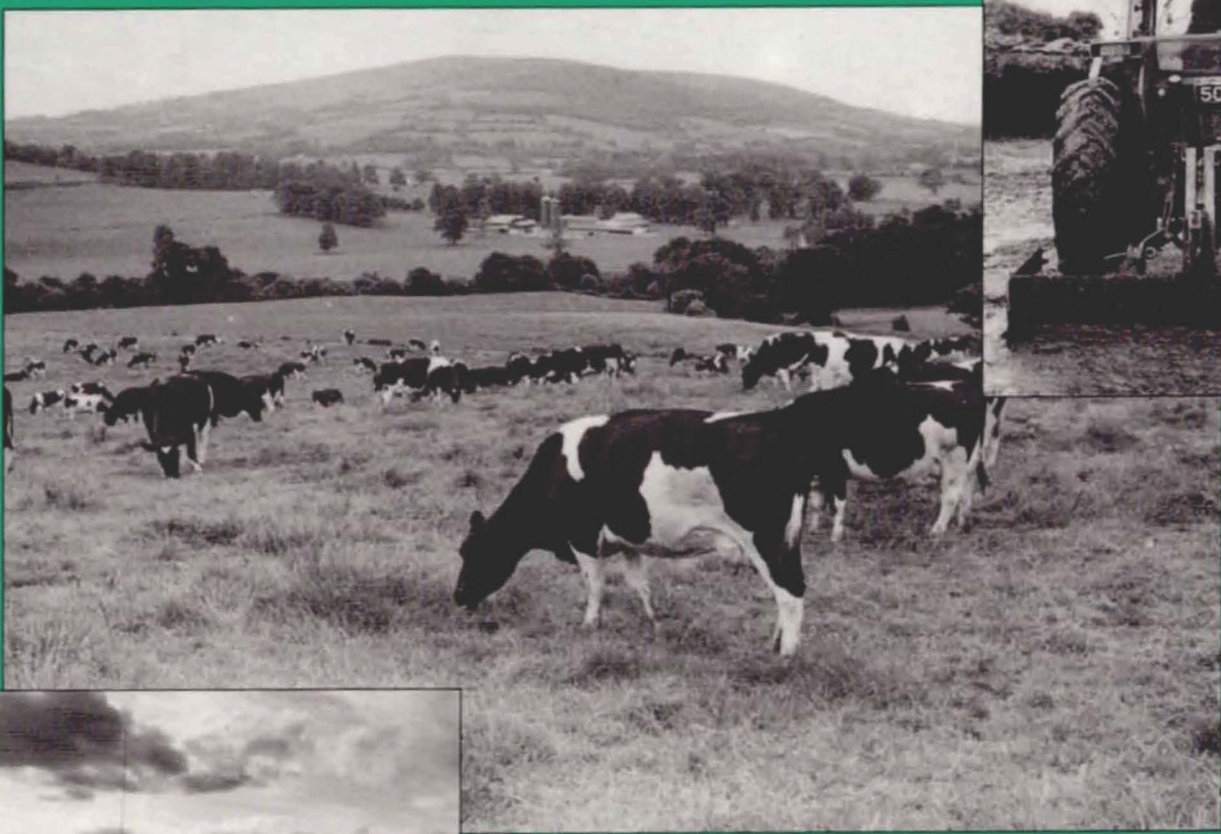
AGMET

WEATHER, SOILS AND POLLUTION FROM AGRICULTURE



Compiled by Marie Sherwood

AGMET

Joint Working Group on
Applied Agricultural Meteorology

WEATHER, SOILS AND POLLUTION FROM AGRICULTURE

Compiled By

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Castlecomer impermeable soil – subject to runoff

Foreword

The Meteorological Service has steadily expanded its forecasting service over recent years, to provide information to farmers on herbage production potential and the onset of conditions suitable for disease spread. There is also a pollen count provided for a wider audience, to alert asthma and hay fever sufferers.

