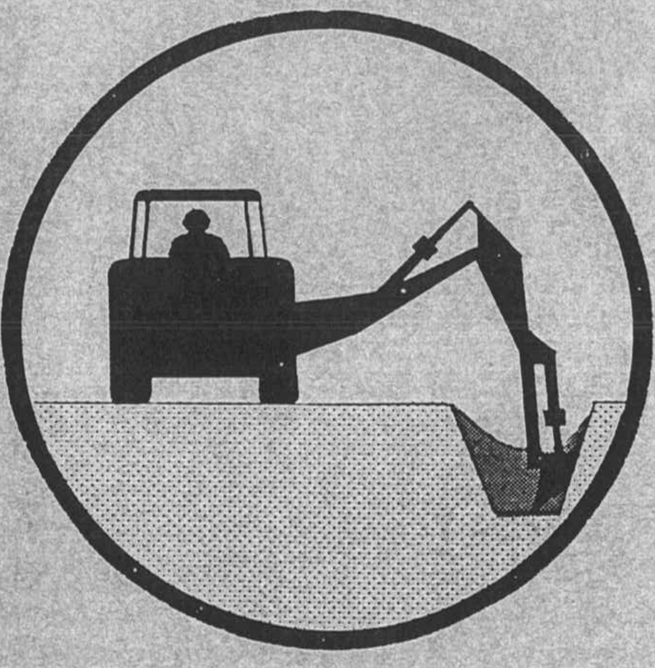
DANI ADVISORY SERVICES

FIELD DRAINAGE COURSE

FOR

ENTERPRISE ADVISERS



J V Courtney
Field Drainage Specialist
Department of Agriculture
Hydebank
4 Hospital Road
BELFAST
BT8 8JP

FIELD DRAINAGE COURSE

for

ENTERPRISE ADVISERS

CONTENTS

GEOLOGY

Pre-Cambrian Rocks

The oldest rock sequence in Northern Ireland comprises a great thickness of muds, sands and lime rich oozes now indurated into rock, which were despoisted in a continental shelf environment some 600-700 million years ago. These strata were very much altered by metamorphic action having been deeply buried in the earth's crust and now appear as a succession of slates, schists and metamorphic limestones. Today these outcrop in the Sperrin mountains and over much of Co Derry. (See Fig 1).

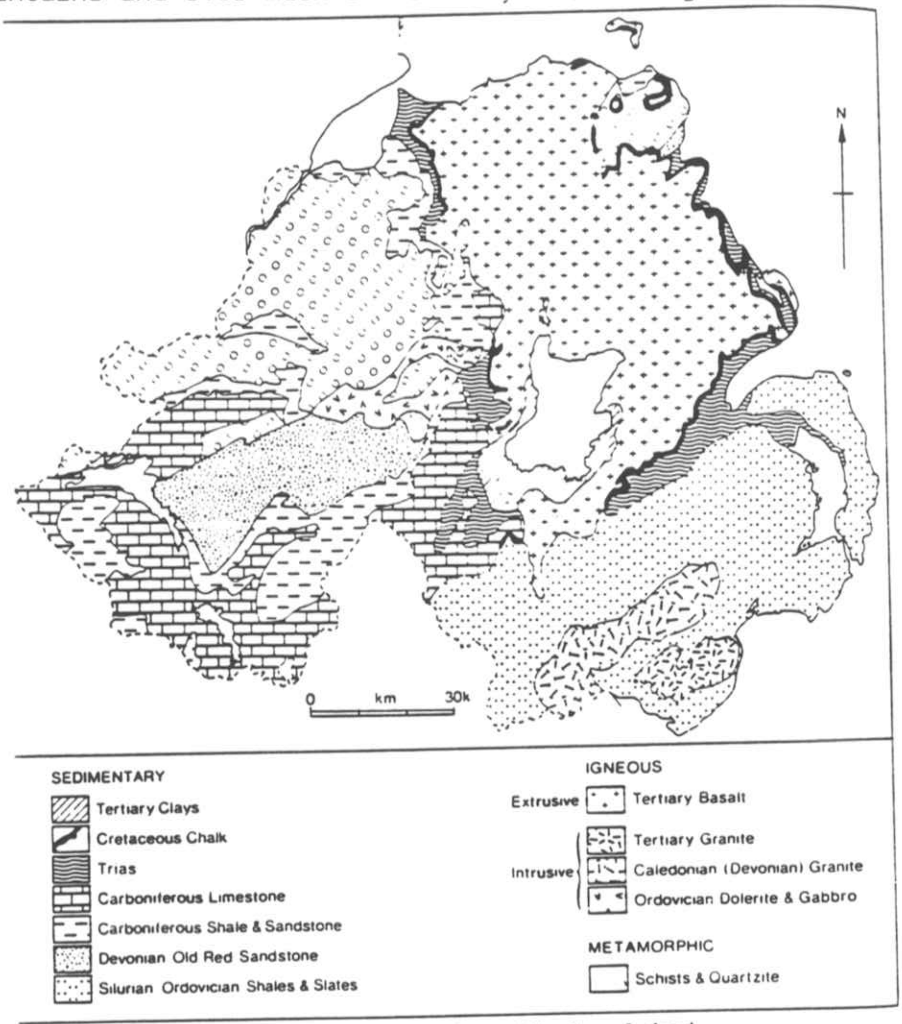


Figure .1 Simplified geology of Northern Ireland.

Lower Palaeozoic Rocks

Strata from this age occur in many parts of Northern Ireland, but predominately in Counties Down and Armagh. These rocks contain the first convincing fossil remains, again of a marine nature, and constitute the Ordovician and Silurian systems (mainly shales) of Northern Ireland.

The Silurian strata mainly comprise alternations of sandstones and shales, now highly deformed by folding and faulting so that muddy or shaly strata have acquired a slaty cleavage. The sandstones are of a particular variety calley greywacke.

Marine sedimentation was terminated by the Caledonian Orogeny This was the final phase of crustal deformation which had started back in Pre-Cambrian times. Rock folding had taken place on an enormous scale in a north-east to south-west direction. Massive igneous intrusions took place, the most widespread of which were the granites of Newry.

Upper Palaezoic Rocks

(a) Old Red Sandstone

At the end of the Caledonian period, great sedimentation again took place. The climate was dry and warm so that iron in the depositing spreads of sand and gravel became oxidised and reddened. The sandstone which formed and which was subsequently folded and uplifted during the Armorican Orogeny became known as Old Red Sandstone. It stretches from Pomeroy in Tyrone to Irvinestown in Fermanagh.

(b) The Carboniferous System

This period saw the progressive invasion of Ireland by encroaching seas. The oldest Carboniferous deposits are a sequence of coarse conglomerates, sandstones and shales indicative of shallow water sedimentation of deltaic character. These basal deposits vary in thickness at around 200 m. As Carboniferous times proceeded true marine conditions set in and the sediment type changed to lime rich muds which eventually lithified into limestones; the limestone sequence varies in thickness from about 300 m at Omagh to over 2,000 m on the eastern shore of Lough Erne. Such thickness variations indicate that the crust subsided at differential rates in the different basins of sedimentation. Sea levels oscillated and periods of terestrial and fresh water environments were experienced at the later stages of the Carboniferous period. The sediments became more laden with organic debris and with silt and clay particles. This resulted in the formation of the Upper Carboniferous shales, Coal Measures and Millstone grits. The shales occur most widely in Fermanagh. Because they are rich in clay and silt they usually weather to form poorly-drained difficult soils. (see figure 2)

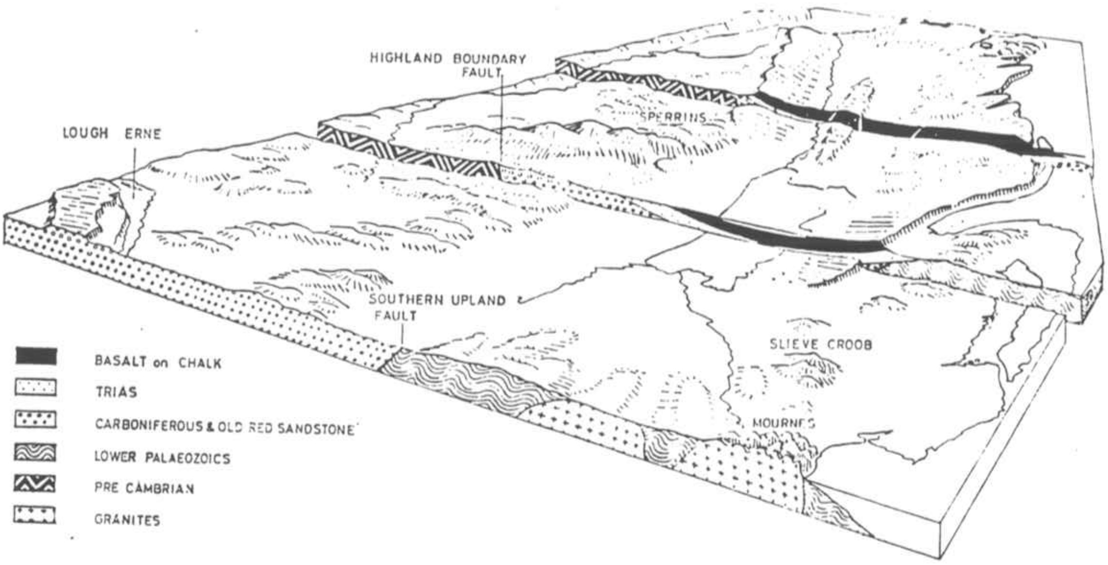


FIGURE 2: GENERALISED BLOCK DIAGRAM OF NORTHERN IRELAND

Mesozoic Rocks

This period stretches from 225 to 70 million years ago. (see Table 1) After the Amorican upheaval great masses of eroded debris were trapped in basins to form the New Red Sandstone, however, its extent is very limited. It is found in small enclaves in Belfast Lough between Armagh and Dungannon and close to Cookstown and in the vicinity of Larne.

Much of the sedimentation, mainly sandstone and shales (marls) seem to be of a non marine origin although the Permian does contain one marine horizon - the magnesian limestone.

Towards the close of Triassic times the environment changed from one of high evaporation to one of increased humidity. This culminated in true marine sedimentation of the Rhaetic beds. The Permo-Triassic varies in thickness and is poorly exposed, but boreholes at Portmore and Longford Lodge reveal thicknesses of 1 200 m and 700 m respectively (Lough Neagh area).

The succeeding Jurassic strata were also deposited in a marine environment. Their dominant rock type is dark blue mudstone. These deposits have been protected in the main from erosion by the latter volcanic rocks but crop-outs are visible around the edge of the Antrim

TABLE 1: GEOLOGICAL TIME-SCALE †

AGE IN MILLIONS OF YEARS	GEOLOGICAL SYSTEMS (Maximum thickness in feet)	
1*	QUATERNARY*	CAENOZOIC ‡
11	PLIOCENE 15,000 ft	CAENOZOIC ‡
25	MIOCENE 21,000 ft	CAENOZOIC ‡
40	OLIGOCENE 26,000 ft	CAENOZOIC ‡
	EOCENE 42,000 ft	CAENOZOIC ‡
70	CRETACEOUS 51,000 ft	MESOZOIC
135	JURASSIC 44,000 ft	MESOZOIC
180	TRIASSIC 30,000 ft	MESOZOIC
225	PERMIAN 19,000 ft	PALAEOZOIC
270	CARBONIFEROUS 46,000 ft	PALAEOZOIC
350	DEVONIAN 38,000 ft	PALAEOZOIC
400	SILURIAN 34,000 ft	PALAEOZOIC
440	ORDOVICIAN 40,000 ft	PALAEOZOIC
500	CAMBRIAN 40,000 ft	PALAEOZOIC
600	Unknown thickness	PRO-TEROZOIC
	PRE-CAMBRIAN	
	Unknown thickness	AZOIC
Origin of Earth's Crust 4500		

† Time-scale approximate with probable error + 5% throughout

* Quaternary (Pleistocene and Holocene) 6,000 feet +

‡ Caenozoic = Tertiary (Pilocene-Eocene) + Quaternary.
Column proportional to time-scale

plateau. Boreholes at Portmore has shown a thickness of 269 m of lower lias.

The final sedimentary episode about 135 million years ago represent marine conditions and the deposition was in the form of a white calcareous ooze with traces of silica. This chalk is a very pure white limestone containing marine fossils of both micro and macroscopic nature.

Chalk and Hibernian Greensand associated with this Cretaceous era are found near Moneymore, Larne, Moira and Ballintoy.

Tertiary Times

The start of the Caeonzoic era saw drastic changes in the geological environment of the north of Ireland. No longer was the area one of marine sedimentation, but now a land mass already quite deeply eroded and destined to be covered by thick lava flows of Eocene age. Volcanism is the keystone of tertiary times in the north of Ireland. Lavas are best seen in County Antrim where today a maximum thickness of 800 m remains but estimates put the original thickness close to 1800 m. Eruption was completely subaerial unlike that at Slieve Gullion and the Mourne mountains. These were the main centres of intrusive volcanity and represent the injection of granitic magmas within the earths crust. This led to slow cooling giving rise to the formation of granitic rocks.

The principal sedimentary events of tertiary times was the deposition of the Lough Neagh clays. The plateau basalts became faulted and warped leaving a large depression - ultimately to become Lough Neagh. Clays were deposited in this depression and were derived by the breakdown of Carboniferous rocks to the west of the Lough plus contributions of clay minerals from other sources. The greatest recorded thickness of the clays is 349 m in the Washing Bay borehole.

GLACIAL GEOLOGY

Ireland was affected by three successive glaciations often named the Elster, Munsterian and Midlandian. Glacial deposits are widespread throughout the country but those of the Elster glaciation occur in a few places only and have had little effect on the subsequent soil pattern.

As the cold conditions of the Munsterian glaciation set in, a powerful ice gap developed in the Scottish Highlands. This eventually sent a massive ice sheet along the bed of the Irish Sea and deposited calcareous till along the east cost of Ireland from Down to Wexford.

Ice accumulated to great thicknesses at this time, up to 1000 mts.

The ice masses of the most recent glaciation, the Midlandian, were less extensive and did not cover the most southern parts of Ireland. Its limits stretched to a line extending from the northern tip of the Wicklow mountains to Loop Head in Clare. (see figure 1).

In the materials deposited by the Munsterian glaciation there is evidence of a greater degree of weathering than those in Midlandian glacation.

However, there is an absence of the well marked topographic features such as kames, eskers, moraines and drumlins which are widespread throughout the area affected by the Midlandian glacation.

These ice sheets were continually in motion and different layers moved at different rates. As it grew and moved the ice picked up a great variety of rocks, stones, sand, silt and clay. In motion the soft coarse materials were strongly worn down and only the hard stones such as sandstones, granites and quartzites remained. As the ice melted it released all its solid material including stones as boulder clay or glacial till. The bulk of this deposit was dropped within 10,000 metres of where it was picked up. Thus local geology will determine the textural and drainage properties of the till.

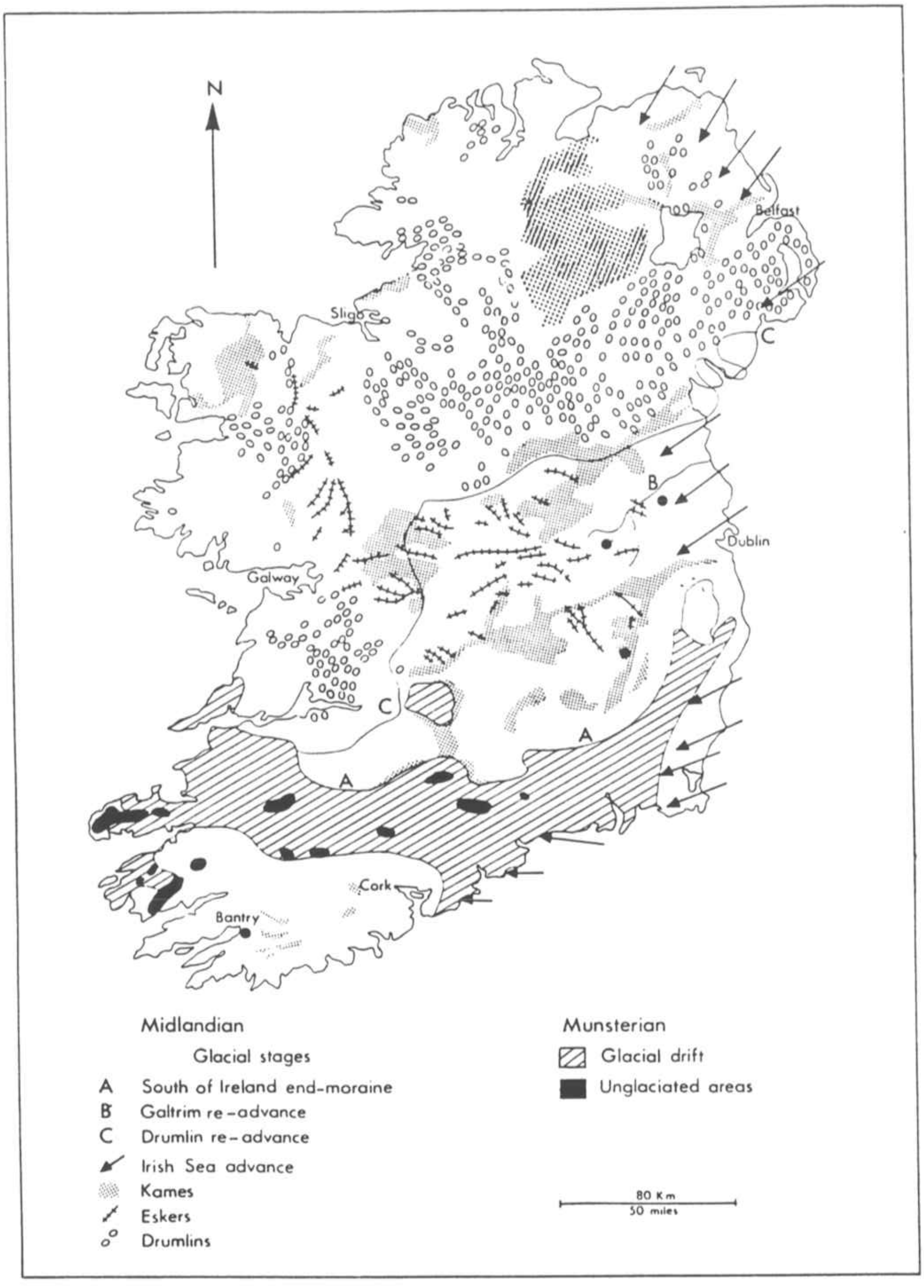


FIGURE 1: GLACIAL GEOLOGY OF IRELAND

THE DRUMLIN BELT

The drumlin belt stretches from the Counties of Down and Louth in the east to Sligo and Donegal in the west. The drumlins cover about 12% of Ireland which is approximately 4,000 sq miles. In Northern Ireland they are well represented in the Counties of Down, Fermanagh and Tyrone.

Drumlins vary in size from about 120 acres to 300 acres averaging about 200 acres and comprise of soils with slight to total impedence of drainage (see figure 1).

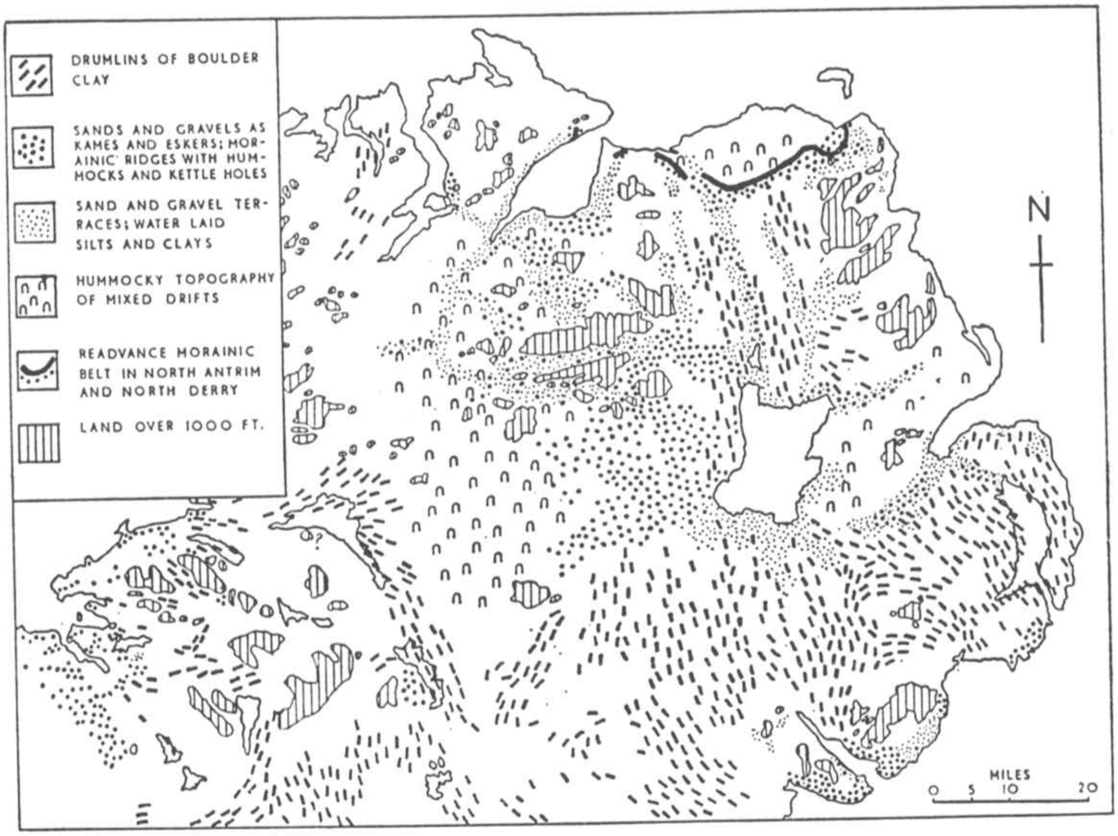


FIGURE 1: DISTRIBUTION AND MORPHOLOGY OF GLACIAL DRIFTS

Topography

Drumlin landscape is characterised by innumerable hills interspersed with valleys and lakes. The hills are elliptical or egg-shaped in outline. Their long axis is aligned in the direction of ice flow and the blunt and steep end points to the direction from which the ice flow came. The long axis of drumlins are on average about 800 metres and breadth is usually one-half to three-quarters the length. They can be up to 90 metres in height. Slopes vary from 2° up to 20° with an average of 6°. Most drumlin crests are 30-60 metres above the level of the inter-drumlin flats.

The drumlins may be rock cored or otherwise and may have from less than one metre to over 12 metres of superficial overburden of glacial origin. Although glacial activity has introduced some foreign materials local solid geology has determined to a large extent the composition of the soil forming materials.

Soil Type

Most drumlin soils, particularly those in the western parts, are poorly drained and may be classified as gleys. They have developed under moist conditions throughout most of the year. Even in the short summer season when the water table falls, the subsoils are poorly aerated because of their pore space characteristics. In drumlins with relatively good internal drainage, soils of the brown earth, brown podzolic and podzolic groups have developed. At higher elevations gleys give way to peaty gleys and peats where the parent materials are often poor in lime reserves and high rainfall results in prolonged water-logging and leaching of bases.

SOILS

SOIL

Soil is the weathered surface of the earths crust in which plant growth takes place. It is divided into two main phases.

(a) Topsoil - usually 150-300 mm thick
(b) Subsoil - can be many metres deep

Underlying this is the parent rock and its surface usually shows signs of weathering.

All soils which support plant growth are made up of the following:

1. Mineral matter (sand, silt and clay)
2. Organic matter
3. Soil Solution
4. Soil Air
5. Soil Organisms

Thos most important zone for plant growth is the topsoil which is easily distinguished as a rule from the underlying material because of its difference in colour and structure.

Mineral Matter

This is the largest constitution of most soils with the exception of peat and provides the framework or skeleton in which the other constituents exist. The mineral matter which is derived from the breakdown of the earths elemental rock determines the soils basic characteristics.

The elemental rocks fall into three classifications.

(1) Igneous Rock - these are formed by the cooling and solidifying of molten lava at the earths crust eg basalt and granites.

(2) Sedimentatary Rocks - formed from the weathering of igneous rocks mainly which are deposited in low lying areas. Sea creatures are often incorporated in these rocks which form under water. The pressure of water and chemcial actives cause the fragments to be cemented together forming rock once more eg sandstone, shale, limestone.

(3) Metamorphic Rocks - formed under heat and pressure. Both igneous and sedimentary rocks can be changed into other forms eg limestone to marble, and shale into slate.

Weathering

Three weathering agents are responsible for the breakdown of these rocks.

(a) physical agents
(b) chemical agents
(c) biological agents

Physical Agents

(1) Water - In rivers and seas water acts as a cutting agent wearing away rocks. Rock particles carried by water increases the abrasive effect. Chemicals removed in solution from rocks cause structural weaknesses.

(2) Wind - Rock particles carried by wind have a sand blast effect.

(3) Ice - Frost action causes swelling and breakdown - abrasive action of glaciers also important in the past.

(4) Temperature - Alternative heating and cooling cause rocks to shatter.

Chemical Agents

(1) Solution - Carbon dioxide dissolved in water forms weak carbonic acid which can dissolve cementing agents in softer rocks causing fragmentation ($CO_2 + H_2O = H_2CO_3$)

(2) Hydration - This is the chemical combination of water with another substance causing a change of volume and fragmentation ($CaO + H_2O = Ca(OH)_2$).

(3) Hydrolysis - This is the removal of water from a chemical set up which often gives rise to the dissociation of components.

<u>Oxidation and Reduction</u> - Both processes can cause instability in structure.

<u>Biological Agents</u>

(1) <u>Animals</u> - Burrowing animals cause disturbance to soil material and expose it to further agents also their decaying remains produce acids causing further breakdown.

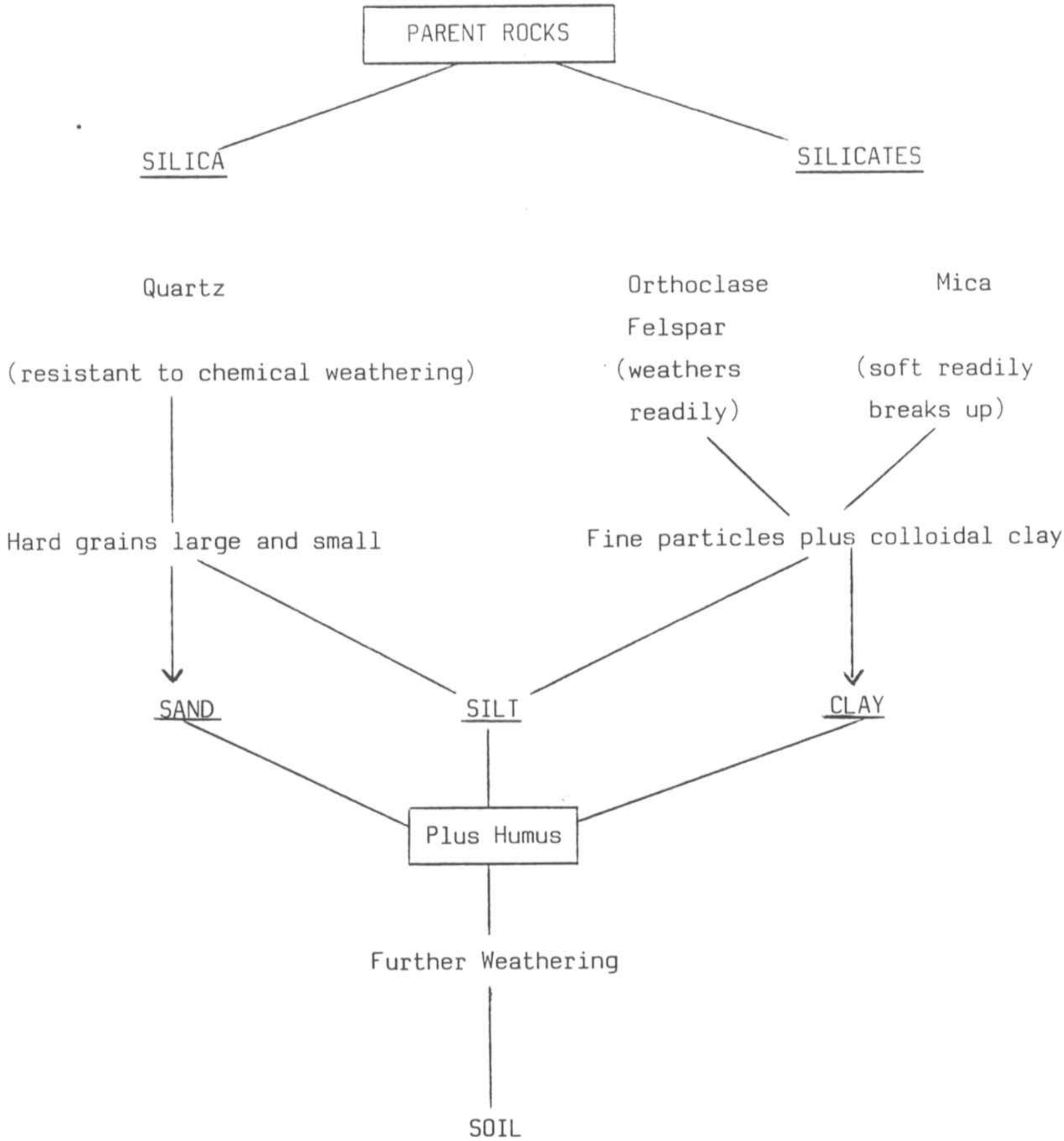
(2) <u>Plants</u> - Their roots can enter rock crevices and expand causing fractures also their decay gives rise to acids.

(3) Bacteria - Through their action on plants and animal remains acids are produced which attack rocks. Some bacteria can work on the rocks directly.

All these agents described above can work together and assist each other in the final weathering of rocks. This is a continual process.

The various weathering processes give use to a collection of particles (sand, silt, clay) which form the framework of the soil (figure 1).

Since there are a great number of different kinds of soil, varying from one another in different degrees to contrast, it is necessary to group them into progressively high categories - called Great Soil Groups.


PARENT ROCKS
SILICA
SILICATES
Quartz
(resistant to chemical weathering)
Orthoclase
Felspar
(weathers readily)
Mica
(soft readily breaks up)
Hard grains large and small
Fine particles plus colloidal clay
SAND
SILT
CLAY
Plus Humus
Further Weathering
SOIL

THE SOIL PROFILE

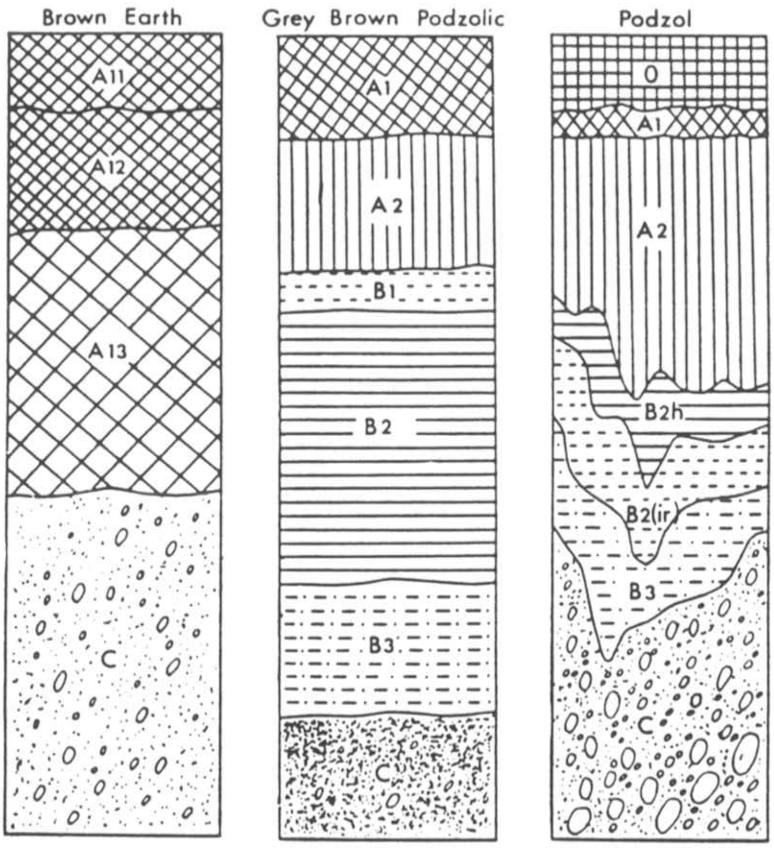
The soil profile refers to a vertical section of the soil down to and including the geological parent material. The nature of the profile is important in many aspects of plant growth including root development, moisture storage and nutrients supply.

The profile usually displays a succession of layers that may differ in properties such as colour, texture, structure, consistence, porosity, chemical constitution, organic matter contents and biological composition. These layers, known as soil horizons, occur approximately parallel to the land surface.

SOIL HORIZONS

Most soil profiles include 3 main horizons. They are usually identified by the letters A, B, C (figure 1).

SOIL SURVEY METHOD



The combined A and B horizons constitute the so called true soil whilst C refers to the parent material beneath. Some soils have no B horizon and are said to have AC profiles. In some soils, organic layers (O horizons) overlie the mineral horizons.

Certain soils are so complex that they possess many sub-divisions within the A+B horizons.

The A Horizon

This horizon is the uppermost layer in mineral soils. It is that part of the soil in which living matter eg plant roots, bacteria, fungi, earthworms and small animals, is most abundant and in which organic matter is usually most plentiful. The A horizon is more leached than any other horizon. Two sub-divisions of the A horizon are commonly made ie A1 and A2. Either the A1 or both may be represented in a profile. The A1 is a surface mineral horizon that usually contains a higher proportion of organic matter incorporated with the mineral matter than any of the underlying horizons. The A2 refers to the horizon which has undergone the greatest degree of leaching and usually has a bleached appearance due to the partial removal of colouring constituents.

The B Horizon

The horizon lies immediately below the A and corresponds closely to the so-called 'sub-soil'. Lying between the A and C horizons it possesses some of the properties of both. Compared with the A horizon the B horizon is one of accumulation and usually has a relatively high content of iron and aluminium oxides, humus or clay that, in part at least, have been leached from the over-lying horizons. Stronger colours are usually more apparent in the B horizon especially when the accumulation products are iron oxides. Several divisions of this horizon can also occur. B1 and B3 denote transitional horizons from A to B and from B to C horizons respectively. If the B horizon is without any appreciable accumulation of leached products but has distinctive colour or structure characteristics it is usually referred to as a B horizon.

The C Horizon

This horizon refers to the geological material beneath the A and B horizons. It consists of the upper part of the loose and partly decayed rock or other geological material such as glacial drift, similar to that from which the soil has developed. The C horizon is less weathered, has less organic matter and is usually lighter in colour than overlying horizons.

The O Horizon

This horizon refers to a surface layer of raw partly decomposed organic soils. Where little or no decomposition has taken place, the symbol O_1 is used; O_2 denotes more advanced decomposition. The organic matter contents of the O horizons is commonly several times greater than that of the underlying mineral horizons or of surface A horizons.

GREAT SOIL GROUPS

These are soils having the same kind, arrangements and degree of expression of horizons in the soil profile. They also have close similarity in soil moisture and temperature regimes and in base status.

The main great soil groups occuring in Northern Ireland are indicated below.

Great Soil Groups

1. Podzols
2. Brown Podzolics
3. Brown Earths
4. Grey Brown Podzolics
5. Blanket Peat
6. Gleys
7. Basin Peat

Podzols

Through the podzdisation process, soils are first subject to leaching. They are depleted of nutrients, become acid and develop eluvial A_2 horizons (subsurface layers of removal) and illuvial B horizons (layers of accumulation). Specifically the term podzolisation refers to the removal of iron and aliminium in solution from the surface horizons. This occurs when conditions become sufficiently acid. Sometimes these accumulations in the B horizon become cemented and are referred to as an iron pan.

Podzols are generally poor soils with high lime and fertilizer requirements. Usually formed on hill and mountain areas where mechanical means of reclamation and cultivation are often difficult. In many areas they are devoted to forestry. (see figure 1).

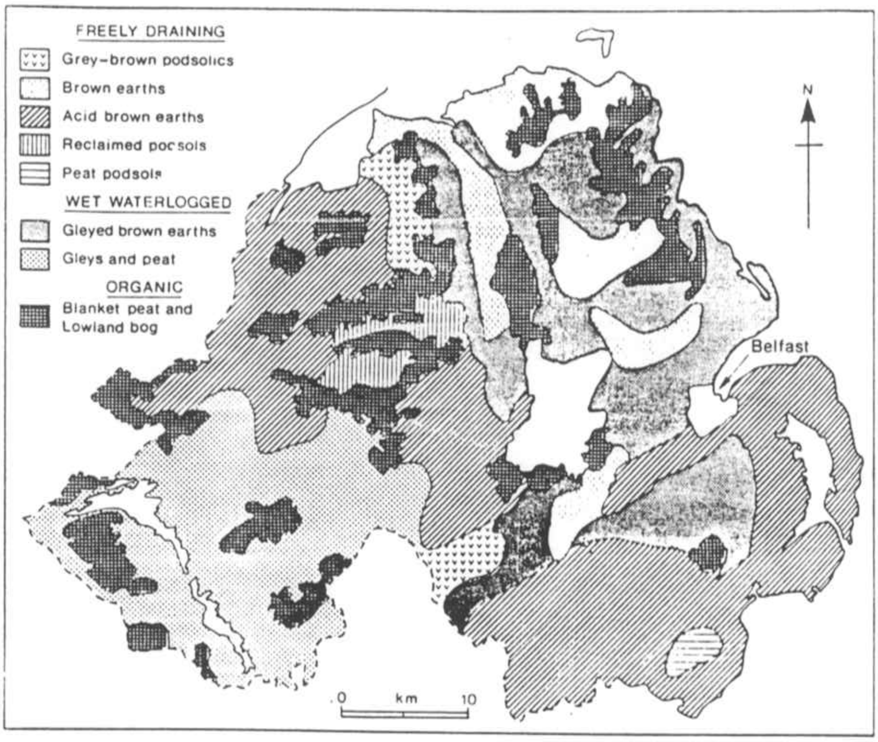


FIGURE 1: SIMPLIFIED SOIL MAP ON NORTHERN IRELAND

Brown Podzolics

These soils are somewhat similar to the podzols being formed under the influence of the podzolisation process. They consist of a surface AI horizon in which the organic matter is intimately mixed with the mineral matter. This is unlike the podzol where there is a separate organic O horizon on the surface. Brown podzols are less depleted than podzols and although they have iron and aluminium and sometimes organic matter deposited in the B horizon no pan is present.

Because of their desirable physical characteristics Brown Podzolics are often devoted extensively to cultivated cropping and pasture production. However, they require high lime and fertiliser inputs.

Brown Earths

These are relatively mature, well drained, mineral soils possessing a rather uniform profile with little differentiation into horizons. These soils have not been too extensively leached or degraded although there is often some translocation of soluble constituents notably calcium and magnesium, depending on whether they occur on lime rich or lime deficient soils. Brown Earths are divided into those of high base status and low base status.

These soils, in general, possess medium textures and this together with their friability desirable structures and drainage characteristics account for the fact that they are among the most productive soils in this country.

Grey Brown Podzolics

These soils are usually formed from a calcareous parent material which counteracts the effect of leaching. The principal materials translocated in the podzolisation process are the clay particles themselves. The B horizon, therefore, becomes heavier in texture than the A horizon.

The lighter textured Grey Brown Podzolics are good all-purpose soils while the heavier textured members are highly suited to pasture production.

Gleys

Gleys are soils in which the effects of drainage impedance dominate and which have developed under the influence of permanent or intermittent waterlogging. There are 3 types of gleys:

(i) Surface water gley - due to perched water-table caused by soils.

(ii) Ground water gley - due to high water-table or seepage.

(iii) Peaty gleys - developed under wetter conditions than for Gley soil. These soils have a relatively thick organic horizon (20-40 cm) which contains 10-30% organic carbon.

