detail here. It must suffice to alert all working on drainage of agricultural lands in Ireland that disruptions in natural drainage may well refer back to a melting which started some 10,000 years before the present. Little is known of most of the Quaternary ice age in Ireland; there is a gap of at least 1.8 million years (say from 1,900,000 BP to 100,000 BP). How often in this period was a surface drainage reestablished and again obliterated by a succeeding ice sheet?

Postglacial Topography

The postglacial topography and drainage systems have evolved under varying climatical conditions (Littletonian Warm Stage), with July temperatures rising to some 18.5°C at about 5000—4000 BP, and now in the range of a little above or below 16°C. (Iversen, 1973).

Much has been written on the history of the establishment of the drainage system in pre-Quaternary times. For some, it was incised on a Namurian succession; for others, it was incised on a Cretaceous (or even early Tertiary) surface. Since the main mountains are all older, such earlier drainage systems must, for the greater part, resemble the present drainage system. This system was reestablished after the meltings of the ice caps.

The current surface water drainage system is only some 10,000 years old for most of Ireland. To a great extent, the main drainage channels have been reopened; but there are many places where reopening has diverted from the original channels, leaving shorter or longer buried valleys, often filled with permeable material.

Farrington's studies on the Shannon around Killaloe give an indication of how complex can be such reevacuation of old channels and diversions from them. The River Liffey has often changed its course, and this is in part due to changed lines of reevacuation after glacial cover. The presence of a tremendous number of lakes, and of raised bogs which are but vegetation-filled lakes, is evidence of the inability of the river system to cut down and back to the extent necessary to drain these lakes. And beyond and as it were as an extension of these lakes, are marshes of all types, all in need of agricultural, if not arterial, drainage.

In the south of Munster, the last glaciation (c. 30,000–12,000 BP) was not present, and the end of the earlier Munsterian cold period was much earlier; so there, the main rivers (Bandon, Lee, and Blackwater) have had much longer to reestablish or establish the full surface natural drainage system rather than elsewhere in the Midlands and North of Ireland. Elsewhere, there has been but some 10,000 years to establish the natural, fully topographical drainage, and so residuals of the glacial topography are more usual, with bogs on the large scale, and many many small areas requiring drainage on the small scale.

Rising and Sinking Coastlines

The evolution of the natural drainage system has been much affected by rises and falls of the coastline over the past 15,000 years. These rises and falls have been due to both eustatic (sea level) changes and isostatic (land level) changes.

Falls in sea level were worldwide during the last glacial period, from say 35,000 to 15,000 years BP. These falls were due to the vast quantities of water locked up in the great ice sheets piled up high over the north and south of the world. At some 15,000 BP, sea level was some 130 m below present level. As the great ice sheets melted from 15,000 to 10,000 BP, sea levels rose. At the beginning of this period, the amount of water flowing in the rivers was small; they froze for much of the year. At the end, flows were large, larger than today, due to melting ice. Those torrents and floods must have removed much of the glacial till, and also formed the fluvioglacial deposits which cover much of Ireland, and are generally well drained.

From about 6000 to 4000 years BP, sea level rose above its present level, to a maximum of +4 or 5 m. This would have reduced the gradients of the riverbeds, and tended to reduce flow. However, the remaining amount of icemelt was probably sufficient to maintain the ability of the flowing waters to erode away still more of the glacial deposits and to cut down into the underlying solid rock.

The main isostatic movement during the same period was also due to the ice, to the unloading of the ice cap from the Baltic Shield and the surrounding regions. The Shield reacted to the unloading of the ice by upward movements of considerable amounts, greatest in the middle of the Shield, declining towards its periphery. Thus, the east coast of Ireland was raised considerably, with the formation of long and wide coastal marshes where such was feasible, as the slob lands of Wexford. Deep river valleys were cut and have been refilled; they are sometimes revealed by drillings or when establishing foundations for bridges.

On the other hand, the west coast was lowered, with the formation of rias, the great drowned river valleys of Dunmanus Bay, Bantry Bay, Kenmare River, Dingle Bay, and Tralee Bay. It would seem that in the south of Ireland, the tilting effect was more important than the isostatic rising after removal of the ice cap. This greater sinking on the west will have reduced the gradients of the older Blackwater, Lee, and Bandon, which essentially flow from the west to east. This will have encouraged deposition rather than erosion, and the wide alluvial flats and floodplains, characteristic of these rivers, may well be a result of decreased gradients in eastward-flowing rivers.

There may be other isostatic movements in Ireland, but they are small. Only around the Newry granites and in the Cooley peninsula might be expected some form of Tertiary uplift in alpine style. This may have affected the large thicknesses of Quaternary deposits formed on the flanks of the Cooley peninsula.

Geological Influences

Figure 3 gives an outline of the geology of Ireland, with emphasis on the Carboniferous, the Dinantian, and the Namurian. On such a scale, it can give but a rough idea of the geology. Likewise, these notes on geological influences have had to be very condensed, and give only the main ways in which geology can influence drainage and produce natural conditions where agriculture drainage is desirable.

Impermeable Formations

A major cause of poor drainage is noninfiltration of the precipitation due to the impermeable nature of the underlying rock or superficial deposits. Some 34.8% of the 68,900 km² of the Republic of Ireland are underlain by rocks which can be considered impermeable and having low to nil infiltration characteristics. They are (as estimated by Burdon, 1983, Table 26) as follows:

Granites	4,125 km²
Quartzites	1,081 km²
Metamorphics	5,134 km²
Cambrian	727 km²
Ordovician	4,014 km²
Silurian	3,219 km²
Namurian	5,700 km²
Total	24,000 km² = 34.8%

These rocks are mainly impermeable, but due to many factors (weathering, shearing, folding, jointing, etc.) are slightly permeable to varying degrees. And of the other major formations, some can be quite impermeable locally; this is true of the Calp of the Carboniferous, and parts of the Old Red Sandstones, so widespread in the south.

Of the superficial deposits, essentially Quaternary and related to the ice, many are also highly impermeable and have nil or low infiltration characteristics. They cover some 64.1% of Ireland and are (as estimated by Burdon, 1983, Table 24) as follows:

Boulder clay, new, Midlandian	18,980 km² or 27.5%
Boulder clay, old, Munsterian	9,290 km² or 13.5%
Boulder clay, Irish Sea	4,270 km² or 6.2%
Drumlins	11,600 km² or 16.9%
Total	44,140 km² or 64.1%

Of course, many of these impermeable Quaternary deposits (probably the most) are deposited on solid impermeable rocks, so that in no sense does the sum of the two (99%) represent the area of Ireland underlain by impermeable formations. The impermeable Quaternary deposits also vary in the degree of their permeability. Boulder clay deposited by ice scouring the seabed of the Irish Sea can be quite permeable in places. The old Boulder Clay has often been decalcified, indicating some flow of groundwater through it.

Permeable Formations

In their infiltration zones, the permeable formations should soak up all the precipitation, and not give rise to drainage problems. In their discharge areas, however, they may give rise to drainage problems, discharging their groundwaters into the soil of mainly low-lying areas. Again, many formations which are mainly permeable may contain beds which are locally impermeable. The Calp of the Carboniferous (hard to map, and in some places nonpersistent) is an example of beds with low permeability amongst generally permeable (and possibly karstified) limestones.