Proposals for extension of weather forecasting services are generally discussed and debated by the Joint Working Group on Applied Agricultural Meteorology (AGMET), with members from the Meteorological Service, Teagasc, Department of Agriculture and Food, Universities, Fisheries and Farming Organisations. AGMET considered that a special Environmental Sub-group should be set up to examine the possibility of using weather forecasts to assist farmers in decision-making, to help minimise pollution from agriculture. This booklet is a Report of the Environmental Sub-group's considerations and was compiled from submissions received from several members. It explains the nature of the relationship between weather and pollution of water from agriculture. It also attempts to show how weather forecasts could help farmers to make responsible decisions and adopt management practices which would ensure protection of our environment.

We acknowledge, with thanks, the work of Dr B. Coulter and E. McDonald, who used GIS facilities to plot the map, and also V. Staples, who produced the figures.

Marie Sherwood,
February, 1992

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CHAPTER 1

Potential Polluting Effects of Agriculture on Water Quality

The amounts of waste generated in farming activities in Ireland are about ten times the combined total amounts arising from sewage systems and industry. The main water pollution potential of farm wastes arises from their very high concentrations of biodegradable organic matter leading to increased biological oxygen demand (BOD), phosphorus (P) and nitrogen (N) as shown in Table 1. High BOD causes *deoxygenation*; nutrients such as P and to a lesser extent N, cause *eutrophication;* N may persist in some soils and subsoils and reach groundwater as *nitrate*. Nitrate is considered to be a health hazard if present in drinking water in concentrations greater than 50 mg/l. Water contamination can also arise from accidental spillage of *toxic chemicals* such as pesticides or sheep dip which are poisonous to both humans and fish.

Table 1: BOD, total N, and total P contents of farm wastes, sewage, milk and clean water.

	mg/litre		
	BOD	N	P
Silage effluent	65,000	2,700	560
Poultry slurry (layers)	35,000	14,000	5,000
Pig slurry	25,000	4,000	1,400
Cattle slurry	17,000	4,000	700
Dungstead effluent	up to 10,000	1,100	300
Dirty water (soiled yardwater)	1,500	300	30
Untreated sewage	400	55	15
Milk	100,000	5,000	1,000
Clean Water	<4	<1	0.005

Deoxygenation

Deoxygenation can occur when any material which has a very high BOD reaches water. Such materials supply food for the rapid multiplication of bacteria, especially in warm weather. As the bacteria grow and multiply, they use up the very small amount (8-12 mg/l) of oxygen which is dissolved in water. Fish also need oxygen in water but are unable to compete with the growing bacteria. Salmon and trout require dissolved oxygen levels greater than 6 mg/l, and mortalities will occur at less than 3 mg/l. The higher the BOD value of the material reaching water, the greater amounts of oxygen which will be used.

It can be seen in Table 1 that silage effluent has a BOD of 65,000 which explains why it is very often responsible for fish kills. The deoxygenation effect may be exacerbated by the presence in wastes of other compounds such as ammonia and hydrogen sulphide. These are also extremely toxic to fish but it is important to understand that even "clean" materials such as milk or sugar can cause deoxygenation in water because they provide an energy source for rapid bacterial growth.

Eutrophication

Eutrophic waters are defined as those which are rich in nutrients, especially P and to a lesser extent N. Some waters are naturally eutrophic, but in most cases excessive levels of nutrients derive from inputs of farm, domestic and industrial wastes at point sources. Nutrients from diffuse sources resulting from runoff or leaching following landspreading of either farm wastes or fertilizers also contribute to eutrophication. Excessive nutrients in small fast flowing rivers cause increased growth of rooted weeds and attached filamentous algae.

In lakes and large rivers, high levels of nutrients, particularly P, allow the growth of planktonic algae which live suspended in the water, leading to surface and shoreline scums, turbidity and discoloration. Such developments have distinctly adverse effects on amenity use and abstraction of water for public water supplies. They also have serious implications for fisheries.