Peats

Peats are characterised by a high content of organic matter, over 30%, and by being at least 30 cm in depth. Two basically different types, blanket and basin peats occur in this country.

Because of poor drainage, adverse physical conditions and their occurrence in areas of poor climate, the range of uses of blanket peats in agriculture is very limited. When drained and reclaimed some basin peats can have a wide use range in agriculture.

SOIL ASSOCIATIONS

Basalt

Tertiary basalts lavas cover 1,548 sq miles and comprise almost one-third of the landscape of Northern Ireland. They represent the largest continuous unit of basic igneous rock in the British Isles. Basalt extends over a wide altitudinal range from sea level to over 500 mOD but more than three-quarters of the area of basalt soil is within the agriculturally improved land below 300 mOD.

The basalt soils which occur mostly in Co Antrim are most commonly developed on clay-rich glacial till and are usually gleys or gleyed brown earths of medium to high base status. They are usually fertile soils, highly suitable for grassland farming especially in the north, central and southern parts of Co Antrim (see Table 1). The basalt soils can be divided into 3 groups:

(i) Peat and peaty gleys - above 300 mOD. These soils have only limited value for hill sheep and cattle but have been used extensively for forestry.

(ii) Gleys on middle slopes: This accounts for about half the basalt area and supports mineral gleys on dry rich till.

(iii) Brown earths and some gleys on loam till: This last group of slightly gleyed and freely draining brown earths or sand deposits or loamy till are to be found around Coleraine, Kilrea, Ballymena, Antrim and Lurgan. This group has the highest potential productivity of the basalt soils.

Basalt soils are identified by a characteristic chocolate-brown colour, with gleying expressed by ferric orange and purple brown mottling. Soil structure is usually strongly and clearly developed on drying-out, in crumb or block peds. They tend to be rich in exchangeable calcium and magnesium and also in oxides of iron and aluminium, weathered from ferro-magnesian minerals. This iron-aluminium complex is often responsible for cementing of subsoil horizons where leaching has taken place.

Shale and Greywacke

This is the second most common soil parent material and is derived from rocks of the Ordovician and Silurian periods. These soils are found mainly in Co Down and Co Armagh and comprise about 26% of the total land area.

These are greywackes, shales and slate rocks which are weathered to produce predominantly loam and silt-loam textured soils. About half the shale-greywacke derived soils are gleys and gleyed acid brown earths of the drumlins, while the other half is mostly composed of acid brown earths with some leaching on steeper slopes and sandy textures in east and west-central Co Down.

These soils are not of high base status and where sandy textures and soil conditions allow leaching they become acid. Generous liming and fertilisation is necessary to maintain a high level of fertility.

Mica-Schist

Mica schists are found mainly in the Sperrins in Cos Londonderry and Tyrone and in north-east Antrim. If the fluvio glacial sand deposits of Co Tyrone are included these metamorphosed sediments provide parent material for about 18% of the soils of Northern Ireland. At elevations of between 100 and 300 mOD in the Sperrins and their outliers there is a combination of high rainfall and low temperatures. This gives rise to excessive leaching and acidification. Approximately half the schist soils are peaty gleys or peat due to site wetness in locations above 200 mOD. The rest are leached to some degree either as brown podsolics or acid brown earths in the Sperrin valleys or as podsols on the schists derived sand and gravel deposits around Pomeroy in Co Tyrone.

Due to the high rainfall and leaching with these sandy textured soils there can form a cemented subsoil pan giving rise to poor drainage and displaying surface water gleying.

With the addition of high Potash and lime inputs and good management these soils can be very productive.

Another point worth noting about schistose soils in the Tyrone-Londonderry region is the high incidence of springs and springline seepage problems.

Carboniferous Limestone

Sedimentary deposits from the carboniferous period provide parent materials for a variety of soil types covering about 14% of the land area of Northern Ireland. (See Table 1).

TABLE 1: NORTHERN IRELAND SOILS ARRANGED BY ROCK TYPE PARENT MATERIAL

Soil parent rock	*Soil profile type*	*Approx. area hectares*	*% area of N.I.*	
BASALT	Peat and peaty soils over 300 m O.D.	100,000	7.4	30.3
	Gleys on middle slopes	180,000	13.3	
	Brown earths and some gleys on loam till	130,000	9.6	
MICA-SCHIST	Peat and peaty gleys	90,000	6.6	17.6
	Acid brown earths and brown podsolics	110,000	8.0	
	Podsols and peat podsols on gravel in County Tyrone	40,000	3.0	
CARBONIFEROUS LIMESTONE	Gleys and peat gleys of Fermanagh and Tyrone	170,000	12.6	14.1
	Grey-brown podsolics in Armagh and Londonderry	20,000	1.5	
SILURIAN SHALE AND GREYWACKE	Gleys and acid brown earths on drumlins	140,000	10.4	26.0
	Acid brown earths and gleys on sloping ground	160,000	11.8	
	Acid brown earths in east coastal County Down	50,000	3.8	
GRANITES AND TRIASSIC SANDSTONE	Acid brown earths and brown podsolics	140,000	10.4	
OLD RED SANDSTONE	Gleys and gleyed acid brown earths in Counties Tyrone-Fermanagh	20,000	1.5	

These rocks are calcareous sediments, limestones, shales and sandstones, mainly from the Middle and Lower Carboniferous. Most of the soils are gleyed especially around the Upper Lough Erne area of Fermanagh. Here the fine grained soils give rise to tenacious material with very slow drainage rates. Because the quantities of water moving vertically through these soils are very small per annum weathering has had very little effect on them, other than on the shallow rooting topsoil.

Such soils are very difficult and expensive to drain as intensive drainage is required. Mole and gravel tunnel drainage systems have proved very successful in coping with such extreme soils. However, in West Armagh and to the east side of the Roe valley in Londonderry where loam textures occur, grey-brown podsolic soils are in evidence. Here the drainage is good and the land is of high agricultural value.

Old Red Sandstone

There is a very large area of Old Red Sandstone series extending from Pomeroy in mid-Tyrone to Irvinestown in Co Fermanagh. This is in the drumlin belt and has a deep covering of gracial till. Texture varies from a clay loam around the Dromore-Trillick area to a sandy loam as one extends westwards into Fermanagh. These soils are heavy and susceptible to poaching if not managed carefully.

Granite and Triassic Sandstone

Soils developed on different parent materials, but sharing a common characteristic of sandy textures, are found on the upland granite of Slieve Croob and the Mournes and on much less resistant Triassic sandstone of the Lagan valley and the Cookstown-Dungannon area of Co Tyrone. In the granite marginal land of Co Down soils are usually well drained and leached to the stage of acid brown podsolics or podsols. With the higher rainfall and steep slopes of higher ground, farming is much more difficult.

In the sandstone lowland areas, soils are acid brown earths or brown podsolics with good physical properties. Collectively these sandy soils make up about 10% of the land area of Northern Ireland.

The massive granites of the Mournes are strongly resistant to weathering and are almost totally impervious. Where the soil layer is thin and rests on these rocks it is not drainable.

TEXTURE AND STRUCTURE

Soil is regarded as a 3 phase system ie solids, water and air. The physical properties of soil depend on the nature of the solids and/or the amounts of water and air in the soil. The solid phase of the soil is relatively constant and the water and air phases are complementary and occupy the pore spaces.

A good soil will normally have 50 to 60 per cent of its volume consisting of pore space and ideally about one half of this pore space will be filled with stored water ie water that will not drain away.

Soil Solids

The solids in a soil consist of mineral and organic materials. When organic matter is dominant the soil is peaty and a raw-bog has almost 100% organic matter in its solids. In a normal tillage soil organic matter will be no more than about 3 to 4% by weight and often less. In pasture soils it will generally range upwards from this value. Organic matter is useful in a soil as a conditioner for soil structure and as a storage facility for water and nutrients. As the amount increases it causes problems associated with weakness, because of the low strength of organic matter, and wetness, because of its ability to absorb and retain water. The ultimate condition is a wet bog but heavy pasture soils often have a peaty layer on the surface giving rise to widespread poaching problems.

In most soils the most important material is the mineral portion. This consists of a vast number of small particles. These vary in size from clay particles which are very small to sand particles which are much larger. The relative sizes of these different particles are given in Table 1.

TABLE 1

Relative Sizes of Different Particles in a Mineral Soil

Fraction	Effective diameter (mm)
Stones	Greater than 2
Coarse sand	2 - 0.2
Fine sand	0.2 - 0.02
Silt	0.02 - 0.002
Clay	less than 0.002

To put this into perspective a sand particle is 1000 times bigger than a clay particle. If you think of a sand particle as a beach ball then a clay particle would be similar in size to a dot made on a piece of paper with a well sharpened pencil.

Soil Texture

The individual particles of a soil are called textured seperates and are classified on the basis of size. Soil texture is the term used to describe the relative proportions of these seperates in a soil (less than 2mm diameter). If the majority of the particles are coarse (gravelly or sandy) the soil is coarse textured; if the majority are fine (silt or clay) the soil is fine textured.

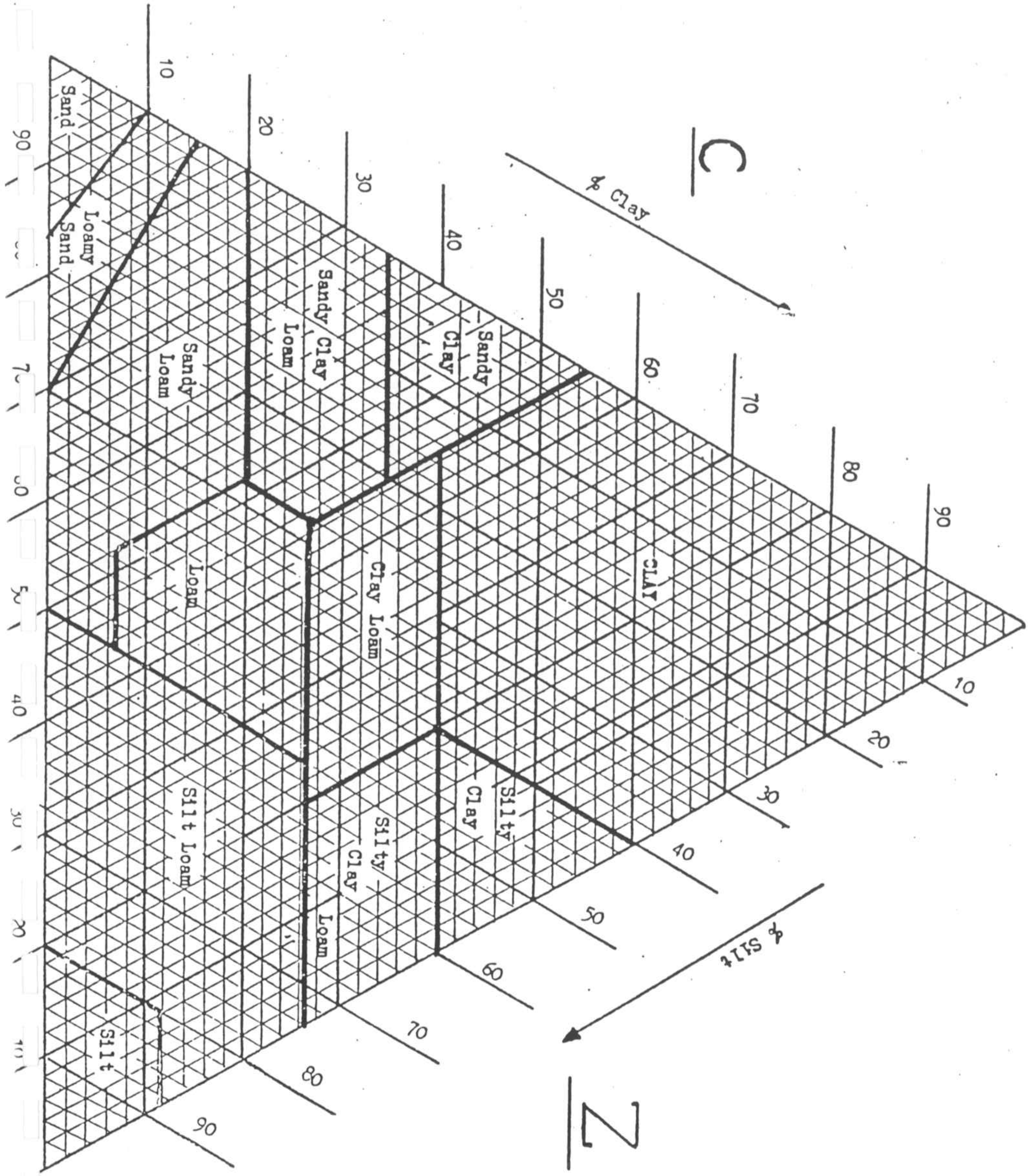
Table 2 and Figure 1 show the texture of different soils found in the country.

BLE 2: LIMITING VALUES FOR SOIL TEXTURE CLASSES

Sand	Material containing at least 85% sand, provided that the percentage of silt plus 1·5 times the percentage of clay shall not exceed 15.
Loamy sand	Material containing not more than 90% nor less than 70% sand, together with a percentage of silt plus 1·5 times the percentage of clay not less than 15 at the upper sand limit, or a percentage of clay to not exceed 30 at the lower sand limit.
Sandy loam	Material containing either less than 20% of clay with the percentage of silt plus twice the percentage of clay exceeding 30, or having between 43 and 52% of sand with less than 7% of clay and less than 50% of silt.
Loam	Material containing between 7 and 27% of clay, 28 to 50% of silt with less than 52% of sand.
Silt loam	Material containing either more than 50% of silt together with between 12 and 27% of clay, or which has between 50 and 80% of silt with less than 12% of clay.
Silt	Material that contains more than 80% of silt with less than 12% of clay.
Sandy clay loam	Material containing between 20 and 35% of clay, with less than 28% of silt and more than 45% of sand.
Clay loam	Material that contains between 27 and 40% of clay and between 20 and 45% of sand.
Silty clay loam	Material that contains between 27 and 40% of clay and less than 20% of sand.
Sandy clay	Material that contains 35% or more of clay together with 45% or more of sand.
Silty clay	Material that contains 40% or more of clay together with 40% or more of silt.
Clay	Material that contains more than 40% of clay together with less than 45% of sand and less than 40% of silt.

FIGURE 1

TEXTURE TRIANGLE - UNITED STATES DEPARTMENT OF AGRICULTURE



Field Assessment of Soil Texture

This involves a subjective assessment of the proportion of sand of different grain sizes, silt and clay in the soil. In the field it is done by taking a sample and wetting it. The sample is then worked between the finger and thumb until any aggregates are destroyed. The soil is assigned to the textural class according to the estimated proportions of sand. silt and clay in the sample eg:-

Grittiness indicates a preponderance of sand
Silkiness " " " " silt
Stickiness " " " " clay

A soil which is neither gritty, silty or sticky is a loam.
A more comprehensive summary of texture is given in Table 3.

TABLE 3

Soil Texture

Sand	Cannot be moulded into cohesive ball. Does not soil fingers.	Grain size determines category.
Loamy sand	Shows signs of cohesion. Will soil fingers.	Grain size determines category.
Sandy loam	Can be moulded into a cohesive ball.	Grain size determines category
Loam	A handfull of moist soil may be moulded into a cohesive ball.	Neither gritty, silky or sticky
Silty loam	As for loam	Silky feeling Just recognisable
Silt loam	As for loam. Soil more difficult to deform.	Silky feeling Just recognisable
Sandy Clay loam	As for silt loam	Stickier than loams Gritty
Silty clay loam	As for silt loam When rolled into a ball will take a polish	Stickier than loams.
Clay loams	As for silty clay loam.	Sticky with no silky feeling
Sandy clay	MOULDED Easily moulded into cohesive ball. Will take a polish. Difficult to deform.	Very sticky when wet. Gritty.
Clay	As for sandy clay.	Very sticky

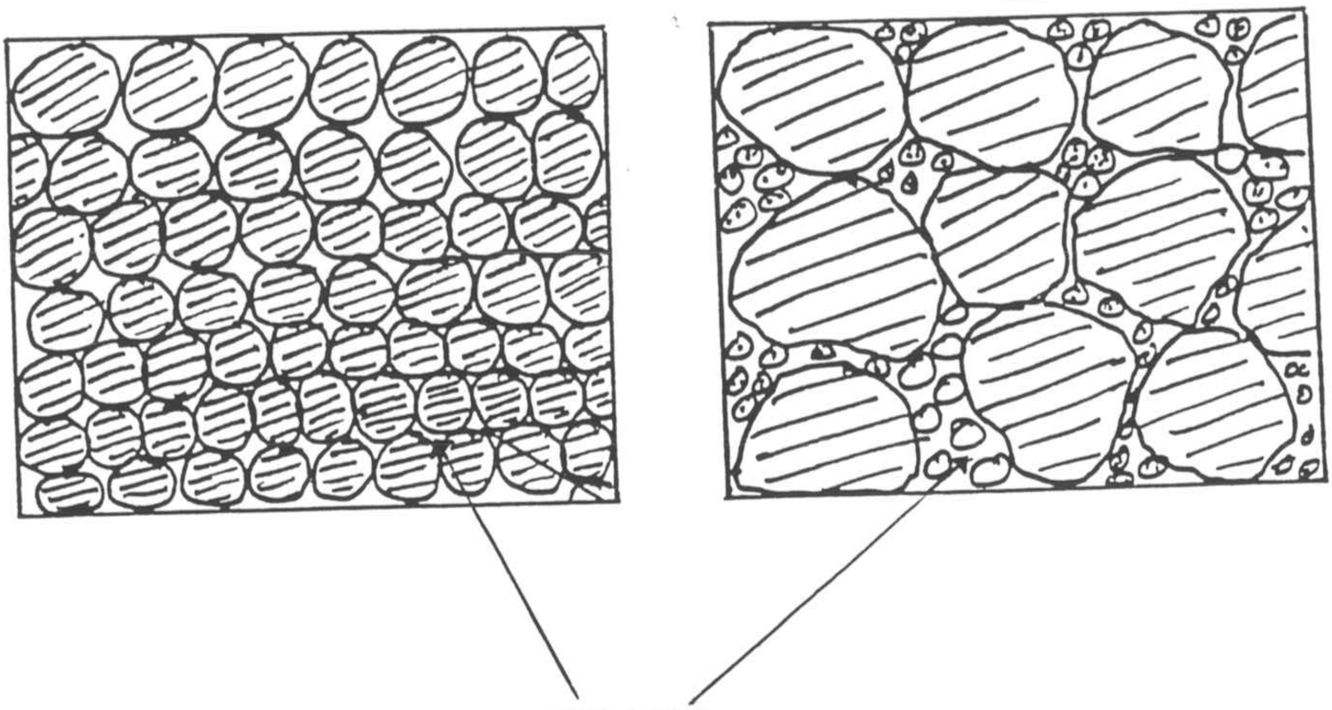
In assessing texture particularly in the surface layers allowance must be made for the influence of organic matter, significant amounts of which tend to make sandy clay soils feel more silty.

With experience one can become very accurate at assessing the textural classification of soils by this method. Further details are given in Tables 3 and 5.

Pore Space

Since all soils are composed of particles of solid matter then there must of necessity be spaces between the particles irrespective of how tightly packed the particles are.

UNIFORM AGGREGATE MIXED AGGREGATE



PORE SPACE

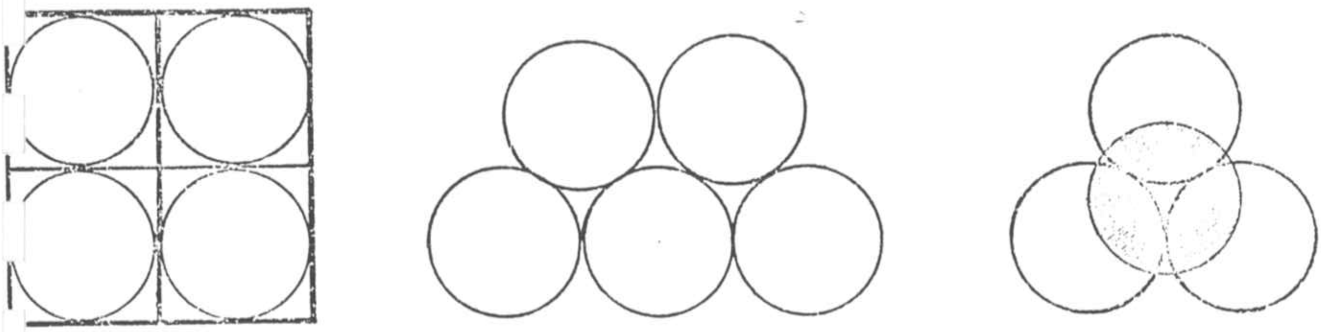
These spaces are called pore spaces and are filled either with air or water. In soils the pore space makes up 30-60% of the total volume.

Soils made up largely of very small particles tend to have a greater volume of pore space than soils composed of larger particles. For example clays normally have a greater volume of pore space than sandy soils.

TABLE 4

Material	Porosity %
Clay	45 - 55
Silt	40 - 50
Coarse sand	35 - 40
Gravel	30 - 40

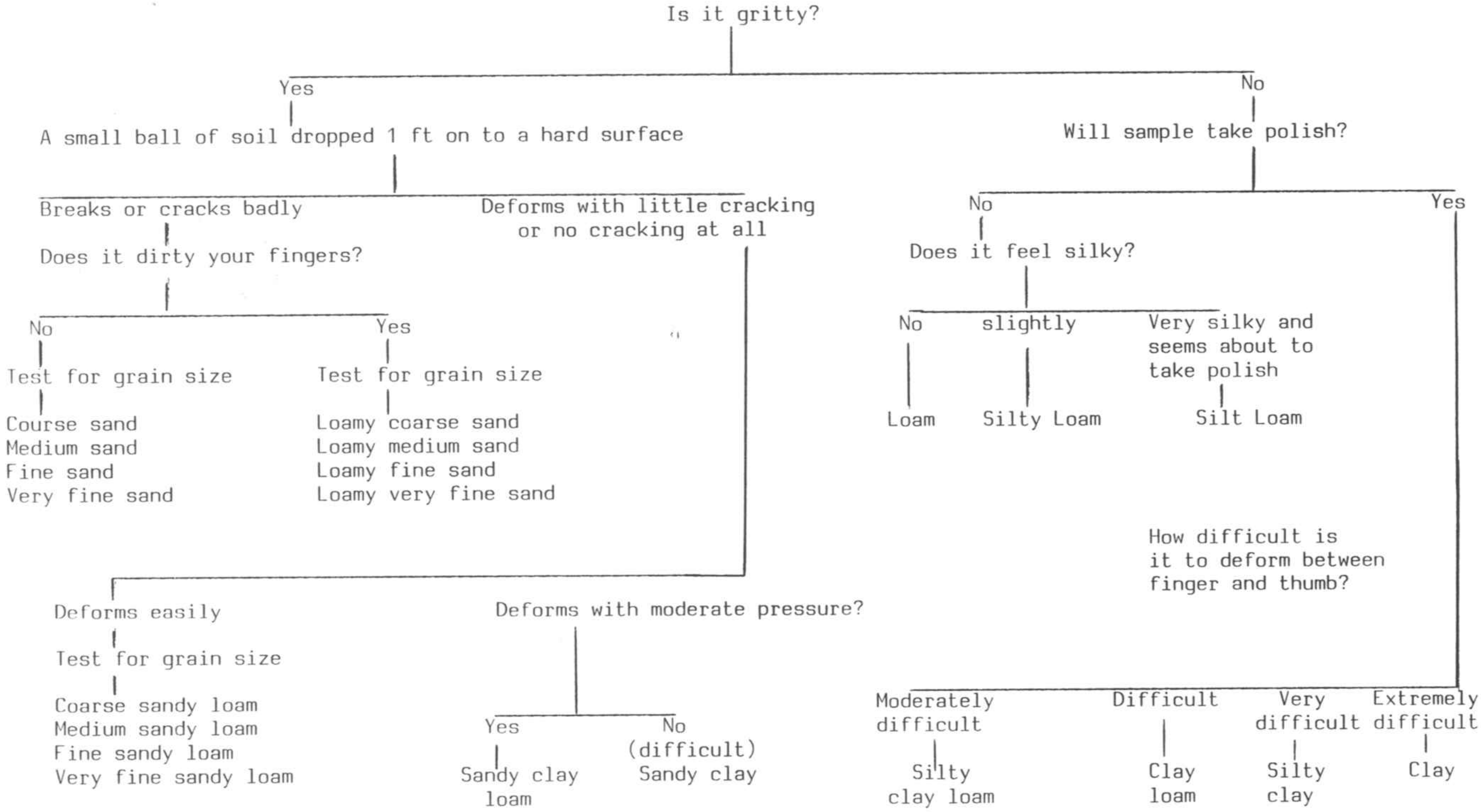
The diagrams below illustrate how porosity depends on the arrangement of Particles.



Porosity 47.64% 39.54% 25.95%

TABLE 5

Procedure for Determining the Textural Classification of a Dry Mineral Soil



The high porosity of clay soils explains why these soils when saturated hold much more water than sandy soils simply because there is more space available.

Drainage Pores

While the total volume of pore space in a soil is important perhaps of more importance from the point of view of water movement is the size of the individual pores. Clay soils tend to have vast numbers of tiny pores many of which are so small that they will not permit water to move downward at all. These are known a capillary pores. In sandy soils a much higher percentage of pores tend to be larger and as a result sandy soils tend to drain more quickly. This is illustrated in Table 6.

TABLE 6

Drainage Pores as % of Total Pore Space

Soil Type	Drainage Pores
Poorly drained clays	0.5%
Clay loam	6.0%
Sandy loam	15.0%

In clay soils only a very small proportion of the pores are capable of allowing water to move freely downward.

Soil Water

For the purpose of drainage soil water can be divided into 2 types:-

(a) "Held" water and (b) "Free" Water

(a) "Held" water

As the name implies this refers to water which cannot be removed in the form of drainage. It is trapped in the capillary pores and held as a thick film around the surface of the small particles. In clay soils a very high percentage of the water which the soil is capable of holding is in this form.

(b) "Free" water

This is water which can drain freely due to gavitational force and to the difference in potential between the points in the soil profile and the zero potential head at the drain.

Free water can move downwards throught the soil in a number of ways eg

1. Large pore spaces.
2. The channels left by the movement of small animals eg worms.
3. The channels left by the decay of plant roots.
4. The space between the aggregates of peds.

Soil Structure

This is the term used to describe the way in which the primary soil particles come together to form compound units separated by voids or surfaces of weakness. The natural development of structure is influenced by:

(a) Texture and physiochemical condition of the soil.
(b) Biological agencies particularly soil fauna.
(c) Seasonal wetting, drying and freezing.
(d) Land use and in particular cultivations.

Ped

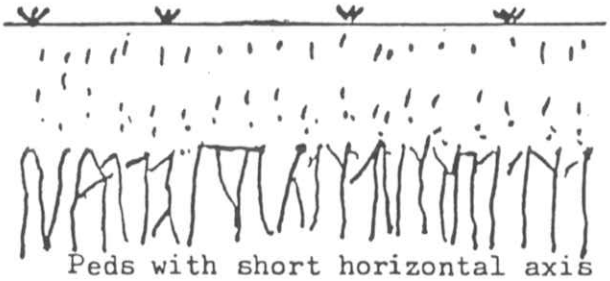
Is the name given to the smallest stable unit formed by the coming together of different soil particles. Some soils have the ability to form stable peds while others have not eg if you dig a spade full of coarse sandy soil and turn it over onto the ground it disintegrates into single grains ie it has a poor ability to form stable peds. On the other hand some clay soils have a marked ability to form stable peds. This is a very important characteristic as such soils then behave as if they were composed of much larger particles and so the drainage is improved. A soil with a good structure will have well formed stable peds while one with a poor structure will have few or no peds at all.

Assessment of Soil Structure

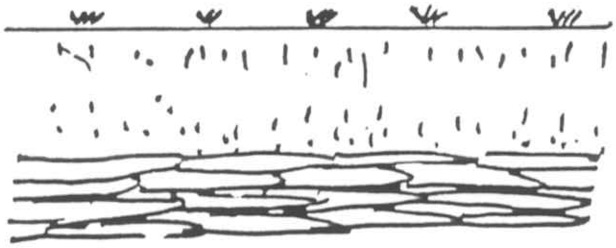
In assessing soil structure 4 things are important. These are:-

(a) Shape of the ped.
(b) Size of the ped.
(c) The durability of the ped.
(d) The type of crack development.

(a) Shape of ped: Obviously the shorter the horizontal axis of the peds the greater the downward movement of water.



Peds with short horizontal axis



Peds with short vertical axis

Terms used to descripe Ped Shapes are:-

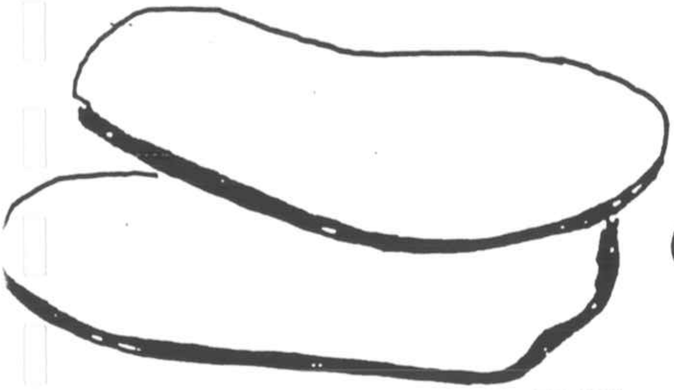
(i) Platy - where the horizontal axis is longer than the vertical axis.

(ii) Prismatic - where the vertical axis is longer than the horizontal one.

(iii) Blocky - where the axis are roughly equal.

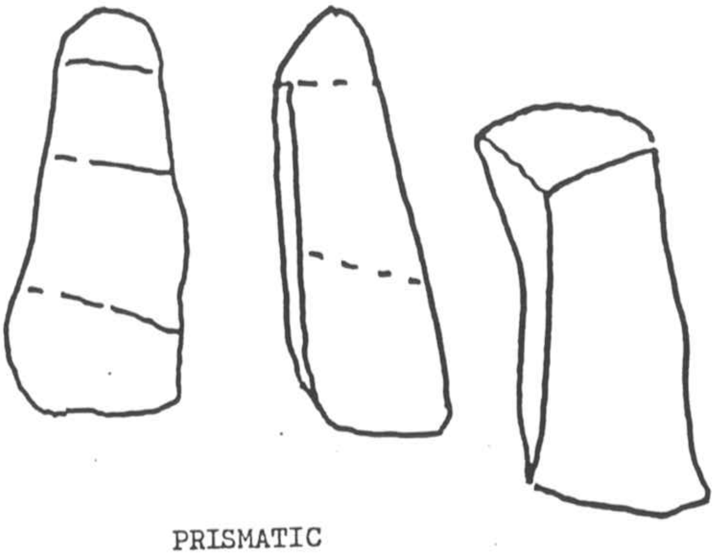
(iv) Crumb- soft porous granular aggegate.

(v) Massive - structureless - no peds.

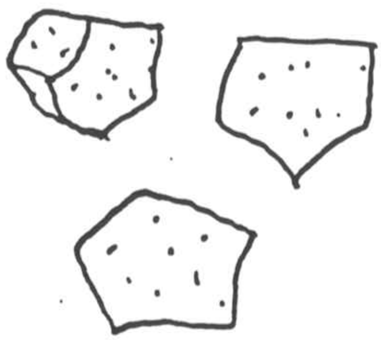


PLATY

CRUMB



PRISMATIC



BLOCKY

(b) Size of ped - the different shapes of ped can be sub-divided into fine, medium and coarse on the basis of size as indicated in Table 7 Within reason the smaller the peds the better the drainage.

TABLE 7

Ped Size

Ped Shape	Fine	Medium	Coarse
Massive M) (or single) grain) SG) No structure	-	-	-
Platy P1	Less than 1/5" thick	1/5 - 1/2" thick	Over 1/2"
Prismatic Pr	Less than 2" in the smaller dimension	2" - 5"	Over 5"
Angular Blocky ab	Less than 3/4"	3/4" - 3"	Over 3"
Sub-angular Blocky sab	Less than 3/4"	3/4" - 2"	Over 2"
Granular gr	Less than 1/5"	1/5" - ½"	Over ½"
Crumby cr	Less than 1/5"	1/5" - ½"	Over ½"

(c) The durability of peds - the more durable the peds the better the drainage. Durability can be classified into 5 categories ranging from structureless to very strong as can be seen in Table 8.

TABLE 8

Durability of Peds

Structureless - No planes of weakness or observable aggregation in either the moist or dry condition; massive if coherent; single-grain if non-coherent.

Weak - Poorly formed, indistinct units which break easily on displacement, yielding much unaggregated or fragmental material.

Moderate	- Well formed, distinct units that are moderately resistant to disruption on disturbance.
Strong	- Well formed units which adhere only weakly and can be separated without disruption when the soil is disturbed.
Very Strong	- Well formed units, the cracks between which are easily seen in an undistrubed profile.

(d) The type of crack development - the wider the cracks the better the drainage. Where the cracks are normal or fine the peds may close completely on swelling creating a degree of impeded drainage. Again crack development can be classified into 5 categories ranging from open to compacted as can be seen in Table 9.

TABLE 9

Crack Development

Structural Development	Fine Textures Soils	Coarse Textured Soils
Structure-less	No ped faces visible. Digging difficult.	No ped faces visible. Digging difficult.
Weak	Cube parts with diffi-culty. Few clear ped faces	Cube breaks when tipped from spade. Few clear ped faces.
Moderate	Cube parts more easily, but peds break and broken surfaces equal formed surfaces	Cube shatter when turned onto the ground. A few ped faces are distinguishable.
Strong	Peds easily separated by hand once the cube has been disturbed.	Peds separate clearly when the cube is tipped off the spade.
Very Strong	Peds separate under their own weight as each spadeful is placed on the ground	Peds separate under their own weight during digging.

Many soil horizons have compound structures either of peds of different sizes, or of smaller peds held together as larger aggregates. Thus, many surface horizons contain both sub-angular blocky and granular peds (the latter often as worm casts or their residues) and fine textured sub-soil horizons frequently consist of large prisms which, when disturbed, break into distinct angler blocky peds.

Stability of Soil Structure

Factors conducive to stable structures are:-

(1) Clay Content - In general the higher the clay content of a soil the more stable the structure is likely to be. Because of their large surface area clay particles dominate both physical and chemical properties of soils. This applies particularly to sandy soils.

(2) Soil Organic Matter - In mineral soils the stability of structure is directly related to the content of organic matter and in particular to the products of organic decay.

(3) Iron Oxide - Soils rich in iron oxides are fequently very stable. This explains why reddish soils usually have an excellent structure.

(4) Free $Ca\ Co_3$- In heavy soils better developed and more stable structures are sometimes but not always associated with free Calcium Carbonate, $Ca\ Co_3$.

(5) Drainage - Good drainage promotes structural development and stability.

Factors which are conjucive to weak structures:-

(1) Fine sand, very fine sand and silt

(2) Poor Drainage - Wet soils tend to have weaker structures. This instability is often associated with the reduction of ferric iron and in some soils with the movement and breakdown of clay leaving unstable bleached horizons.

(3) Sodium - Partial saturation by seawater flooding causes instability through clay dispersion.

(4) Cultivations - The action of machinery on soil causes structural breakdown by direct fracture of peds in moist or dry soils; by squeezing peds together in wet soils and by causing smearing, leading to waterlogging and slaking.

ORGANIC SOILS

Peats are characterised by a high content of organic matter, over 30%, and by being at least 30 cm in depth. They were formed in a wet environment because the natural decay of vegetable matter is arrested by anaerobic conditions.

Almost all the peat in Northern Ireland dates from the post-glacial period which began about 10,000 years ago when the climate became rapidly warmer. Vegetation cover increased in density and organic-rich deposits started to accumulate in wet sites. Almost all the peatland lies in the west of the Province and on the uplands of the north-east, usually in association with wet gleyed mineral soils (see Figure 1).

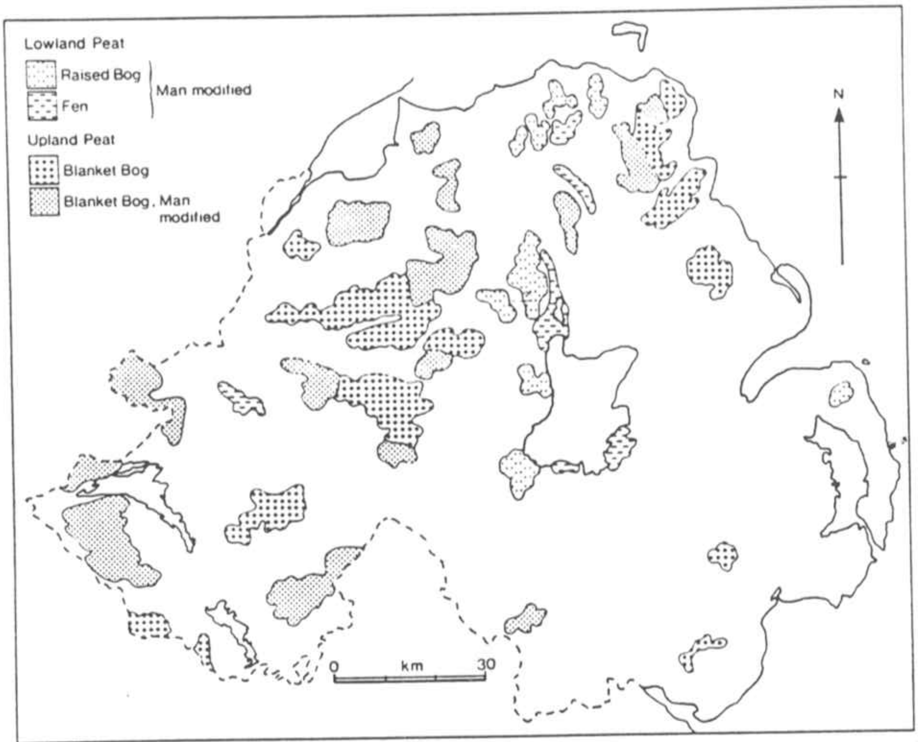


Figure 1 Simplified peatland map of Northern Ireland, based on the map by Hammond (1979). Almost all peatland lies in the west and on the uplands of the north-east, usually in close association with wet, gleyed mineral soils.

Two basically different types of peat occur in the country:

(i) Blanket peat - 130,000 ha
(ii) Basin peat - 41,000 ha.

1. Blanket Peat

Blanket peat, often referred to as climatic peat, accumulated under conditions of high rainfall and humidity. The deposits occur on hills and mountains in all topographical situations except for very steep slopes ($> 20^{\circ}$). The blanket peat profile varies from 1-2 metres in depth. Although it is rather homogeneous in appearance 3 strata can sometimes be discerned. (Figure 2)

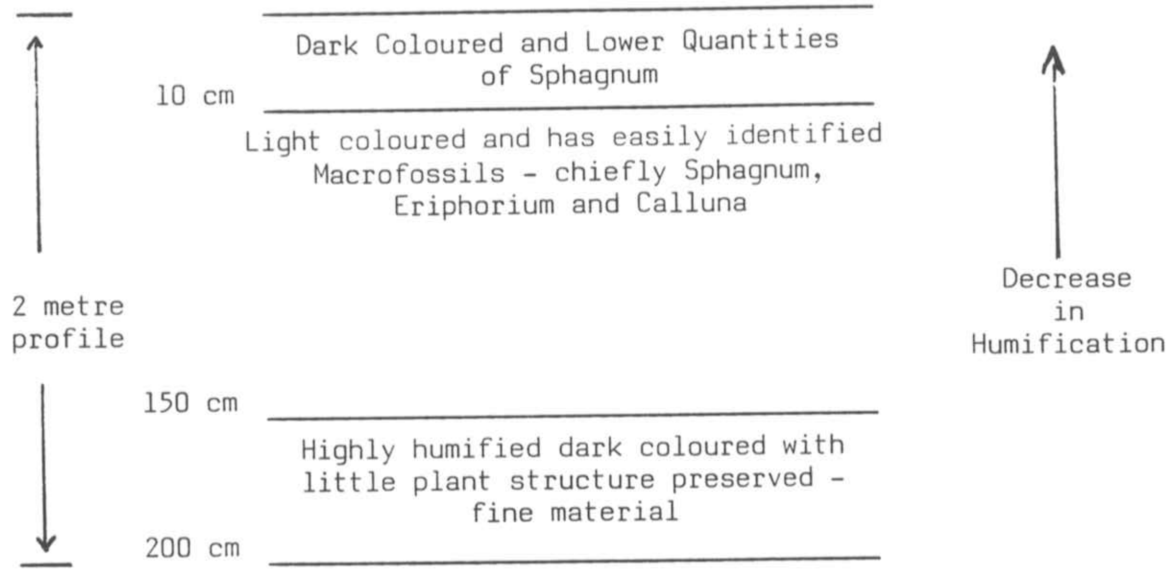


Figure 2: BLANKET PEAT PROFILE

The dominant plant remains include bog cotton (Eriphorium spp) purple moor grass (Molinia), black bog rush (Schoenus) and bog asphodel.