The permeable rock formations of Ireland may be listed as follows, again as estimated by Burdon (1983):

Basic Intrusives	42 km^2
Ordovician Volcanics	846 km^2
Marble (mainly Donegal)	43 km^2
Devonian (ORS)	12,793 km^2
Lower Carboniferous	31,149 km^2
Permo-Triassic (Kingscourt)	27 km^2
Total	44,900 km^2 or 65.2%

As in Figure 3, these permeable formations, and indeed Irish geology, are dominated by the Lower Carboniferous, covering some 45.2% of the Republic of Ireland's 68,900 km^2. These limestones are karstified to varying degrees, as treated under hydrogeology. The Devonian, the Old Red Sandstone, is in part impermeable; but it bears such a resemblance to the "Sandstones of Nubian Facies" which are good aquifers throughout the Middle East (Burdon, 1982) that it seems better to classify them as permeable.

Of the superficial deposits, essentially Quaternary and related to the ice, some are permeable or very permeable, and have high infiltration characteristics. They cover some 25.3% of Ireland, estimated as follows:

Fluvioglacial deposits	13,150 km^2
River alluvium	3,150 km^2
Moraines & eskers	1,150 km^2
Total	17,450 km^2 or 25.3%

While the soils derived from these formations are usually well drained, there are exceptions. Thus, of the river alluvium, formed in postglacial times, areas may be waterlogged due to drainage being blocked by natural (and artificial) levees, or in ox-bow bends and old meanders, which are now cut off from the main river, but are low-lying and liable to flooding and to marshy conditions (so-called back swamps). Low hydraulic gradients close to rivers and streams also contribute to poor drainage.

Weathering and Soil Development

Weathering can render an impermeable rock permeable for an appreciable depth, and such must always be taken into consideration when studying water movement in a rock. However, much of the old weathering of Irish rocks has been removed by glacial scour and the fresh rock covered with till; this may, or may not, allow postglacial weathering to take place. It must be recalled that water as ice has no solution effect on minerals, rock, or glacial debris; chemical attack on its containers takes place only after the ice has changed to liquid water. Only on the hills, above the elevation of the ice sheets, is there deep weathering, as on the granites and schists of the Leinster ranges. And in many regions, especially in high rainfall regions of the west, this weathering has been covered by blanket bog. However, all these weathered materials are permeable, and must be taken into consideration when planning the agricultural drainage on lands with weathering products cover.

Weathering proceeds to soil formation. This is a specialized subject, outside the scope of this article and covered in a more efficient manner by An Foras Taluntais, as in the books describing the soils of Leitrim (1973) and Meath (Finch and others, 1983). Some notes have been given on the soils of two counties (Leitrim and Meath) as examples of the amount of drainage required in Ireland; but this is not considered in any way as a note on the application of soil surveying to the problems of drainage.

Pans

Impermeable pans form in many soils and weathering products in Ireland, and such can affect considerably the drainage and the permeability of otherwise permeable formations. They were noted by Kilroe as early as 1907.

Pans with a cement of calcite or other carbonates are common. They are not entirely impermeable, and retard rather than block drainage. Pans with a cement of silica are also common, and have more water-blocking effects. But the most impermeable pans are those with an iron (and sometimes manganese) cement, and they can be thick (Burke, 1972a). When iron and manganese in solution in water under anaerobic conditions move into aerobic conditions (as at zones of discharge of groundwater) the iron and manganese precipitate and cement the aquifer or its overlying soils and regolith. Solution of iron and manganese is greater as the water becomes more acid; for thick pans to form, a deep water table is, or was, usually required. Chalybite springs are common in Ireland, and are often mentioned in the Memoirs of the Geological Survey; they might indicate mineral deposits. The amount of iron precipitation may be large, and it would seem that in the past such iron nodules have been mined and smelted.

Hydrogeological Influences

An understanding of the hydrogeological control of drainage is a basic necessity. Such is assumed here, when discussing such effects as those of seasonal variations in groundwater levels, karstification, and turloughs, the strange "dry lakes" found only in the west of Ireland. The general position is covered by Dooge and others (1973) and FAO (1971).

Hydrological Cycle

The hydrological cycle in Ireland has a few specific characteristics which affect the supply of water requiring agricultural drainage (Rohan, 1975). Two are of particular importance.

It would seem that in many areas, the aquifers are completely filled by infiltration from September to January, and that in January–February the phenomenon of "rejected recharge" can occur. Infiltration ceases, runoff takes place, and some water is left on surface, to form marshes and other types of land requiring drainage in winter. In the spring, and as discharge and evapotranspiration becomes greater, such conditions of "rejected recharge" cease, and the marshy or swampy area dries up.

Again, it would seem that the amount of recharge to the aquifers becomes small, or may cease, during the main warm growing season. Transpiration is very strong in Ireland, and such rainfall as is not evaporated is transpired. As a rough preliminary estimate, it may be taken that there is nil infiltration and groundwater replenishment during the months of June, July, and August. Hence, effective infiltration is confined to the nine months from September to May. As a result, there is little pollution of groundwater by N, K, and P fertilizers, which are mainly used in the spring and summer months. And such pollution may be removed by groundwater drainage, skimming off the polluted upper layer of groundwater, and protecting from pollution the deeper parts of the aquifer. Such effects are more important in shallow rather than in deep aquifers, and can be completely eliminated under artesian conditions.

Transpiration

Transpiration by deep-rooted vegetation, in particular by trees and shrubs, can be an important auxiliary to agricultural drainage operations (Connaughton, 1976). In many areas of the Middle East, swampy areas have been dried up by tree planting, in particular by the planting of eucalyptus. In some cases, they extracted so much groundwater that they had to be cut down. Trees and shrubs also intercept precipitation and increase evaporation; they thereby contribute to the amount of water falling on the soil.

Such an increase in this portion of the hydrological cycle may be feasible in Ireland. Evergreens, with transpiration in the winter as well as the summer, should be most beneficial. Holm-oak, pines, conifers, holly, laurel, furze, and related plants would seem most desirable. Willows commence to transpire early in the year. Observations in the Appalachians (Swank and Douglas, 1974) showed that when pines replaced deciduous hardwoods, stream flow decreased by 20%; decrease was greater in the dormant and early growing seasons.

Karstification

With the Lower Carboniferous Limestone underlying some 31,150 km^2 of Ireland (45.2% of 68,900 km^2), karstification of this limestone has important effects on the drainage. Not all the limestone is karstified; in places it is protected from current karstification by a cover of Namurian shale strata, or by the presence of the Calp or other beds with a low solubility in circulating groundwater. Again, the effect of the impermeable cover, as boulder clays and drumlins, may retard the karstification of the covered limestone. The concept of "covered karst" has been investigated elsewhere; it needs investigation in Ireland.

Viewed from the drainage angle, karstification is a natural means whereby open drainage channels (capable of turbulent flow) are dissolved at some distance below the ground surface (Drew, 1970, 1982). They are a natural agricultural drainage operation. They provide escape routes or channels for groundwater infiltrating and percolating downwards through the soil and overburden. Thus, they facilitate drainage. This process has been described by Drew and Back (1979). In extreme cases, there is no water whatsoever left on the surface; such topography was the origin of the word *karst* in Yugoslavia. Lands underlain by effective karst are well-drained lands.

In some cases, these drainage channels, buried in the karst, have been filled or partially filled with sediment derived from the melting ice cap and the precipitation. The sediment is now under removal, and these old buried drainage channels are being reestablished. The volume of water flowing in them must be much less than the great torrents from the melting ice.

Turloughs

Turloughs (tuar lough = dry lake) are an unusual feature, and seem to be restricted to Ireland, and there to areas underlain by Carboniferous Limestone; so they are a karst feature. They are well-nigh undrainable.