It is recognised internationally that the only effective way to prevent the deleterious effects of algal blooms or excessive weed growth is to limit the amount of P in the waters and thus prevent the growth of weeds or algae through P starvation. Eutrophication problems from excessive P have been encountered in many countries. Famous Lakes such as the Great Lakes and Lake Tahoe in the US and the beautiful Swiss lakes suffered severe algal problems in the fifties and sixties. The problems were solved by reducing the P inputs to the Lakes at point sources, mainly through banning the use of P-containing detergents and treating sewage effluents to remove P.

In Ireland, eutrophication problems in Lough Ennell and Lough Leane were also solved by treating sewage to remove P. However, an increasing number of waterbodies in Ireland (such as Lough Sheelin, Lough Derg and the River Lee) are experiencing eutrophication problems where P inputs from agriculture outweigh inputs from sewage or industries by a large factor. The sources of agricultural P may be either from accidental or other discharges of wastes from farmyards or through runoff from land following landspreading of slurry or fertilizers. *This is the area where attention to weather forecasting can have the greatest potential impact in pollution prevention, and will be dealt with in more detail in later chapters.*

It is very difficult to control the inputs of P to water from agriculture because it occurs in a diffuse manner over a very wide area. Phosphorus is an essential element for plant and animal growth. Inputs to a grassland dairy farm average about 20 kg P/ha/year. If even *1%* of this reaches water, it provides more than sufficient P for algal growth in lakes as algae can grow when the soluble P concentration in water reaches 0.01 mg/l under otherwise optimum conditions. This low level is very difficult to achieve in practice.

Rivers can tolerate a higher level of P than lakes without showing eutrophic symptoms, but if the river flows through a lake or a reservoir, the lower P limit would be more desirable for control of algal growth. The levels are so difficult to achieve that it is apparent that *NO* agricultural wastes, however dilute, should be allowed to discharge directly to waterbodies and that management practices should be adopted to ensure that no runoff from land occurs following landspreading of slurry or fertilizers. Local Authorities will also need to ensure that sewage treatment plants have adequate facilities to remove P, but this is now the subject of an EC Directive (91/271/EC) and will be implemented over the coming years.

Nitrate in groundwater

Nitrate in groundwater can arise from untimely or excessive applications of N fertilizer or farm wastes such as animal manures, which contain high concentrations of N (Table 1). Whenever these materials are applied during the active growing season, N uptake by growing plants is rapid and there is little danger of nitrate leaching. Nitrogen which is applied outside the growing season and especially in autumn and early winter, may exceed the crop's capacity for N uptake and nitrate leaching may result. *Soil* is another potential source of nitrate in groundwater, especially where cereal crops are sown. Soil type has an important effect on nitrate leaching, with coarse-textured, free draining soils most at risk.

Toxic chemicals

Some of the chemicals which farmers use, e.g. weedkillers, fungicides, insecticides and sheep dip, may be toxic to both people and fish if they reach water. Great care must be exercised during spraying operations to avoid accidental overflow of sprayers. Containers must always be rinsed several times into the spraying machine, before disposal.

CHAPTER 2

Trends in Water Quality in Ireland

Water quality in Ireland is generally good. National water quality surveys of both rivers and lakes have been carried out since 1971 by An Foras Forbartha and more recently by the Environmental Research Unit (ERU) of the Department of the Environment. In river surveys, water quality is assessed on the basis of the nature of the macroinvertebrate fauna. The ERU recently reported their latest assessment of river water quality as a result of examinations carried out at 4,500 locations on 13,465 km of river and stream channel:

Unpolluted	Slightly polluted	Moderately polluted	Seriously polluted	Total river length surveyed
10,300 km	1616 km	1414 km	135 km	13,465 km
76.5 %	12.0%	10.5 %	1.0%	100%

Source: Water in Ireland, Ed. L.M. McCumiskey, Publ. ERU, Dublin. 1992

Pollution was mostly of the chronic type as a result of more or less continuous discharges of waste over relatively long periods and agriculture was considered to be responsible for at least 20-30%. It would be a great mistake to be complacent about the data presented in the ERU Report because the trends show that slight and moderate pollution from agriculture tend to increase in each successive survey.