Because of poor drainage, adverse physical conditions and their occurrence in areas of poor climate the range of uses of blanket peat in agriculture is very limited. In some cases however, if the peat layer is shallow (<600 mm) and overlies mineral soils with reasonable drainage properties, the 2 layers can be mixed successfully.

2. Basin Peats

Basin peats have formed in lake basins, hollows and river valleys or where the subsoil is sufficiently impermeable to give a high water table.

Basin peats are divided into 2 types:

(a) Fen Peats
(b) Raised Bog Peats.

(a) Fen Peats

These are not found to any great extent in Northern Ireland. Fen peat was formed under the influence of base-rich ground water and is composed mainly of the remains of reeds, sedges and other semi-aquatic or woody plants. (See Figure 3).

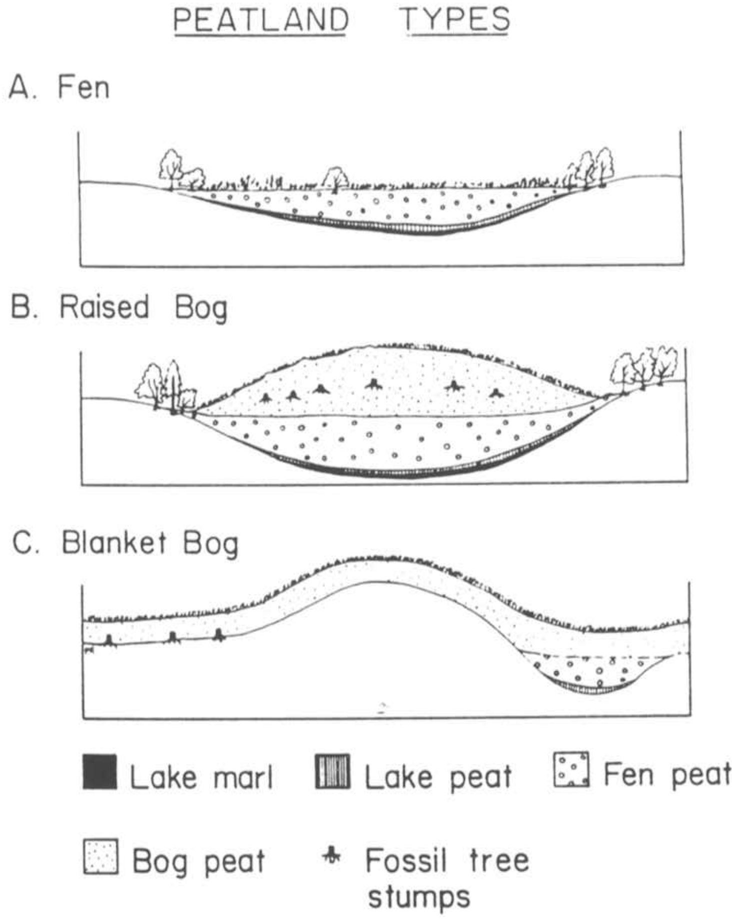


Figure 3—Transverse sections of Irish peatland types. Profile A shows fen, B shows raised bog and C shows blanket bog.

(c) Raised Bog Peats

Raised bogs or red bogs are usually found at relatively low altitudes, on relatively flat ground and many were originally lakes. They lie mainly in the valley of the Lower Bann, the river basins of West Tyrone, in North Antrim and near the southern shore of Lough Neagh. Almost all have been affected to some extent by peat-cutting and many have been partly reclaimed for agriculture.

In their undisturbed state they typically possess an inverted-saucer shape, the following 3 zones being distinguishable; a central part which is slightly convex or nearly flat (the dome), a sloping margin (the rand) and a marginal low-lying area (the lagg).

Raised bogs can be built up on top of fen peats under suitable climatic conditions. As the depth of fen peats increases its living vegetation is less influenced by groundwater and more dependent on atmospheric precipitation as a source of moisture. (Figure 4).

This change in moisture supply results in the growth and development of a raised bog with its characteristic convex surface and acid plant remains.

Raised bogs have a high proportion of sphagnum moss laid down in horizontal layers. Sphagnum moss has the disadvantage that it is easily rewetted after drying so that effective drainage is difficult. However, many basin fen peats have been successfully reclaimed where the depth of sphagnum has not been excessive.

In their natural state raised bogs vary from 3 to 10 m in depth and are typically acid in reaction.

Other Peat Deposits

In Counties Down, Armagh and Fermanagh there is a large number of peat deposits present in the hollows between drumlins. Such peat deposits have formed from a high water level situation caused mainly from inadequate outfalls. These inter-drumlin hollows in many cases are subjected to numerous floods and are under the influence of springs and springline seepage.

If peat deposition is relatively shallow or has been cut away this land can be reclaimed satisfactorily - the lower layers will have some mineral content adding to the fertility of the soil.

RAISED BOG DEVELOPMENT

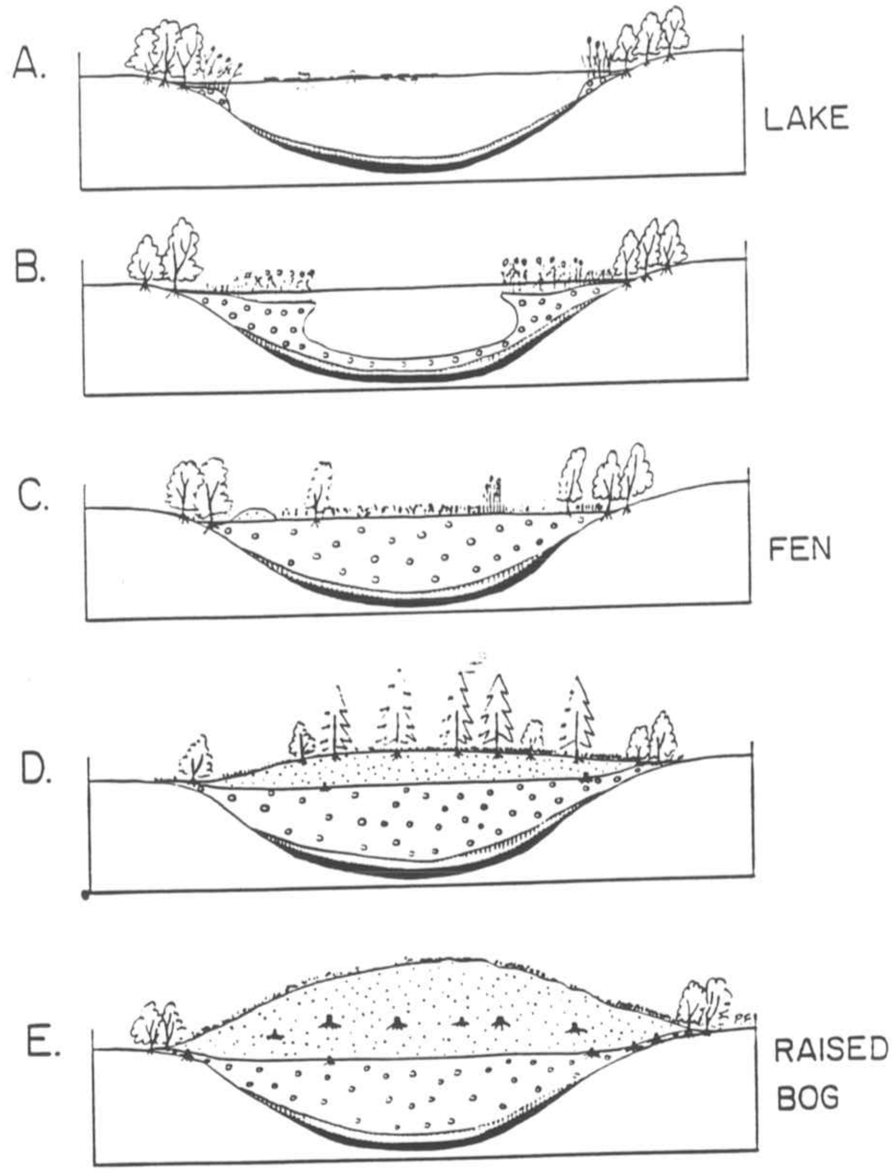


Figure 4—The developmental stages from a lake to a raised bog. A represents a lake with an open body of water and marginal reedbeds. The lake has thin layers of marl and lake peat (for an explanation of the symbols, see previous figure). B represents a lake which is being infilled with fen reed peat. C is the fen stage. D is the raised bog woodland phase and E is a profile through a present raised showing a Pine stump layer buried in acid peat.

The combined effects of peat removal for fuel and of reclamation for agriculture must have greatly decreased the extent of such small peat deposits in Northern Ireland. The example of Co Down is shown in Figure 5.

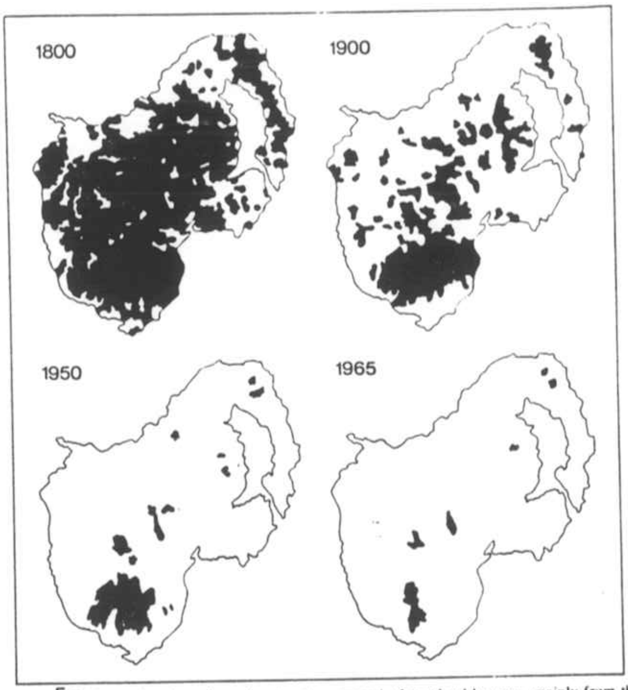


Figure 5: Maps of various dates showing the removal of peatland by man, mainly from the lowlands, in County Down (Brown, 1968).

Texture and Structure

Texture and structure of peats depend to a large extent on the degree of humification which has taken place. Since humification affects hydraulic conductivity it is useful when contemplating a drainage scheme on peat soils to determine the degree of decomposition which has already taken place. Van Post and Granlund have given a 10 point scale of the degree of humification (Table 1) and this is related to the hydraulic conductivity (figure 6).

Hydraulic Conductivity

Peats have a wide range of hydraulic conductivity values, and there is a decline in the rate of water movement with time after drainage.

TABLE 1

Modified version of the Van Post scale for assessing the degree of decomposition of peat.

(In this field test a sample of wet peat is squeezed in the closed hand and the colour of the liquid that is expressed between the fingers, the proportion of the original sample that is extruded and the nature of the plant residues are observed).

Degree of Decomposition	Nature of liquid expressed on squeezing	Proportion of peat extruded between fingers	Nature of Plant Residues	Description
H1	Clear, colourless	None	Plant structure unaltered; fibrous, elastic.	Undecomposed
H2	Almost clear yellow-brown	None	Plant structure distinct; almost unaltered.	Almost undecomposed
H3	Slightly turbid, brown	None	Plant structure distinct; most remains easily identififiable.	Very weakly decomposed
H4	Strongly turbid, brown	None	Plant structure distinct; most remains identifiable	Weakly decomposed.
H5	Strongly turbid, contains a little peat in suspension	Very little	Plant structure clear but becoming indistinct; most remains difficult to identify.	Moderately decomposed
H6	Muddy, much peat in suspension	One-third	Plant structure indistinct but clearer in the squeezed residue than in the undisturbed peat; most remains unidentifiable.	Well decomposed.
H7	Strongly muddy	One-half	Plant structure indistinct but recognisable; few remains identifiable.	Strongly decomposed
H8	Thick mud, little free water.	Two-thirds	Plant structure very indistinct; only resistant remains such as root fibres and wood identifiable	Very strongly decomposed.
H9	No free water	Nearly all	Plant structure almost unrecognisable practically no identifiable remains	Almost
H10	No free water	All	Plant structure unrecognisable; completely amorphous	Completely decomposed

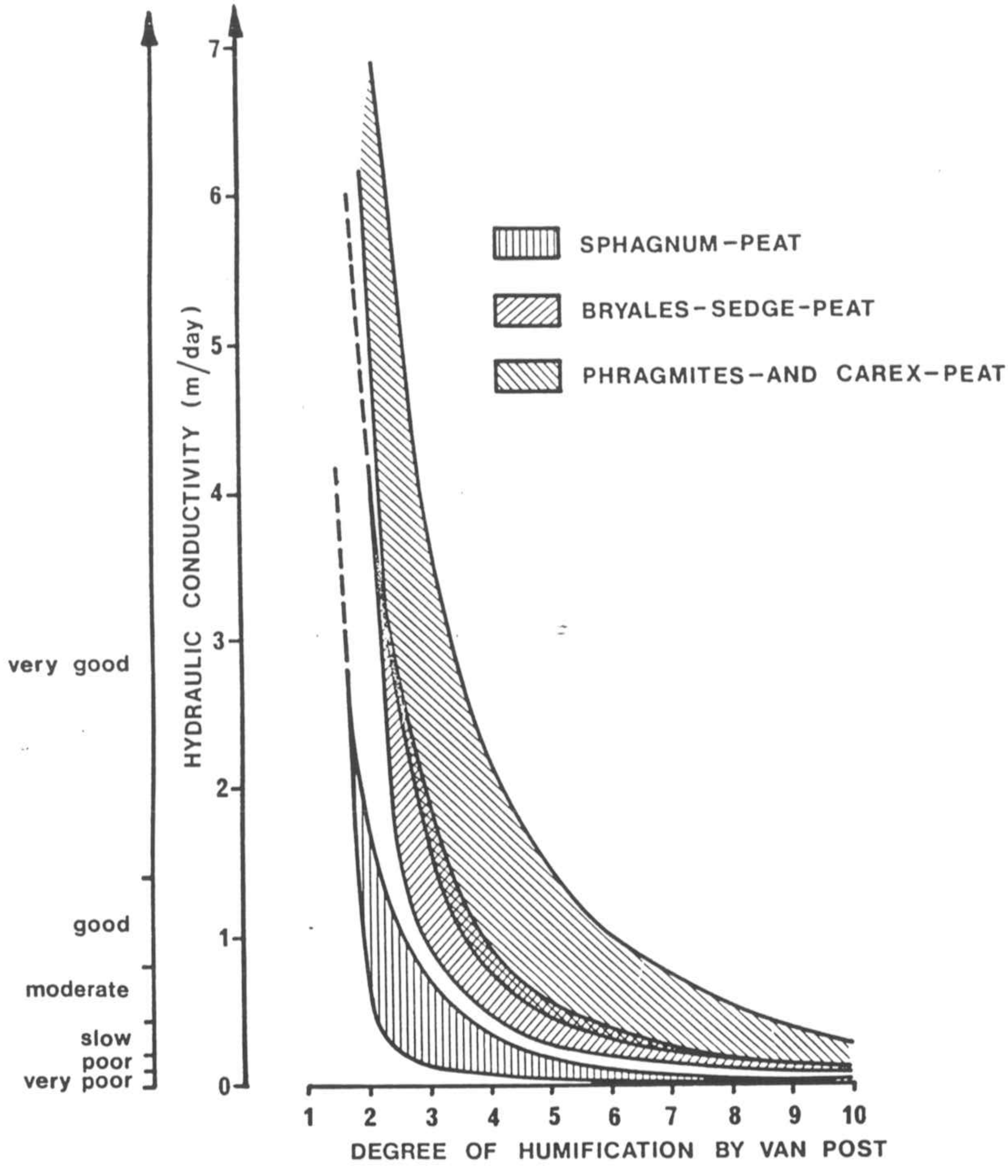
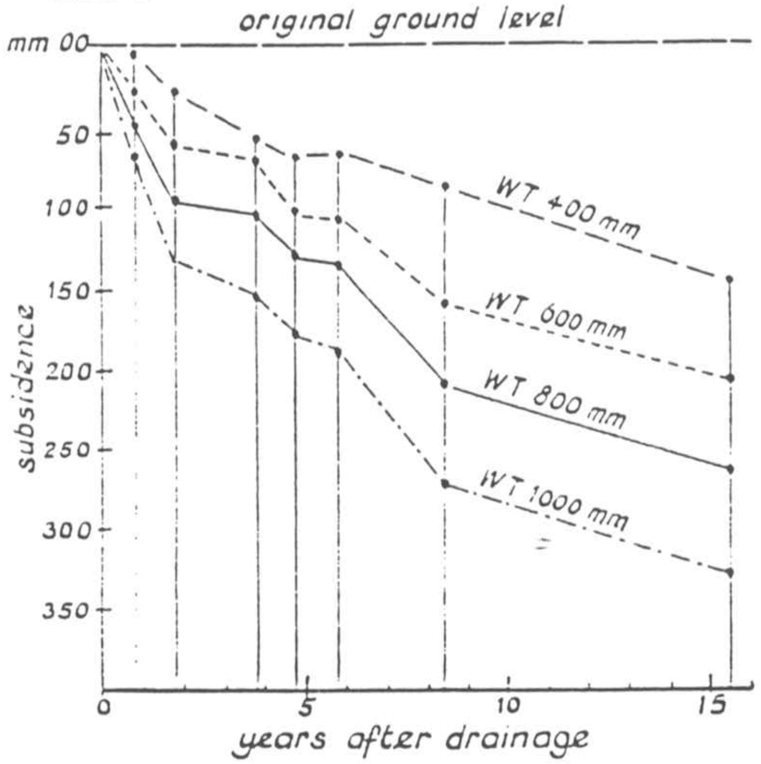


Figure 6: The relationship between the hydraulic conductivity of various peats and the degree of humification (after Egglesmann 1972)

Immediately after drainage there will be a sharp decline in hydraulic conductivity followed by a gradual decline for some 25 years or so. The sharp initial decline is due partly to the increased oxidation but mainly to consolidation of the peats following drainage.

FIGURE 7

RATE OF SHRINKAGE OF PEAT (Castle McCunnal & Trivy)



Peat Shringage

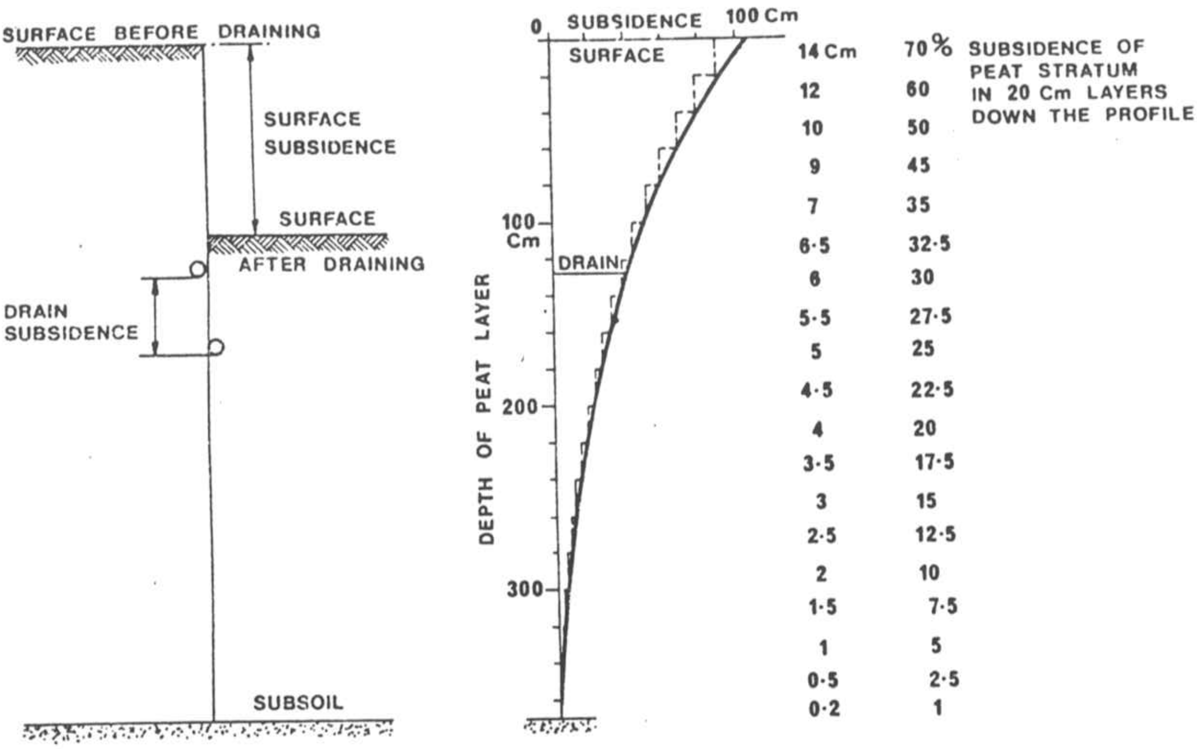
Peat shrinkage and surface subsidence are an inevitable consequence of successful drainage. When designing drainage works it is therefore necessary to take into account the fact that shrinkage will occur and will affect drain depths (Figure 7).

The amount and rate of shrinkage can vary quite considerably, depending on the original dry bulk density of the peat, the amount of mineral matter present and the extent to which the peat is dewatered. Typical bulk density values are shown in Table 2 .

TABLE 2 Physical properties of various peats (Galvin, 1976)

	Type of peat					
	Sphagnum			*Woody-fen*		
	Blanket	Young	Old	Reed-fen	B	B/C
Degree of decomposition	H8	H2	H8	H8	H6	H7
pH	4.1	4.2	4.7	6.0	5.4	4.5
Ash content (% by vol)	1.5	1.6	1.0	7.3	7.8	7.4
Specific gravity	1.31	1.36	1.36	1.38	1.38	1.36
Porosity (%)	94.7	95.8	93.7	93.5	92.7	93.7
Dry bulk density (kg/m^3)	70.0	56.0	85.0	89.0	101.0	86.0
Solid matter volume ratio	4.35	3.48	5.29	5.41	6.12	5.22
Saturated hydraulic conductivity (cm/d)						
Laboratory	1.3	20.8	0.5	4.9	0.8 – 18.3	0.6
Field	0.6	20.9	2.8	12.6	56.4	64.8

It has been shown that in peat which is still waterlogged shrinkage takes place under the drain as well as above the drain level. This is important because it clearly leads to the drain itself sinking with obvious risks to drains without some longitudinal continuity. (Figure 8).



SUBSIDENCE IN DIFFERENT PEAT LAYERS

Figure 8: The subsidence of peat after drainage showing the distribution of the sinkage throughout the profile (after Egglesmann 1972).

General Design Points

Interceptor Drain

Whenever possible high-level water should be kept out of the area to be drained, by an interceptor drain.

Individual Outfalls

In peats as in other flat land individual drains without junctions should be used to allow the best gradients and simplify future drain cleansing.

Headwalls

Care should be taken when constructing outfall headwalls to ensure they do not sink.

Drain Depth

When deciding on drain depth in peats it is necessary to give due consideration to shrinkage after drainage. It is normal to construct drains at least one metre deep.

Permeable Fill

It is not recommended to use large size stone in excess of 25-30 mm. The need for permeable fill to the surface is also unnecessary.

Primary Dewatering

In a permanently waterlogged peat soil it is recommended that some preliminary ditches or trenches be cut, perhaps a season or so in advance of pipe drainage, to allow a primary dewatering.

Trenching

If this type of machine is used the work should be carried out quickly and a complete run made without stopping, otherwise there is a danger of the machine pipe layer sinking appreciably.

SUMMARY OF AGRICULTURAL POTENTIAL FROM VARIOUS TYPES OF BOGLAND

Shallow Blanket Bog (Mountain)	Depth of peat can be 10-20 cm deep, often over an impermeable subsoil which may contain an iron pan. <u>Reclamation techniques</u> (a) Deep ploughing to 900 mm, need 2:1 ratio of peat to till. (b) Deep ripping - down to 1.2 m - shatter iron pan. (c) Deep digging and mixing - 1.3-1.5 m. (d) If subsoil impermeable - then field drainage required.
Deep Blanket Bog (Mountain)	Depth of peat 60-240 cm. <u>Reclamation techniques</u> (a) Often too deep for ploughing or digging over. (b) Shallow open drains may give some improvement.
Man Modified Mountain Bog	Can sometimes be reclaimed, depending on subsoil type, rock outcrops, outfall and rainfall.
Deep Lowland Bog (Virgin)	Not suited for any agricultural purposes. Cannot be drained to meet the requirements of trafficability
Deep Lowland Bog (Cut Over)	Some of these cut-over areas can be reclaimed successfully depending on the kind of peat present and the depth. Other limitations include subsoil type, rock outcrops and drainage outfall.

Procedure for Determining Textural Classification of Organic Soils

I vegetable matter easily visible at a depth greater than 12 in (0.3 m) ?

- Yes — Is it saturated?
  - Yes — Is green, white or light brown colours visible?
    - Yes — Undecomposed vegetation
    - No — Can coarse fibre be seen?
      - Yes — Coarse fibrous peat
      - No — Can fine fibres be seen?
        - Yes — Moss peat
        - No — Bog peat or sedge
  - No — Can coarse fibres be easily distinguished?
    - Yes — Coarse fibrous peat
    - No — Can fine fibres be seen?
      - Yes — Moss peat
      - No — Bog Peat
- No — Is the feel of the mineral content of the soil masked by the organic matter?
  - Yes — Bog, sedge or moss peat
  - No — Is soil silky and smooth even though the mineral matter can be distinguished?
    - Yes — Gritty? Sandy Peat / Loamy? Loamy Sand
    - No — Gritty? Peaty Sand / Loamy? Loamy Sand

Note:- moss, bog and sedge peats can be grouped as peat

DRAINAGE

THE BENEFITS OF DRAINAGE

Benefits from drainage are very extensive and include a wide range of factors affecting crops, livestock and machinery performance. It is, however difficult to quantify drainage benefits in econimic terms; in respect of improved yields, liveweight gains and working conditions as these will depend on a number of variable factors such as the soil, the climate and the standard of management.

Most of the land in Northern Ireland is under permanent pasture so we will concentrate on the benefits to grassland. The main benefits include.

(1) Improve Grassland Productivity

Where there is excessive soil moisture, aeration for root development is restricted. Under such conditions roots are confined to a shallow layer and consequently may suffer in periods of drought.

Experiments at Castle Archdatle during 1963-1968 on herbage productivity showed reductions in yields of 16-20% during wet seasons. High yielding grasses like ryegrasses and some varieties of Timothy and clover cannot withstand more than one weeks inundation during the growing season and these will be rapidly replaced by low growing species eg Agrostis, Yorkshire Fog and Poas.

In a recent trial in Wiltshire on a clay soil the effect of drainage on yield is clearly shown in Table 1.

The effect of drainage on the botanical composition of the sward shows almost twice as much weed grass in the undrained areas as in the drained (Table 2)

The nigrogen uptake on the drained ploTs (Table 3) was greater than on the undrained ploTs, demonstrating the more efficient use of expensive nitrogenous fertiliser, yielding extra dry matter of 2 tonnes/ha/year which gives a silage equivalent of 10 tonnes/ha/year. Losses of phosphorus and potasium from undrained land can be as high as three times those from similar drained land.

(2) Extending the grazing season

The temperature of poorly drained soils are 4-8° lower than those of comparable well drained soils and consequently more heat is required to warm up these

Table 1 Yield response to drainage – Lawford soil series.

Total Annual Yields (tonnes/ha dry matter)

	1980	1981	1982	Average
Undrained	13.9	14.5	11.6	13.3
Drained	15.8	15.0	15.2	15.3

Increase in Spring Yields (as a percentage)

Undrained	100%	100%	100%	100%
Drained	136%	100%	208%	148%

Table 2 Effect of drainage on botanical composition.

Date	*Perennial Ryegrass*		*Weed Grasses*		*Other Species*		*Bare Ground*	
	UD	D	UD	D	UD	D	UD	D
1980	59.0	68.0	18.8	9.6	17.5	18.6	4.5	3.8
1981	63.8	69.5	15.5	8.0	16.2	17.3	4.5	5.2
1982	65.2	72.4	10.6	6.8	13.8	17.0	10.4	3.8

The site was re-seeded in 1979 and the above figures represent the % composition.

Table 3 Nitrogen uptake.

Date	*Fertiliser N kg/ha*	*Total N Uptake kg/ha*		*% Increase in Spring N Uptake First 3 Cuts*
		Undrained	Drained	Drained
1980	215	402	484	144
1981	269	373	426	109
1982	351	304	388	132

soils, explaining the delay of grass growth in spring.

Studies on trial drainage sites in several parts of the country show an increase in length of grazing season between 4 and 6 weeks in a year, without poaching. This alone represents a considerable financial saving in purchased feeding stuffs, at both the beginning and end of the winter period. Other benefits include the possibility of better quality hay and silage, with the opportunity of an earlier first cut giving rise to additional cuts later on.

(3) Reduce risk and degree of poaching

One of the biggest problems with grassland in moderately high rainfall areas is the damage to the soil surface and the sward by grazing animals. When stocking density is high in the spring and autumn months then poaching is severe and the surface soil layer looses its crumb structure and becomes soft and weak as a result. Hoof pressures exerted by the grazing animal vary greatly depending upon bodyweight and hoof area, and whether or not the animal is standing or walking (Table 4).

The bearing strength of the soil is directly related to the soil moisture content which in turn is a function of watertable depth. Field Trials have measured the penetration resistance of the soil against watertable depth and evidence of poaching (Figure 1).

Whilst poaching damage can never be entirely avoided it is apparent that a watertable depth of about 500 mm along with careful gazing managements will minimise poaching.

(4) Reduction in diseases risk to livestock

Although several animal diseases and foot problems can be associated with wet pastures, the greatest benefit from drainage is probably the reduction in the incidence of liver fluke due to the control of the host snail Lymnaea Iruncatula which can only exist in wet conditions.

(5) More efficient use of machinery

Effective work with farm machinery can only be carried out if the soil surface has the bearing strength to support the weight and provide traction. For a tractor to move over the soil there has to be sufficient resistance in the soil

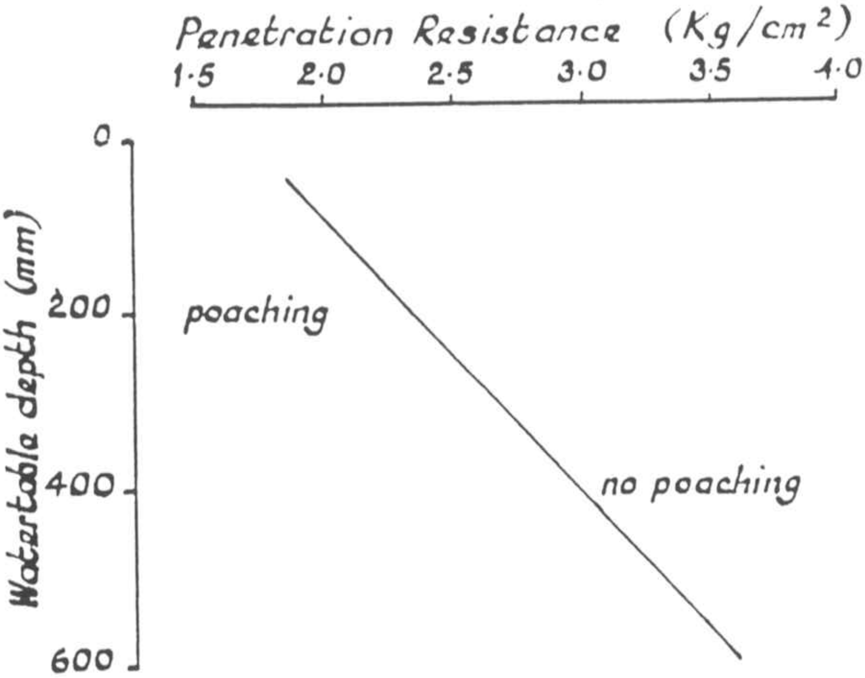


FIGURE 1: PENETRATION RESISTANCE AND WATERTABLE DEPTH.

Table 4 Hoof pressures kg/cm².

	Standing	*Walking*
Cattle – 500kg bodyweight	1.5	3.0
– 1000kg bodyweight	2.5	4.0
Sheep	0.8	1.7

surface layers for the tyre or track to act against. This is termed the shear strength and as with bearing strength, it increases as the watertable falls. (Figure 2).

Operating machinery under heavy wet conditions increases the wear and tear due to the increase in draught forces. This will in turn show in higher operating costs.

With well drained soils there can be an increase in the number of work days per year during which heavy machinery can be taken onto the field causing damage.

(6) Management Factors

Drainage greatly eases farm management in that it provides greater flexibility in the planning and timing of operations and allows for versatility of cropping. Farm operations such as silage harvesting can be planned in advance with confidence and be kept to schedule. Other examples of ease of management are reduced slurry storage and spreading due to shorter in-wintering of stock, less winter feed requirements, more milk and animal production from going out to grass earlier, and easier preparation of cows for milking as teats do not become spattered with clay.

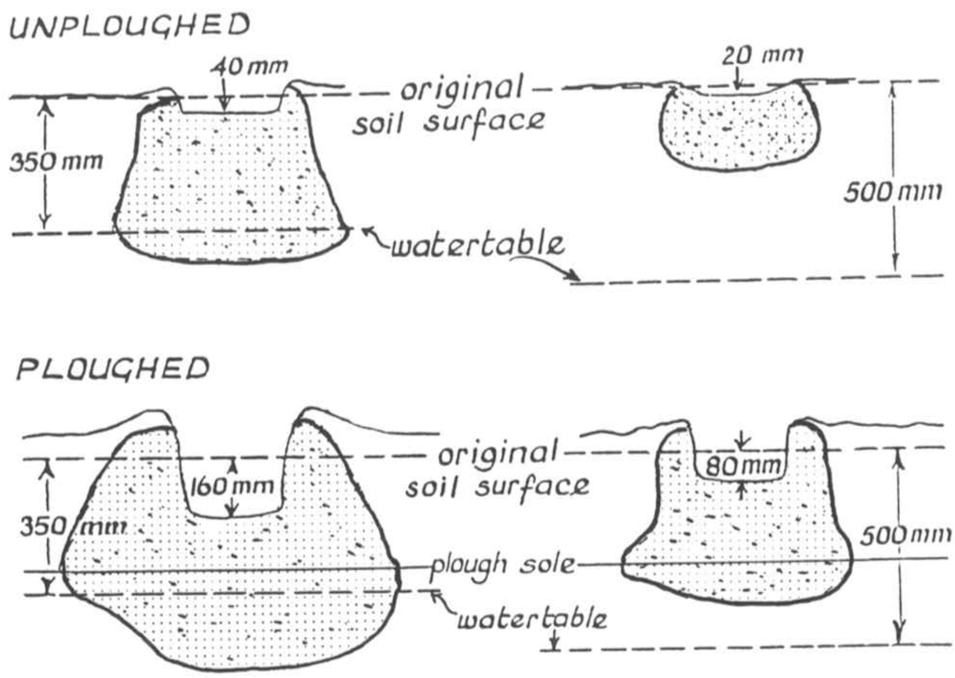


FIGURE 2: RELATIONSHIP BETWEEN WATERTABLE DEPTH AND WHEEL SINKAGE.

CLIMATE AND HYDROLOGY

Ireland has a cool-temperate west maritime climate with mild, moist winters and cool cloudy summers. For the greater part of the year warm maritime air associated with the Gulf Stream helps to moderate the climate. The prevailing winds are westerly to south-westerly. Average relative humidity is high. Annual average precipitation, which exceeds evapotranspiration by over 500 mm is highest on the west coast and in inland areas of high relief. (Figure 1).

Temperature and Growing Season

The Gulf Stream has a warming effect in the winter and a cooling effect in the summer and the average temperature for the year is about 9.5°C. Winter temperatures are higher in Northern Ireland than most other parts of the world at the same latitude.

The growing season is most often taken as that period when the mean daily air temperature exceeds 5.6°C. The length of the growing season is governed principally by altitude and maritime influences. In general the growing season decreases by about 4 days with every 30 metres of altitude. (Table 1).

TABLE 1: Growing Days Related to Altitude

Highest Areas	-	<210	Growing days
Uplands	-	<235	" "
Central Lowlands	-	250-265	" "
Coastal Strips	-	280-300	" "

A special unit, termed a degree day, is used to measure intensity rather than length of growing season. Much of Northern Ireland receives between 2,000 and 2,500 degree days annually. The limit for cereal cultivation in the British Isles is 1,500 degree days of accumulated temperature each year. All areas in Northern Ireland under 150 mOD have 2,000-2,500 degree days annually. Increased precipitation, humidity and wind speed, accompanied by lower temperatures, limit cultivation above the 210 mOD line. This marks the lower limit of rough grazing.

Northern Ireland experiences on average about 170 grass-growing days a year in comparison with 130 days in south-east England. However, the reason for this is mainly due to high soil moisture deficits in England.