They occur in depressions and irregularities in the till cover of much of the limestone. They fill in winter, dry out in summer. Hence, they are due to the fluctuations in the level of the groundwater table, either inland due to imbalance between recharge and discharge, or in coastal areas as affected by the tides and winds. Thus, Caherglassan Lough, which is some 6 km from the sea, fluctuates with a 4-h lag with the ebb and flow of the tides in Galway Bay. Dr. Praeger investigated these turloughs and notes, "The most conspicuous indication of a turlough is the abrupt cessation of all shrubby growth below a well-marked contour. The herb vegetation, which extends from this level to the bottom of even the deepest turlough (which may measure as much as twenty feet), is very closely nibbled by rabbits or sheep, and forms a dense fine green sward" (Praeger, 1937).

Variations in Groundwater Levels

Irish groundwaters are subjected to considerable variations in level, both inland and on the coast. Levels may vary by as much as 15 m in infiltration and recharge areas; they are more likely to be 1 to 3 m in discharge areas. This is shown by Figure 5 (after Daly, 1979). High levels occur, of course, in winter and spring; low levels in autumn.

In coastal areas, there are tides of up to 5 m, plus up to 1 m raising or lowering due to heavy winds. These have been described in some detail by Aldwell and Wright (1978). Naturally, such tidal fluctuations, extending inland in the estuaries, surface waters, and rivers, and in the underground water, all provide areas which are much in need of protection, both by banks and dykes, and by drainage operations. However, such have generally to be undertaken on a large scale, and do not form a farm drainage operation. In some local areas, such drainage can be possible; but attention must then always be paid to tidal and wind influences in the sea or estuary.

These are factors which must be taken into account when selecting areas for drainage and in planning the drainage operations.

Vegetative Influences

Vegetative influences on drainage in Ireland are great, and are almost entirely due to the growth of several types of peat. The study of peat is a highly specialized subject, and only an outline can be given here (Dooge, 1975). To emphasize its importance, it is presented under three subheadings. Figure 6 sets out some ideas on the growth of peat, based mainly on Mitchell (1977). The cutting of the forests which once clothed the land must have had major effects on drainage, but these do not seem to have been as yet studied (see McCracken, 1971).

As in Table 4 (after Hammond, 1981), peats cover some 17.05% (1,175,579 ha) of Ireland. They have accumulated almost entirely over the past 7000 years. They caused and are causing considerable blockage to surface drainage, though not as much as the calcite-precipitating mosses which have formed some 14 lakes in limestone regions of Croatia (Petrik, 1965). Mitchell (1977, p. 113) notes, "The raised-bog can be likened to an enormous bag of water. . . . It is obvious that such a mass of saturated material may well have important effects on the water table in the area surrounding it. As it expanded, it built up a natural dam across valleys which had previously been free to discharge surface water."

There are three main divisions: Fens, with surface or groundwater inflow, covering 1.34% of Ireland; raised bogs, dependent on precipitation, covering some 3.04% of Ireland; and blanket bog, and some associated raised bog, mainly on hills and uplands, also dependent mainly on precipitation, covering some 12.68% of Ireland.

The task of draining such bogs and rendering them useful for agriculture is a complex one, and the subject of much research. The reclamation of these bogs is mainly by Bord na Mona and farmers. An Foras Taluntais has done much research (Galvin, 1974, 1976, 1978, and 1979; Burke, 1967, 1972, and 1978; Mulqueen, 1975, 1979; Mulqueen and Lee, 1973; Mulqueen and Gleeson, 1981). This article can only touch on this major undertaking, and restricts itself to outlining the problem, mainly as it applies to agriculture on the farm scale. The economics of such bog reclamation is a matter of controversy and is not elaborated here.

Table 5 is from Galvin (1976), who has determined the hydraulic properties of the Irish fens and bogs; he presents the data in a form readily acceptable to hydrogeologists. "The drainable porosity figures represent the difference between saturation and at pF2. These figures indicate the maximum proportion of water likely to be removed from the peat as the water table falls or is artificially lowered by drainage. . . . The equation relating drainage porosity to hydraulic conductivity would seem to be well established for a wide range of Irish peats" (Galvin, 1976, p. 219).

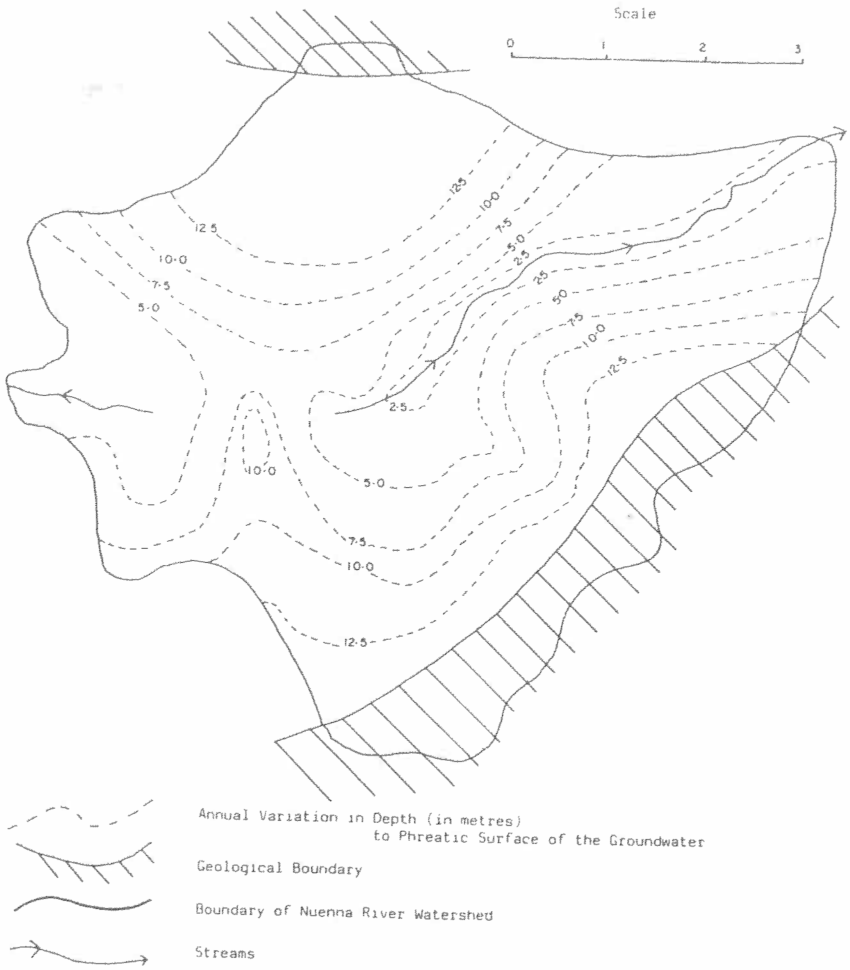


Figure 5. Annual fluctuations in groundwater levels; example from the Cullahill Limestone aquifer, Nuenna Watershed (after E. P. Daly, 1979).

Fens

Fens are mires or marshy areas where the specialized vegetation is supplied with water and minerals from surface and underground sources, as well as from precipitation water with little mineral content. Some groundwater is quite high in mineral content (Table 6). The fens usually block one or more drainage channels, often towards the upper portion of a watershed. They have inflow to them and outflow from them, and the usual water balance equations can apply. They will consist of an active upper layer with growing and recently fallen vegetation, which is highly permeable; and they will have a lower layer, of highly decomposed and compacted organic matter, with some soil, which can have very low permeability. It is this lower layer which blocks the drainage.