There is much less information available on water quality in Irish lakes, but there is strong circumstantial evidence that P from agriculture is causing eutrophication in a number of cases. The other sources of P are untreated sewage and industrial discharges.

Why Do We Need Clean Rivers and Lakes?

Clean water is one of our most precious national assets and nobody has the right to pollute it. It is part of the clean, "green" image we try to portray in the marketing of both our food and our tourism potential. It is also our main source of drinking water and is of extreme importance for inland fisheries. Farmers also benefit from clean water for watering stock. However, they have an obligation to ensure that the water passes from their property in an unpolluted state, so that neighbours downstream may also enjoy their natural rights.

Public Health Implications

Surface water accounts for about 75% of all public water supplies in Ireland. Severe pollution incidents from farm wastes may result in a fish kill and attract a lot of media attention, but of much greater concern to Local Authorities is the potential impact on public water supplies. The large content of bacteria and viruses in the wastes, particularly livestock manures, represent a direct threat to human health and can overwhelm the capabilities of water treatment plants and necessitate temporary shut-down. Even "slight pollution" can incur high treatment costs for Local Authorities in order to conform with Drinking Water Standards (EC/88/778).

Water Quality Requirements for Fish

All kinds of pollution, no matter how minor, are detrimental to fisheries, which are an important amenity and an economic asset. A recent economic evaluation has shown that expenditure by anglers on freshwater fishing is approximately £44 million per annum, but it is widely recognised that there is considerable potential for further job creation within this sector. Good fishing, available locally, may be a distinct advantage in formulating packages for developing agritourism.

Clean water, with a varied aquatic flora and fauna, is a fundamental requirement for sustained development of freshwater fisheries resources and the Fisheries Boards have statutory responsibility to manage, develop and promote our inland fisheries. Different fish species have different pollution tolerance levels. Salmon and trout (salmonids) occur in almost every body of surface water in Ireland. These species are most sensitive to pollution, so water quality standards need to be very stringent.

Salmonids are cold water species which require high levels of oxygen and the juvenile stages are found in the most aerated parts of the rivers i.e. the shallow "riffles". As a general rule, these locations also contain clean water plants and pollution sensitive invertebrate fauna. The fish must be able to swim and feed throughout the system, without hindrance, all year round, in order to grow to maturity and reproduce properly.

Coarse fish such as pike, bream, roach, rudd, tench and carp (cyprinids) are more tolerant of pollution. They occur principally in still or slow-flowing areas and in waters which may be just that little bit too polluted for salmon or trout.

Fish kills and eutrophication

Fish kills normally result from a sudden discharge of a strong pollutant (high BOD) into a clean watercourse where conditions change too quickly for the fish to escape. Numerous other pollution incidents occur without the appearance of dead fish because being mobile, the fish can move out of the area when conditions become progressively unsuitable for survival. As a result, fish may be absent from long stretches of some rivers. This situation prevails immediately downstream of many towns which discharge sewage to rivers, but it escapes media attention because there are no fish kills. You cannot have a fish kill where there are no fish!

When livestock manures are discharged into water the main effect is that they cause deoxygenation and also hydrogen sulphide and ammonia toxicity. Discharge of farm wastes can also result in deposition of solid material which can smother the gravels in the stream beds. Further damage may be caused by discoloration of the receiving water so that light cannot penetrate to allow the growth of desirable aquatic plants. Such plants contribute to aeration and are also an important part of the foodchain. In extreme cases, decomposing algae can cause fish kills.