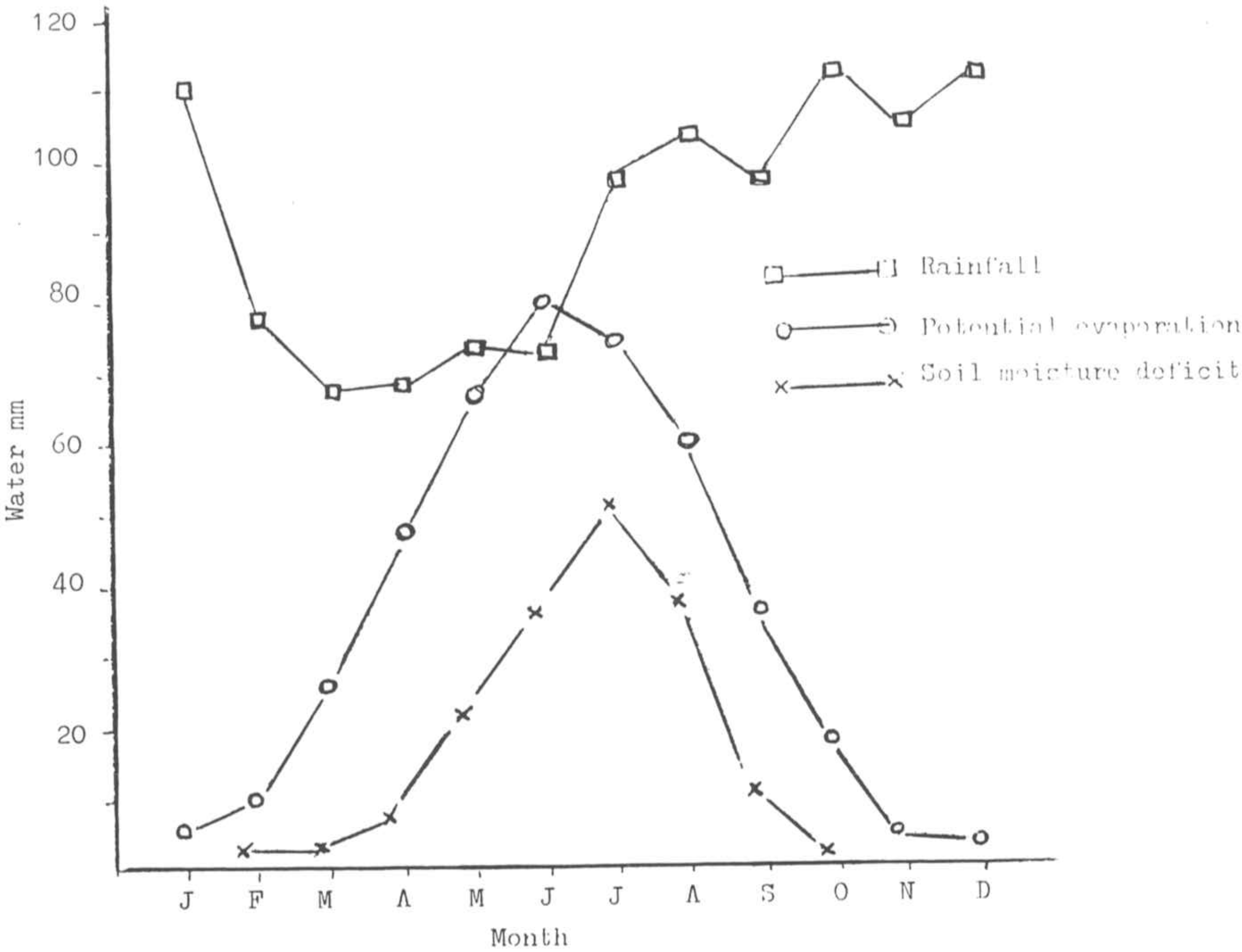


Figure 1: Monthly average rainfall, potential evaporation, and soil moisture deficit figures for N. Ireland

(Source: Meteorological Office, Belfast)

Sunshine

The frequency of cloud cover and rainfall limits the amount of sunshine received. The average duration of bright sunshine per day is 3.5 hours. May and June are the sunniest months.

Frost

Frost occurs on an average of less than 25 days per year in coastal districts of the west and on more than 50 days in the interior of the Country.

Precipitation

Precipitation in Nrothern Ireland is principally in the form of rain or drizzle. Snowfall and hail are infrequent. Precipitation is caused by 3 principal mechanicms: frontal activity within extra-Tropical cyclones, convection and orographic ascent of moist air. These 3 mechanisms often interact though the cyclonic component contributes most rainfall, particularly in the west.

Figure 2 shows the mean annual rainfall over Northern Ireland. A general decrease in rainfall totals from west to east is apparent although upland areas with their heavier rainfall complicate this pattern. Whereas the lowlands around Lough Neagh average less than 900 mm annually, the Mourne and Sperrin mountains record over 1600 mm.

The amount of rain and the cloudy conditions which reduce evaporation result in waterlogging of soils which in turn hinders farming, particularly in Fermanagh and west Tyrone and on the uplands. Another confirmation of our damp climate is the number of rain days and wet days recorded.

			Fermanagh	Hillsborough
Rain days	- 0.2 mm or more	-	232	210
Wet days	- 1.0 mm or more	-	208	158

The Hydrological Cycle

Hydrology is the study of water in its many forms moving above, on and under the earth's surface. This movement is know as the hydrological cycle, the land phase of which, shown in figure 3 is of interest to designers of field drainage.

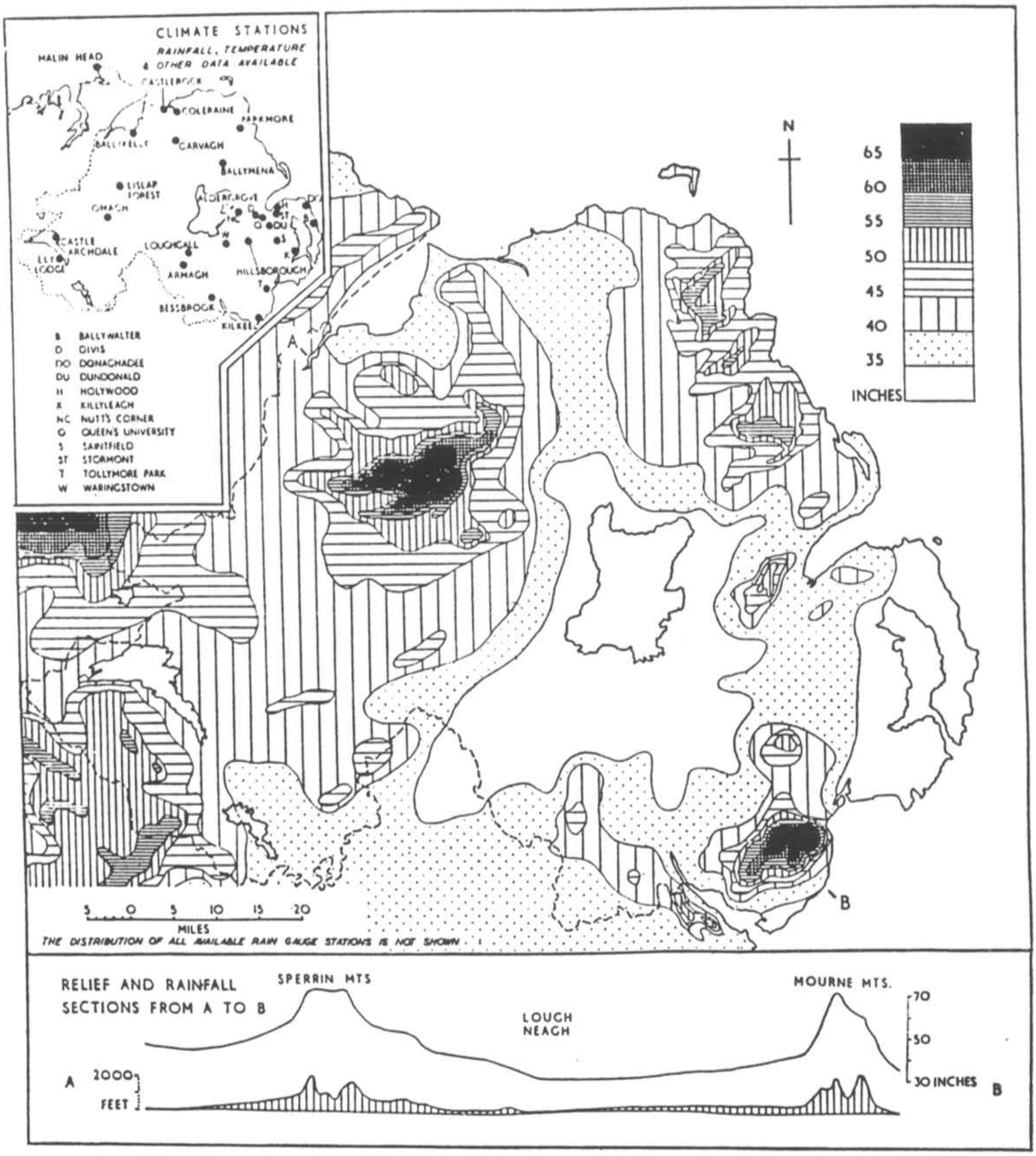


FIG. 2 . ANNUAL AVERAGE RAINFALL (1916–50) (*After N. Stephens*)

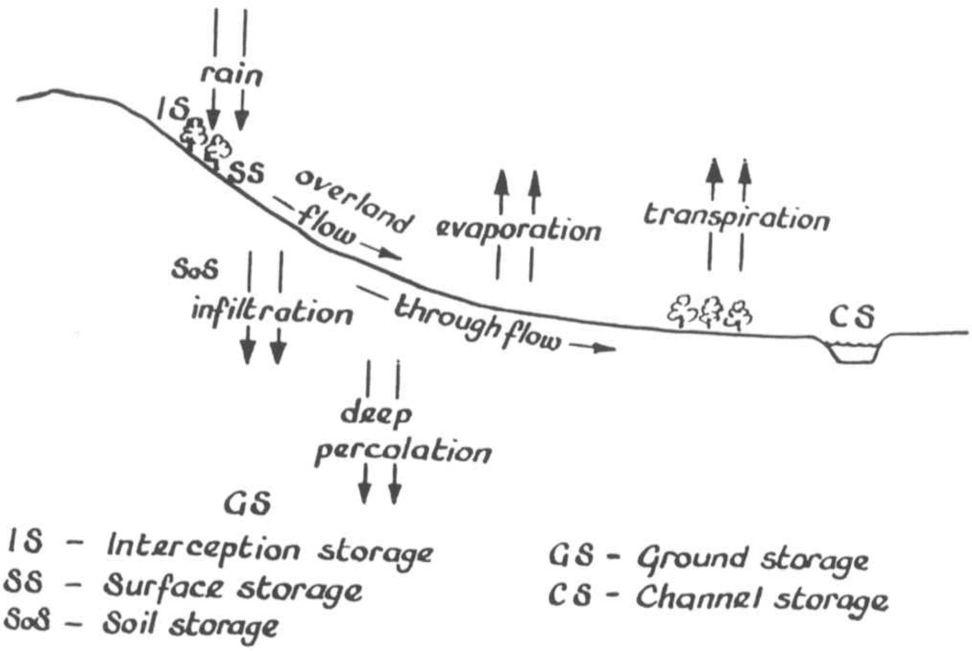


FIGURE 3: LAND PHASE OF WATER CYCLE

Water evaporated by the sun's energy from the ocean is carried by moving air masses and falls as rain or snow on land masses. Some of this water returns to the oceans by surface run-off into the streams or after percolation through soils and rocks. The remainder is returned to the atmosphere by evaporation from land and bodies of water such as lakes and streams and by transpiration through plants.

Our main concern is what happens rainfall after it reaches the ground? The water cycle over land can be broadly summed up as follows:

Rainfall = Run-off + Evaporation + Storage.

When precipitation falls upon a catchment, there are a number of alternatives that can occur.

(a) Water may gather at the earth's land surface as surface detention or storage and be subject to evaporation.

(b) If there is sufficient depth of water available, gravitational forces will cause the water to move over the earth's surface as overland flow.

(c) If the land surface is permeable water will be absorbed into the soil under the combined forces of gravity and capilliarity in a process known as infiltration. Infiltration can be defined as the process whereby liquid water enters the surface layers of a soil, during and after rainfall.

The infiltration capacity of a soil is influenced by many factors including:

Soil type
Porosity
Vegetal cover
Rainfall characteristics
Frost
Moisture content

Soil structure has a profound effect on the physical properties of a soil and hence on infiltration rate.

Initial infiltration rate may be high on dry soil but it settles down to a steady state as the soil becomes wet. When the surface is saturated, pools of water may form and surface flow may occur finding its way into natural drainage channels. Drainage channels afford a certain amount of temporary water storage.

Once rainfall ceases and the humidity decreases, evaporation and transpiration increase again removing water from pools, vegetation and the soil itself. Eventually there is a net movement upwards of soil water under suction forces which is finally returned by evaporation and transpiration to the atmosphere. The water-table falls and channel flow decreases.

The effect of Field Drainage

The role of drainage, both natural and artificial, is to remove the excess water from the soil surface and/or the soil profile. The designer of a drainage scheme is therefore influencing the hydrological cycle as he seeks to remove the excess water as quickly as possible to prevent waterlogging and possible damage to soil structure and crops.

His main considerations are:

(i) Drainflow - The quantity of water moving through the soil profile to the underdrainage pipes.

(ii) Water moving as throughflow to a seepage line or acquifer.

(iii) Water flowing over the soil surface as run-off.

DRAINFLOW AND CATCHMENT AREAS

1. Type of Drainage System

The type of drainage system is important. A pipes-only system means that water moving through the soil profile may have some distance to travel through the soil pores before reaching a drain. In coarse soils this will be relatively fast and as little water is held in the soil moisture reservoir the drainflow can be a high percentage of the rainfall.

For soils with low permeability and on a sloping site only a small amount of the rainfall will be removed in the drains.

Secondary Treatments

The drainflow in soils with a pipe and moling, gravel tunnelling or sub-soiling system will be significantly higher than for pipes only. Outflows from these systems in clay soils are characterised by intense flushes.

Distance between drains

Outflow per unit of time for a given area will increase with reduction in drain spacing.

Depth of drains

Provided there are no outfall limitations, increasing the depth of pipe systems in pervious soil increases the amounts of water intake.

2. Seepage Flows and Interception

Springline problems are usually corrected by the meticulous placement of drains on the upslope side of the seepage. The result is to lower the water-table downslope of the drain. The effective distance being directly related to the depth of the drain installed. The random nature of the drainage problem and its complexity make it impracticable to use any developed design criteria. Every situation must be treated separately and specific examples will be described in a separate section on springs.

Land smoothing means the planning of the land surface without changing its general topography. The smoothing operation is designed to eliminate small differences in elevation and to ensure a continual slope from all points of the field to a surface drain. Land smoothing should be used to as great an extent as possible on every drainage scheme especially in reclamation of heavy soils in high rainfall situations.

Determination of Design Flow

When designing a piped ditch or a carrier ditch it is necessary to know the quantity of run-off which the pipe or open ditch will be expected to carry. Direct measurement of the flow is usually impracticable so the designer can only use emperical methods.

In determining the design flow the following steps should be taken:

(1) Identify the area of land which falls within the catchment. An OS map to a scale of not less than 1:10000 can be useful.

(2) Catchment length should be calculated ie the greatest distance from the head of the pipe or open ditch to the catchment boundary.

(3) The catchment slope is obtained by locating the highest points on the catchment boundary and subtracting from this the elevation of invert of pipe or open channel. The difference between these points divided by catchment length gives the slope.

(4) Catchments characteristic C is found by using the formula $C = 0.0001 \frac{L}{S}$ (see Figure 2 No 4).

(5) The dominant crop is noted.

(6) Average annual rainfall can be obtained from nearest recording station.

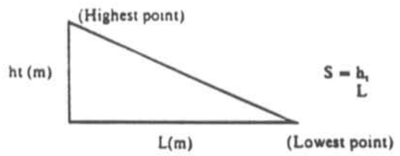
(7) Soil type factor S_T can be obtained by soils information from inspection pits. Permeability values can be assessed using Table 1.

(8) An F number is calculated using a graphical solution from Figure 3 feeding in catchment characteristic C.

The final design flow $Q_o = S_T \times F \times A$ is then obtained.

Determination of design flow

1. Locate a suitable map of the area and determine the catchment area A in hectares.
2. Determine the maximum length of catchment L in metres
3. Determine the average slope of the catchment S



4. Determine the catchment of characteristic C

$C = 0.0001\frac{L}{S}$

5. Determine the dominant crop type — Grass / Arable / Horticulture
6. Determine the average annual rainfall AAR in mm from table 5.3.
7. Determine the soil type factor S_T

Permeability Class	*Range (m/day)*	*Ranges for Soil Textures*	S_T
—	—	Peat (Upland)	1.3
Very slow	<0.01- 0.1	C	1.0
Slow - Mod	0.1 - 0.3	ZC, SC	0.8
Moderate	0.3 - 1.0	CL	0.5
Mod - Rapid	1.0 -10.0	A, S, SL, ZCL	
Very Rapid	>10	(low)	0.1

Note: for complex areas interpolation between soil types may be desirable

8. At fig. 6.4 enter the graph at C. Move across (left) to crop type, down to average annual rainfall (AAR), across (right) to the standard line and up to F number.
9. Design Flow $Q_o = S_T \times F \times A$
10. For each per cent of paved areas add 1% to the derived Design Flow. (Where paved area exceeds 10% of the catchment this method is not appropriate).

A(ha)	
L(m)	
S	
C(m)	
	G A H
AAR (mm)	
S_T	
F	
Q_o (l/s)	
Total Q_o (l/s)	

Figure 2: Determination of design flow.

When a figure for Design Flow is obtained pipe size can be determined from appropriate design charts. Knowledge of pipe gradient is necessary when using these charts.

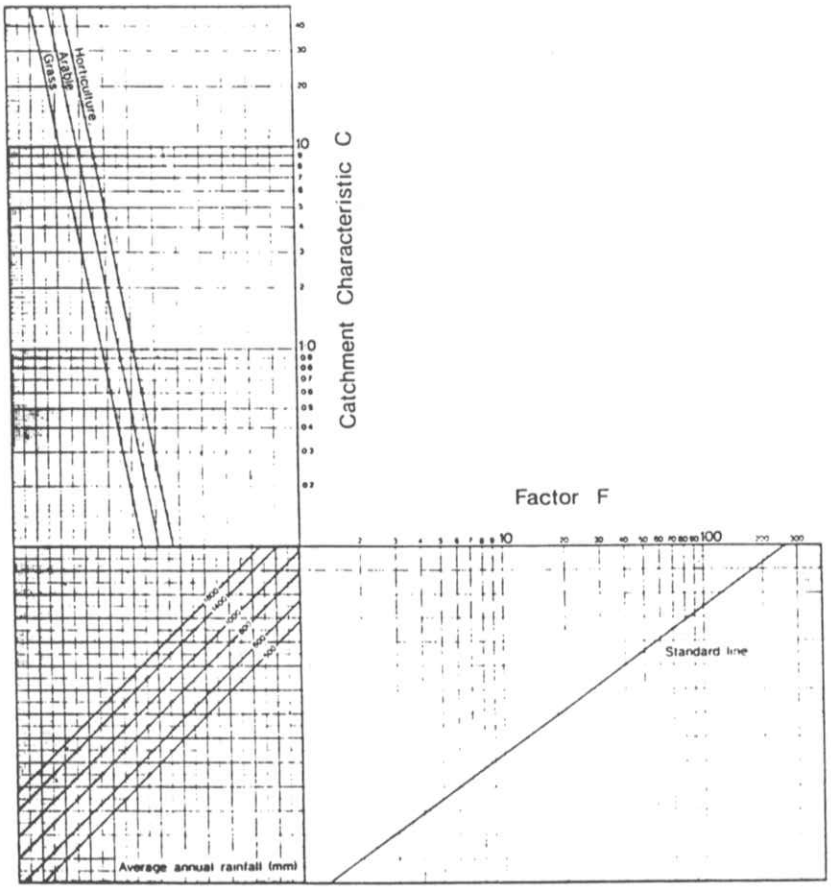


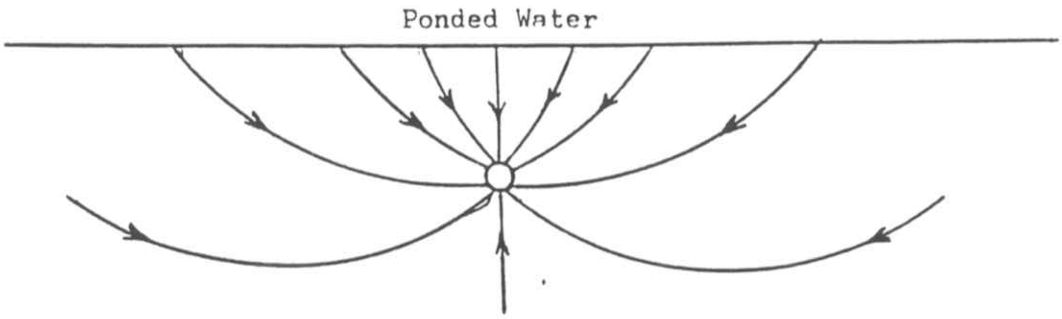
Figure 3: Catchment characteristics design flow intensity relationship.

FLOW PATH AND DRAIN SPACING

Water moves through a soil in paths similar to that shown in fig 1.

FIGURE 1

STREAM LINES IN A DRAIN TUBE BELOW PONDED WATER



Lines indicating the path of flow are called streamlines. The reason for the shape of the streamlines is explained by the equipotential lines which exists around a drain. Lines connecting points of equal hydraulic head are called equipotential lines.

The potential at any point in the profile is the resultants of all forces acting on the water at that point. The two main forces are

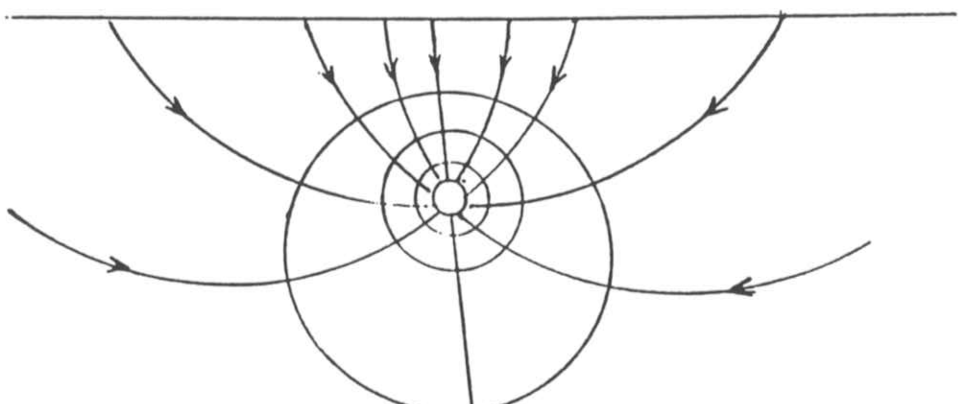
1. Hydraulic gradient forces ie the difference in potential head between any point in the profile and the zero potential at the drain.

2. Gravitational forces.

Equipotential lines therefore do no occur in circles around a drain but are extended downwards below the drain because of the effect of the gravitational potential. Hydraulic gradients tend to move water along the line of force normal to the equipotential surfaces. Equipotential and streamlines for a flow system is called a flow net. (Figure 2)

FIGURE 2

FLOW NET OF EQUIPOTENTIALS AND STREAMLINES FOR A DRAIN TUBE IN SOIL BELOW PONDED WATER



is tropic ie if the hydraulic conductivity is the same in all directions
low will be perpendicular to the equipotential surfaces. However if
h. gher K value in one direction the flow path will not be perpendicular
tential surface. This soil is said to be anisotropic
e soils often have bedding planes or particle orientation causing
isotropic (Figure 3).

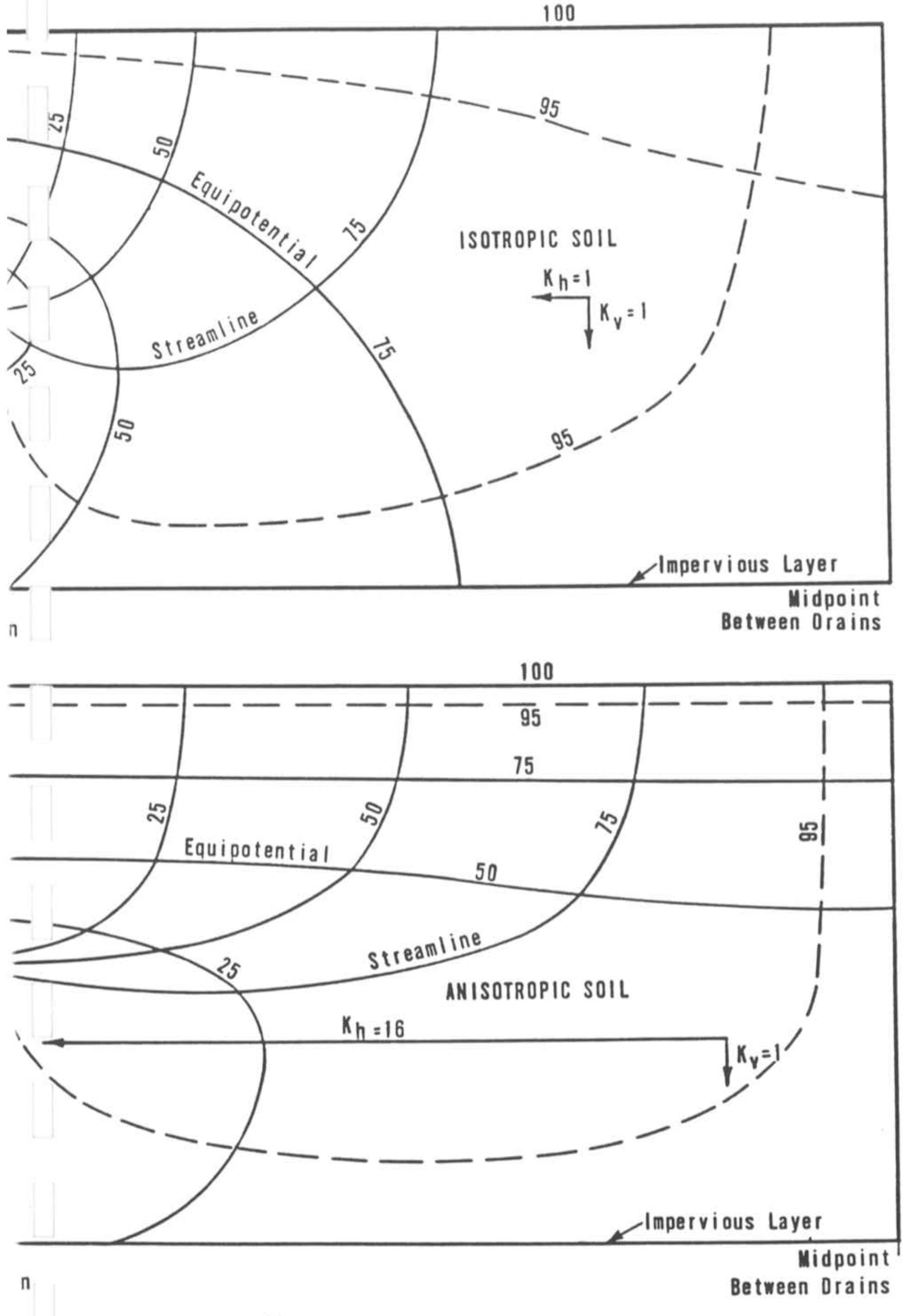


Figure . 3 , Streamlines and equipotentials h flow net determinies the path water has to follow to the drain. The velocity of low will be dependent upon the hydraulic conductivity of the soil along the path.

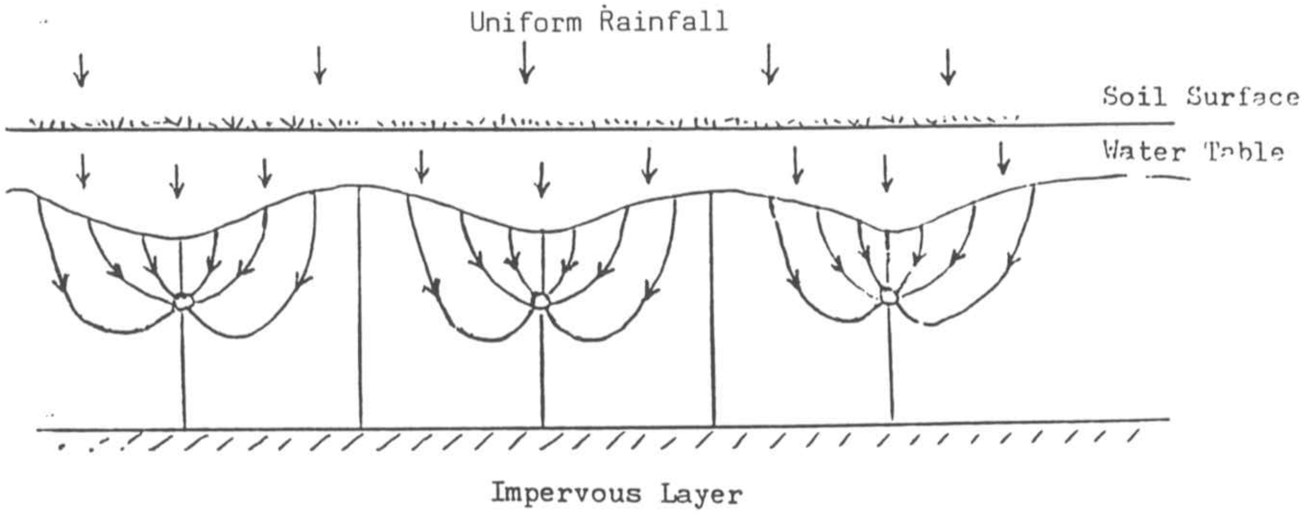
l..., nets are used to study:

1 Depth and spacing of drains.
2) Best locations for drain pipe designed to intercept flow over an impermeable layer.
3) Effects of permeable backfill.
4 Quantity of flow entering bottom half of drain.
5) Canal seepage.

Th idealised flow net situation which occurs is shown in Figure 4.

FIGURE 4

IDEALISED FLOW PATTERN FOR STEADY-STATE DRAINAGE OF HOMOGENEOUS SOIL

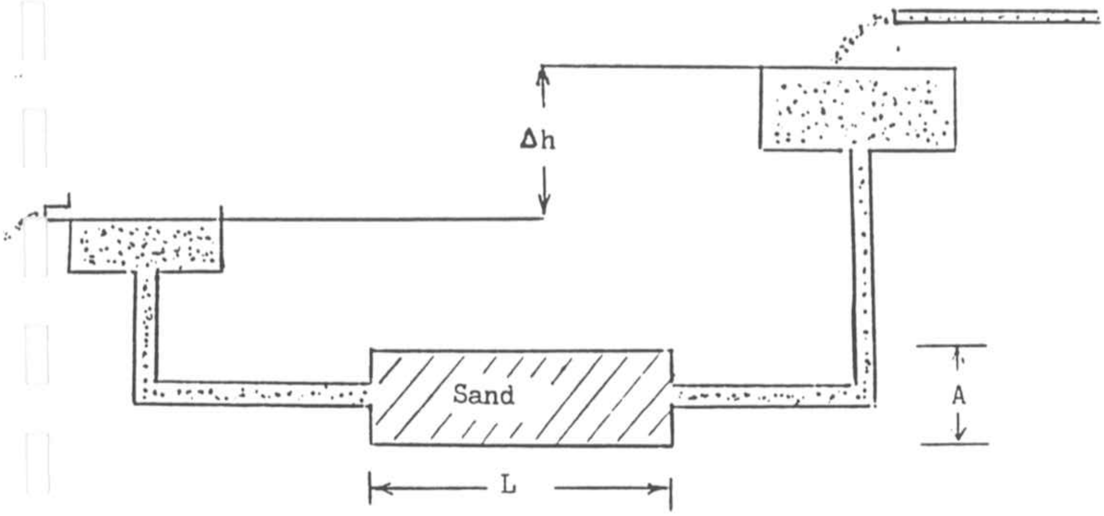


I 'DRAULIC CONDUCTIVITY

ıe soil property which most directly affects water movements is that of hydraulic conductivity . The hydraulic conductivity of a soil is defined as the rate of flow 'hrough unit cross section caused by a unit hydraulic potential or head gradient. .t is symbolised by K and is really a numerical value for soil permeability.

DARCY'S LAW

The movement of water through soils is a complete process and various attempts h ve been made to describe it mathematically. One of the earliest experiments was carried out by a man called Darcy in 1856. He set up a sand column similar to that ıown in Figure 5, and observed that the amount of water (Q) flowing through the m le in unit time (ie the rate of flow or discharge) was proportional to ference Δ h between the fluid heads at the inlet and outlet faces of the a d inversely proportional to the length of the sand sample (L) which is the th.



UF 5: DIAGRAM OF TYPE OF APPARATUS USED BY DARCY

The equation he produced was -

$$Q = K\frac{\Delta h}{L} A \text{ where}$$

Q = rate of flow through the sample

h = the head loss

L = the length of the sample

A = the cross sectioned area of the tube

K = the proportionability constant termed the
<u>hydraulic conductivity</u>

undamental equation is Darcy's Law

$$Q = K\ i\ A$$

Where Q = quantity of flow (m/day)

i = hydraulic gradient (dimension loss)

K = permeability or hydraulic conductivity (m/day)

A = cross sectioned area

d aulic conductivity of the soil gives a good indication of its drainability. with high hydraulic conductivities are easily drained while those with low l c conductivities are difficult to drain. A rough and ready guide to the onship between hydraulic conductivity and drainage design is given in Table 1

TABLE 1

Hydraulic Conductivity (metres/day)	Class of Hydraulic Conductivity	Type of drainage likely to be effective and likely range of drain spacings
More than 10	Very Rapid	Very wide spacing; cleaning of the sheughs is probably all that is needed
1.0-10.0	Rapid	Normal pipe drainage; spacing more than 10 m and probably 20 m or more
0.1-1.0	Medium	Pipe drainage practicable in deep soils but drains need to be closely spaced to give effective drainage
0.01-0.1	Slow	Mole drainage likely to be necessary
Below 0.01	Very Slow	No sub-surface drainage possible without a change in the physical condition of the sub-soil. Moling gravel tunnelling or sub-soiling is a must. If soil not suitable for these then don't attempt drainage.

h draulic conductivity of a soil can be measured both in the field and in the ratory. However to do this accurately you need a uniform sample and this is i ult to get in many Irish soils. While hydraulic conductivity values can do vary considerably for different soils of the same type the figures given in e 2 are considered to be reasonably representative of the position in hern Ireland

TABLE 2

Hydraulic conductivity values for Irish soils

Material	Hydraulic Conductivity range (metres/day)
Gravel	1,000 - 100,000
Top Soil	0.1 - 10
Sandy Soils	1 - 100
Blanket Peat	.001 - .01
Clay Soils	.00001 - 1

Typically top soils on impervious sub-soils, have hydraulic conductivity values of 0.3 metres per day, sandy soils 1 metre per day, coarse sandy soils about 100 metres, per day while for a clay sub-soil the figure is about .00001 metres per day.

As was seen in Table 2 soils with a hydraulic conductivity below the minimum value of 0.01 cannot be drained without structuring. Structuring or loosening when carried out under suitable conditions can raise the hydraulic conductivity from 0.00001 metres per day to 1 metre per day. Normally this structuring is done with sub-soilers, rippers or mole ploughs and should be part of any drainage treatment when the hydraulic conductivity of the sub-soil being drained is less than 1 metre per day.

Drainage Coefficient

On average, in our climate, soils need to be capable of draining at least 0.01 metres per day to prevent waterlogging. The drainage rate is known as the drainage coefficient and is usually expressed in mm/24 hours. The drainage coefficient is related to rainfall, cropping practice and to a lesser extent soils.

The drainage coefficients considered satisfactory are given in Table

Drainage Coefficients

Average Annual Rainfall (mm)	Drainage Coefficient (mm/24 hours)
Under 900	10
1,000	12
1,500	18
2,000	24

Where high value horticultural crops are grown these values should be increased by 20%.

Drain Spacing

Drain spacing can be calculated for each site provided the hydraulic conductivity, the drainable porosity and the depth of permeable soil are known; the mathematics however are very complicated and it is not often attempted in the field. Furthermore when used on clay soils the drain spacings indicated are of the order of 1-3 metres.

Comprehensive systems can be designed from measurable climatic and soil data which are specific to the site. A common approach is used for both watertable and low permeability problems but no satisfactory mathematical solution is available for seepage water problems.

The design is achieved by using one of a number of drain spacing equations, which have been derived by research workers from a knowledge of the principles of water movement in soils and from field experiments.

A simple and effective equation by Kirkham will be used in the following examples: Toksoz and Kirkham devised a graphical solution to the equation (Figure 6). For drain spacing calculations use K values shown in Table 4.

Design Requirements

The design calculations for any water table problem are usually based on the following criteria:

(a) Soil permeability - if there is more than one layer the permeability of each layer must be found.

(b) The thickness of each layer and the depth to the impermeable layer. Generally speaking a layer is deemed to be impermeable if its permeablity is less than 1/10th of the upper layer.

(c) The minimum depth at which the watertable is to be controlled.

(d) The design coefficient, already mentioned, which is the amount of water that must be removed in a given period.

Recently Toksoz and Kirkham (1975) produced a table giving drain spacings for soils of different hydraulic conductivities on different slopes for rainfalls of 10 mm per day (see Table 3).

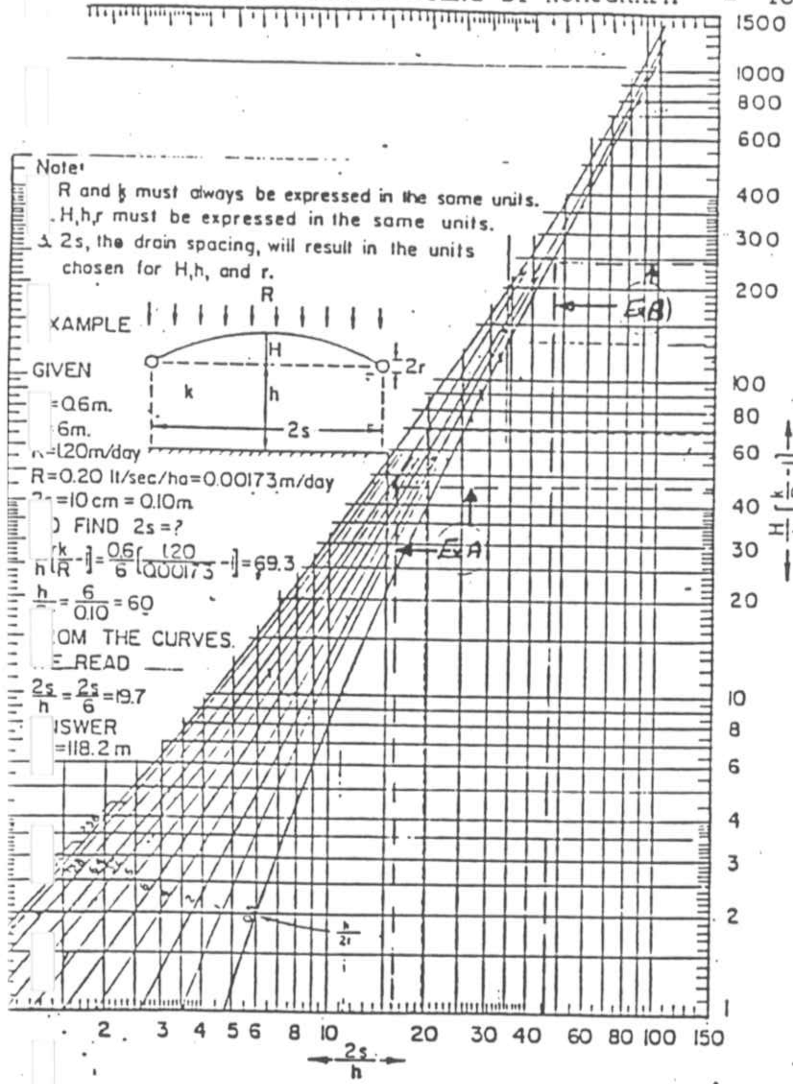
TABLE 3

Hydraulic Conductivity (metres/day)	Drain Spacing (Metres) Flat	10% Slope	20% Slope
10	10	36	63
1	3.2	5.6	7.9
0.1	1.0	1.6	1.7
0.01	Continuous gravel layer required.		

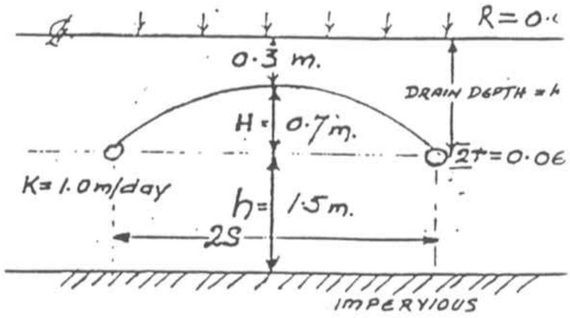
It is obvious from Table 3 that for soils of hydraulic conductivities of <0.1 metres per day it will be necessary to bring the drains close together (1-2 metres) in order to achieve satisfactory drainage. Such close spacing is not economic using plastic pipe drains.

The improvement of the drainage characteristics of these impervious soils can only be achieved by disrupting the soil so that its pore structure is changed and its permeability increased. The methods most generally used are subsoiling, ripping, mole drains and gravel tunnel drains.