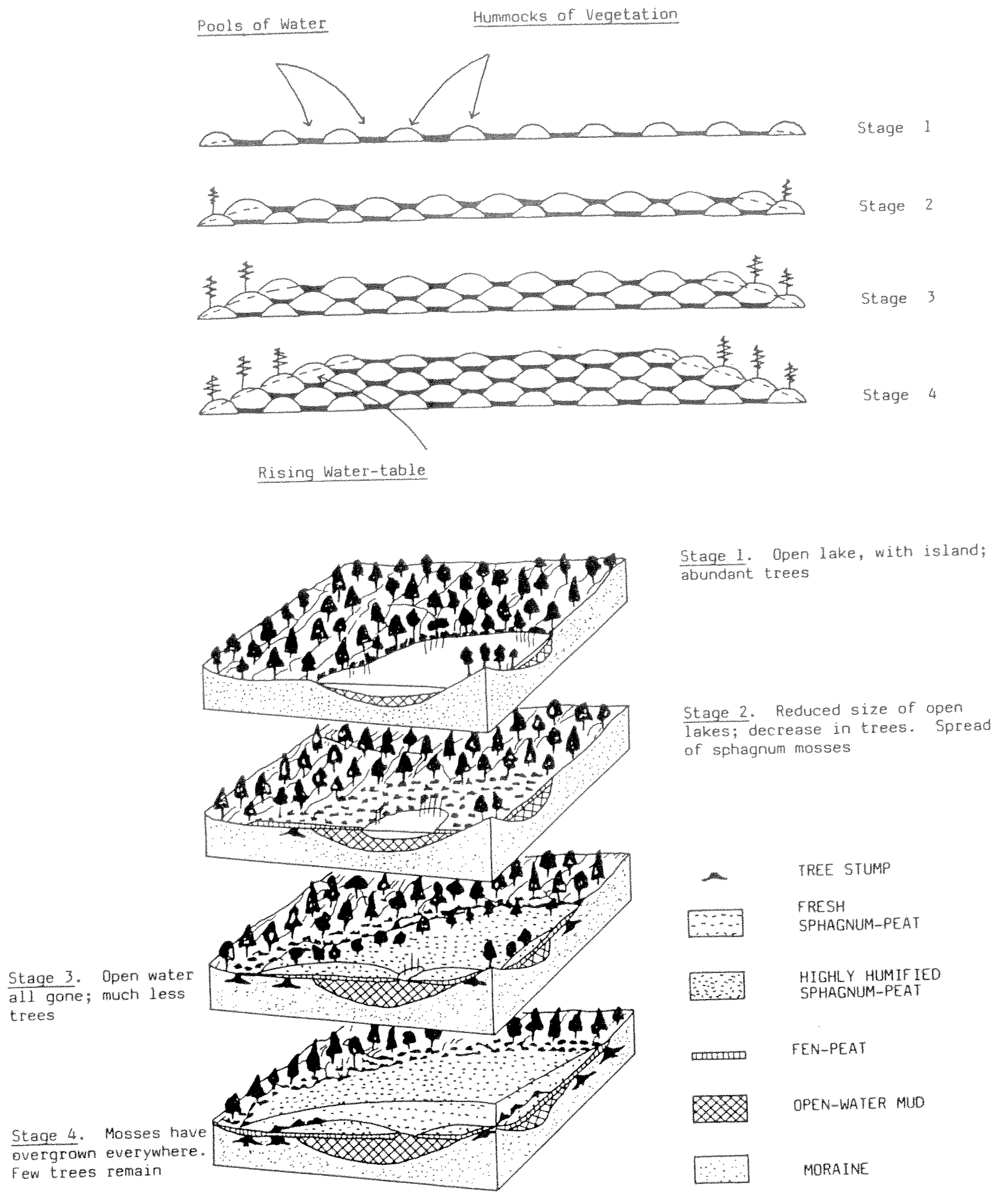
Fens may develop in small lakes, lakelets, or on slight blockages on streamlets. The underlying rock may be impermeable or have some permeability but a high water table. There may be some lacustrine marl under the fen, attesting to the lacustrine origin of the deposit.

It would seem that fens underlie most or all bogs, and serve to isolate them from mineral-rich surface and underground waters. A fen therefore acts as a barrier to groundwater flow, and protects the bog from it. As the fen grows upwards, it moves above the water table of the area. From then on, the vegetation is fed by rainwater with low or very low mineral content.

Raised Bogs

Raised bogs are mires in which the vegetation is supplied almost entirely with water from precipitation, and so with low to very low mineral content. Initially, they may have had some groundwater or/and surface inflow. But they grow above this level, and while initially fens, become true raised bogs.

Growth is large, and bogs with thicknesses of 9 m are not uncommon. Over 60% of the true raised bogs



A post-glacial lake converted into a bog by the growth of sphagnum (s. cuspidatum, s. fuscum, s. imbricatum)

Figure 6. Aspects of bog development in Ireland, after Mitchell (1977).

Table 4. Areas of bog and fen in Ireland (Hammond, 1981).

Provinces	Raised bog (M)	Fen	Blanket bog	Raised bog (T)	Total (Ha)
Leinster	133,476	42,007	25,293	—	200,776
Munster	17,161	17,802	246,756	17,766	299,485
Connaught	53,297	32,618	338,500	87,970	512,385
Ulster	5,467	81	153,257	4,128	162,933
Totals	209,401	92,508	763,806	109,864	1,175,579
% BOG + Fen	27.8%	7.9%	65.0%	9.3%	100.0%
% 68,900 km²	3.04%	1.34%	11.09%	1.59%	17.06%

Table 5. Hydraulic characteristics of Irish bogs and fens, as determined and reported by Galvin (1976).

Type of deposit	Porosity %	Hydraulic conductivity mm/d		Infil-tration mm/d	Drainable porosity ml/ml
		Lab	Field		
Blanket peat	94.7	13	6	4	0.16
Younger sphagnum	95.8	208	209	61	0.38
Older sphagnum	93.7	5	28	3	0.17
Woody fen (Type B)	92.7	8-183	564	29	0.08
Reed fen (Type C)	93.5	49	126	13	0.14
Woody fen phragmites (Type B/C)	93.7	6	648	2	0.11

Table 6. Comparative view of hydrochemistry of groundwater in 9 major aquifer systems, with an attempted average (after Daly, 1979).

Table	Aquifer	Ions, in mg/l or ppm							Total hardness $CaCO_3$
		Ca	Mg	Na	K	Cl	SO_4	TDS	
37.	Sand/gravel (L'ste)	86	14	12	3	26	Tr	393	309
38.	Sandstone (Castlecomer)	34	14	38	2	15	1	252	212
39.	Up. Visean L'ste	101	16	8	2	21	4	388	315
40.	Dolomitized reef	85	22	ND	ND	27	75	478	302
41.	Limestone, Wexford	85	22	29	4	40	14	420	303
42.	Courceyan limestone	176	39	ND	ND	31	254	736	502
43.	Limestone, Cork	98	7	18	2	34	11	381	275
44.	ORS sandstone	9	6	ND	ND	28	ND	92	46
45.	Volcanics (Waterford)	24	18	ND	ND	32	29	240	130
	Averages	77	17	21	3	28	49	376	299

are found in Leinster, and they seem to have originated mainly in the postglacial lacustrine terrain of the Midlands of Ireland.

When the upper layer is drained, there is considerable shrinkage; this can affect the drainage layout. Problems encountered and solutions found to such drainage are given in Mulqueen (1975). There is also heat generated in the drying layer, due to oxidation. The author recalls that in 1952/54, when the extensive marshes of the Ghab on the Orontes in Syria were being drained, the peat beds went on fire, all the land sank, and drainage canals had to be realigned. In Ireland this only happens with very mineral-rich peat in milled peat piles and is rare.