Priority Fishing Waters

In 1988, legislation was enacted to implement an EC Directive (78/659/EEC) on "the quality of fresh waters needing protection or improvement in order to support fish life". Under the Directive, Member States were asked to designate waters suitable for salmonid fish,

Table 2: Priority waters regarding pollution prevention and/or abatement.

Designated Waters (subject to EC Directive Standards)	Branded Fisheries (Bord Fáilte)
Aherlow	L. Leane
Arigdeen	Waterville lakes
Blackwater (Munster)	L. Corrib/Mask/Carra
Boyne	L. Conn, L. Cullin
Bride	L. Melvin
Br. Flesk	R. Slaney
Corrib including	R. Nore
L. Corrib	Blackwater (Munster) plus tribs:
Dargle	- Funcheon, Awbeg
Feale	Upper R. Caragh
Fergus	R. Boyne
Finn	R. Corrib
Glashagh	R. Erriff, Delphi and Lakes
Lee	R. Owenmore
	(Ballynahinch Castle Fishery)
Leannan	R. Bundrowes
Lurgy	Costello, Cashel, Screebe,
Maggisburn	(Rivers and Lakes)
Maine	Ballynahinch Castle Fishery
Moy plus following	Gowla/Inver FIsheries (River/Lakes)
tributaries	Kylemore/Inagh/Muck and Fee
Owengarve	Ballynahinch (Tullyboy)
Mullaghanoe	L. Beltra, Newport R.
Spaddagh	Burrishoole Fisheries
Trimoge	(L. Feagh, Furnace)
Glore	The Rosses Fishery, Glenveagh Lake
Yellow	R. Fane/Deel/Glyde
Gweestion	Mid + Lower Suir and Tributaries
Manulla	Little Brosna, Clody and Silver Rivers
Castlebar	R. Suck, Bunown, Shiven, L. O'Flynn
Deel	R. Moy + Tributaries
Corry	L. Arrow, L. Key
Nore	L. Ennell, L. Owel
Slaney	L. Rea, L. Inchiquin, L. Dromore
Swilly	West Cork/Kenmare Stocked Lakes
Vartry	L. Sheelin

and there is a legal obligation on each Member State to maintain specific water quality standards in designated waters.

The first list of designated rivers submitted from Ireland is shown in Table 2 and these should be regarded as priority waters for pollution prevention and abatement. Another group of waters for which pollution prevention is a priority are the "Branded Fisheries" which are actively promoted by Bord Fáilte, at home and abroad, as quality fisheries. These waters are also listed in Table 2. The Dept. of the Environment hopes to greatly expand the list of designated salmonid waters, so that water quality suitable for salmonids must be the objective at all times. Eutrophication is not the only agricultural threat to developing our fishing resources. The Fisheries Boards are also increasingly concerned that salmon and sea trout stocks in hitherto unpolluted waters draining thinly populated regions of blanket bog are now threatened by acidification from afforestation and siltation from soil erosion, both of which have been exacerbated by recent EC policies on afforestation and headage payments, respectively.

Athy gravel – *very* free draining – *no* runoff risk

Rathangan soil – subject to runoff

CHAPTER 3

Soil - The Living Filter

Soil is one of the greatest assets man has for safe disposal of wastes. It is a very complex medium which includes all of the material that extends from the surface of the ground to the bedrock below, and has very complex physical and chemical properties. It supports within its framework a very wide variety of living things from minute microbes to giant tree roots and it operates very complex systems of water control and chemical reactions.

A great variety of soils are found even in a small country like Ireland. This great diversity arises from many factors. Among the most important ones are (i) parent materials (or the kind of rock debris from which the soil has been formed), (ii) climate, (iii) time - the development of a soil requires a long time, and is in fact a never ending process, (iv) vegetative cover - different plants interact in different ways with the soil. Most Irish soils have been developing over the past 10,000 years, i.e. since the end of the ice age. Soil physical and chemical properties as well as the biological behaviour, govern the movement of water and other materials into and through the soil.