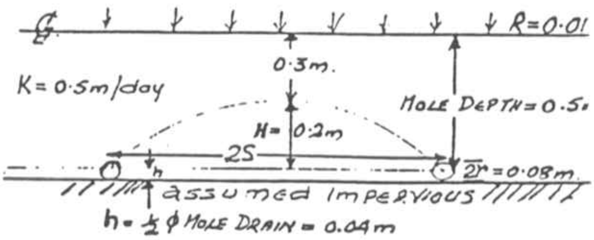
SOLUTION OF DRAIN SPACING BY NOMOGRAPH - TOKSOZ-KIRKHAM



EXAMPLE A (see below)



EXAMPLE B - MOLES & GRAVEL MOLES (See below)



NOTE: SKETCHES NOT TO SCALE

:a. 6-6. Dimensionless chart of $(H/h)\ (k/R\text{-}1)$ versus $2s/h$ for various values of $h/2r$, for ntaining drain spacings $2s$ for the removal of steady rainfall or excess irrigation water 'oksöz and Kirkham [80].)

o se the Nomograph certain parameters must be known or assumed.

- The value for K (Soil Permeability) must be measured or estimated.
- The design level of crown of water table below ground level normally assumed to be 0.3m for Irish conditions.
- A drain depth below ground level must be decided to calculate H.
- The depth of the impervious layer below the pipe drain (h) must be found or estimated
- The pipe diameter (2r) must be known.
- Under steady state conditions the quantity of water removed by the drains is equal to the design rainfall R. R = 0.01m/day. It will be necessary in certain circumstances to use a much higher rainfall figure if condition 2 above is to be maintained.

XAMPLE A

ssume K = 1m/day; Depth of drain 1.0m ∴ H = (1.0 - 0.3) = 0.7; h = 1.5m; 2r = 0.06m; R = 0.01

alculate (i) $H/h\left[K/R - 1\right] = \frac{0.7}{1.5}\left[1/0.01 - 1\right] = 0.47\left[100-1\right] = 46.5$

(ii) $h/2r = \frac{1.5}{0.06} = 25$

sing these two figures on the nomograph (interpolating $h/2r = 25$ between 16 & 32)

$2s/h = 16$ ∴ 2s (Drain spacing) = 16 x 1.5 = 24m

XAMPLE B (Moles or Gravel Moles)

k K (after ripping) = 0.5 H=(0.5 - 0.3) = 0.2; h=(½φ Mole Drain) = 0.04; 2r = 0.08; R=0.01m/d

alculate (i) $\frac{H}{h}\left[K/R - 1\right] = \frac{0.2}{0.04}\left[\frac{0.5}{0.01} - 1\right] = 5\left[50 - 1\right] = 245$

(ii) $\frac{h}{2r} = \frac{0.04}{0.08} = 0.5$

om nomograph as before $\frac{2s}{h} = 46$; 2s (spacing) = 46 x 0.04 = 1.84m say 2m

TABLE 4: PERMEABILITY (K) VALUES FOR SOILS AND GRAVELS

REF	DESCRIPTION	K IN METERS PER DAY
1.	Topsoil	0.5 - 1.0
2.	Woody Peat	0.5 - 1.0
3.	Reed or Sedge Peat	0.005 - 0.1
4.	Cracked Sedge Peat	0.1 - 1.0
5.	White Marl	0.03 - 0.05
6.	Alluvial Mud	0.001 - 0.01
7.	*Loam	0.001 - 1.0
8.	*Sandy Loam	0.5 - 5.0
9.	*Silty Loam	0.001 - 1.0
10.	*Clay Loam	0.0001 - 1.0
11.	Compacted Sandstone + Shale Subsoil	0.001 - 0.1
12.	Tight Boulder Clay	less than .001
13.	Soil After Ripping/Subsoiling	0.5 - 1.0
14.	Fine Sand (0.02mm - 0.2mm)	0.1 - 1.0
15.	Sand (0.1mm)	1.0
16.	Sea Sand (0.2mm)	10.0
17.	Sand 2mm	100.0
18.	Sand 2mm - 6mm	1000.0
19.	Gravel 75% (10 - 20mm) 25% (2 - 6mm)	5000.0
20.	Gravel 90% (10 - 20mm) 10% (2 - 6mm)	15,000.0
21.	Weathered Shale Rock	1.0 - 10.0
22.	Fissured Rock	1000.0 - 100,000.0

* Permeability of Loams depends very much on how the soil is packed and structured.

PIPE SIZE DESIGN

Having decided the drain spacing it is important to establish the correct diameter f pipe for each part of the drainage system.Before attempting to determine a pipe iameter it is necessary to define the functions of drainage pipes and to understand something of pipe hydraulics.

1. A lateral is a drainage pipe which collects soil water continuously over its full length through slits or pipe joints.

. A restricted inlet main is a pipe which collects water from the laterals and conveys the combined flow to the outfall. It may also receive soil water throughout its length.

3. An interceptor drain is one or more drains located to drain areas of seepage such as springlines.

. An open inlet piped ditch is defined as the replacement of an open ditch with a line of pipes which receive the ditch discharge at its inlet and conveys it to an outfall.

. A culvert is the piping of a ditch for a short distance to allow access etc, a short distance is defined as up to 15 metres in length.

n determining the capacity of underdrainage pipes an allowable surcharge is acceptable and incorporated into lateral pipe design. However with restricted inlet mains and pen inlet piped ditches no surcharge is allowed.

t the design rate for laterals, surcharge has been allowed up to a level not exceeding 200 mm above the pipe soffit, which in practice means that the surcharge will be ontained at least 600 mm below the surface.

Investigations in England and Wales have shown that a lateral length of 300 m covers .5% of all drainage schemes. In Northern Ireland because of the small field sizes and irregularity of the ground surface most laterals would not exceed 160 metres.

SEDIMENTATION

To provide for the loss of pipe capacity due to sedimentation there is a 25%

reduction in capacity included in the design. Theoretically, cohesive clay soil should not cause any sedimentation whereas fine sands can totally block a pipe.

DESIGN CHARTS

There are charts available for two cases. The first being for laterals where water is entering the pipe throughout its length. The second is for restricted inlet mains and open inlet piped ditches where no surcharge is expected. If the required pipe capacity and design gradient were known then the required pipe internal diameter may be read directly off the chart.

The quantity of water which a pipe can carry depends upon its diameter, the gradient to which it is laid and the roughness of the pipe material. An increase in gradient increases the carrying capacity whilst an increase in pipe roughness decreases carrying capacity.

PIPE DISCHARGE RATE

As a field drain has a cathment area related to drain spacing (s) and drain length (L) expressed as

$$\text{Area} = \frac{S \times L}{10{,}000} \text{ ha}$$

Where S and L are in metres, we can state

$Q = q\,L$ as (q = inflow along unit length of pipe)

Pipe discharge Q = C x rainfall (r) x drainflow factor (F)
x pipe catchment area (A)

Where Q is in litres/s
r is in mm/day - (usually 10 - 12 mm in Northern Ireland
f is dimensionless - drainflow factor
A is in hectares
C 0.13 a conversion factor for mm/ha /day to litres/sec

The full formula is - $Q = 0.13 \times r \times f \times A$.

When designing collector drain size for mole drainage the discharge is more rapid and it is usual to design for 20-24 mm/24 hrs.

rassland, arable or horticulture;

n dium or low permeability;

te to the district, intended land use and type

a: fall (r);

nr the drainflow factor (f);

ne the catchment per lateral A_L) from the

| nd maximum required length of lateral;

ow Q_L (litres/s);

d ipe gradient (%).

gradient to charts 1-4 according to the type of

te mine the required pipe size. If the inter-

lies between pipe sizes select the larger size

fa turers' range.

has a slope of <1% with medium subsoil

nd use is grass and the proposed drainage system

pes and moling at 30 m spacing and lateral

= 10 mm/day

(f) = 0.8

L = 0.42

0 8 x 0.42.

s/s (multiply x 2 for moling operation).

ip gradient of 2% the pipe size required is

nearest pipe size available here is 50 mm.

Table . 1. Drainflow factors (f).

Drainage System	Land Use/ Cultivation	*Slope* <1% Rapid	<1% Med	<1% Slow	1%-3% Rapid	1%-3% Med	1%-3% Slow	>3% Rapid	>3% Med	>3% Slow
		Subsoil Permeability Class								
Pipes only	Arable	1.0	0.8	0.7	0.9	0.7	0.6	0.7	0.6	0.5
	Grass	0.9	0.7	0.6	0.8	0.6	0.5	0.6	0.5	0.4
Pipes* and subsoiling	Arable	—	0.9	0.8	—	0.8	0.7	—	0.7	0.6
	Grass	—	0.8	0.7	—	0.7	0.6	—	0.6	0.5
Pipes and Moling	Arable Grass	—	—	0.8	—	—	0.8	—	—	0.7

Table 2 Ready reckoner for lateral length, drain spacing and area; maximum permissible lateral length in metres.

Area (Ha)	*Drain spacing (m)* 40	30	20	18	16	14	12	10
1.6	400							
1.5	375							
1.4	350							
1.3	325							
1.2	300	400						
1.1	275	367						
1.0	250	333						
0.95	238	317						
0.90	225	300						
0.85	213	283						
0.80	200	267	400					
0.75	188	250	375					
0.70	175	233	350	389				
0.65	163	217	325	361				
0.60	150	200	300	333	375			
0.55	138	183	275	306	344	393		
0.50	125	167	250	278	313	357		
0.49	123	163	245	272	306	350		
0.48	120	160	240	267	300	343	400	
0.47	118	157	235	261	294	336	392	
0.46	115	153	230	256	288	329	383	
0.45	113	150	225	250	281	321	375	
0.44	110	147	220	244	275	314	367	
0.43	108	143	215	239	269	307	358	
0.42	105	140	210	233	263	300	350	
0.41	103	137	205	228	256	293	342	
0.40	100	133	200	222	250	286	333	400
0.39	98	130	195	217	244	279	325	390
0.38	98	127	190	211	238	271	317	380
0.37	93	123	185	206	231	264	308	370
0.36	90	120	180	200	225	257	300	360
0.35	88	117	175	194	219	250	292	350
0.34	85	113	1·70	189	213	243	283	340
0.33	83	110	165	183	206	236	275	330
0.32	80	107	160	178	200	229	267	320
0.31	78	103	155	172	194	221	258	310
0.30	75	100	150	167	188	214	250	300
0.29	73	97	145	161	181	207	242	290
0.28	70	93	140	156	175	200	233	280
0.27	68	90	135	150	169	193	225	270
0.26	65	87	130	144	163	186	217	260
0.25	63	83	125	139	156	179	208	250
0.24	60	80	120	133	150	171	200	240
0.23	58	77	115	128	144	164	192	230
0.22	55	73	110	122	138	157	183	220
0.21	53	70	105	117	131	150	175	210
0.20	50	67	100	111	125	143	167	200
0.19	48	63	95	106	119	136	158	190
0.18	45	60	90	100	113	129	150	180
0.17	43	57	85	94	106	121	142	170
0.16	40	53	80	89	100	114	133	160
0.15	38	50	75	83	94	107	125	150
0.14	35	47	70	78	88	100	117	140
0.13	33	43	65	72	81	93	108	130
0.12	30	40	60	67	75	86	100	120
0.11	28	37	55	61	69	79	92	110
0.10	25	33	50	56	63	71	83	100
0.09	23	30	45	50	56	64	75	90
0.08	20	27	40	44	50	57	67	80
0.07	18	23	35	39	44	50	58	70
0.06	15	20	30	33	38	43	50	60
0.05	13	17	25	28	31	36	42	50

The following Table gives some idea of the areas drained by various pipe sizes.

TABLE 3: **Hectarage Drained by Various Pipes**

Type	Nominal Size	Area Drained at 10 mm/24 hours at a Slope of 1/200 adjusted for deterioration by a factor of 0.75 (ha)
Clay	3"	1.25
Tiles	4"	2.67
	6"	7.93
Smooth	50 mm	0.40
Plastic	70 mm	1.13
	90 mm	2.27
Corrugated	50 mm	0.24
Plastic	61 mm	0.40
	65 mm	0.49
	70 mm	0.65
	80 mm	0.93
	100 mm	1.34
	110 mm	2.27

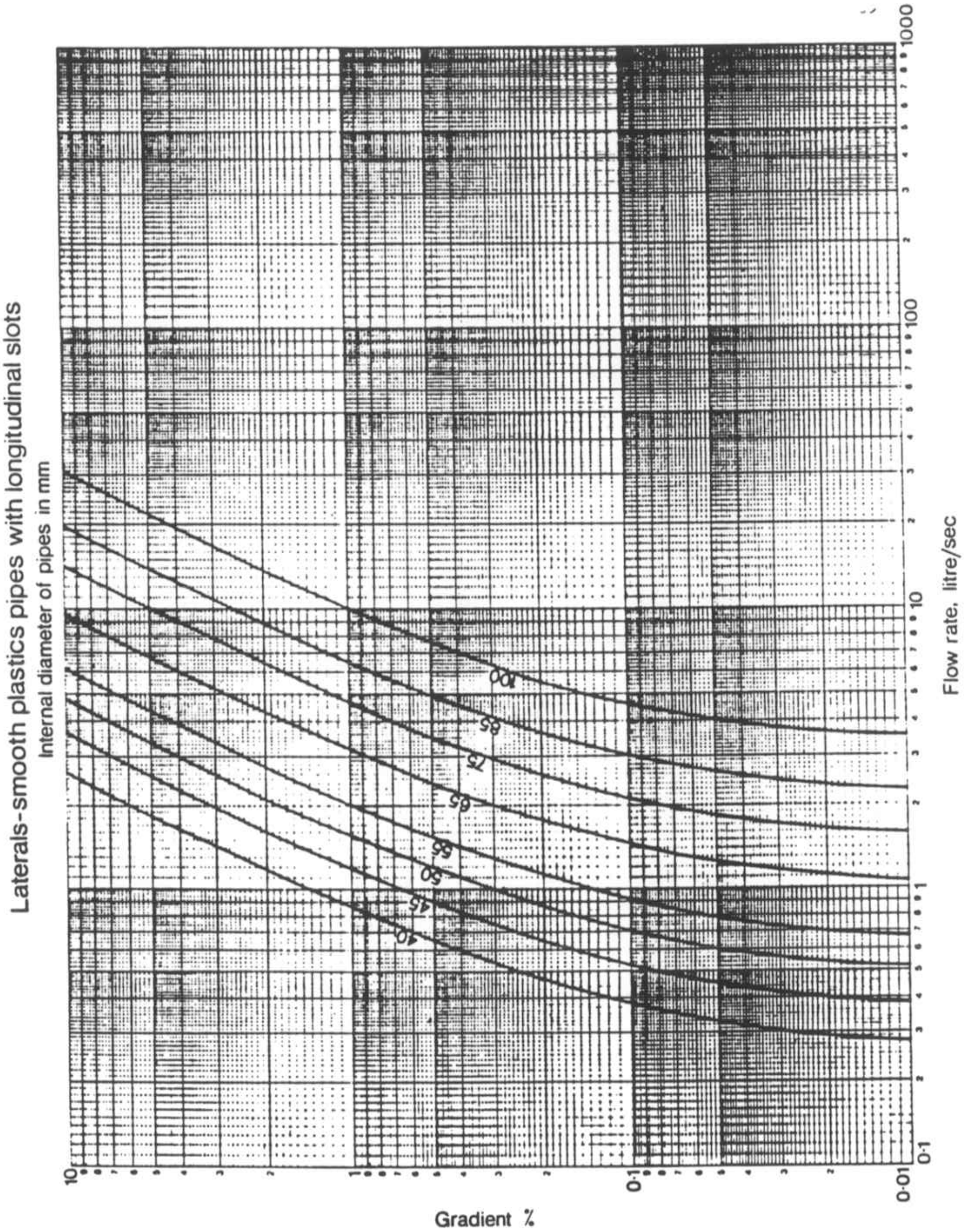
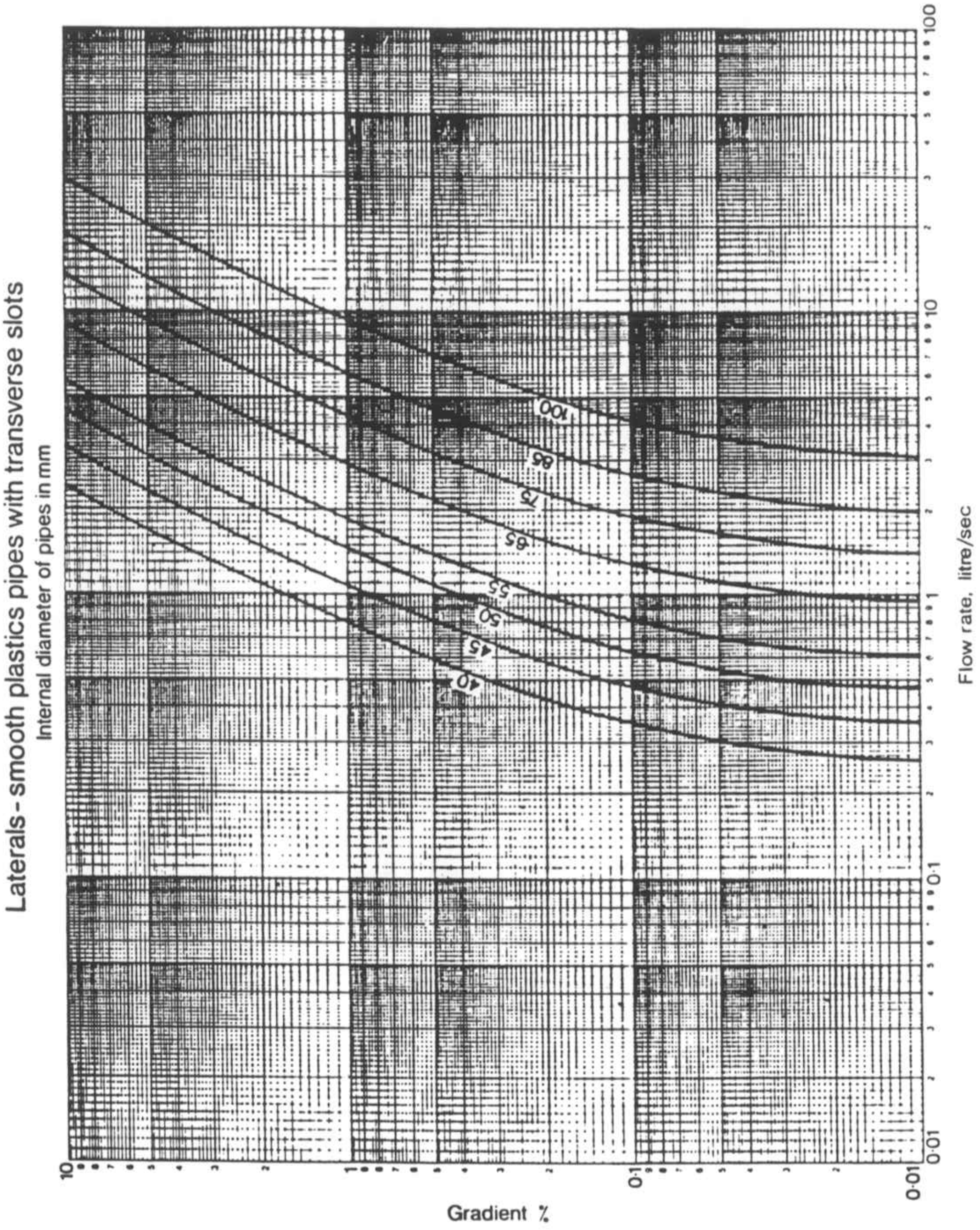

Laterals-smooth plastics pipes with longitudinal slots
Internal diameter of pipes in mm
100
85
75
65
55
50
45
40
Gradient %
10
1
0·1
0·01
Flow rate, litre/sec
0·1
10
100
1000

Chart 1



Laterals - smooth plastics pipes with transverse slots
Internal diameter of pipes in mm
100
85
75
65
55
50
45
40
Gradient %
10
1
0·1
0·01
Flow rate, litre/sec
0·01
0·1
1
10
100

CHART 2.

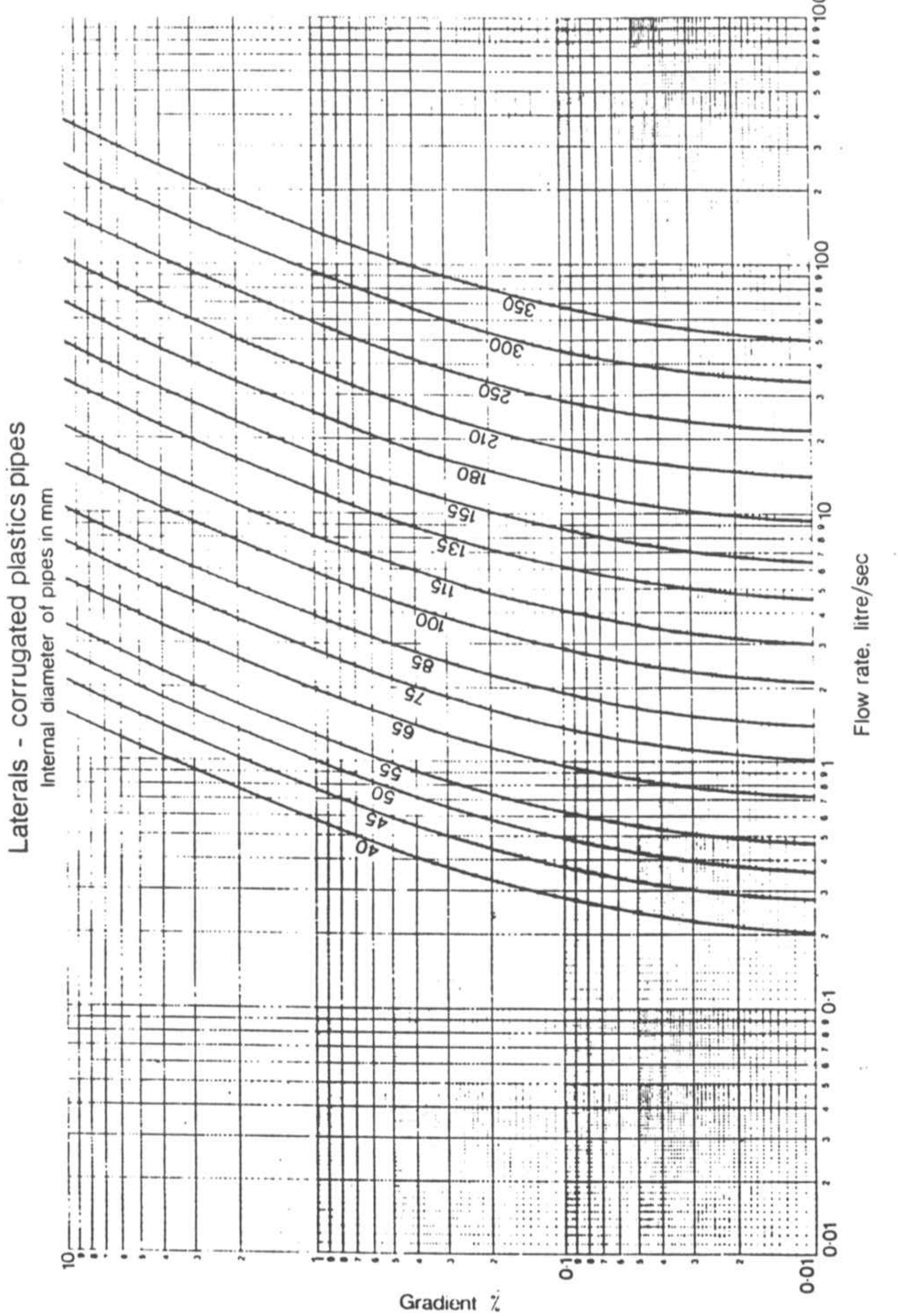

Laterals - corrugated plastics pipes
Internal diameter of pipes in mm
Flow rate, litre/sec
Gradient %
350
300
250
210
180
155
135
115
100
85
75
65
55
50
45
40

Chart 3

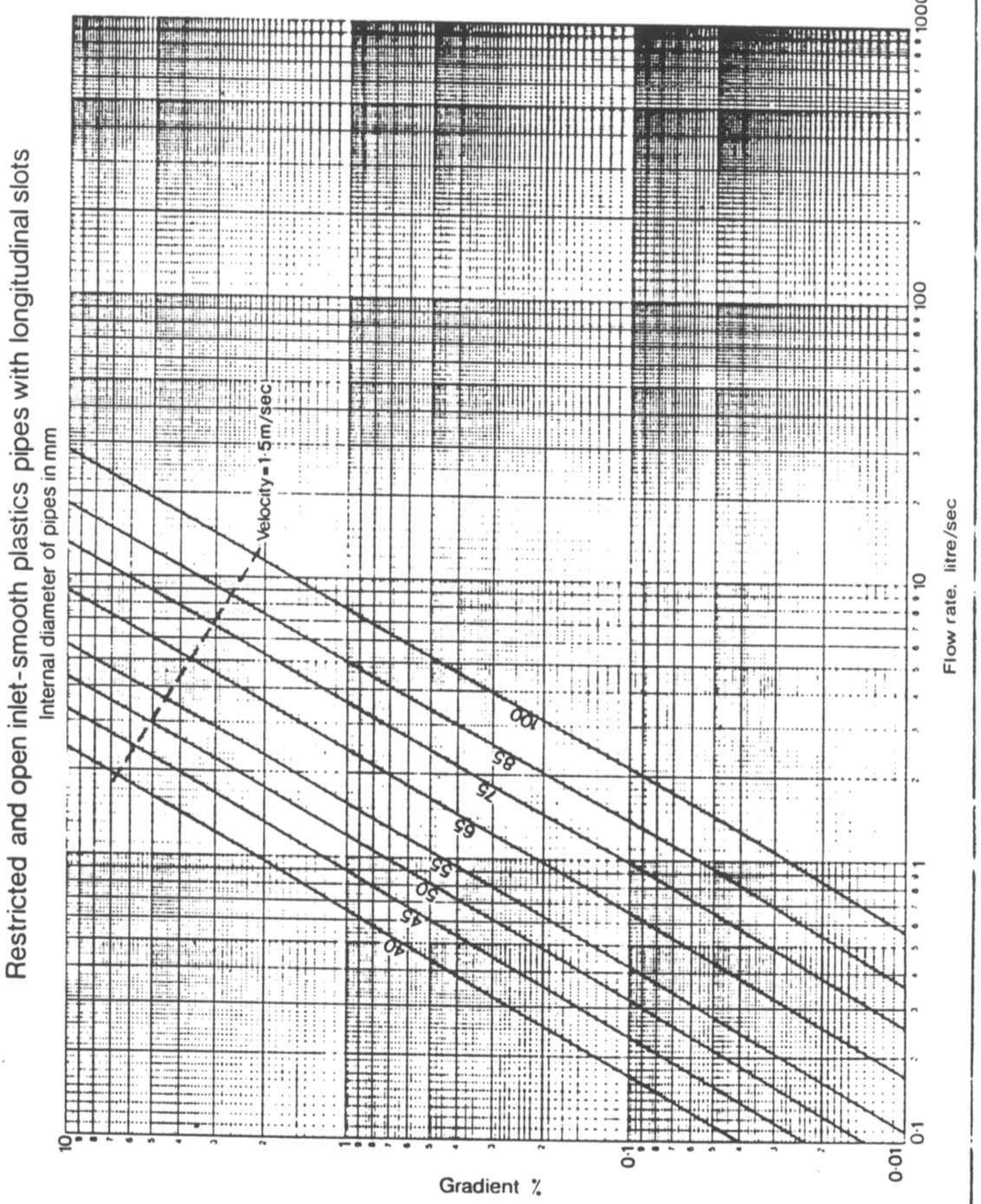

Restricted and open inlet-smooth plastics pipes with longitudinal slots
Internal diameter of pipes in mm
Velocity = 1·5m/sec
100
85
75
65
55
50
45
40
Gradient %
10
1
0·1
0·01
Flow rate, litre/sec
0·1
1
10
100
1000

Chart 4

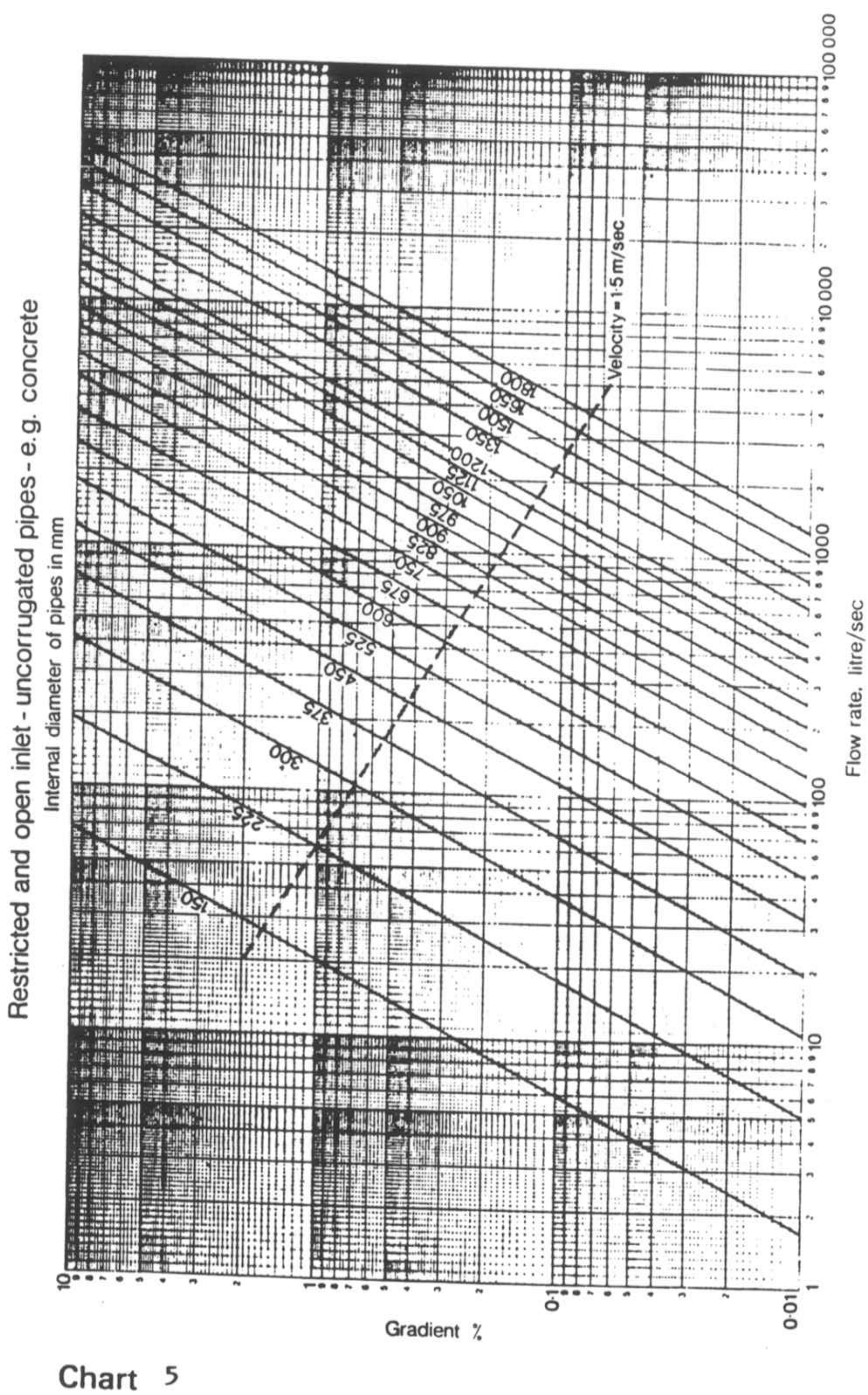
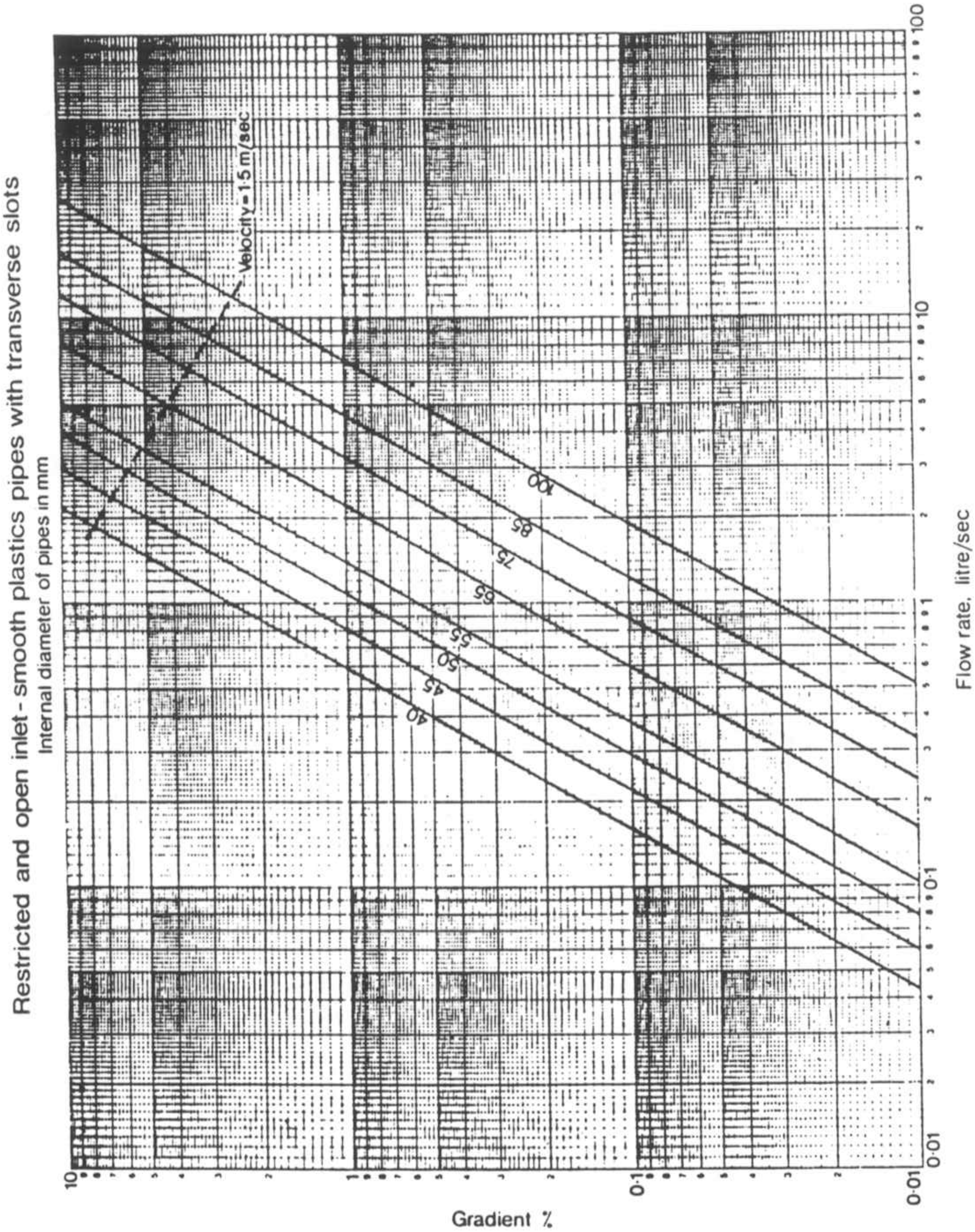

Restricted and open inlet - uncorrugated pipes - e.g. concrete
Internal diameter of pipes in mm
150
225
300
375
450
525
600
675
750
825
900
975
1050
1125
1200
1350
1500
1650
1800
Velocity = 1·5 m/sec
Gradient %
10
1
0·1
0·01
Flow rate, litre/sec
10
100
1000
10 000
100 000

Chart 5



Restricted and open inlet - smooth plastics pipes with transverse slots
Internal diameter of pipes in mm
Velocity = 1·5 m/sec
100
85
75
65
55
50
45
40
0·01
0·1
1
10
100
Flow rate, litre/sec
10
1
0·1
0·01
Gradient %

Chart 6

DRAINAGE SYSTEMS

Conventional Drainage

This method of drainage with pipes or tiles laid to depth from 500-900 mm and backfilled with permeable material to plough depth and in many cases to ground surface is known as conventional drainage. In the past most of the clay soils in Northern Ireland were drained in this way with a drain spacing of approximately six metres. This method has two big disadvantages:

1. It is an expensive system.
2. Even at this close spacing the ground between the drains remains fairly wet.

Experience by many workers suggest that equally spaced parallel tile or plastic pipe drains installed in the conventional manner do no provide efficient drainage, do not intercept surface run-off and unless they are very close together do no control the water table. To overcome this problem the soil's permeability must be artifically improved by shattering and fissuring so that water can pass from the surface down to a system of under drainage. This can be achieved by a combination of conventional drains at wide spacings and one of the following secondary drainage treatments:

(a) Subsoiling
(b) Mole drainage
(c) Gravel tunnel drainage

However there are a number of situations where the conventional plastic pipe drain is the only solution to a particular problem.

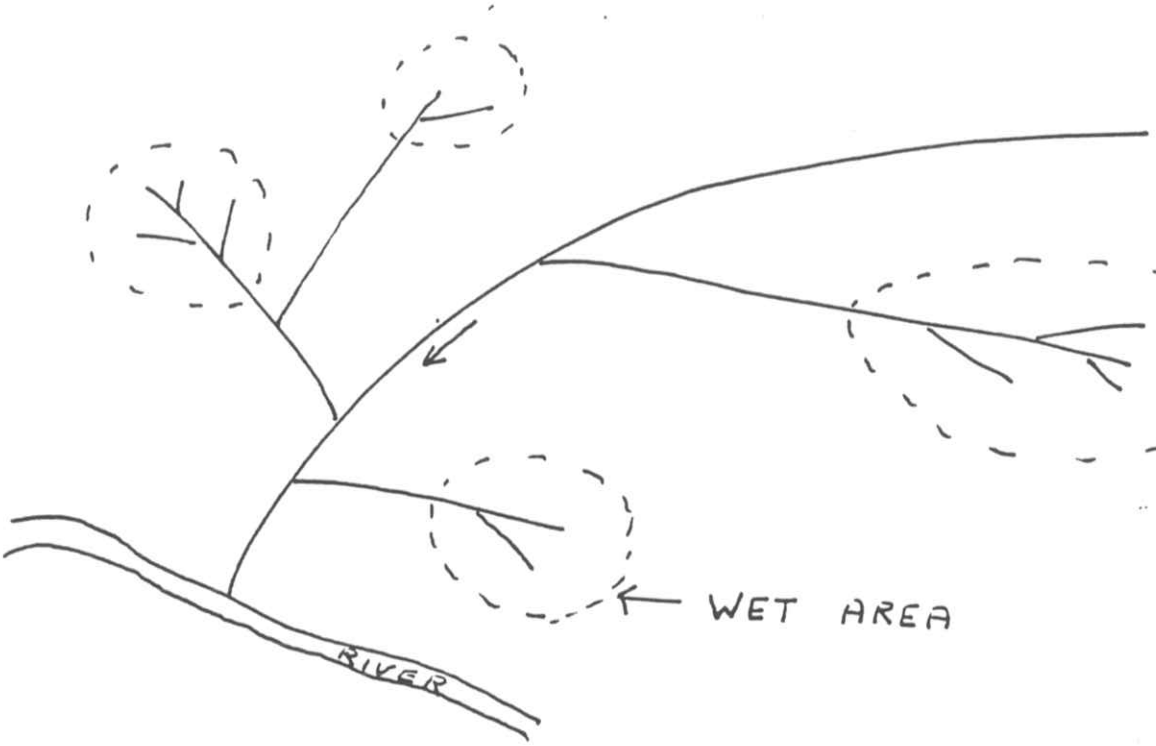
1. Relatively permeable mineral soils with high ground water table ie, alluvial soil on flat sites.
2. Organic soils - mainly basin peats and interdrumlin hollows.
3. Localised wet spots.
4. Springline and artesian seepage.

Drainage Layouts

There are a number of different drainage layouts. The one selected will be determined by the site topography, by any physical obstructions such as trees and pylons above ground and by the point or points for a suitable outfall.