In a detailed study of the stratigraphy and hydrology of a cutover raised bog near Ballinrobe, Co. Mayo, Finn and others (1982) have given the stratigraphy and some data on the permeability. The stratigraphy may be summarized as follows:

Top:	Mainly sphagnum moss peat;
Raised peat strata	some Eriophorum/Calluna
Fen peat strata	Mixture of Phragmites (reed) and Carex (sedge); some wood

Gyttja material	Coprogenic material, averaging 10 cm in thickness
Lake marl	Comminuted with molluscan shells common; up to 1 m thick
Lake clay	Only slightly calcareous clays and muds up to 0.8 m thick
Bottom: Boulder clay till bed	Forming the base of the deposit; uneven surface

The permeability of the peat was measured; it ranged from 0.03 to 1.05 m/d, with an average of 0.25 m/d. The lake marl had almost nil permeability, averaging 0.04 m/d. In their Figure 6, Finn and others show a model of the water flows, which would be of great assistance in planning and executing a drainage of this small raised bog.

Boelter (1965) gives the following values of the permeability of peat in standard hydrogeological units:

Undecomposed peat	33.0 m/d ($m^3/m^2/d$)
Partially decomposed peat	0.12 m/d
Decomposed peat	0.01 m/d

Blanket Bog

Blanket bog covers some 11.09% of Ireland, and with it may be classified some raised bog (T) as indicated by Hammond (1981). It is quite recent, having been initiated some 4000 BP. It is climate-controlled, requiring cool summers, not too cold winters, high rainfall (exceeding 1250/mm/yr), rain on at least 225 d/yr, and high humidity. The western coast and hinterland are ideally suited to the growth of blanket bog, which can have thicknesses of up to 6 m. In places, it develops still greater thicknesses; Hammond classes some 109,864 ha of raised bog with the blanket bog, existing mainly in Connaught.

The blanket bog is often underlain by varying thicknesses of the weathered rock. The cover of peat arrests further weathering. All incoming energy is used to evaporate the moisture stored in the upper layer of the peat and in supplying the growth; none penetrates to the underlying rock (Pitty, 1971, p. 292). When examined hydrologically, there seems to be considerable water movement in this layer of weathered rock. Such water may enter on the higher slopes, where blanket bog is thin, irregular, or nonexistent. Hillside streams seem to be fed by such sub-bog flow. But the main decomposed bog is, as elsewhere, well-nigh impermeable.

It would seem that blanket bog has developed mainly on impermeable rocks or glacial boulder clay. Where infiltration is good, initial conditions for the formation of blanket bog do not seem to have existed. However, blanket bog may spread over permeable outcrops, since its growth depends to a great extent on the precipitation. Permeable formations may be rendered impermeable by the formation of iron, manganese, and silica pans with humus under the spreading blanket bog. Blanket bog is generally thinner on the high ground than in the valleys, where rising groundwater may aid in its formation. The combination of wet ground, acidic soils, and the high precipitation spread throughout the year produce blanket bog.

Burke (1978) has closely studied the drainage of blanket bog at Glenamoy, where he studied (1) undrained blanket bog, (2) a forest site where open ploughed ditches were used, (3) a forest site where tunnel drains had been installed, and (4) an intensively drained pasture site. Burke reports, "Blanket peat is highly colloidal and in consequence its hydraulic conductivity, strength and proportion of drainable pores are extremely low. . . . The net effect of installing 0.75 m deep drains at 4.5 m intervals is to lower the average water table by 0.15 m to 0.20 m. In order to obtain this intensity of drainage at an economic cost, two special ploughs were developed . . . the tunnel plough and the gravel plough" (p. 316).

Forests

In dealing with agricultural drainage, it must not be forgotten that the climax vegetation of Ireland was forest (oak, elm, and ash; understory of hazel and holly; alder, willow, and birch in poorer areas) and that this forest has been removed slowly over the past 1500 years, much of it in the period 1500–1700 AD, but commencing say 5000 years before the present. McCracken (1971) estimates that in 1600 12% of Ireland was still covered by primeval forests.

Forests generally favor and increase infiltration, and so may help to deal with conditions causing swamps, mires, and bogs. The roots of forest and understory growth open up and increases the permeability of the soil and underlying rock. Forest cover intercepts rainfall, and may increase evaporation. Trees use up and transpire much water from the ground. Forests increase the rate of evapotranspiration, and may be claimed to increase precipitation. But overall, the effect is to use up the water and dry up the soils underlying forests, woods, and coppices. Since evergreen trees and plants continue to transpire throughout the 12 months of the year, they may overall be more effective in drying up the ground under them than deciduous trees, as already noted for the Appalachians (Swank and Douglass, 1974). The contest between peat and forest, shown in Figure 6, is generally attested by the large amounts of black "bog oak" found buried in many raised bogs. When forest changed to bog, drainage was much impeded, and areas in need of drainage, on the large and small scale, were created.

In turn, the planting of woods and even shrubs will soak up much water by transpiration, and will tend to open the soil and increase infiltration where the subsurface is suitable.

Hydrochemical Influences

Whereas liquid water is a powerful agent in dissolving and taking into solution rocks, minerals, and glacial debris, solid water (ice) makes no chemical attack on the materials with which it comes in contact. So, while water was mainly solid in and over Ireland, the amount of chemical weathering and change were small. There was some, for the eskers show that streams ran under and over the ice; in some cases (as HCO_3) cold water is chemically more aggressive than warm water.

There was a major change in this respect when the ice melted. The liquid water attacked the minerals, the rocks, and the glacial debris. Its main effect was in soil formation, in part moving down with fine material, in part with hydrochemical reactions and solution of the glacial debris. Attack on carbonate rocks was intensified. Pans of carbonate, silica, iron, and manganese were formed. And in many ways this hydrochemical action of liquid water has molded the topography and helped to develop areas which are now in need of drainage.

Man's Influences

Man's activities have in places created areas in need of agricultural drainage, and man has drained lands in the course of other than agricultural activities. Some of the cases in which drainage problems are created will be noted here; but this subject is not elaborated or presented under subheadings.

One of the most striking ways in which man has interfered with the natural drainage is in the building of the railways. These were mainly built between 1845 and 1880, and were pushed ahead in a determined manner. To what extent the railway engineers were forced to lay their track on poor ground (marshy, boggy, etc.) is not known; but as such railways had compulsory purchase rights they could lay the line where gradients were best for them, and not over poor ground where foundations might be a problem. The location of railways in relation to drainage needs would be an interesting study. Bridges, some very beautiful, were built over rivers and major streams. But streamlets and rills were ignored, and the amount of land in need of drainage bordering all Irish railways is quite remarkable. In addition, on lower ground, the railway engineers obtained additional embankment material from borrow pits on one or both sides of the track. Many of these are deep, and are now marshes.

Another striking form of blocked drainage is the levees, natural and artificial, bordering many of our rivers; behind these levees, there can be water meadows and fluvial flats in need of drainage. Some of this is inherent in such fluvial and alluvial flats. But drainage needs and problems have been increased by the dumping of the material drained from the bed of the river along the right bank. These may be additions to initial levees, but in many cases they have much aggravated the drainage problem. On the large scale, drainage of such lands is provided by channels, sluices, and other devices; these take off the main surface flow. But at a more local and farm level, many drainage problems remain, and one has only to look along the banks, floodplains, and fluvial flats of many of the Irish rivers to realize the extent of the problem.

In another way, the provision of piped water to stock has affected the drainage problem, but in a positive manner. Where stock were watered from ponds, branches of streams or river, pools, and other depressions in one or more fields of a farm, such watering points were often in marshy areas, in need of drainage. Now that most stock are watered from piped supplies, the old watering ponds and surrounding areas can be drained.

The changing pattern of the vegetation under agriculture may have good and bad effects on the drainage. The cutting down of the woods has unquestionably increased the amount of land in need of drainage. The present removal of many fences and ditches may improve drainage. Likewise, the substitution of open ditches, usually along the edge of (and forming part of) the fences, by covered drains will affect the drainage, as set out in more detail in the next section of this article.