Soil texture and soil structure

To understand better the manner in which a soil functions as a physical system it is necessary to examine it from two points of view :

- Texture or the individual particles of which the soil consists
- Soil structure - or the manner and order in which these particles are held together

Textural analysis is a common procedure carried out in Soil Physical Laboratories. This analysis separates out the individual particles into different size categories and the amount of material in each category determines the texture of the soil. For example if the soil has a high proportion of coarse particles it is classified as coarse or sandy. If it has a lot of small particles, it is fine or a clay soil. It is of course possible to have a very large range of texturally different soils and many of the physical properties of soil depend on texture.

Structure is the second concept that arises in the soil's physical properties. The word comes from the Latin verb "Struere", to build. This is precisely the meaning it has in relation to the soil. It refers to the manner in which the individual textural particles are built together. There are two concepts: the arrangement of the individual particles and the stability of this arrangement. It is helpful to use a building analogy. A house basically consists of walls and rooms. In the soil the "walls" consist of textural particles bonded together, and the "rooms" are the empty spaces between the walls. In the soil we refer to them as voids or pore spaces. Although it is not immediately obvious on casual inspection, a good top soil has about 50 per cent of pore volume or 'empty' space in its make up.

Soil pores, permeability and water retention

The nature of these pores is of fundamental importance in determining many of soil's physical properties. All the soils microbes, plant roots, insects etc. live in these pores, and it is also the pores that transmit water and air through the soil, and store water for use by plants in dry weather. It is obvious that if we pour water onto a pile of large stones it runs rapidly through them and the only water remaining afterwards is that which adheres to the surfaces of the stones. Similarly, it we pour water on to a pile of fine material the water percolates slowly through, and afterwards a substantial amount of the water is retained within the material.

This concept of pore sizes illustrates a well known and widely applied phenomenon in Soil Physics. Two concepts arise: water flow through the soil, and water retention by the soil. It is a well known fact that both soil permeability (or the ability of the soil to permit *flow-through* to occur), and soil water *retention* capacity (or the capacity of the soil to retain water) are both related to pore sizes.

Permeability is proportional to the fourth power of the pore's radius for cylindrical pores. For parallel sided pores it is proportional to the cube of the distance between the sides of the pore. The effect of this is that if pore sizes double, permeability increases between eight and sixteen times. There is, of course a corresponding reduction when pores are smaller. Thus a soil with a high proportion of large pores is very permeable while a soil with a high proportion of small pores is poorly permeable.

Water retention capacity depends on a different principle which is also dependant on pore size. In this case the phenomenon is surface tension. If a tube of very narrow bore is placed vertically in water, surface tension will cause water to rise in the tube and the height to which it rises is inversely related to the radius of the tube. Thus if all of the pores in a soil are very small, it is physically impossible for water to drain from that soil. There are soils in this country, with such a high proportion of very small pores that for all practical purposes water cannot flow through them. These soils are described as having very low *hydraulic conductivity*. In some soils the whole profile is impermeable; in others, certain layers can seriously restrict flow.

If we take a microbes view of the soil pores, we will see that they consist of a network of interconnecting channels of different sizes. We will notice that water flows much faster through the larger pores but that some of the smaller pores are for all purposes stagnant. We will also notice that if the water contains materials either in suspension or in solution that a lot of them are rapidly removed by the soil. Some of the larger particles get physically trapped in pores. Some of the smaller ones, and especially those in solution, attach themselves to the side walls of the pores.

Water flowing in larger pores passes through rapidly and loses but little of its impurities on the way. The trapping of the larger-sized impurities is similar to the action of a sieve or a filter. The trapping of the dissolved material depends on a chemical/physical reaction with the soil. Soil textural particles, especially the smaller clay size particles have active sites onto which some dissolved materials (mineral ions) become bonded and it is these small particles that control most of the chemical and biological reactions.