Layouts should be kept as simple as possible for ease of setting out, machinery operation and future maintenance. The following layouts are often found in the North of Ireland

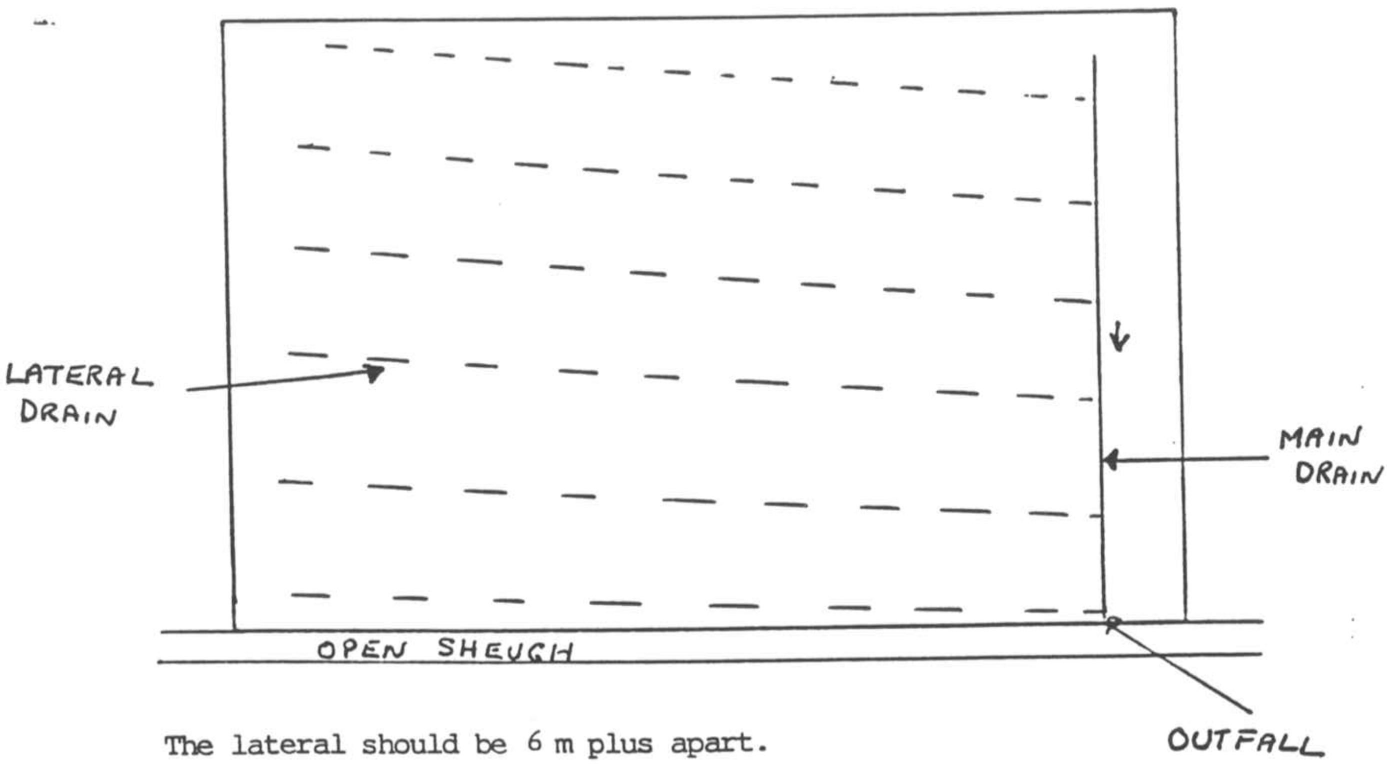
(a) Random System



This system is normally used where the drainage problem is confined to a few localised wet spots.

(b) Parallel System

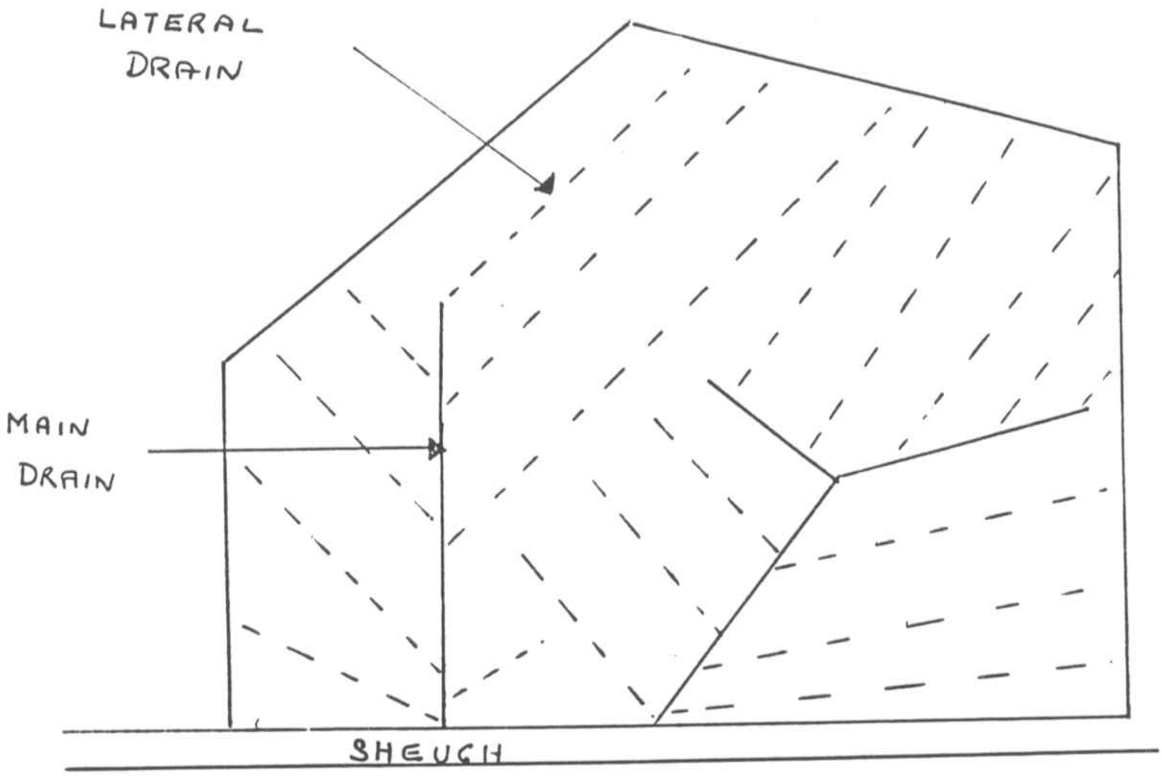
This is best suited to land with a relatively uniform slope or flat ground.



The lateral should be 6 m plus apart.

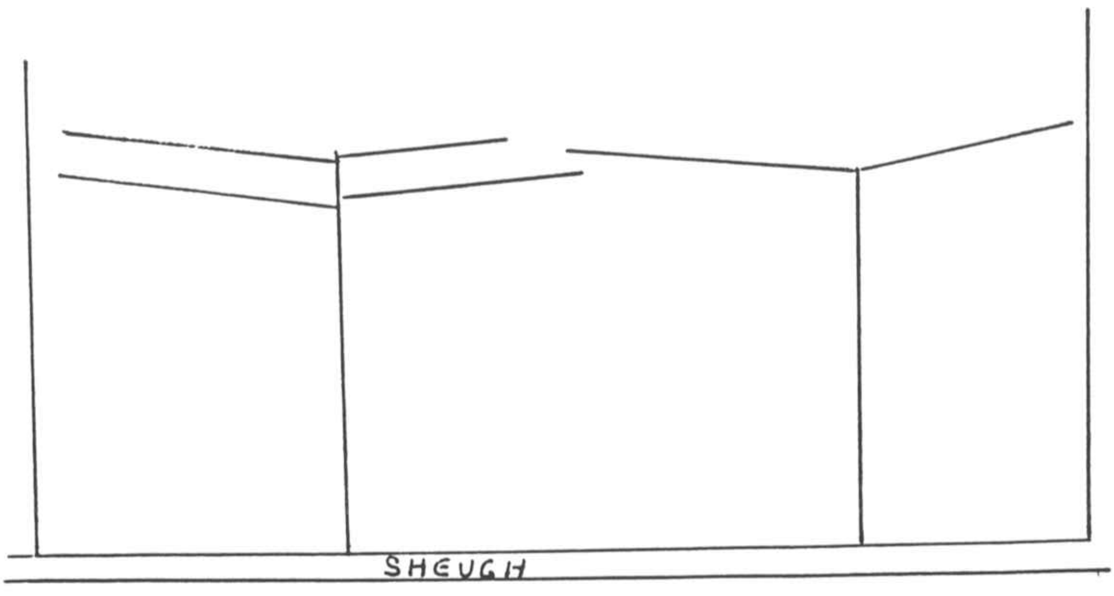
(c) Herringbone System

The Herringbone or Irregular system is likely to be best where the field has a number of different slopes.



(d) Interceptor System

This system is used when the problem is surface seepage or a spring-line.



MOLE DRAINAGE

A mole drain is effectively an unlined soil pipe with a fairly regularly spaced series of well defined cracks or fissures in the roof and side walls. The fissures connect the drainage channel to the surface soil and provide the major flow paths for water movement into the drain.

Mole drainage is a very old practice with reference to it drawn from an article in the 'Practical Fruit Gardener' (1724) by Stephen Switzer. Switzer recommended that a trench should be dug in the clay soil, at the bottom of which a tube was to be formed by pressing clay around a tapered cyclinder, 4" to 5" diameter and 4' long, after which the cyclinder was to be withdrawn. This method of draining became known as plug draining. In 1797 Harry Watts devised a mole plough to be drawn by 4-8 horses but it was not until the application of the steam engine to mole draining by Fowler (1857) that moling began to be used on a wide scale. (figure 1)

Mole Ploughs

A mole plough creates a channel in the subsoil as it is pulled across the field. The mole consists of a solid, circular section, steel rod about 7-9 cm in diameter, pointed at the front to give penetration and trailing an expander piece behind. This is also cyclindrical and slightly larger than the mole, to give the channel its final shape. A vertically set blade or line attaches the mole unit to the frame of the implement and allows the selection of a range of depths of working.

There is a range of mole plough designs available. These include;

1. short beam - three points linkage type
2. scrubbing long beam ploughs
   a. complete beam
   b. stepped beam
   c. hitch scrubbing beam
3. floating beam mole ploughs (see figures 1, 2, 3, 4)

Most popular in this country is the cheaper, short beam plough which operates from the 3-point linkage of a heavy tractor. On most of our sloping drumlin countryside gradient poses no problem and this machine is adequate.

However where numerous surface irregularities exist it is recommended that the long beam type plough be used. In this case the mole blade is attached to an iron beam up to 3 m long which slides along the ground surface and smoothes out the mole channel gradients over minor undulations. The disadvantages with this

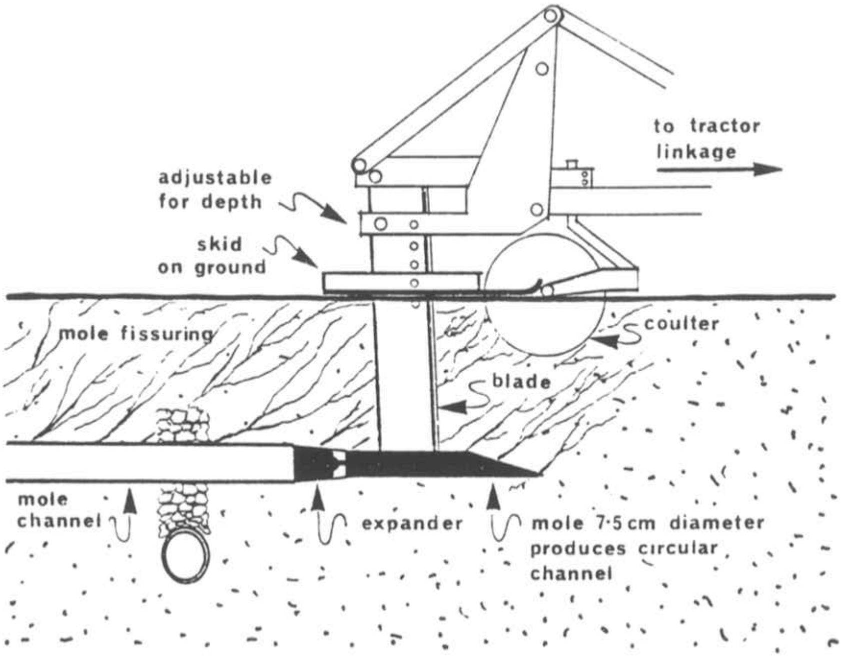


FIGURE 1: 3 POINTS LINKAGE MOLE PLOUGH

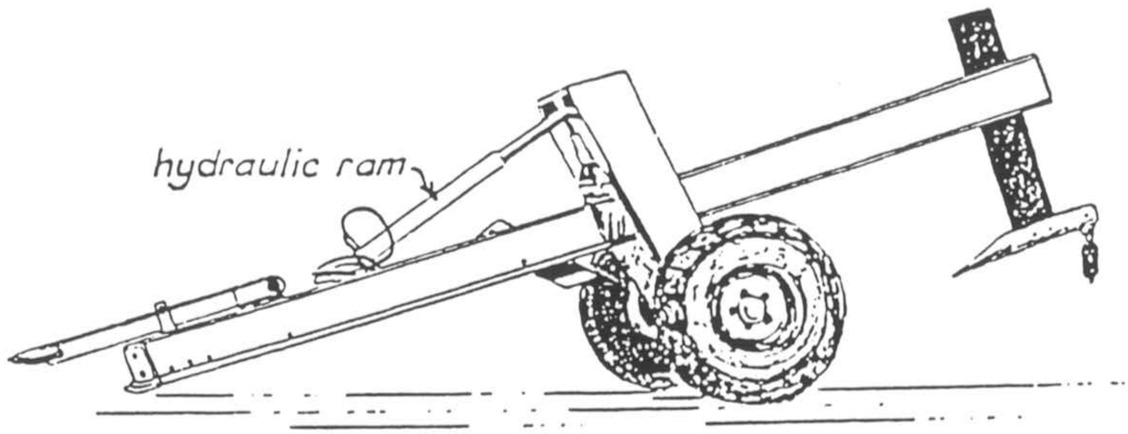
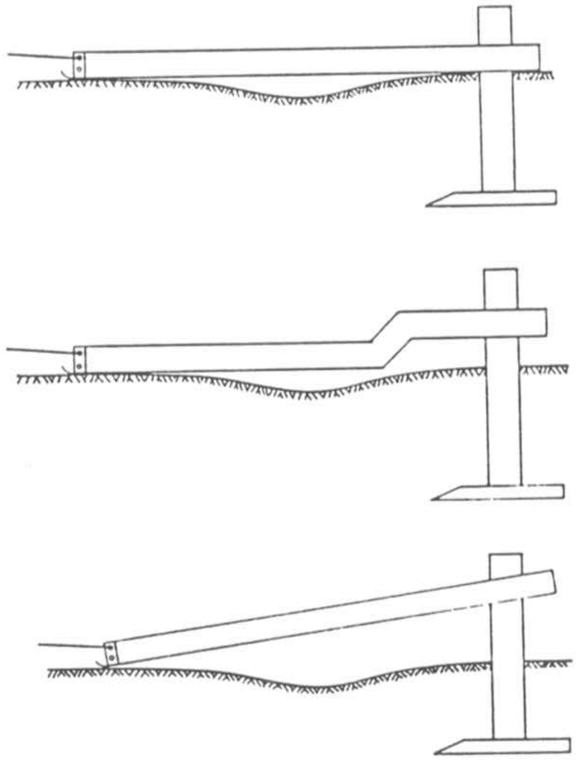
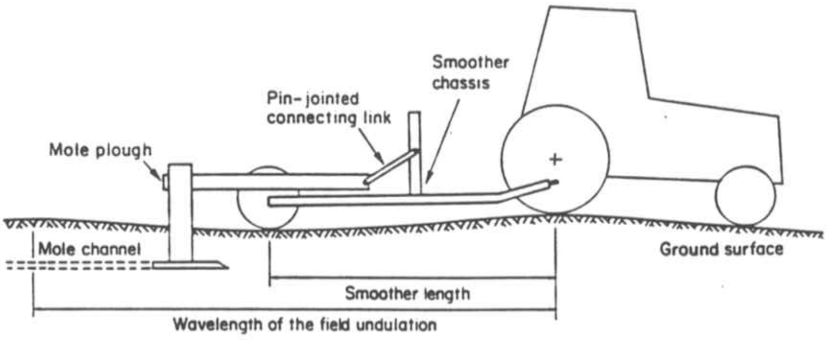


FIGURE 2: FLOATING BEAM MOLE PLOUGH



G RE 3: COMPLETE BEAM (TOP). STEPPED BEAM (MIDDLE) AND MITCH SCRUBBING (BOTTOM) SYSTEMS.



gure 4: SYSTEMATIC DIAGRAM OF GRADE SMOOTHER.

equipment is that the sliding beam causes considerable friction as it moves along, greatly increasing the power and traction needed. Also there is a tendency for blockage when moling in trashy conditions.

The most recent innovation is the floating beam type. In addition to negotiating undulations better than the scrubbing beam plough the draught force can be reduced by up to 40%. Simple adjustments to the working depth can be made from the tractor cab, the purpose of which is to produce rises or falls in the mole channel in flat fields. Also the problem with thrash accumulation is eliminated.

Conditions for Good Mole Draining

Successful mole drainage is very dependant upon the long term stability of the mole channel and its associated soil fissures. This stability can be influenced by soil, climatic and implement factors.

Soil

Homogeneous clay rich soils are most favourable for good moling. High cohesion is essential for stability and this means soil having a high clay content (30%+) with low sand content. Soils with a clay content in excess of 45% are in most cases very suitable for mole drainage. It is essential that potential sites be examined by digging a number of profile pits to a depth of 600 mm. The presence of large stones, gravel or sand pockets will indicate the unsuitability of this location.

Climatic

Ground and weather conditions at the time of moling are important. The ground surface should be dry enough for efficient traction. Soil moisture content is a critical factor affecting the success of the treatment. The best conditions occur when the soil around moling depth is in a plastic state and the soil above it is in a friable state.

When moled in this condition a clean smooth channel and slots are formed and the passage of the blade leaves and fractures a cone shaped zone above to increase the soil permeability to a marked extent. (figure 5)

Dry weather during and after moling is very important for prolonging the life of the mole. If the channel walls are saturated soon after formation; the recently remoulded clay particles which have lost some of their cohesion will become very unstable and collapse.

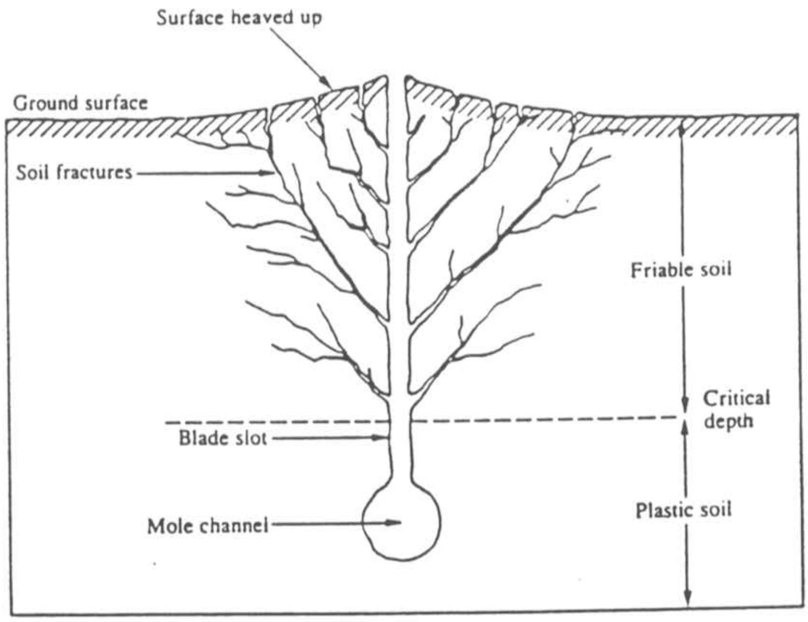


FIGURE 5: MOLE DRAIN SHOWING FISSUEING

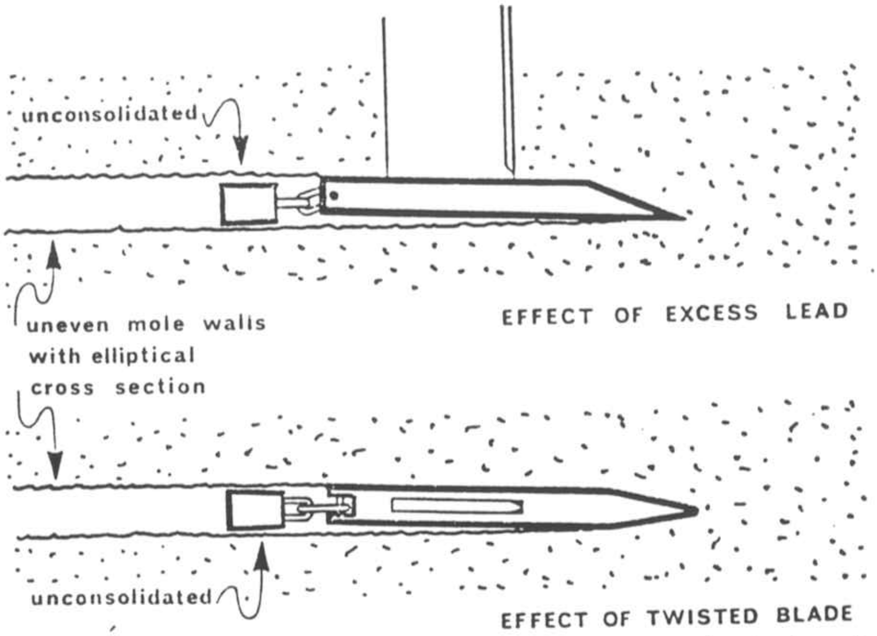


Figure 6: Effect of faulty setting of mole plough on formation of mole channel.

Implements

Mole drainage is a fairly simple operation with very little to go wrong when conditions are favourable. The basic requirements are that the machine be in good condition and well set up and that sufficient power and traction are available to provide an even pull.

The mole itself must be in good condition, truly aligned to run parallel to the surface and in line with the direction of travel. Insufficient 'bite' will cause the mole to ride out at hard sections while a mole pointed downwards will travel at an angle to the surface and will tear a ragged oval-sectioned channel which lacks stability. In the same way a bent blade causes the mole to crab also producing an oval, ragged channel. (Figure 6). Care is needed to ensure that a clean circular sectioned channel is being formed at the correct depth and this can be inspected only by exposing the soil profile.

Collector Drains

Some mole drainage systems are drawn directly from an open watercourse and plastic pipe inserts fitted to stabilise the outlet. However most schemes incorporate a well designed piped collector system. Generally the top of the collector pipe should be at least 15 cm below the bottom of the required mole channel. The drain trench must be filled with permeable material to at least 15 cm above the mole runs: collectors are normally 700 mm deep with permeable fill to within 350 mm from the surface and are constructed across the slope. Mole drains are then drawn across the collectors and discharge their water through the permeable fill into the pipe. (Figure 7)

The spacing between collectors is a function of the likely stability of the soil and is usually about 20-30 mts. A closer spacing may be required on very flat sites.

Where the slope is uneven, moling is still possible by siting collector drains to run through hollows and along lines of changes of slope. (Figure 8).

Gradient, Spacing and Depth

The mole channel must have an even gradient to its discharge point. For general work the minimum acceptable gradient is about 0.5 per cent since, on lesser slopes standing water will occur causing channel collapse. On the other hand excessive gradients encourage erosion of the channel which tends to cause silting up at the junction with the lateral. It is necessary to limit gradients to a maximum of 8 per cent. On steeper sites moles should be angled across the slope.

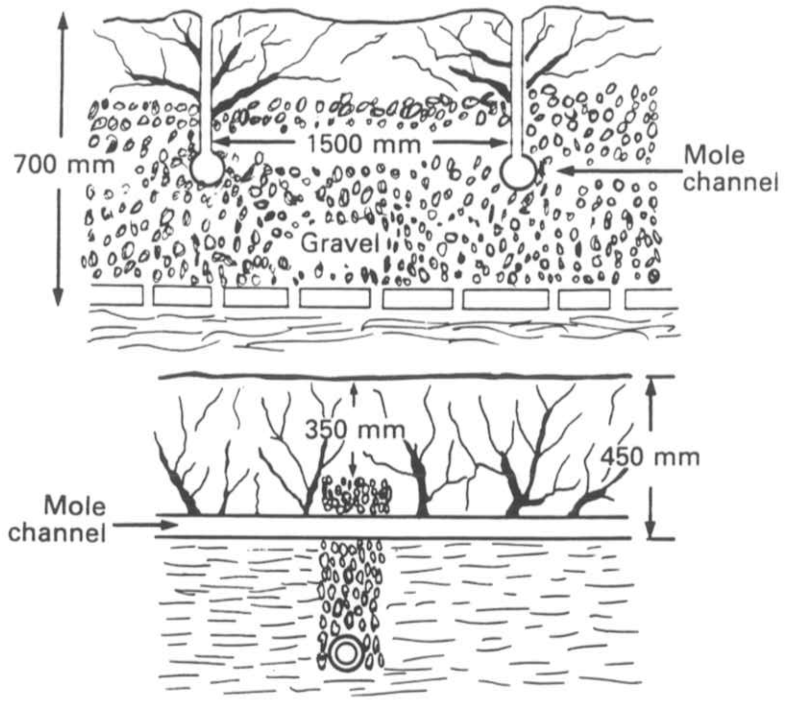


FIGURE 7: GRAVEL CONNECTS MOLE TO PIPED DRAIN COLLECTOR

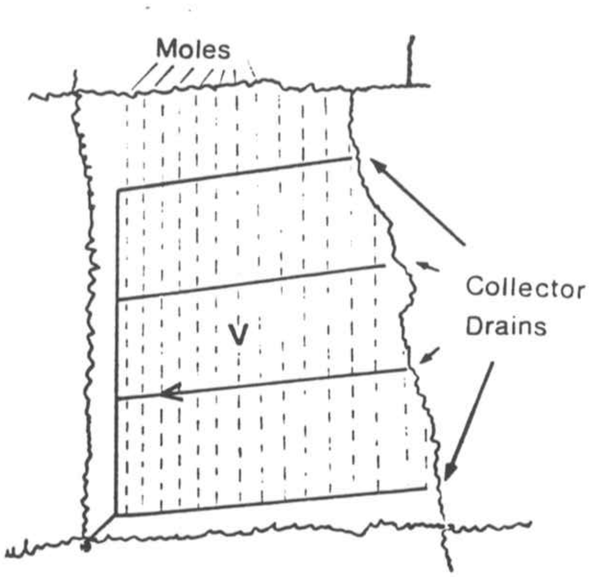


FIGURE 8: TYPICAL LAYOUT OF COLLECTORS

Intervals between mole channels depends on the soil type but in general they should be as close as possible, preferably at 1-1½ m intervals.

Channels should be drawn to a depth of 450-500 mm, however many clay subsoils in Ireland never really dry out and under such conditions moling at this depth often gives dissappointing results, due to failure to shatter the subsoil and to the closing of the slit above the mole. With new schemes on wet heavy clay soils it may be advantageous to carry out a first sacrificial moling at 300-350 mm to assist drying out, followed by a deeper moling at 450 mm in a subsequent year.

Effective Life of Mole Drains

Mole channels constructed in suitable soils under optimum moisture conditions can last for 5-10 years or even longer. However the normal life expectancy is in the region of 5 years. They should therefore be installed with the intention of remoling at certain time intervals in the future.

Mole Channel Failure Mechanisms

Six major types of failure have been identified to date, namely;

1. Cyclical swell/shrink failure
2. Expander failure
3. Subsoiler failure
4. Unconfined swelling failure
5. Slurry failure
6. Topsoil failure

1. Cyclical Swell/Shrink Failure

Repeated changes in moisture content in the soil surrounding a mole channel causes swelling and shrinkage which eventually weakens an initially stable channel roof area inducing roof collapse. Further falls of soil peds may occur and eventually block the channel. Risk of failure increases with increase in soil clay content and % smectitic clay. (figure 9)

2. Expander Failure

In this type of failure, the soil, in the channel roof area, disturbed by the expander at installation, collapses into the channel leaving an arch shaped roof section. This type of failure occurs as a result of a weak bond between the soil deformed by the expander and the 'undisturbed' soil on the other side of the failure plane. This bond tends to be weakest when the channel has been formed at relatively low moisture contents. (figure 10)

3. Unconfirmed Swelling Failure

With this type of failure the channel diameter decreases progressively without any significant change in shape, until it effectively disappears completely. The decrease in channel diameter occurs due to a steady swelling of the soil surrounding the channel into the channel area itself, a process termed unconfined swelling. (Figure 11) This type of failure usually occurs with weakly structured soils and in situations where there is rarely a moisture deficit at mole channel depth soil density in the closed channel increases outwardly. (Figure 12)

4. Subsoiler Failure

When the mole plough is working close to or above its critical depth, a complete wedge of soil is broken out to the surface from half way up the channel wall, with time this wedge settles, leaving the channel with either a flattened roof or with the upper channel section moving into the lower section. (Figure 13)

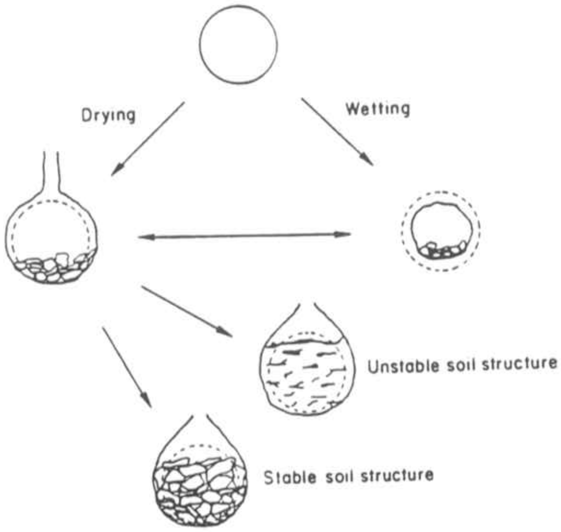
5. Slurry Failure

Slurry failure occurs mainly as a result of unstable structured soil moving into the channel and swelling excessively to form a slurry, which can block the channel completely. This situation is most likely to arise in the less stable structured soils when significant channel wetting and water flow occurs soon after channel formation.

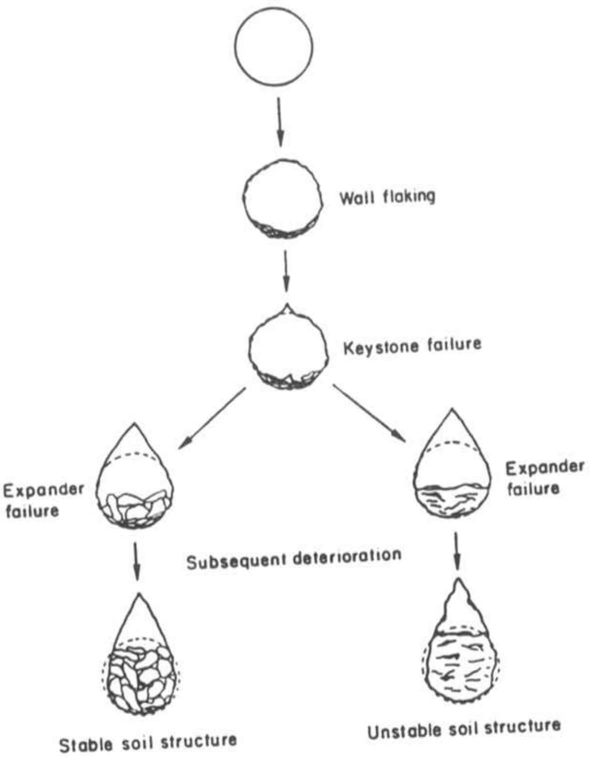
The problem can be reduced by moling at the beginning of a dry period, so that time is available for the soil to age and restabilise after disturbance, before it is wetted.

6. Topsoil Failure

Failure occurs in this situation as a direct result of topsoil falling into the channel through the leg slot and associated leg fissures formed by the mole plough. The rate of infill is frequently increased by surface cultivations when the cracks are wide. The situation can arise following installations under dry soil conditions when large leg fissures are formed or as a result of extensive soil drying and shrinkage to mole channel depth later.



CYCLICAL SWELL-SHRINK FAILURE



): EXPANDER FAILURE

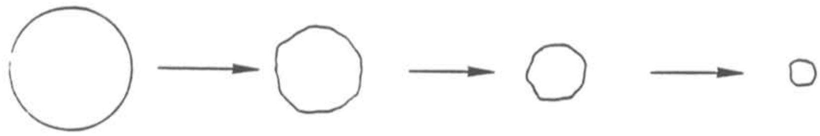


FIGURE 11: UNCONFINED SWELLING FAILURE

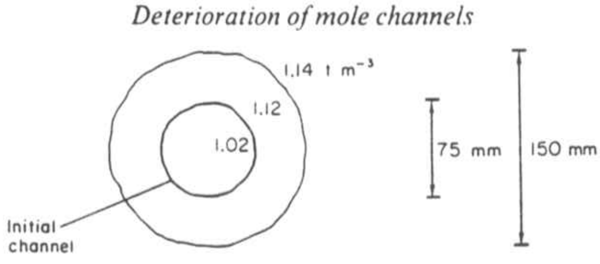


FIGURE 12: SOIL DENSITY AROUND CHANNEL

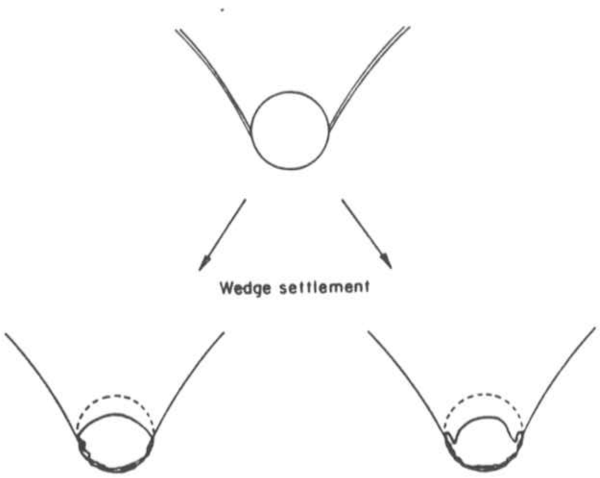


FIGURE 13: SUBSOILER FAILURE

GRAVEL TUNNEL DRAINAGE

To overcome the difficulties associated with mole collapse a system of installing mole channels filled with stone chippings was devised called the Gravel Tunnel System.

Generally the channels are 85 mm x 65 mm in section and are filled with either crushed stone or washed gravel graded 13 - 19 mm (see Figure 14). The purpose built machine consists of a 1 tonne capacity hopper with a 65 mm i.d chute mounted over a standard mole bullet. Because the width of the chute (tine width) is approximately three times greater than the standard mole drainage tine, the critical depth is increased somewhat . Furthermore, as there is no need to form a stable channel in the soil, the working depth can be above the critical depth thus giving complete crescent failure.

The installation of a gravel mole system is relatively expensive compared to normal mole drainage, subsoiling or ripping because of the cost of providing the extra on site machinery for loading, transporting and installing the gravel.

Spacing and Depth

At present gravel moles are usually installed at spacings of 1 to 1.5 mm. It may be possible to increase the spacing by the addition of winged tines or to shallow tine an area prior to installing the gravel moles. They are usually drawn down the greatest slope over collector drains which can be spaced from 20 - 60 m depending on the gradient. However due to the presence of numerous surface hollows, springlines, broken-down existing drains and small fields the average spacing of collectors would be about 35 m (see Figure 15).

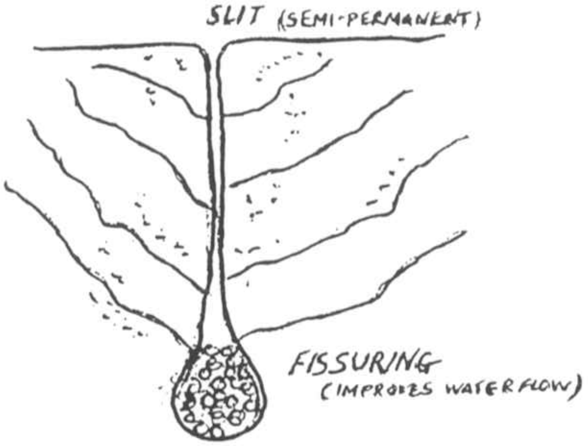


Figure 14: Cross section of gravel tunnel drain

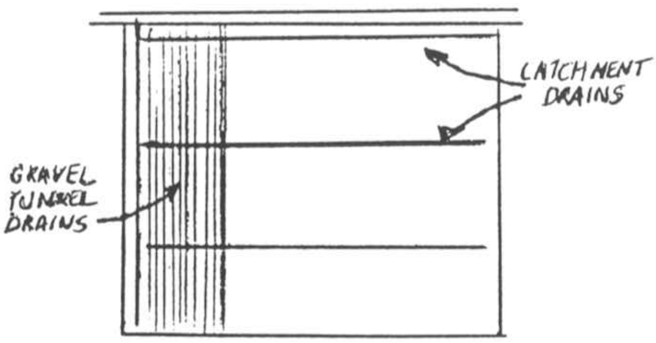


Figure 15: Field plan of drainage system

SUBSOILING

This is the act of loosening the sub-soil with a suitable shaped tine. The aim of sub-soiling is to improve the soil structure by creating a zone of fissuring and cracks, breaking up the compacted soil and so improve the drainage status of the profile and encourage better plant growth. It can be beneficial in 3 situations;

(a) Compaction pan
(b) Chemical pan
(c) Sub-soil with low permeability

Compaction Pans

In arable situations, in particular if field operations are carried out when soil conditions are wet rutting and compaction often occur.

Implements can also create a compaction pan, hence the alternative name 'plough pan' which arises from ploughing each year at the same depth. The base of the ploughshare and the wheel in the furrow smears and compresses the wet soil.

With grassland farming carrying out operations like slurry spreading and silage harvesting under unsuitable soil conditions can cause compaction. This problem can also occur in the top 300 mm of the soil profile with intensive grazing by heavy stock under wet conditions. For example horses exert 40 psi on the ground compared with 24 psi for cows and 9 psi for sheep, over their bearing areas. Under heavy grazing, an increase in soil density from 1.54 to 1.91 has been documented with accompanying reduction in macroporosity.

Drainage works can also cause serious compaction problems with the heavy machinery, permeable fill trailers and bulk lorries delivering materials to the site. The pressure exerted on soils varies with the type of machine used and might range between 3-9 psi for Track-Type Tractors. Track type tractors have been found to produce a 35% reduction in permeability, 2.4% soil density increase and 11% decrease in macroporosity.

Many earthmoving operations which were carried out in the past on relatively free draining land have given disappointing results. This is a result of failure to loosen and relieve compaction after such work is completed.

Loading from wheeled vehicles is greater, trucks exerting a pressure from 50-100 psi.

Compaction pans can build up over several years and will be found in most soils giving rise to perched watertables and top water drainage problems. Subsoiling can be used to disrupt the compaction pan but requires that the subsoil below the pan is of high permeability allowing natural drainage or that a suitable pipe drain system exists.

Chemical or Natural Pans

Over a period of hundreds of years the downward movement of clay particles and/or iron and humus in acid solution has created a layer of high clay content or an iron pan has developed. Many iron pan situations are found around the Carrickmore/Pomeroy area and in the uplands of the Sperrins. Such pans cause an impermeable layer giving rise to a perched water table situation. Sometimes this pan can be too difficult for normal subsoilers to distrupt, in which case a deep ripper may be more suitable.