Drainage—Quantity and Quality

This section deals first with the ways in which areas requiring drainage are formed by low or nil infiltration to solid rock, to drift, to lacustrine marls, to impermeable soil layers and pans, and to "rejected recharge." It then deals with areas where there are groundwater discharges from the aquifers, from rock and drift aquifers, and from the moraines and eskers. The drainage of peats is based on the experience of Bord na Mona. There is a short note on the chemistry and pollution of drainage waters. The section ends with consideration of some harmful effects of drainage; while drainage does not affect our abundant resources of groundwater, it can sometimes intensify floods, while wet lands have value in the rare periods of drought in Ireland. Peat dust in waters is a source of pollution from the drainage of bogs. And the changed agriculture can affect the environment in many ways, including the reduction of the habitat for water and marsh birds.

Areas of Low or Nil Groundwater Infiltration

Areas of low or nil groundwater infiltration are areas underlain by impermeable or almost impermeable rocks; they may also be due to rejected recharge to seasonally full or overfull aquifers in low-lying zones.

Solid Rock Aquicludes

A major reason for formation of lands requiring drainage is that they are underlain by impermeable or very slightly permeable solid rock. While precipitation falling on such areas may percolate down through the soil and weathered rock, it cannot go deeper. Unless it can move laterally, as on steep slopes or through fluvioglacial cover, it must remain in place and cause waterlogging and marshy conditions. Weathering of such impermeable rock may produce some permeability; but in general, this is insufficient to allow infiltration to pass laterally from under the waterlogged or marshy area.

Some 24,000 km^2 (almost 35%) of Ireland is underlain with rocks (granites, metamorphics, Ordovician, Silurian, Namurian) which are essentially impermeable. And there are some 44,125 km^2 (64%) of Ireland underlain by glacial deposits (boulder clays, drumlins) which also are essentially impermeable. This does not mean, however, that some 99% of Ireland is underlain by impermeable ground, since in many places the impermeable glacial deposits overlie impermeable bedrock.

Due to tectonic action (such as folding), weathering, soil formation, and other operations, the topmost layer of these impermeable rocks may be rendered slightly permeable, so there can be a little infiltration. But the water cannot go deep, and types of swamps, marshes, and mires are formed.

Drift Aquicludes

Drumlins (11,597 km^2) and three types of boulder clay (32,528 km^2) cover some 64% of the 66,900 km^2 of Ireland. Over them, swamps, marshes, and mires must form. Of these, drumlins and the new boulder clay (18,976 km^2) of the Midlandian Cold Period are the most impermeable. The old boulder clay of the Munsterian Cold Period mainly in the south has shown signs of goundwater movement by its decalcification. The Irish Sea boulder clay contains much material gouged from the seabed, and is less fine than the rock flour and related materials scoured by the ice from the underlying rock which form the new boulder clay.

As with the rock impermeables, some weathering and soil formation from these glacial deposits have rendered the topmost layer slightly permeable. But any infiltration which takes place is shallow, and marshes are bound to form over these deposits.

On the sides of the drumlins, there are considerable slopes, up to 13°–15°. These cause runoff, and concentration of the waters in the interdrumlin lows, which are mainly marshes and lakes in winter. Drainage of drumlins is highly specialized, and indeed is not often undertaken with success. As noted by Burke and others (1974), "Drumlin hills are about 80 ha in area. Ellipsoidal in outline, with a steep sloped nose and a more gently sloping tail. Slopes vary from flat to 20°; weighted average slope is 10°." They go on to describe experimental mole drainage of such a drumlin at Ballinamore, Co. Leitrim.

Lacustrine Marls

Lacustrine marls were formed in the extensive lakes (mainly shallow) which covered much of Ireland when the ice first melted; some idea as to the extent of the main lakes is shown in Figure 4. Marls are a combination of clay with medium to large amount of carbonate minerals, mainly calcite and aragonite; shell beds are common. The lakes formed in areas of flat terrain and on impermeable formations, often boulder clay. The permafrost would have rendered impermeable some other formations, such as the fluvioglacial deposits, so lakes could form on them also. The incoming waters from icemelt and precipitation contain clay particles and were rich in bicarbonates in solution and carbonates (as rock flour) in suspension. It is not known if their deposition was a seasonal occurrence; if so, they could resemble the varied clays so typical of glaciated conditions elsewhere. They supported a large molluscean fauna, and shell beds are common; diatoms may occur, but have not been positively identified.

There are conflicting ideas to their permeability. From a lithological viewpoint, and slightly consolidated rock composed of clay and carbonate precipitates would be expected to have low permeability and would not drain easily. Finn and others (1982) obtained a figure of 0.04 m^3/m^2/d (m/d); this is as would be expected hydrogeologically. However, J. Mulqueen has commented as follows on the first draft of this article: "Extensive areas of marl have been easily drained. Drainability depends on the thickness of the marl layer, but primarily on the permeability of the underlying strata. Permeabilities of 10–50 mm/d have been measured at Creagh; this is adequate to soak the rainfall in a vertical direction. In marl situations, the drain spacing depends *only* on the permeability of the underlying drift or rock." Of course, sands and gravels were likely to be deposited in these lakes when first formed, and flows were large. So it is not unusual to find lacustrine gravel, sand, and silt underlying the lacustrine marl, formed when flows were smaller and waters were more tranquil.

There is room for research here, though the differences may be those of terminology rather than of fact. However, it is hard to see how lacustrine marl could form except in a lake. It is hard to see how a lake could form on permeable strata, unless there were permafrost effects. So, it is hard to see how most lacustrine marl can lie on anything but low-permeability strata.

The extent of these lacustrine marls is not shown on any geological or soil map. They are buried under peats, fens, swamps, encroaching vegetation, and lakelets. Where they are underlain by impermeable strata, they must act as water barrier. Where they are overlain by bogs, the barrier effect is increased.

Impermeable Soil Layers

In some places, impermeable layers develop in the soil and prevent or greatly reduce infiltration. Likewise, heavy machinery used in farming operations can compact the soil and reduce or stop infiltration. Other types of compaction are possible, as reported by An Foras Taluntais (1983, p. 42): "Very high inputs in terms of energy, machinery and labour, and such operations carried on over a long period lead to a deterioration of the weak soil structure (Ashbourne Series, Co. Meath) and the formation of a compact layer or pan below ploughing depth."

For such impermeable soil layers, the main method of drainage must be by suitable tillage and ploughing operations. Where the impermeable layers are below ploughing depths, ripping or the possibility of shallow drilling to open up passages through the impermeable layer may be considered.

Pans

The development of pans is common in Irish soils, and these can be impermeable and give rise to marshy areas and mires, usually covered by rushes. The pans are of several types of chemical composition. The most striking are the iron and manganese pans, which can be hard and thick, and of a black to reddish-brown color, sometimes dark brown. Their mode of formation is outlined above. They thus occur in groundwater discharge areas, though this may be only seepage down a hill and into the swamp or marsh at its base. Some of their characteristics are described by Burke (1972).

Pans cemented by silica and by carbonates are also common. They impede the drainage and cause swamps and mires.

It would seem that the breaking up of these pans by bulldozers or similar scarifiers would allow water to move down through the broken pans. Aspects of such are described by Galvin and MacGrath (1977).

Rejected Recharge

There is considerable evidence that some aquifers in Ireland are so full of groundwater that in January and February they reject any further recharge. Swamps caused by this mechanism are winter–spring swamps; later in the year there is normal infiltration and the water moves down below damage level. Thus, rejected recharge is closely related to fluctuations in groundwater level, as already noted above.