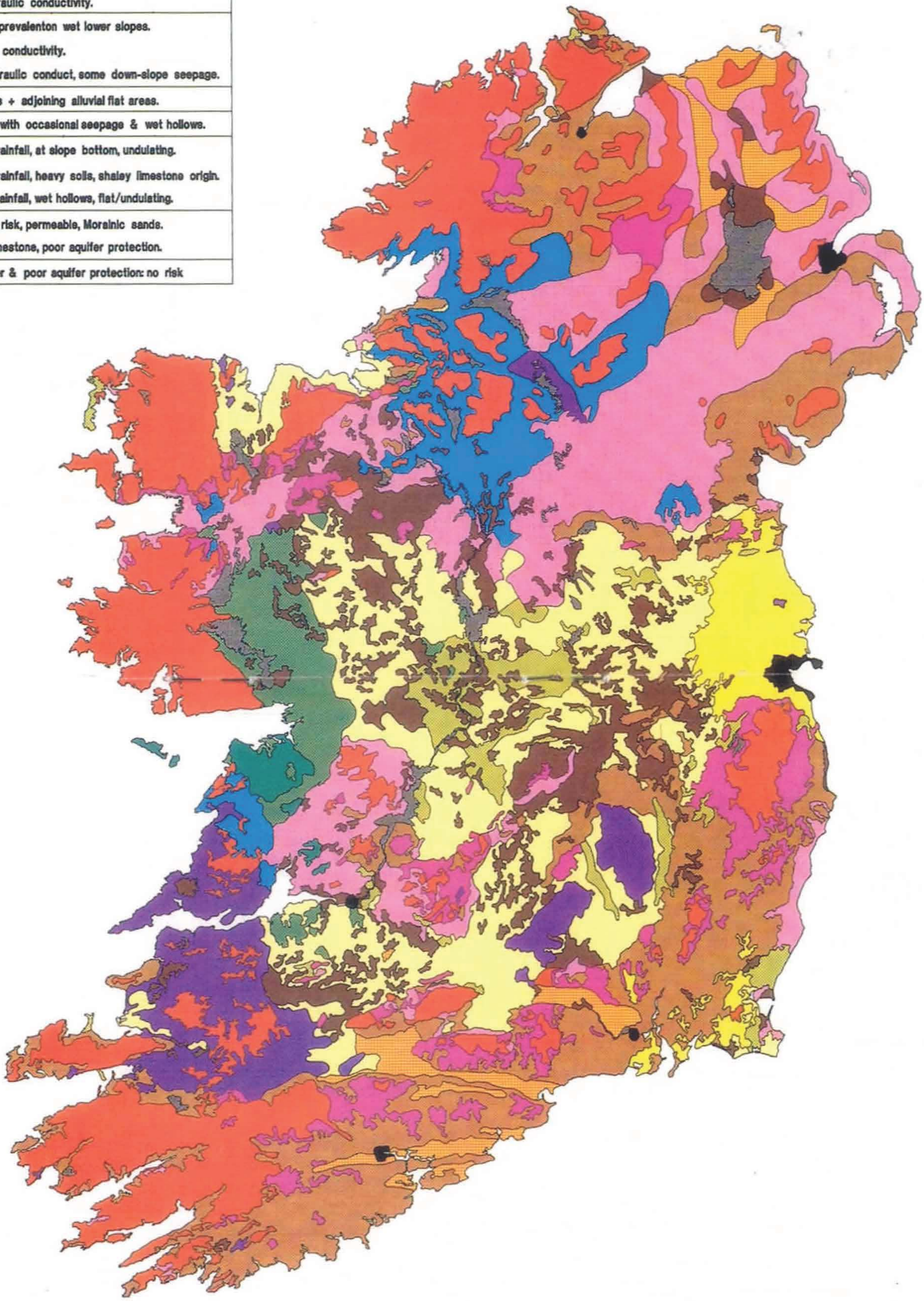
It follows therefore that the quantity of waste materials that can be added to a soil is limited. Too much waste applied at once will clog the pores; too much soluble material will fill all the reactive sites. Such soil must be allowed time to recover. Bacteria decompose the organic wastes and crops gradually remove the mineral materials from the reactive sites. Thus, soil has a great capacity for disposing of wastes and renewing itself as a purifying agent, provided it is not overloaded and that it is reasonably well managed.