Subsoils with Low Permeability

In the majority of clay soils in Northern Ireland the subsoil permeability decreases with depth, preventing the downward movement of water. In many areas where the subsoil is suitable for channel formation mole drainage is the most economic system to use. However, subsoiling can sometimes be useful where variable soil texture might cause rapid failure in mole channels and where gravel filled moles are considered too expensive.

In some cases of severe compaction in the upper subsoil more extensive loosening is required than can be achieved by a mole plough.

A combination of moling and subsoiling can be carried out with the subsoiling being undertaken after the moling at a shallower level than the mole drainage.

Inferior Moling

High rainfall combined with poor quality subsoils in this country leave the soil at subsoiling depth plastic in many cases.

Instead of shattering, a square channel is created. This square channel is less stable than a circular one and so we get inferior moling. With the exception of a very dry year and substantial soil moisture deficits the depths of effective subsoiling will be confined to the order of 20-30 cm.

Types of Sub-soiling

1. Conventional sub-soiler (Figure 16).
   This consists of a frame to which is attached a leg or blade and at the base of the blade there is a foot to which is attached a share. To give optimim heave the share should be set at an angle of 25 degrees. Provided the foot is not working below the critical depth the share will lift and loosen the soil forwards and upwards at an angle of 45 degrees from the tip.

2. Winged Sub-soiler:
   The extent of soil loosening at the working depth produced by the sub-soiler can be increased by 2-3 times with only a 15-20% increase in draught by fitting inclined blades or wings to the side of the foot. These wings should be set at the same angle as the share, about 25 degrees. (Figures 17 and 18).

Critical Depth

Research has shown that there is a maximum depth known as the 'critical' depth below which soil loosening does not take place but the soil is displaced sideways and a channel formed (Figure 19). This varies according to the soil type and moisture content and can vary from close to the surface in a wet soil, to a depth of 450 mm in drier soils. The critical depth can be increased by increasing the effective working width of the sub-soiler foot or by loosening the soil surface layers prior to sub-soiling. This can be achieved by fitting the sub-soiler with leading shallow working tines. These tines should be fitted ahead and to either side of the subsoiler foot as shown in Figure 20 . The result is a three-fold increase in the area of disturbed soil over that produced by a conventional sub-soiler.

Timing of Subsoiling

Ideally land should only be subsoiled when the subsoil is in a dry and

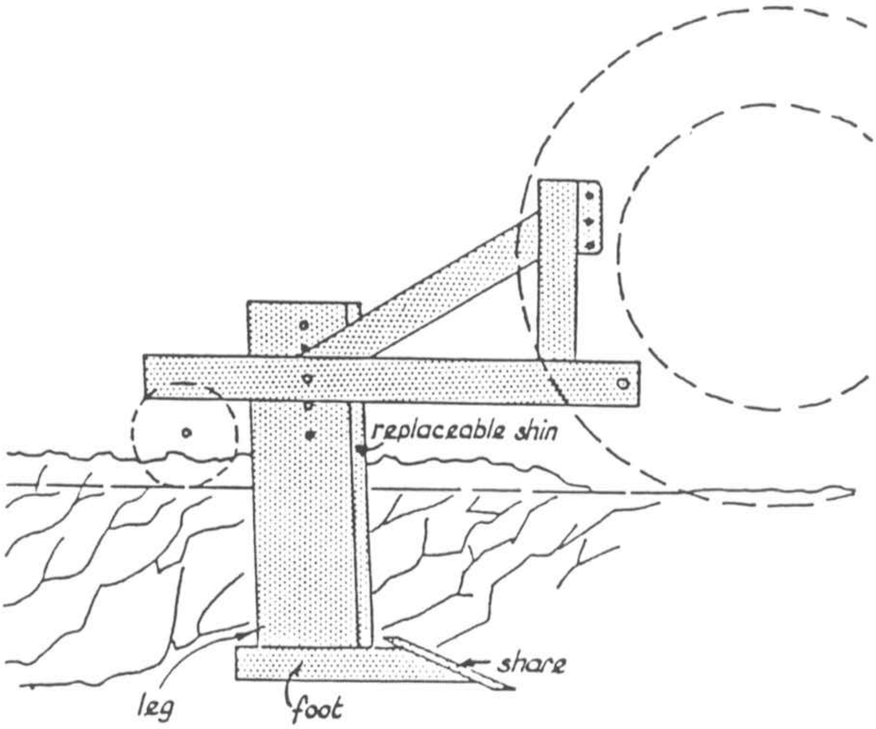


FIGURE 16: TYPICAL SUBSOILER

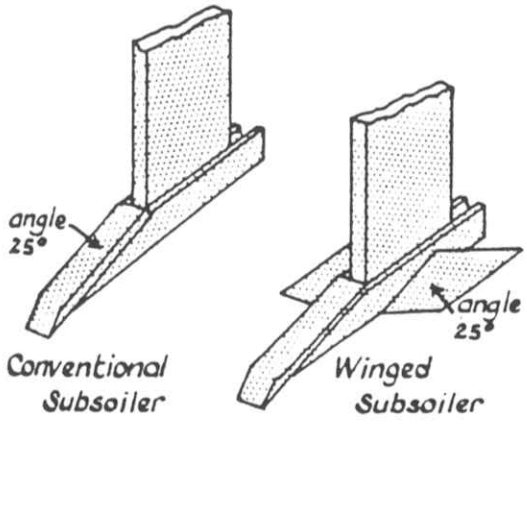


FIGURE 17: CONVENTIONAL AND WINGED FOOT

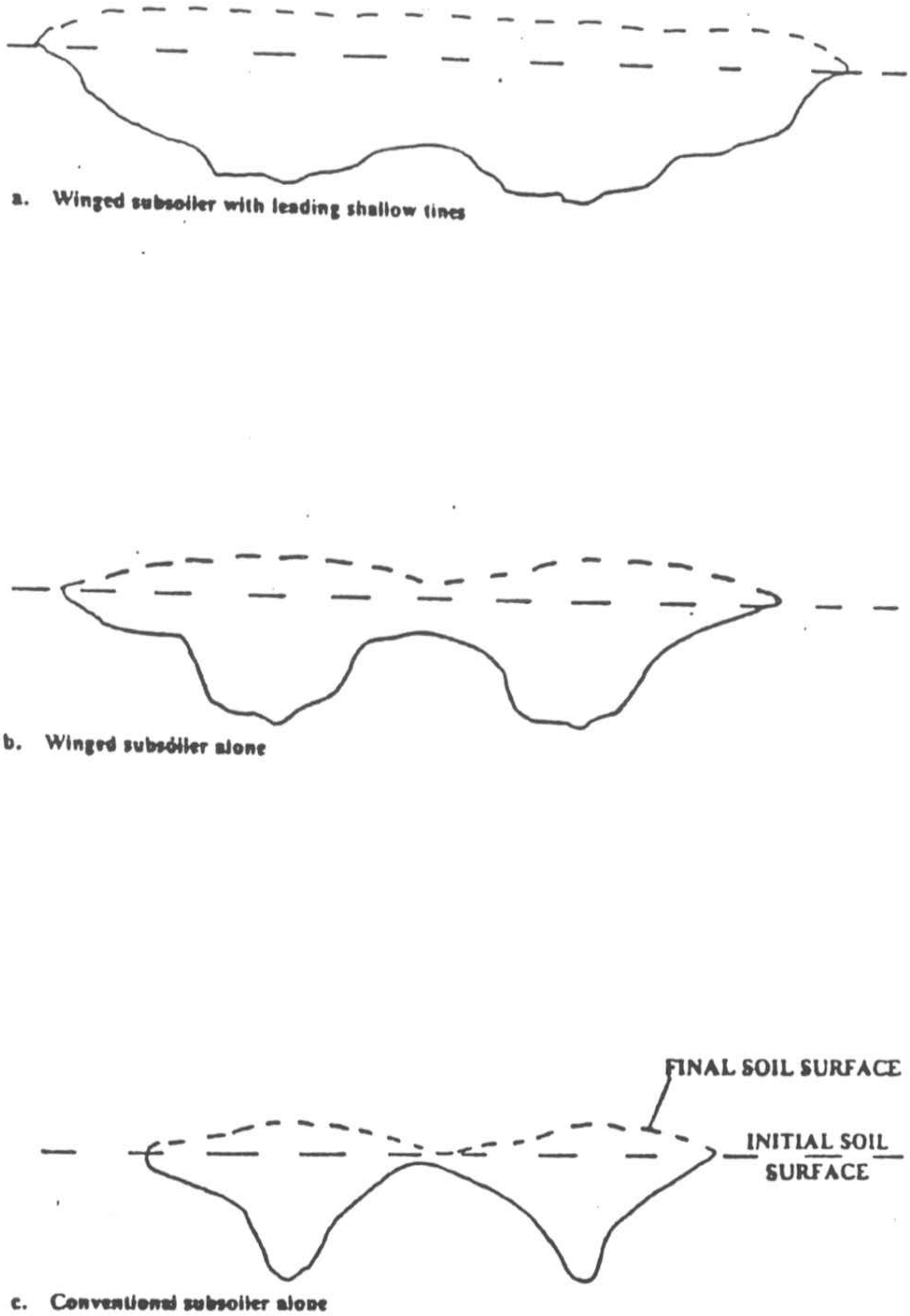
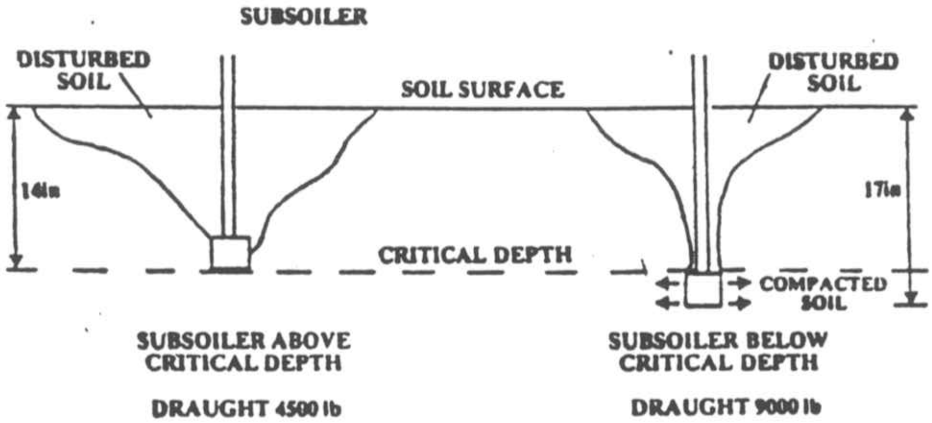


FIGURE 18: SOIL DISTURBANCE WITH DIFFERENT SUBSOILERS

FIGURE 19: **Cross-section showing soil disturbance caused by subsoilers working just above and just below the critical depth.**



Leading tines

Shallow tines, 200 mm deep, in front of the subsoiler blade lift and loosen the soil. This enables the main tines to disturb a greater volume of soil than had they been working alone, and reduces the overall draught requirements - see Figure 8.

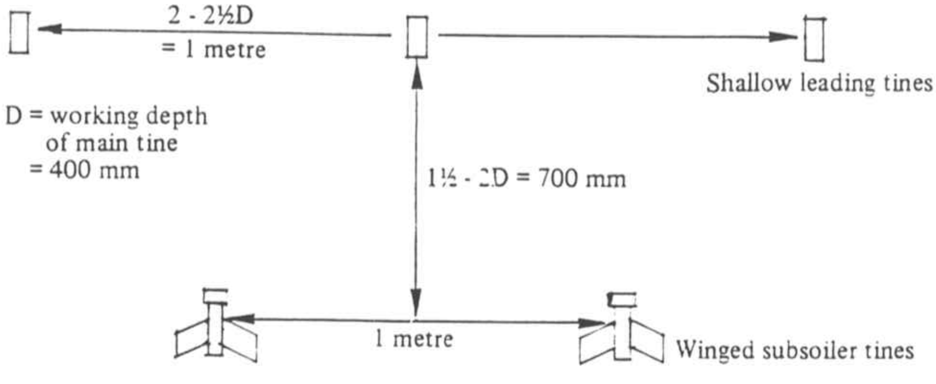


FIGURE 20: ARRANGEMENT OF LEADING TINES

friable condition and the ground surface firm enough for good traction. When it is too dry, draught is excessive and the soil tends to break into very large blocks. However this is rarely a problem here.

When dealing with pans, the depth at which subsoiling should be carried out is determined by the depth of the pan. The bottom of the foot should run just below the bottom of the pan and not deeper than 50 mm below if at all possible.

Spacing for Subsoiling

	Times Working Depth	Common Spacings within these limits
Conventional subsoiler alone	$1-1\frac{1}{2}$	600 mm
Winged subsoiler alone	$1\frac{1}{2}-2$	750 mm
Winged subsoiler with leading tines.	$2-2\frac{1}{4}$	1000 mm

SOIL LOOSENING TECHNIQUES

In grassland situations where generally the compaction from poaching and traffic is quite shallow loosening can be carried out by either (a) the paraplough or (b) the shakerator. Unlike the subsoiler these machines give best results at shallow depth, not usually exceeding 35 cms.

The idea of soil loosening is to break up all the soil below the surface without inverting it.

Paraplough

The Howard Paraplow was developed from the original concept of the slant-leg subsoiler. The action of the Paraplow is to lift and bend the soil so that it breaks along its natural lines of weakness, and thereby leaves the blocks in a more stable condition to take subsequent traffic than if they had been cut and crushed.

Shakerator

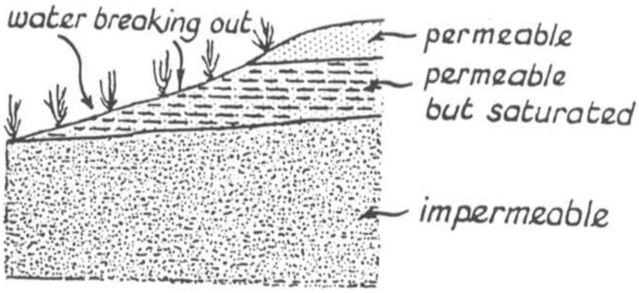
The McConnell shakerator is made up of two rows of tines on a tool frame. With the aid of an hydraulically driven motor the tines oscillate to provide a shaking cutting action which is transmitted to the deep fissuring toes of the implement.

SEEPAGE PROBLEMS

Springline seepages are easily recognised as rush lines along the toes of hills. They are dominant in some areas of the drumlin belt. Sometimes in drumlins of intermediate composition the upper layer of soil may be permeable permitting lateral seepage down the hillside. Due to reduction of gradients near the toe of the hill and/or reductions in thickness of the flow layer, water often bursts out giving rise to seepage problems.

The most common situation of springline seepage is to be found at the point where a porous subsoil meets an underlying one of an impervious nature. Water moves down through the permeable strata until it is impeded by the impermeable layer. It then moves along the top of this layer and issues out on the surface. (See Figure 1)

FIGURE 1: SPRINGLINE SEEPAGE



This formation can occur several times on one hillside and at each line where the porous soil meets the non-porous, water will have to take the overland route until it reaches the next porous belt. (See Figure 2).

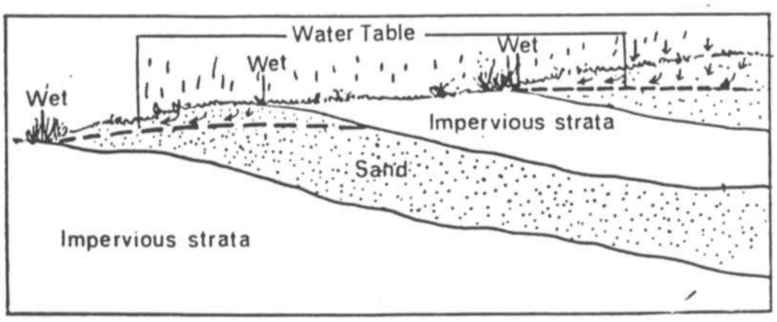


FIGURE 2: LAYERED STRATA AND WATER TABLE

In some cases the impervious layer may be of rock but the effect is the same only the cure is more difficult. The more important spring lines in the country become aggressively apparent in February or March in most years and particularly after wet winters.

Treatments of Spring Lines

The usual practice in solving a springline problem is to keep the water entirely underground, at a depth where it cannot affect surface growth. This is done by the construction of an interceptor ditch or pipe drain meticulously placed in the correct position and at the correct depth. Where the junction between the differing soils is clearly defined a single drain may be sufficent. However, the junction is often irregular and more than one drain may be required to deal with the problem.

The depth of the drains will depend very much on the particular situation but if possible the base should be laid in the impermeable layer so that no water can continue to run under them. (Figure 3). Drains should be constructed across the slope and may in some cases have to be as deep as 3 m to be successful. In many cases running sand may be encountered and consequently this work should only be carried out in the summer months when the water table is at its lowest.

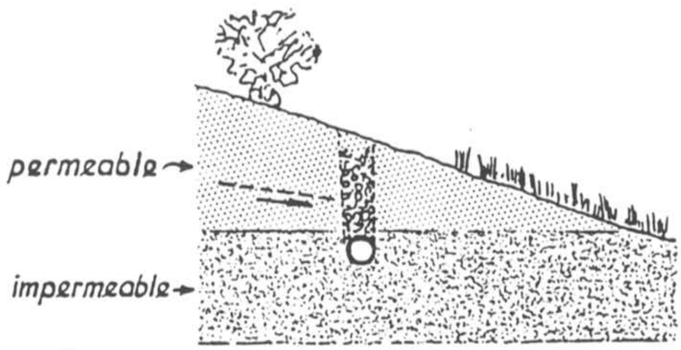


Figure 3. Springline interception.

Artesian Seepage

Localised springs can occur in undulating land where permeable strata are overlain by impermeable strata. When the gound water in the permeable strata is under pressure it often forces its way through points of weakness in the overlying soil to the surface. (Figure 4).

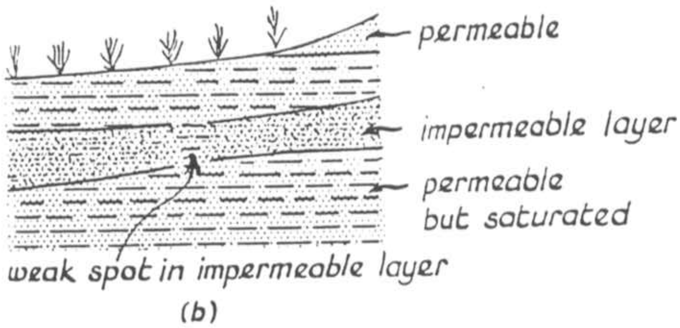


Figure 4**:** Spring problems – (a) outcrop between two strata (b) weakness in impermeable layer.

This creates an artesian spring with the water rising to the surface under a hydraulic head.

Artesian problems are often associated with gravel and sand moraines deposited during the Ice Age. These outwash deposits can be found on a large scale often underlying boulder clay in valleys 1,000 m or more wide. These deposits are fed by water from high ground and where they become discontinuous and merge into boulder clay plains artesian seepage occurs. (Figure 5).

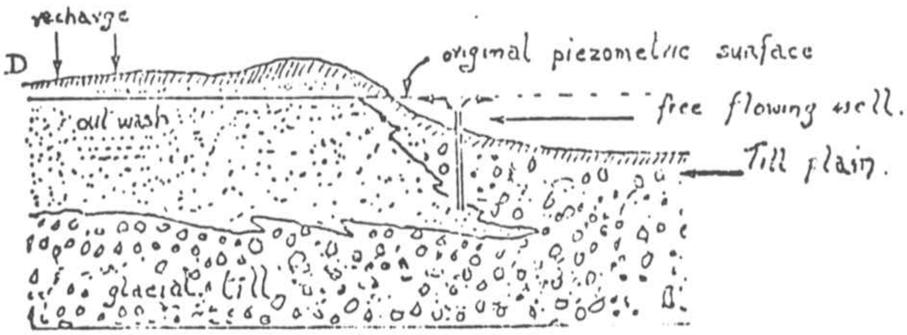


FIGURE 5: GROUNDWATER CONDITIONS IN GLACIAL LANDFORMS

Artesian seepage is also associated with mountains comprising of permeable rocks such as sand stones, shales and limestones. Here artesian water breaks through cracks in the valley floors. The strength of springs depends on the extent of high ground in the vicinity that receives and retains rainfall and forms large reservoirs. Thus bog-springs or those that rise in valleys are much stronger and have a more regular discharge than those which break out on higher ground or on the sides of hills. Artesian seepage is usually easily recognised. Plants like flaggers (Iris sp) and water cress which require mineral rich water are evident. Areas where the soil is practically floating or dangerous to walk on is diagnostic. This is usually found where there is high ground close by and water pressures are high.

Most valleys affected by artesian pressure are peaty and where blanket bog has developed seepage areas grow jointed rush instead of the normal bog vegetation. Some artesian waters are extremely rich in iron oxides and this gives a precipitate of iron ochre on exposure to air.

Treatment of Artesian Seepage

Conventional drainage is not successful in drying out artesian seepage problems. Deep drains intersecting cracks connected to the aquifer (water bearing layer) or intercepting the aquifer itself are required. The procedure adopted is to lay a drain to the point where the spring issues. Here a hole is usually dug in the spring area and filled with permeable material. This acts as a collecting sump and helps reduce the pressure of the rising water. Water is lead away from this area in the drain whose diameter will be relative to the strength of the spring.

FARM DITCHES

Ditches are open watercourses bordering or surrounding individual fields. They are the most fundamental part of field drainage. In the main ditches are of 2 kinds, natural and artificial. Natural ditches in the form of rivers and streams have existed long before land was enclosed and they can be recognised by their irregular courses. Artificially cut ditches on the other hand often run in straight lines. It is frequently found, especially when they lie across the slope of the ground, that their position coincides with a change in soil type.

Ditches may have one or more of the following functions:

(1) Surface Water Interceptor

Generally an open ditch is the simplest way of intercepting surface run-off which would inevitably build up and cause flooding or possibly erosion on arable ground. They are usually constructed running across sloping ground and are cut with a vertical ditch axis, thus avoiding too steep a batter on the higher side and reducing the likelihood of slips. (See Figure 1).

The class of land will determine the incidence and importance of ditches. High-lying and free-draining land is characterised by a marked absence of them.

(2) Underground Flow Interceptor

A ditch is usually preferred to an underdrain when it has the dual function of intercepting both surface and underground water.

Many ditches were originally excavated on the line of a change of soil structure. A ditch between a light soil on the upper side and a clay soil on the lower side will obviously draw water from the lighter soil, that without the ditch, would rise to the surface and flow over the clay. (See Figure 2).

A ditch may even act as a collector of water from small springs rising in its bed. This may explain the winding and devious routes sometimes taken by ditches.

(3) Water-Table Controller

In many low-lying areas with poor gradients for pipe drains, ditches at regular spacings can lower the water-table. In reclamation situations on waterlogged sites a temporary system of closely spaced ditches may be used to de-water the site sufficiently to allow the installation of a permanent underdrainage system. (See Figure 3).

(4) Carrier Ditches

Carrier ditches collect large quantities of water collected from other ditches, springs and underdrainage systems and lead it away to a larger watercourse. The cost of providing pipes of adequate size for these ditches is usually prohibitive. (See Figure 4).

(5) Outfall for Underdrainage

In certain low-lying areas with an iron ochre problem open main drains are recommended. This allows individual lateral drains to be rodded and cleaned if ochre build up occurs. This would not be possible in a complete piped system.

(6) Storage Channel

In tidal areas or low-lying areas adjacent to sluices or pumping stations, ditches may also act as reservoirs. Their purpose is to store water during periods when the tide is high or when the sluices or pumps are not operating.

(7) Water Supply

Stock are often watered from ditches where mains water supply is not easily accessible. However it can be difficult to keep the water clean and it is advisable that proper drinking bays be constructed to avoid accidental drownings.

(8) Wet Fences

In many low areas water is retained in ditches to prevent stock moving from one field to another. This avoids the need for fencing but can conflict with the drainage needs of the land. Stock often become trapped in ditches and die.

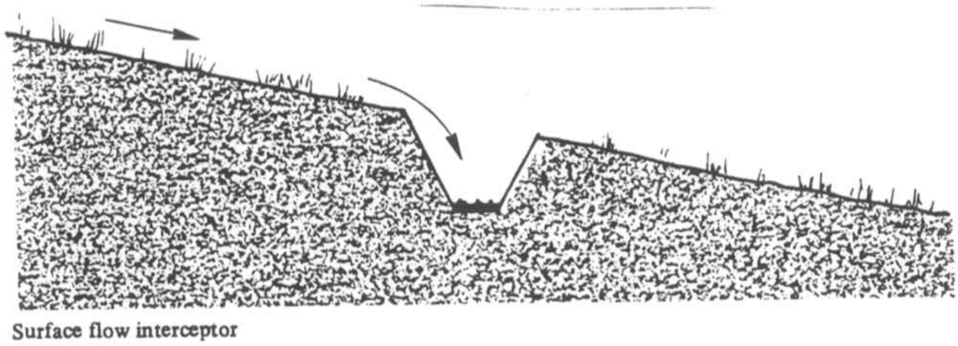


FIGURE 1: DITCH AS SURFACE FLOW INTERCEPTOR

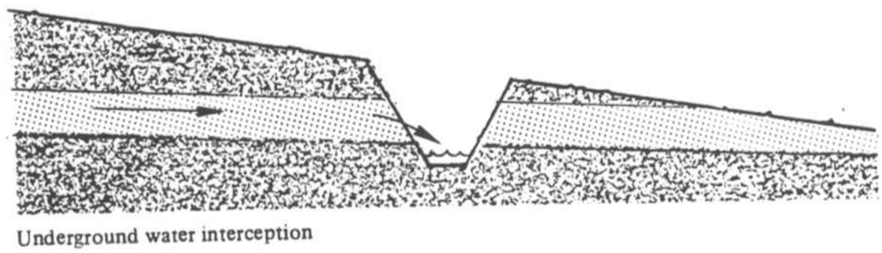


FIGURE 2: DITCH AS UNDERGROUND WATER INTERCEPTOR

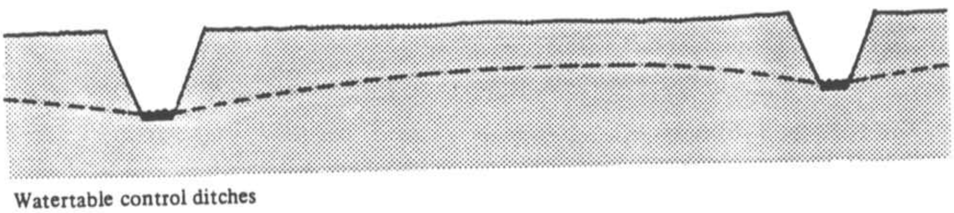


FIGURE 3: WATERTABLE CONTROL DITCHES

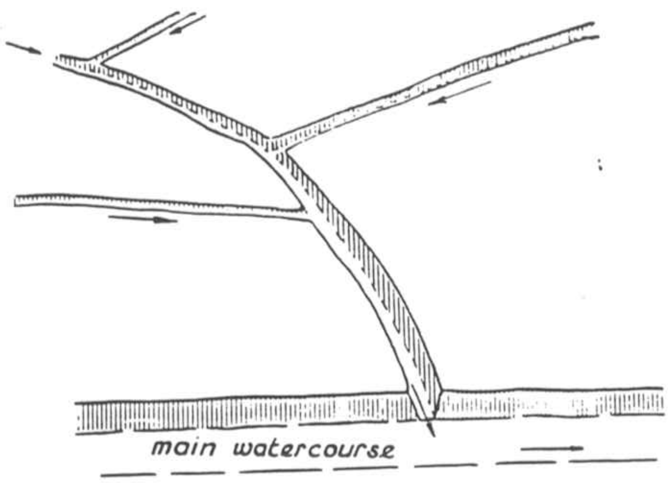


FIGURE 4: CARRIER DITCH

This system is used in certain parts of England where vast areas of flat land are flooded all winter but can be grazed in the summer months. Any fencing constructed here would be destroyed by the floods.

PIPING OF DITCHES

The general tendency today is to pipe ditches and remove the need for maintenance but in many cases this piping may not be justified except where the fields are small and the ditch only serves a very small area of land.

When deciding to eliminate ditches a number of factors should be considered including the size and shape of the fields, the desirability of preserving the natural beauty and amenities of the area and the historical importance of field boundaries.

Eliminating ditches to form larger areas often means eliminating associated hedges. The value of hedges as shelter for livestock and crops and as a wild-life habitat should not be underestimated.

Why Pipe?

There are several reasons why a decision is made to pipe a ditch:

(1) Reduction if maintenance costs

Constant maintenance of both ditch and back-fence if applicable can prove expensive and time consuming. Often where protective stock fencing is erected it can be difficult to carry out ditch cleaning operations over it.

(2) Increase in productive land

Ditches accompanied by hedges or back-fences often take up a considerable area of ground which if eliminated could provide a useful extension of the cropping area. Small irregular shaped fields can often be run together to give more economical working by modern machinery.

(3) Unstable soil

In situations where the banks are unstable and prone to slipping eg running sand or alluvial blue clay, the maintenance of a satisfactory open channel becomes very difficult. In such cases piping may be the only satisfactory solution.

(4) Safety

Deep ditches, close to roads or buildings, can be a potential danger to people, stock, machines, vehicles and buildings.

Ditches which should not be piped

(1) Surface run-off interceptors

If these ditches are collecting water from a large area it may be advisable to leave them open.

(2) Major carriers

These ditches usually carry large quantities of water and are very expensive to pipe. They should be avoided unless for certain stretches which have unstable banks.

(3) Storage Ditches

These provide temporary capacity and their storage capacity would be reduced if piped.

(4) Boundary Ditches

Which mark an estate, farm at parish boundary should remain open unless there is a very good reason to pipe them.

New Ditches

Where possible sharp changes in gradient should be avoided when constructing new ditches. Change in gradients influences the velocity of flow. Erosion can occur in steep gradients and deposition where gradients are reduced.

Care should be taken to ensure that side slope or batter is adequate to prevent slippage. Clay soils are relatively stable and can support ditches with a steeper batter compared to the more unstable sandy soils. (See Table 1).

TABLE 1: *Channel side slopes. Horizontal: Vertical*

Soil	*Channel less than 1.3m deep*	*Channel greater than 1.3m deep*	*Velocity m/sec*
Fen peat	Vertical	½:1	0.3
Heavy clay	½:1	1 :1	1.5
Clay or silt loam	1 :1	1½:1	1.0
Sandy loam	1½:1	2 :1	0.75
Sand	2 :1	3 :1	0.75

Excavated material should not be piled too close to the ditch or the weight may give rise to bank collapse. Leaving the spoil to dry before spreading is the normal custom. Spoil heaped in a continuous ridge can trap surface water and cause flooding so tracks should be cut through the ridge. When spoil is spread care should be taken to ensure that there is adequate gradient to the ditch for overland flow.

Precautions when piping

There are several points which should be remembered when replacing a ditch with a pipe:

(a) Where the ditch bed is soft and unstable, it may be necessary to incorporate a layer of hardcore material or some type of geotextile fabric reinforcement. Some farmers lay the pipe in undisturbed ground to one side of the ditch. There can however be an element of risk in this if there exists old stone or sod drains discharging into the ditch.

(b) When piping ditches alongside hedges, particularly if they are shallow, there is the danger of roots entering the pipes and causing blockages. There are many cases where popular tree roots have blocked drains. Cases involving willow, alder and ash have also been reported. More problems occur when piping through a hedge into a ditch eg with field drains, than actually piping the ditch itself.

(c) Pipe size must be adequate and allowance should be made for possible additional run-off. This applies particularly to pipes leading from farmyards where additional buildings may be constructed in the future.

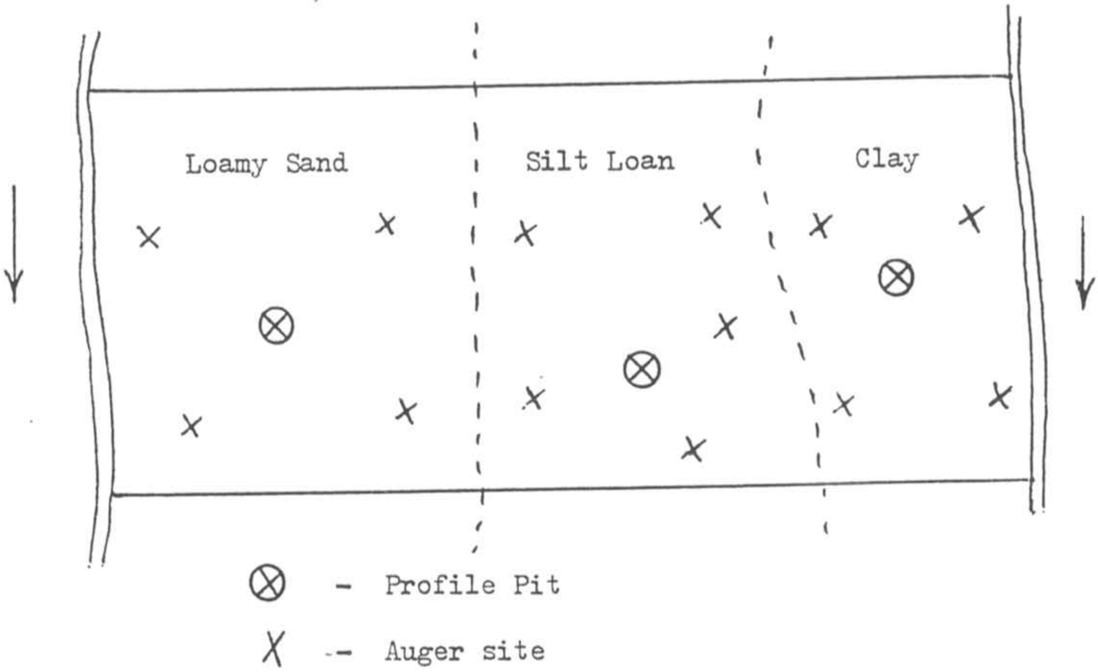
(d) Care must be taken to ensure that all existing drain outfalls are catered for. Rather than have too many connections into the piped ditch itself, separate main drains leading to one or two connection points might be more suitable.

(e) Where water is being diverted or where the ditch no longer has any useful function it should not be just filled in without some form of drainage. Even a small diameter plastic pipe or layer of permeable material will prevent an area of wetness developing along the line of the old ditch.

Sampling Methods

To get an indication of the soil type in a field a number of samples down to 0.9 metres should be taken by auger from several points in the field. If these reveal that the soil type is uniform then a sample pit should be dug in the middle of the field. If the auger survey reveals that there are 2 or more soil types in the field a sample pit should be dug in the middle of each soil type as seen in Figure 1.

FIGURE 1



Getting the Evidence from a Profile Pit

A garden spade can be used to dig the profile pit. Where a number of pits are necessary the farmer should be asked to have these dug in advance of your visit.

The rules for the profile pit are few:-

1. Size, 2 spades width and as long as is necessary to get the depth, working down in steps with about 0.23 metre risers and treads (see figure 2).
2. Keep the pit sides vertical.
3. Keep the profile rough and free from spade marks.

Two things are wanted from each pit, a complete soil profile displayed at one end so that the horizons may be identified and described, and samples of soil from each horizon carefully taken without deformation by cutting them from the "steps" in the pit as digging proceeds.

The depth of the pit depends on the probable depth of under-drainage bearing in mind that digging beyond 0.9 metres rarely justifies the time and effort involved when augering may more easily confirm that there is little further significant change in the lowest horizons.

In describing the horizons it is usual to ignore ploughed soil because its permeability can be so easily altered by weather and good and bad management. Texture is assessed for each horizon, and structure by digging out a soil sample (a step) and turning it gently onto the ground and in the case of cohesive soils, pulling it apart. The accurate description of the crack development is very important because water movements in medium to heavy soils depend on the number, width and arrangement of the cracks between peds, hence it is necessary to determine the shape and size of the peds and the ease with which they separate in order to assess the relative permeability of the horizons.

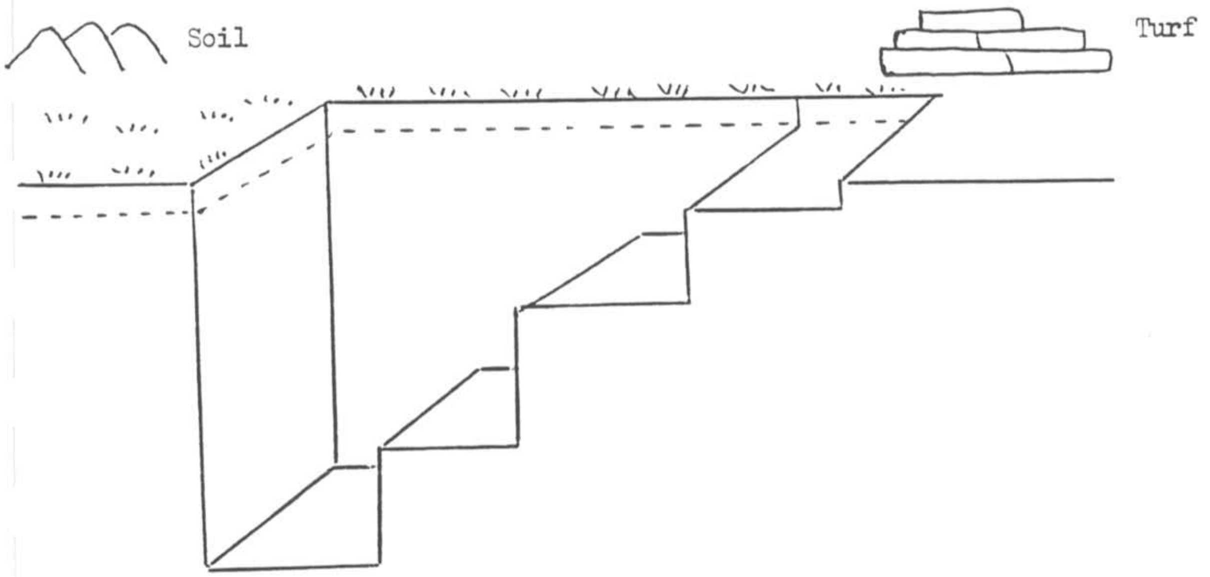


FIGURE 2: Typical Profile Pit

Information from Profile Pit Examination

The main features assessed from a profile pit are soil colour, texture and structure. These should be carefully recorded along with observations of stoniness, consistence, acidity, organic matter levels, depth of rust penetration and indications of worm activity.

Soil Colour

Soil colour at various depths will give useful information on the drainage status of the soil, as a rule uniform brown or brownish shades throughout the depth of the profile suggests that there is no drainage problem. Waterlogging induces anaerobic conditions and the intensity of colour patterns indicate the frequency and severity of oxygen deprivation. Grey colours in the soil increase with increasing wetness. Dark grey, blue or blackish tones indicate waterlogging and such horizons are described as "gleyed". Mottling, a mixture of gleying and oxidised colour patterns, indicates fluctuations in the water regime.

A degree of expertise is required to interpret colours as in some soils there is no change in soil colour whether drained or undrained. Other factors have also to be considered:-

1. Rusty coloured mottles may persist in the soil for many years after drainage has been improved.
2. Slight mottling may also be caused in the profile by an occasional very wet winter.
3. Under permanent grassland rusty mottles can be seen within a few cm of the surface; these are usually an indication of the high demand for oxygen in the topsoil rather than of waterlogged soils.

Soil Texture

Soil Texture in the different layers down the profile can be assessed by rubbing a small moist ball of soil between fingers and thumb.

Soil Structure

A visual examination of the shape size and development of structure can give an indication of the hydraulic conductivity of the soil. In heavy soils, air, water and rust entry into the soil is governed by the degree of fissuring. Where prismatic structures dominate it is necessary to examine the top of the peds to see if the fissures are continuous with the topsoil and not sealed off by compact soil. In most heavy soils coarse prismatic structure is an indication of the likelihood of slow permeability in the winter also where the structure is medium or coarse angular blocky, and the units fit tightly together the permeability is likely to be very slow.