Clearly, increased extraction from the aquifer would lower its water-table level and reduce or stop rejected recharge. This may happen in the future, but the amount of groundwater now used in Ireland is small. Some 170 million m^3 are extracted from an annual groundwater recharge estimated at from 25 km^3 to 11 km^3 (Aldwell and others, 1983). So it is unlikely that increased extraction of groundwater will solve this aspect of the agricultural drainage problem.

Areas of High and Medium Groundwater Discharge

Much groundwater discharge is into streams, rivers, and lakes, and in coastal areas, into the sea or on beaches. Very little of such groundwater discharge gives rise to agricultural drainage problems. Some groundwater discharges through large or medium springs, the headwaters of streamlets and streams; again, no drainage problem arises. But a considerable amount of groundwater discharge is diffuse, and where such is underground or subsurface to overlying Quaternary deposits, major drainage problems arise. Probably the worst case is a rock aquifer discharging into a semipermeable Quaternary clay-silt-sand deposit, where the water can spread for large distances, yet lack ability to drain itself due to small or nil slopes, presence of barrier deposits of boulder clay, and other drainage obstacles. The volume of discharge can be large, up to 50 or 100 times the rainfall. Groundwater originating in Quaternary deposits, as fluvioglacial outwash, can also discharge in many ways which can contribute to the formation of mires, fens, peats, and marshes, all requiring agricultural drainage.

In coastal areas, back swamps form behind coastal sand dunes; the fresh groundwater may be underlain by saline groundwater, and both may fluctuate with the tide. Such swamps present complex drainage problems.

Rock Aquifers

Carbonate aquifers are the most extensive in Ireland, underlying some 45% of the country. While there are some badly drained areas (as the Calp), the limestones and dolomites of the Lower Carboniferous are well drained and in places karstified to varying extents. Then drainage is often through comparatively open channels some 5 to 15 m below ground level, and is often highly effective.

However, there is the problem of resurgences. In truly karstified areas, there are springs, often very large and very seasonal. The water may form swamps, but more usually drains away as a temporary, but large, river or stream. Where, however, drainage is impeded by Quaternary deposits, by soil formation, or by vegetation, there the major discharge points of karst drainage can give rise to swamps and marshes. Where there is small or minimum karstification, and discharge is diffuse and locally small, there also swamps and mires are easily developed.

For the other aquifers, including Ordovician volcanics, the Old Red Sandstone, and the smaller aquifers, discharge is more likely to be diffuse, unless concentrated along different types of tectonic disturbances. So areas in need of agricultural drainage are likely to be found in the discharge regions of these aquifers.

Quaternary Aquifers

The main Quaternary aquifers are the fluvioglacial deposits (13,144 km^2) covering some 19% of Ireland. River alluvium (3152 km^2) and moraines and eskers (1147 km^2) are of lesser importance. Where they overlie impermeable rocks, there drainage problems are most likely to arise.

In general, the Quaternary fluvioglacial deposits are rather thin beds of silt, sand, and gravel, with some cobbles and boulders. They are thin, and have a variable amount of groundwater, so their levels fluctuate from winter to summer. When water tables are high, swamps and marshes develop; these may be large in winter, yet small in summer. Agricultural drainage of such regions must take note of these natural hydrogeological controls.

River alluvium seldom discharges groundwater so as to cause swamps. River alluvium is at the topographical bottom of any area, and while bank storage can fill, empty, and refill such river alluvium over short periods of time, discharge is back into the river. Low permeability and very low hydraulic gradients are the main adverse factors to drainage of such lands. However, many large springs can occur in river alluvium, fed by large rock (or even Quaternary) aquifers. Where such springs are large, the water flows in a stream to join the river. Where small or diffuse, swamps and mires can be created. They are easily drainable to the river or stream beside which they occur.

Moraines and Eskers

Moraines and eskers are curvilinear features, and they have very high permeability, so they may convey groundwater for long to short distances, depending on the topography over which they were deposited. In many cases, this topography is the kettle-and-kame topography, which in itself is hummocky to ridgy, and can also have very irregular points of groundwater discharge.

As a result, a very complex pattern of lands requiring drainage can interdigitate with areas of high drainage and, indeed, subjected to drought in dry summers. Each farm or small area must be studied on its own; it is seldom that large-scale drainage schemes can apply in eskers, moraines, and even kettle-and-kame areas.

Drainage of Peats

Bord na Mona has operated on some 93,000 ha of peatlands over the past 37 years; all this has had to be drained. Naturally, an efficient and standard approach to such drainage has been evolved; many aspects of it are contained in an article by Lee (1976). Since high bogs are almost entirely nourished by the precipitation, drainage is of precipitation. When there are inflows of groundwater or surface water, fens are formed; fens do not give rise to peat which is of use to Bord na Mona, but lower bog horizons are fens in some areas.

Virgin bogland, with 90% in the 4.5–7.5 m thickness range, as well as cutover bogs, have first to be surveyed. The initial survey was in 1810–14, when some 280,000 ha of midland bog were mapped. Of these, Bord na Mona now possesses some 52,000 ha.

The bog is first leveled, and cored, to determine depths of turf. The peat is classified on a scale of 10, from moss to completely decomposed.

The objectives of bog drainage are (1) to remove as much as possible of the free water held in the peat, (2) to open stable drains of adequate depth for the intended system of peat winning and for the discharge of surface runoff, (3) to dry the bog surface for spreading, and (4) to improve the bearing strength of the bog surface for the safe working of machinery. The percentage of water to solid matter plus water rises from say 93% at surface to 96% at depths of 1 to 3 m, and thereafter decreases to near 90% in the well-humified layer near the underlying lacustrine marl or other forms of fen. Drains are opened by special ploughs, and the bog is left to drain for five or six years before peat harvesting commences.

Where groundwater levels are too high under or adjacent to bogs, some arterial drainage is carried out on streams. But where gravity flow from the drained bog is impossible, pumps are installed. The Archimedean screw pump is most suitable, and some 150 are installed to drain some 12,000 ha. Some of the water so drained is from the underlying rock, glacial material, and even from the fens which underlie almost all peat bogs, and receive surface or groundwater flow. Hence, there is considerable interaction between the drainage of bogs and the effects on the surrounding groundwater. As far as is known, there have been few studies into such interactions, though the practical side of bog drainage is done most effectively by Bord na Mona.

Quality of Drainage Waters

Not much research has been carried out into the chemical quality of waters released by drainage operations. A summary of the hydrochemistry of Irish groundwaters is given in Table 6, based on D. Daly (1979, March). It will be seen that the groundwaters held in the rock and Quaternary aquifers of Ireland are lowly mineralized, with total dissolved solids averaging some 375 ppm. They are typical waters of limestone aquifers. It is to be expected that drainage waters would closely resemble the chemical composition of the groundwaters in the aquifers drained.

The problem of pollution needs a short note. Agricultural pollution from widespread, diffuse N, K, and P is small; only from spot sources (silage, feedlots) is there pollution (Aldwell and others, 1983). Such spot pollution is unlikely to affect drainage. With regard to the general pollution of groundwater, it is thought that drainage, by skimming water off the top, recharge may in some cases protect the underlying waters from such pollution; clearly this applies only to drainage of infiltration, not to drainage of discharge.

Possible Harmful Effects of Drainage

There are a few possible side effects of agricultural drainage which could be considered in some countries as harmful to groundwater resources and management. Of these, reduction of groundwater resources would be the most serious, but only in countries with limited water resources and where competitive requirements of different water users exist; this is not so in Ireland. Increased flow from drains in winter may increase the possibility of floods and flood damage; such possibility exists in Ireland. Wet lands are useful in droughts and dry spells; again, droughts are unusual, but not unknown, in Ireland. The changing forms of agriculture following drainage may have some side effects, related more to the agricultural changes than to the actual drainage.