The profile should be carefully examined for compacted layers eg plough pans, chemical pans and compaction due to trafficing by machinery and livestock, sometimes a platy or massive structure is visible. Colour changes can also accompany soil compaction and dark grey anaerobic pockets may be found within the compressed soil. The soil can be relatively moist below a hard pan and very dry in and above it, due to the inability of crop roots to penetrate and extract the moisture reserves blow. The absence of pores, fissures or earthworm holes is common with pans.

Root Development

Well developed deep roots indicate good drainage, whereas on poorly drained soils the rooting system will be weak and shallow. Where severe panning has occurred a web of roots may be seen on the upper surface of the pan with few penetrating.

Free Water

The presence of water in the subsoil indicates the presence of the water table either 'perched' on an impervious layer or the local ground water table. It is common to find a fluctuating water table with levels closer to the surface in winter and a much deeper level in summer.

The zone of mottling and iron/manganese concretions usually indicates the normal range of fluctuation. In the case of a pan, water can often accumulate above this layer and begin to flow down the side of the profile pit from this point.

The rate at which water enters a profile pit indicates the permeability of the soil. Pits dug in alluvial and some organic soils will fill up very quickly while in heavy clay soil it may take days to reach equilibrium. If one encounters a seepage flow or acquifer the pit may fill up within minutes.

Stones

Stones can be readily identified visually and the number assessed semi-quantitatively; in situations where they interlock to form a distinct layer, the soil between the stones should be carefully examined and its density and porosity assessed. In some cases where a layer of gravel lies near to the top of a fluctuating water table it becomes cemented with concretions of manganese or manganese/iron oxides. This in addition to restricting drainage may give rise to shallow rooting.

In stony soils the depth at which the stones are encountered and their size should be noted. Their presence could put constraints on the choice of drainage techniques, particularly the feasibility of moling and subsoiling operations, also the presence of solid rock near the surface may severely restrict drainage work.

DRAINAGE PACKAGE

Pre-Visit Preparation

In addition to the normal farm map showing field numbers it is important to have a 1 : 2500 map for illustrating detailed under drainage layouts. There may also be useful additional information on this map ie springs, wells, marshy areas.

A solid geology map or drift map if available will reveal rock type underlying site and indicate what the soil originated from. Soil survey maps when produced will be a great asset to field drainage design. A knowledge of the typical drainage problems of an area and their past solutions is also helpful.

On work in large catchments where channel gradient may be required a 1 : 10,000 Map (6" to mile) will show contours at 5 m intervals.

Site Visit

Plans or the owners knowledge of past drainage schemes will often aid site investigation and provide clues to the present problems.

Before walking the site it is important to determine if this is the most appropriate area of the farm to drain. In many cases land owners overlook areas where they wou get a better return on their investment. From a management point of view it is usually better to drain ground nearest the farm first and work outwards.

Surface Indicators

When taking a preliminary walk over the site indications of poor drainage and its effects should be noted ie

(1) Surface ponding

(2) Boggy conditions

(3) Water emerging at surface

(4) Presence of waterloving vegetation - rush, horse tail, silver weed, sedge

(5) High water level in ditches

(6) Signs of poor drainage such as cattle poaching, excessive rutting by farm machinery

(7) Areas of crop damage with either partial or total loss.

The boundaries and the area of problem land should be considered; also whether the drainage problem applies more or less uniformly to the whole area, to seperate sections of it or to isolated patches only.

Drainage Feasibility

Assess drainage feasibility by considering:

1. The gradients of the site and variation of the gradients - hydraulic gradients for low water flow, from the outlet through the system of mains and laterals to the uppermost subsurface drain in the project, should be determined to ensure that all needed drains can be discharged above it.

2. The outfall points of any existing drainage system.

3. The condition, position etc of any outflow channels (ditches, streams etc) - can the outflow channels be improved.

4. Flood hazard - frequency and height of flooding.

If the scheme appears feasible at this stage further detailed investigations of the soil profile will be required.

Profile Pit

A number of pits are excavated over the site to get an overall picture of the soil or variations of the soil. Soil colour, texture, structure, organic matter content, stoniness and water table level are the main features assessed from the pits.

Often at this point, when the soil texture is examined, the cost-benefit aspect of the project may have to be considered seriously. If a structureless sticky clay of lacustrine origin with little topsoil covering is present, the value of a drainage scheme is highly questionable.

Also if one encounters organic soils with poor drainage properties it may be wise to discourage any investment in drainage works.

If there is evidence of existing drainage schemes then inspection pits should be dug to examine these. In certain cases the rodding of an old system or the replacement of broken or misplaced pipes can solve the major parts of the problem.

Effects of Topography

When it has been established that a new drainage scheme is necessary and feasible. consider :

(a) The position of the site in relation to the surrounding countryside - ie flood plain or steep slope - water spreading or water gathering effects.

(b) Nature of any land forms present - solid rock near the surface.

(c) The direction of travel of soil water ie surface run-off or sub-surface lateral flow and the gradient causing it.

Physical obstructions :

electricity poles and pylons, low overhead wires, trees, underground services like water or sewage lines should all be noted.

Outfall

Every drainage scheme is only as good as its outfall. If freeboard is limiting, and or the proposed outfall looks doubtful then a walk downstream will determine the extent of further works or the existence of a shallow culvert or piped section. In many cases rock or unstable blue clay or running sand have restricted the depth of open-channels. If certain stretches of the channel need culverting check existing culverts both upstream and downstream of the location of refer to design charts for suitable pipe size.

Main and Lateral Drains

Main drains should be located in lines of old open channels or depressions. They should be constructed up the greatest slope where applicable. The position of the outlet joining the main watercourse is very important. Avoid location in unstable banks, on corners where sediment accumulates and never face outlet pipe against the direction of main channel currents.

Area of land and slope will determine size of main drain required. Exceptions to this will be in cases where the site is flat and freeboard limiting. Here large diameter pipes can be used as they can be laid with a smaller gradient.

If piping from farmyards allow for additional pipe capacity to accommodate possible future developments:
Lateral length, spacing and depth will depend on soil type, slope and shape of site. On very flat sites lateral lengths will be short, not usually exceeding 50-70 mts.

Secondary Treatments

Where secondary treatment is being recommended the type, spacing and depth should be specified and the direction indicated on a map. When carrying out the site survey a fairly comprehensive field record should be made in a note book, as relying on memory can often prove fatal. Figures 1 and 2 show the type of detail required and the symbols that can be used.

After all the necessary information has been accumulated a detailed drainage scheme should be drawn on to a 1 : 2500 map. This should be self explanatory to the farmer or drainage contractor.

A specification is also necessary detailing drain lengths, dimension and depths and information on any secondary treatments if applicable.

Finally a report should be enclosed covering the findings of the site investigation diagnosing the drainage problem and suggesting a solution or choice of solutions and their possible costs.

(refer to standards set out in "Technical Note on Workmanship and Materials for Field Drainage Schemes).

Recommended Colour Coding

75 mm pipe	-	Red
100 mm pipe	-	Green
150 mm pipe	-	Blue
225 mm pipe	-	yellow
300 mm pipe	-	Black (with diameter written alongside)

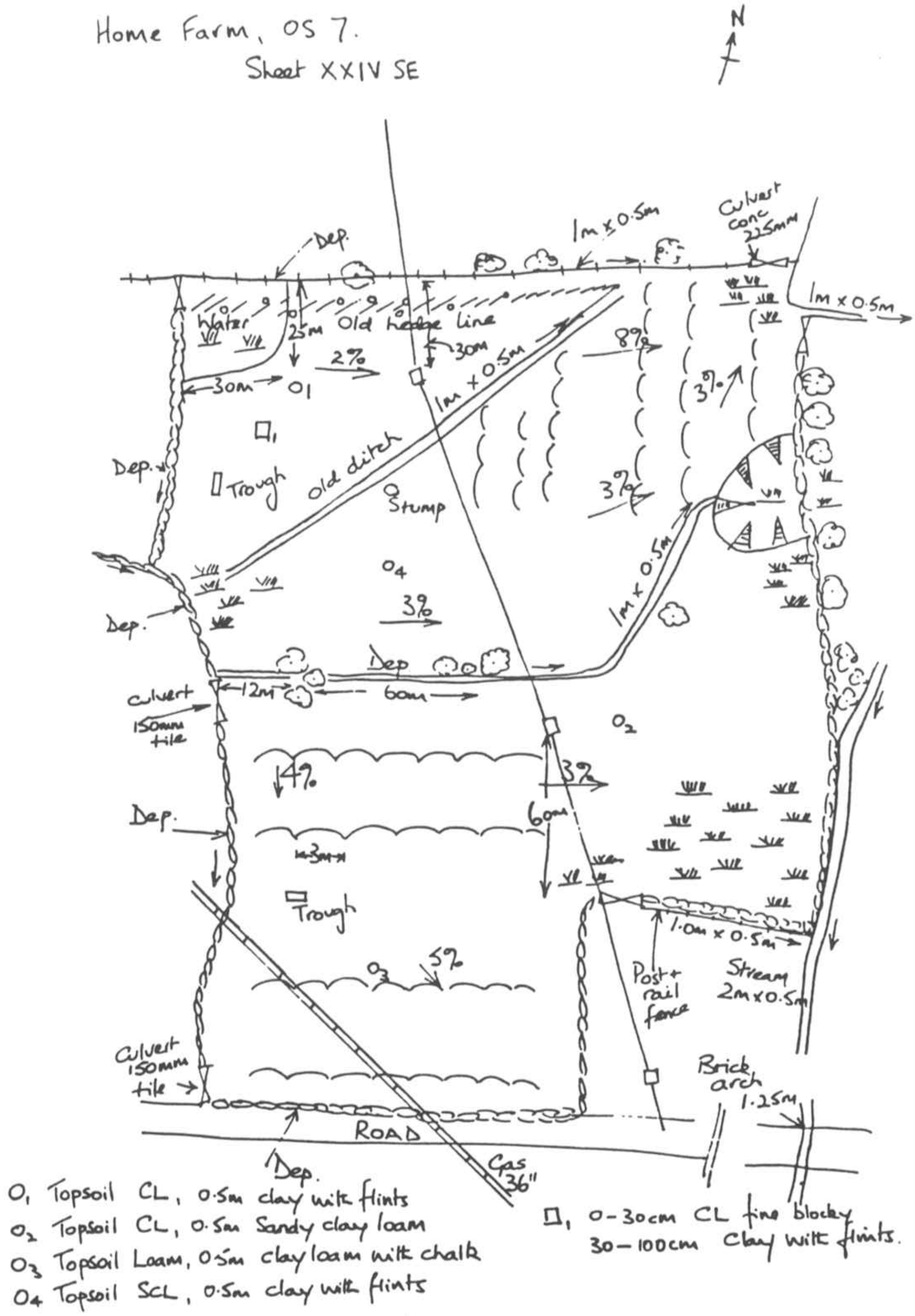


FIGURE 1: TYPICAL FIELD SKETCH

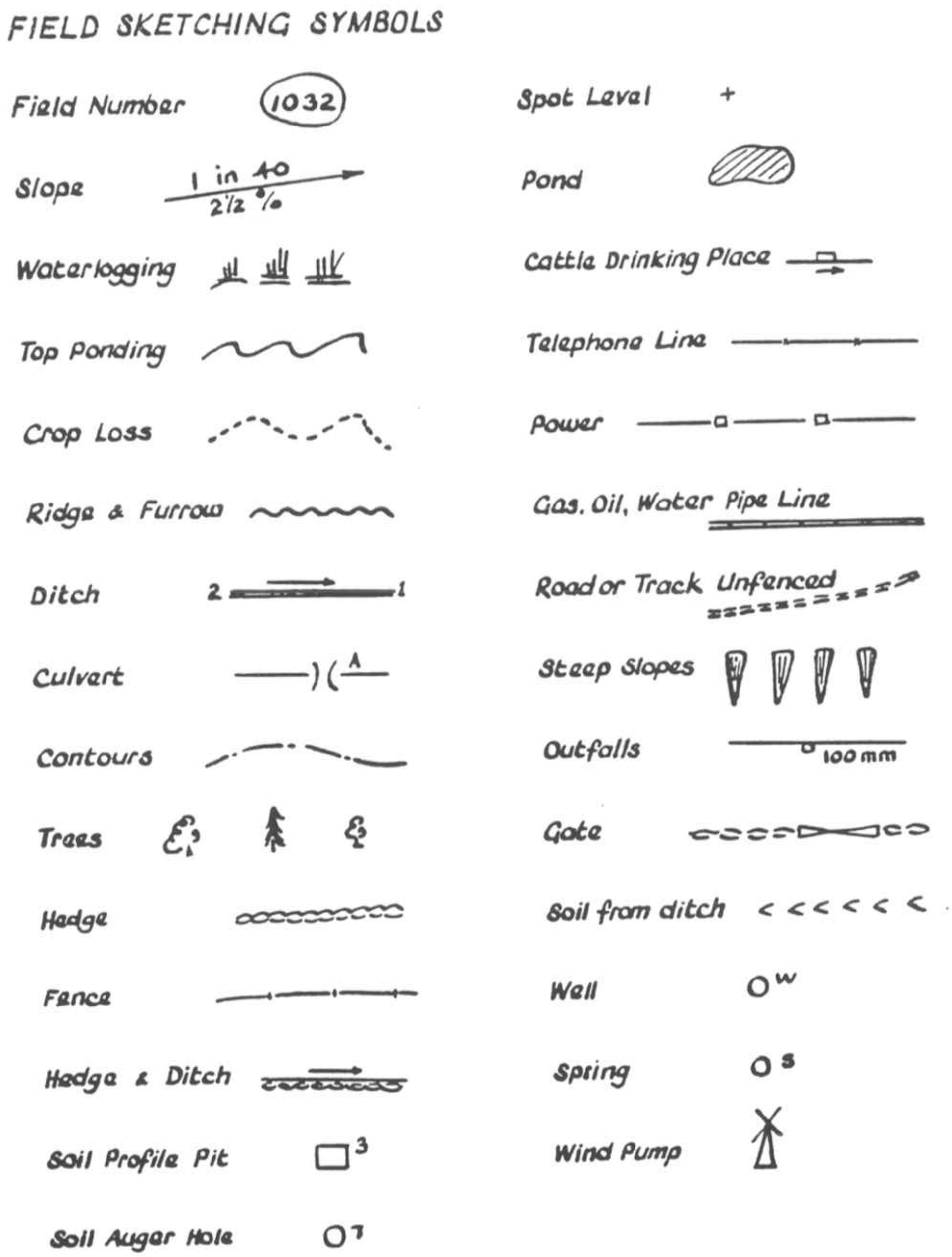


FIGURE 2: FIELD SKETCHING SYMBOLS

DRAINAGE COSTS - 1989

Drainage System	Details of System	Cost/Ac	Cost/ha
Conventional System	Plastic Pipe Drains at 6 m centres 660 m/acre	£750 - 900 (without main drains)	£1,800 - 2,200 without mains
Mole Drainage	1.3 - 1.5 m spacing 450 - 500 mm deep	£30 -40	£75 - 100
Mole Drainage plus collectors (close spacing)	collectors at 15 m spacing x 700 mm deep 266 m/acre	£335 - 400 (without main drains)	£820 - 980
Mole Drainage plus collectors (wide spacing)	Collectors at 30 m spacing x 700 mm deep 133 m/acre	£185 - 220 (without main drains)	£455 - 540
Gravel Tunnels	1.3-1.5 m spacing x 450 - 500 mm deep	£300	£735
Gravel Tunnels plus collectors (close spacing)	Collectors at 30 m spacing x 700 mm deep 133 m/acre	£450 - 480 (without main drains)	£1,100 - 1.180
Gravel Tunnels plus collectors (wide spacing	collectors at 50 m spacing x 700 mm deep 80 m/acre	£395 - 410 (without main drains)	£970 - 1,005
Headwalls and outfalls			£15 - 25
Inspections/ Chambers			£60 - 70

PERMEABLE FILL

Permeable fill is the name given to material of high hydraulic conductivity placed over drainage pipes to assist the flow of water into the drain. The most commonly used materials are washed gravel and broken stone which are readily available in many parts of the country. When deciding on the suitability of a material the following requirements have to be considered.

Durability and Strength

The material must last for the life of a drainage system and consequently must not deteriorate after installation. Also it must be sufficiently strong to withstand the various impact and abrasive forces to which it is subjected during handling, transport and stockpiling.

Size

If the permeable fill is too small it will have insufficient hydraulic conductivity to provide an adequate connection. Conversely, if it is too large, it will cause handling problems, of which the most serious is damage to the pipe when the material is being placed in the trench. Dimensions should not be less than 5.0 mm or greater than 50 mm and the material should be clean and free from soil.

Function of Permeable Fill

1. Connector

The main function of permeable fill is to provide a positive connection with the pipe drains for mole channels, subsoiling fissures, spring lines, existing drains,permeable horizons in the subsoil or sometimes to aid entry from the surface to the drain.

2. Hydraulic Improver

Completely surrounding the pipe with permeable fill as distinct from covering it will in theory improve the rate of entry of water into drains. However the increased costs involved in this is not economically justifiable under normal drainage conditions.

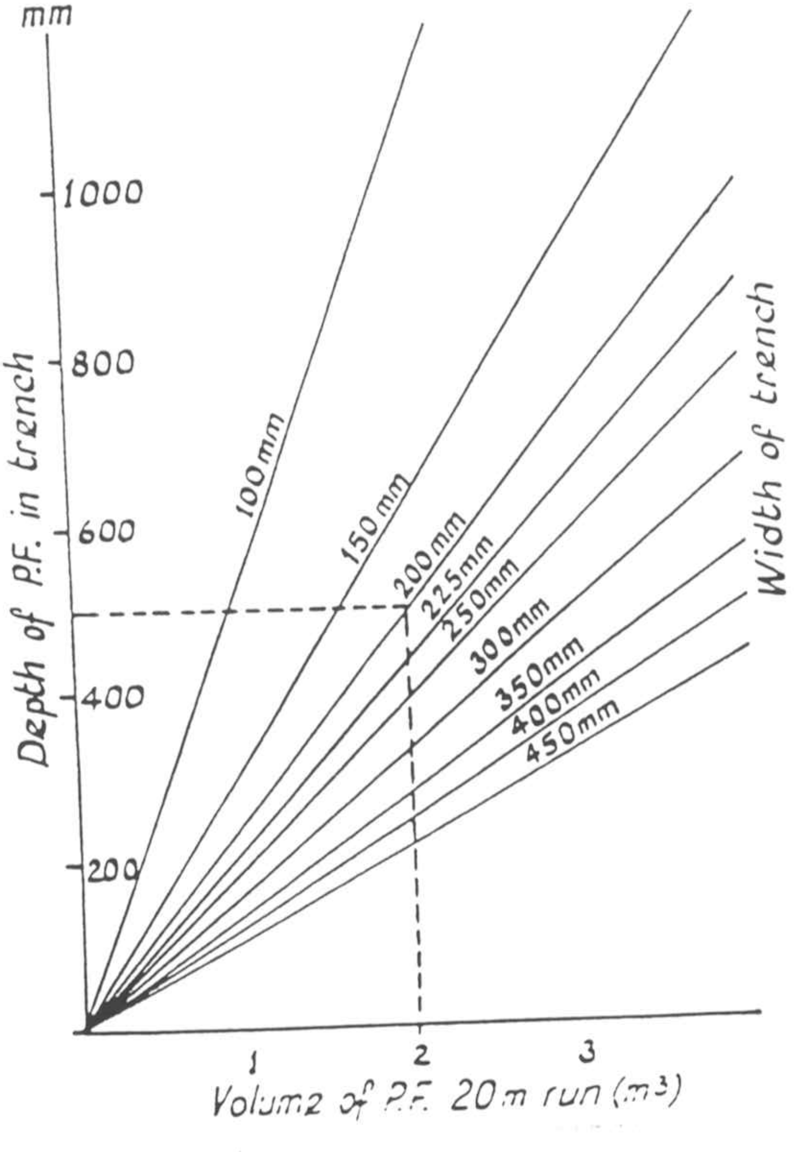


FIGURE 1: READY RECKONER FOR AMOUNTS OF PERMEABLE FILL

3. Filter

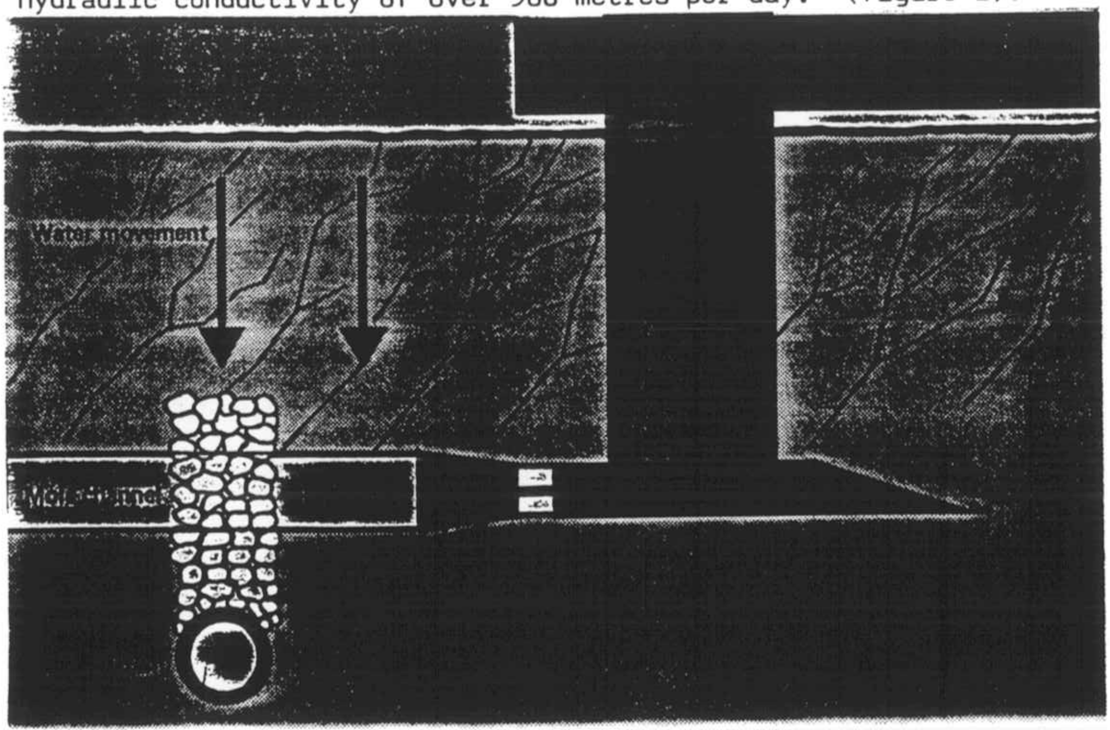
The majority of soils in this country do not give rise to sedimentation problems necessitating the use of filters. Where it does occur permeable fill has been found not to be very effective as a filter, unless designed specifically for the soil involved. It should be placed in layers around the pipe starting with material of the largest dimension nearest the pipe followed by finer layers in succession. If siltation is likely to be a serious problem than the use of pipes with a purpose-made filter wrap should be considered.

Use of Permeable Fill

The cost of using permeable fill is high, it can in fact represent up to 50% of the total cost of a drainage scheme. Figure (1) illustrates a method of estimating the quantity of permeable fill required for different trench sizes. From an economic viewpoint the need for its use must be carefully considered and clearly understood. Its chief function is to assist the passage of water by making a positive connection to a drain in the following circumstances.

a. Mole Drainage

When a soil is moled, water flows via the mole channels to the drains and is concentrated at points along the trench sides. The trench fill should be able to accept the flow and connect it to the pipe, otherwise water may be held in the mole channels leading to premature failure of the system. Permeable backfill for moling schemes should have a hydraulic conductivity of over 500 metres per day. (figure 2).



b. Subsoiling

Where subsoiling below the critical depth is intended to create fissures to improve water movement and the lower horizons of the soil are fairly impermeable then there is a positive connection to drain pipes. Subsoiling below the critical depth creates a discrete channel of square shape which could be described as an inferior mole drain. In impermeable soils this channel will carry water and so require permeable fill for its disposal to the drain.

c. Springlines

The solution to springline problems is usually the installation of interceptor drains. While it may occasionally be possible to cure the problem without the need for permeable fill over the pipe, it is more often necessary to use it as the quantity of water to be intercepted is greater than that which can be conducted through the natural soil to the drain. It is also useful in a layered situation of alternating permeable and impermeable strata. (figure 3).

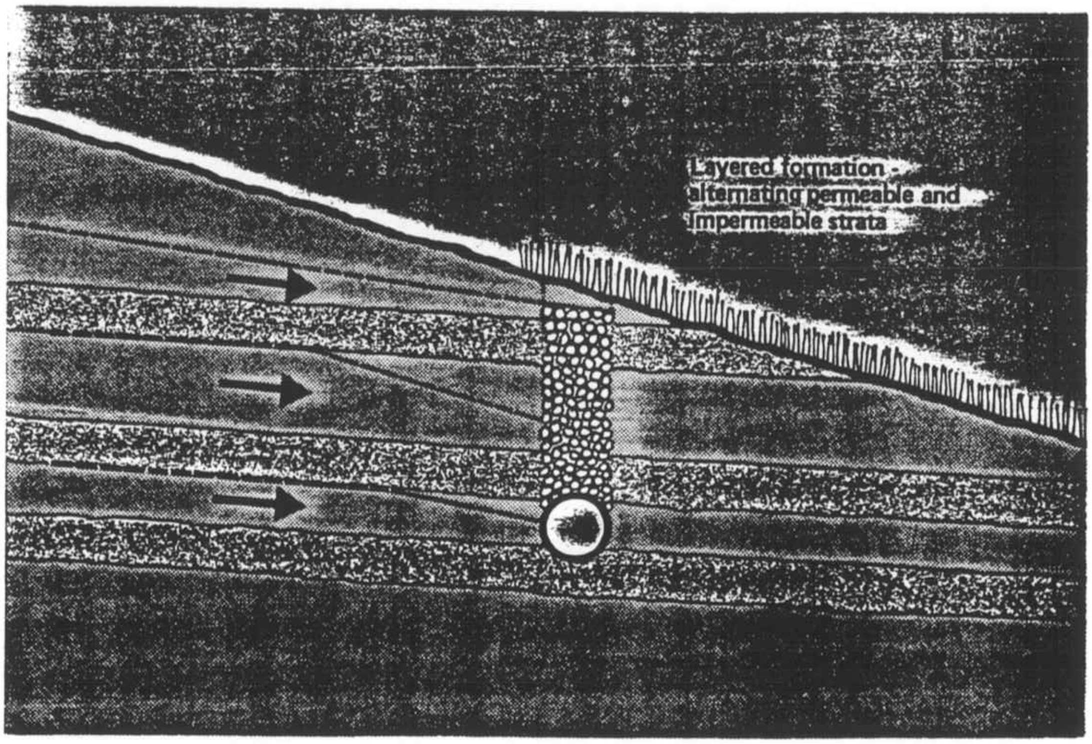


FIGURE 3: PERMEABLE BACKFILL NECESSARY FOR LAYERED SOIL

d. Surface Flow

When a drain is required to accept water from an impermeable surface such as a paved or concreted area, it is essential that the permeable backfill is brought to the surface. This is otherwise known as a 'French Drain' and is often usedto protect playing fields from surface flow coming off surrounding steep banks. Similarily, if a drain in clayey soils in a valley situation is required to accept surface water than the permeable backfill will need to be brought to the surface to avoid ponding. (figure 4)

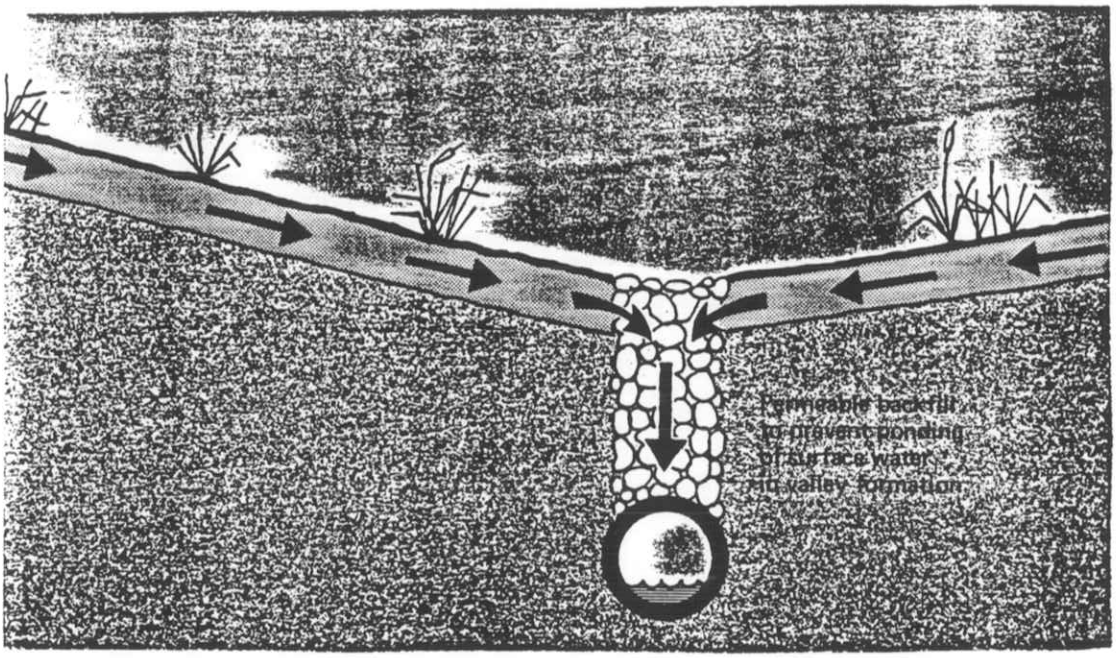


FIGURE 4: PERMEABLE BACKFILL TO PREVENT SURFACE PONDING

e. <u>Plough Layer Flow</u>

In impermeable soils with waterbearing layers where moling is not suitable the fill must be brought up from the drain to the waterbearing layer concerned. If it is surface or plough layer flow this would mean bringing the permeable fill up to about 150-225 mm from the surface. This would be very expensive and may only be worthwhile on strategically sited drains or on an individual drain along the bottom of a valley. (see figure 5).

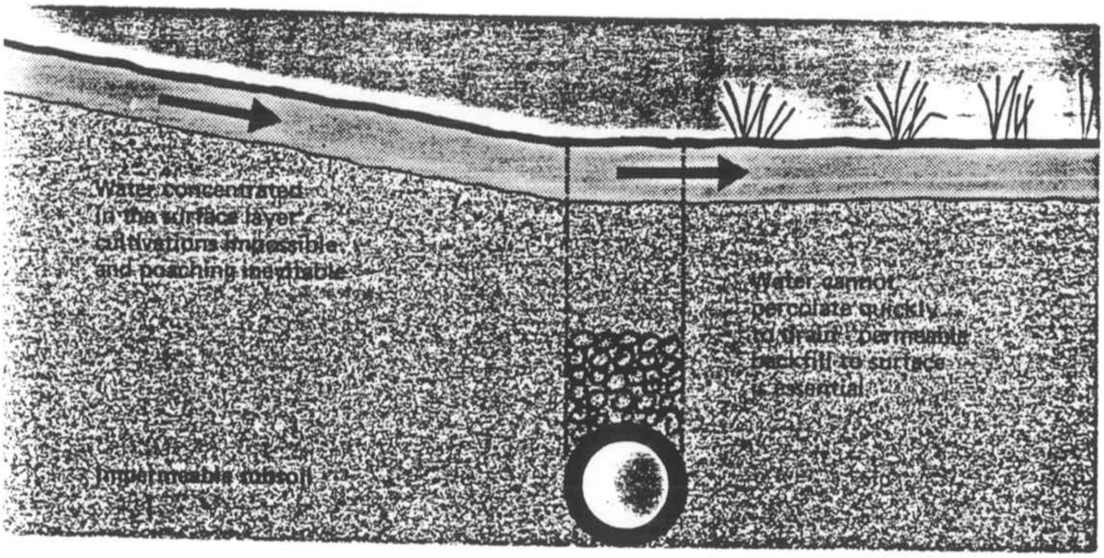


FIGURE 5: PROBLEMS WITH PERMEABLE BACKFILL NOT COMING UP TO PLOUGH LAYER.

f. <u>Old Drains</u>

When new underdrainage systems are installed any existing drains encountered should, where they are still active, be connected to the new system. Whilst it is preferable to use purpose made junctions the relative levels of the old and new systems may be such that this would present difficulties, and so permeable fill can be used to connect these systems.

In the case of piping open channels, particularly in peat areas, it can often be difficult to achieve a stable channel bottom. With using large diameter pipes, particularly the concrete type, it is essential to have a stable base to avoid displacement.

In such cases permeable fill can be used and it may take up to 300 mm in certain difficult areas. Material of small dimension, with some incorporated fines is preferable for its binding qualities and hence bearing strength. The larger single sized stone will tend to sink in soft channel bed material.

Be Economical

Permeable fill is expensive so the following points should always be considered:

(a) Employing a machine that will cut narrow a trench just sufficiently wide for the size of pipe being used. A 100 mm width of permeable backfill is adequate for most purposes.

(b) Laying the drains unnecessarily deep will require more permeable backfill material to provide a connection for moling or subsoiling.

(c) In close spaced conventional schemes it is not necessary to make a connection with permeable fill to the plough layer in every drain.

IRON OCHRE

Iron ochre is a genetic name which is used to describe the iron derived material blocking drains. Ochre can occur in a wide range of conditions the only initial pre-requisite being sufficient iron in the soil in a reduced form. A number of bacteria are also involved in this process and are capable of living in or adapting to very harsh environments.

The Problem

When soils containing iron sulphide are drained for the first time the pH value falls and the soil becomes acid. Iron is also mobilised, leached towards the drains and can be deposited chemically in the drain water entry slots or in the filter surrounding the drain. The process is made worse by iron depositing bacteria that forms a slime or fibrous material preventing water entry, or in extreme cases blocking the drain itself. Similar processes can take place with bacteria using ferrous iron or sulphur as an energy source giving bright orange-red granular ochre deposits.

Ochre Forming Soils

Virtually all soils in this country contain appreciable quantities of iron. Usually in a well drained, aerated soil it occurs as water insoluble iron oxide remaining disposed and immobile in the soil profile and causing no problems. In some badly drained soils, iron occurs in the form of iron sulphide. This is the first substance in the chemical reaction sequence which forms ochre.

These ochre producing soils fall into two main groups:

(a) Peats and marine sediments laid down in the presence of organic material, that have remained waterlogged and anaerobic prior to drainage. In these soils various forms of iron sulphide can occur the main one being:

Iron pyrites (iron disulphide)
Ferrous Sulphide

These sulphides are formed by the reduction of iron oxide and other iron compounds, in the presence of sulphur compounds derived from bacterially reduced sulphates and organic matter under anaerobic conditions. The amounts of iron sulphides present vary widely between different locations and are often localised is particular horizons in the soil profile.

(b) Iron sulphides may often occur in large quantities, usually in the form of the mineral iron pyrites, in soils derived from carboniferous rock strata or igneous pyrite - bearing rock.

With Drainage

Ferrous Sulphide — Soluble Ferrous Sulphate — Sulphuric Acid

$$2\ Fe\ S_2 + 7O_2 + 2H_2O - 2\ Fe\ SO_4 + 2H_2\ SO_4$$

Neutral PH

Insoluble Ferric Oxide

$$4\ Fe\ SO_4 + O_2 + 4H_2O - 2\ Fe_2\ O_3 + 4H_2SO_4$$

If the soil becomes sufficiently acid (pH 4.5) certain acidophilic soil bacteria of the thiobacilli group being to catalyse the oxidation of iron sulphide further increasing the rate of production of ferreous sulphate and sulphuric acid and further lowering the pH. With increasing acidity, these bacteria become progressively more active in accelerating the oxidation rate and causing the reaction to take on a self-promoting cycle until limited, either by the availability rates of iron sulphide and oxygen or by the pH falling below the optimum for the bacteria. (about pH2).

Ochre Deposit

The ferreous sulphate produced by the iron sulphide oxidation will be carried through the soil along with any soluble iron-organic complexes in acid solution in the soil water. It is liable to oxidation either directly by atmospheric oxygen or by bacterial action; the nature of the further oxidation depending on the acidity of the soil water.

Oxidation of the ferreous iron can take place in soil cracks, root channels, at the surface of the watertable - possibly forming an iron pan - and within or around underdrainage pipes. An ochrous deposit of ferric oxide is produces as an orange gel, slurry or crust.

METHODS OF PREVENTING OCHRE FORMATION

Many methods to prevent ochre formation have been tried but the majority have been of limited effect in controlled research conditions. So far a successful practical solution has not been found although the following can be considered.

Preventing Aeration

With air entry prevented, oxygen concentrations within the drain will decline, inhibiting the oxidation reactions causing ochre deposition and the associated aerobic bacteria. This ignores the fact that in flowing water the oxygen concentration will be close to that of the atmosphere. Therefore, only under static conditions in summer are reducing conditions likely to be approached; however, as bacteria are very temperature dependent, summer is the most active period. Some bacteria may be inhibited by lack of oxygen but there is evidence that others especially thiobacillus ferroxidans can thrive at the very low oxygen level.

Prevention of air entry can be achieved by submerging the drain outfall or fitting a 'U' trap on the outfall pipe. However this may only have a marginal effect and is by no means a certain cure, and given the obvious problems of continued drain submergence on the life and efficiency of the drain, this can hardly be recommended. Also periods of high flow velocity may be important in scouring out some form of ochre, particularly from near the outfall. Submergence can reduce this effect.

Lime to Control pH

The objective would be to reduce acidity to a level where the acid thiobacilli are inhibited, thus retarding the rate of oxidation of iron sulphide and production of mobile iron compounds. However, lime applied at the field surface might not greatly affect pH conditions at depth. The alternative is the placement of lime adjacent to the drain at the time of installation. There is recent evidence which suggests that some non-oxidising bacteria are either directly capable of working at any likely pH or capable of adaption to do so.

Limestone Chips Around the Drain

The idea is to raise the pH near the drain and encourage oxidation of mobile iron and subsequently ochre desposition outside and away from the immediate vicinity of the drain. This is unlikely to be effective where there is sufficient ochre to cause serious problems. In fact the situation may be aggravated and ochre formed outside the pipes blocking both slits and permeable fill which is inaccessible to cleaning operations.

METHODS OF REMOVING OCHRE FROM DRAINS

Rodding

Rodding is best carried out when there is sufficient drain flow to assist washing out. This method can be of use where the problem is internal blocking of the drain by extensive ochre deposits. However this only works with straight unbranched drains and ochre, blocking drain slots, is not removed.

Jetting

The method suffers from the same limitations as rodding but may have some effect on the ochre in the slots of drain pipes. However, ochre surrounding the pipes may be fluidised and promptly block up the drain slots again.

Current Research

Anti Ochre Wrap

A pipe wrap material containing mimosa bark has been reasonably successful in limited trials but so far little is known about its effectiveness over a long period of time. A limitation is its replacement if it does become ineffective before the ochre has been leached from the soil profile.

Coniferous Bark

A technique has been developed in Scotland of placing large quantities of coniferous bark in inspection chambers placed at intervals along the drainage system. The drain water passes through the bark filter which absorbs the ochre and remains effective for several months before needing to be replaced. This would seem an expensive and labour intensive operation.

DESIGN POINTS

Temporary Work

It may be necessary to carry out some temporary preliminary work. This could be in the form of open trenches so as to allow the initial ochre formation to occur before a permanent drainage system is installed. The alternative is to install a sacrificial pipe system and to replace this once it has been completely blocked and inoperative.

Individual Outlets

Whenever possible individual outfalls should be laid in order to facilitate jetting or rodding. If this is not possible then provision should be made for inspection chambers at major points in the system so that maintenance work can be carried out.

In deciding on the worthwhileness of installing an underdrainage system in areas where ochre is likely to be a problem, the farmer will have to recognise the fact that maintenance problems and the possible renewal of the system may add to the costs.