Loss of Groundwater Resources

As already noted, groundwater extraction and use in Ireland is only 170 million m^3 of an annual recharge estimated at from 25 km^3 to 11 km^3 (Aldwell and others, 1983), that is between 0.6% and 1.5% of annual recharge, and taking no account of stored capital reserves. Accordingly, there are very large untapped groundwater resources in Ireland.

The depletion of groundwater resources by agricultural drainage applies only to drainage in the infiltration areas, and not in the discharge areas. And in the potential recharge areas, much of the land requiring drainage is underlain by impermeable rock or drift; its drainage will not affect infiltration and formation of groundwater reserves.

Increased Danger of Floods

Agricultural drainage will appreciably increase the winter and spring flow from the drained lands and discharge this water into streams, rivers, and lakes when they are already in full flow. Such agricultural drainage will increase the danger of floods and flood damage.

Agricultural drainage will be from areas of low or nil groundwater infiltration. From these, surface runoff will be initially great, and will be increased by more rapid flow from the drains of waters which otherwise would rest on the ground or in the subsoil. Agricultural drainage will also be from areas of high and medium groundwater discharge, and here again the drainage pipes and channels will speed up the rate of flow and the total amount of water discharging in winter and spring.

While part of this additional flow will originate from farm and agricultural drainage, most of it will be from arterial drainage and will be taken into account when planning, executing, and managing such arterial drainage schemes.

Peat Dust

Drainage waters from precipitation leading to runoff from bogs plus some drainage from ground and surface waters from fens can be polluted with objectionable quantities of peat dust. This dust is fibrous, and the fibers have diameters in the one- and two-micron range. They are difficult to extract, either by settling or filters. They get into streams and rivers, and render water unsuitable for domestic supplies. Bord na Mona is actively engaged on research as to how to remove this peat dust. At present, it would seem that settling ponds and tanks, where the polluted water can be held for three months and then decanted, offer the best solution to the problem.

Droughts and Dry Spells

In many areas and farms awaiting and requiring agricultural drainage, the undrained lands can provide valuable moisture and pasturage during droughts and dry spells. In the past, water meadows were cropped to hay which was made after the main summer hay rush was over. Rushes were sometimes cut and used for bedding. There was a limited special use of such lands.

While droughts and dry spells will still affect Irish agriculture (and there is a very limited amount of sprinkler irrigation), there is little doubt but that drained lands will produce well in excess of undrained land, even allowing for the occasional drought or dry spell.

Changed Agriculture

Agricultural drainage brings about changes in the agriculture as well as in the movement of water. The two effects should not be confused. Thus, the increased dryness of the drained lands may increase nitrification (Prudil, 1982), yet there will also be increased amounts of nitrogen (and other fertilizers and manures) applied to the drained land. Increased nitrogen in the drainage waters may be due to both causes.

Again, shrubs and brushwood, including willows, alder, and birch, are often eradicated as part of the drainage operations. Their removal will change the local environment in several ways, some good, some not good. To some extent the changes are due to drainage; in other ways they are due to agricultural changes. They can have a large effect on wildlife, in particular on water birds.

Conclusions

This article presents the ideas of a hydrogeologist on a subject of which he has little experience, agricultural drainage. Allowing for a lack of knowledge of many aspects of drainage, some interesting conclusions can be drawn. And the study has also thrown up some unusual concepts and ideas on the subject, of which 13 are listed here.

General Conclusions

The drainage of the agricultural lands of Ireland is a great undertaking, which has lasted from 1842 to the present day, and will continue on a similar scale into the future. The rewards have been great in terms of better farm living and production, with many secondary benefits, such as flood alleviation, better communications, and navigation. Costs and social-economic analyses are omitted from this study.

Almost half of the 68,900 km^2 of Ireland were or are in need of drainage. To date, some 20,200 km^2 or over 30% of the whole of Ireland have been drained in one way or another. Some areas may need re-drainage, while standards of agriculture are much higher than when earlier drainage schemes were undertaken. It could be that in 1986, more than 20,000 km^2 of farmlands are still in need of drainage.

The review of the work achieved has been made from the viewpoint of a hydrogeologist, seeking where there are interactions between drainage and groundwater. There are a large number of aspects of drainage which interact closely with hydrogeological concepts and practice. The evolution of a topography molded under solid water and evolving under liquid water is the origin of many drainage problems. The presence of impermeable beds, rock or drift, gives rise to drainage problems. The presence of groundwater discharge from the different aquifers in many ways gives rise to drainage problems. Groundwater hydraulics, such as varying water-table levels, karstification (with development of open underground channels), and turloughs all pose drainage problems and possibilities. Peat, with its fens, raised bog, and blanket bog, are of major interest to Quaternary geologists and hydrogeologists; it poses innumerable drainage problems and has been the subject of much research by drainage experts of An Foras Taluntais, Bord na Mona, and others. Hydrochemical influences are smaller, but it must not be forgotten that liquid water, with all its aggressive solution characteristics, has been active on a wide scale in Ireland only over the past 10,000 years. And man has influenced the drainage pattern too, by building his railways, and by cutting down the forests which once clothed Ireland.

The second main portion of the article deals with the drainage of the problem areas. There are essentially three: (1) impermeable rocks or Quaternary, (2) outflow of groundwater from rock and drift aquifers, and (3) peats. It is hoped that in all cases, the value of hydrogeological thinking and knowledge can provide some useful and practical new ideas to the vast store of knowledge and experience of the engineers, soil scientists, and agriculturists dealing with the drainage problems of Ireland. At its end, the article notes some possible harmful effects of drainage. Ireland has such large, and almost unused reserves of groundwater that even large-scale drainage of groundwater will not affect Irish reserves. There is some danger of increased floods, as discharges are increased in winter and spring. Peat dust in drainage from bogs does represent one of the few identifiable bad effects of groundwater drainage. In the past, marshy areas provided a grazing reserve in periods of drought and dry spells; these will be absent where drainage has been executed. And the changed agriculture represents many impacts on the environment, in particular on marsh and water birds, both inland and along the coasts of Ireland.

To conclude, it is hoped that some of the ideas and concepts presented here will prove of practical use in agricultural drainage; and that in the future, the Irish hydrogeologists will be able to help a little in the great task not only of draining the agricultural lands of Ireland, but also keeping them drained.

Some Unusual Concepts

This article deals mainly with the application of some hydrogeological, and also geological, concepts to the drainage position, achievements, and problems in Ireland. These are scattered throughout but may be summarized here.

1. Topography was molded by solid and not liquid water.
2. Hydrochemical modifications are not made by frozen water.
3. Hydrochemical effects are postglacial, post 10,000 years BP.
4. Permafrost sealed aquifers under glacial lakes.
5. Small glacial lakes did not overflow and so did not drain.
6. Tilting reduced gradients for rivers Blackwater, Lee, and Bandon.
7. Rejected recharge occurs in Jan–Feb.
8. There is nil groundwater recharge in summer.
9. Transpiration can help dry up and drain marshes.
10. Karst can provide open-channel subsurface drainage.
11. Drainage of interface between fen and bog is complicated.
12. Deforestation of Ireland from 5000 BP has affected drainage.
13. Drainage has been impeded by railways.

Acknowledgment

The first draft of this article was prepared early in 1984. The staff of the Agricultural Institute working at Creagh Station in Co. Mayo have kindly read the first draft and made many valuable additions and helpful alterations. These have been incorporated into this version. The article was discussed at the meeting of the Commission on Groundwater of the IAH in Ireland in June 1984; some ideas and comments made then have also been incorporated. But the contents of this article, with possible errors in such a wide field, must remain the responsibility of the author.

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