Infiltration

There is one other factor to be considered in relation to soil as an agent for purifying waste water. This is particularly important where spray irrigation of wastes is in use. It is the infiltration capacity of the soil, *or its ability to allow water to enter the soil surface*. In effect, it is the permeability *at the soil surface*.

RUNOFF RISK CATEGORIES FOR SOILS

RUNOFF RISK LEGEND	
1	Persistently wet soils in high rainfall areas: high risk.
2	Soils of very low hydraulic conductivity.
3a	Soils: seepage locally prevalenton wet lower slopes.
3b	Soils of low hydraulic conductivity.
3c	Soils of moderate hydraulic conduct, some down-slope seepage.
4	Basin & cutover peats + adjoining alluvial flat areas.
5	Soils on drier slopes with occasional seepage & wet hollows.
6a	Mainly dry soils, low rainfall, at slope bottom, undulating.
6b	Mainly dry soils, low rainfall, heavy soils, shaley limestone origin.
6c	Mainly dry soils, low rainfall, wet hollows, flat/undulating.
7a	Dry soils, slight runoff risk, permeable, Morainic sands.
7b	Dry soil, permeable limestone, poor aquifer protection.
8	Soils on thin soil cover & poor aquifer protection: no risk



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CLASSIFICATION BY TIM GLEESON, SOIL PHYSICS LAB, KINSEALY.

PLOTS SUPPLIED BY QC-DATA CORK

Teagasc

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Infiltration capacity is governed by factors including soil type and texture, on whether the ground is covered by vegetation or is bare, on degree of slope and on moisture status of the soil.

Infiltration capacity is measured in millimetres or inches. If we say that the soil has an infiltration capacity of 60 mm per hour, we mean that a 60 mm layer of water can soak into that soil in 1 hr at a steady rate, or 1 mm each minute or 1/60 of 1 mm each second. If at any instant water reaches the soil surface at a greater rate than the infiltration capacity, all of it will not be absorbed and the surplus will start to flow over the surface. Thus if water is applied at a constant rate of one mm per minute to the above soil, 60 mm will be absorbed in 1 hour. If, however, a layer of water 60 mm thick is applied in one minute then one mm will be absorbed and 59 mm will flow off the surface.

Grassland soils have a higher infiltration rate than arable or bare soils because the dense mat of grass roots creates an artificial array of large pores somewhat like a sponge. When slurry is spread at normal rates 33-40 m^3/ha (3,000-3,500 gals/acre) it is unlikely to exceed the infiltration capacity of the soil, so direct runoff of slurry at the time of application is extremely unlikely. Subsequent weather, however, may deliver very heavy rainfall or hail storms or snow which may result in a liquid load which exceeds the infiltration capacity of the soil. In such circumstances runoff will result, washing some of the slurry components to waterways.

Alternatively, the liquid may be able to get into the soil surface initially, but the soil immediately below the grass roots may be poorly drained due to a high watertable, springs or seepage, or a large proportion of small pores. Subsequent heavy or prolonged rainfall may cause runoff because the rate at which the water can pass through the subsoil, may not be sufficiently rapid. This is particularly likely if the soils are not naturally well-drained.

Soil Drainage

Drainage is the process by which water moves through the soil. There are three major reasons for poor drainage in Irish soils. These "drainage problems" as they are called, can be broadly classified as follows:

- High watertable
- Springs and seepage
- impermeable soils

High watertable

High watertable problems occur mainly in extensive flat areas. In these areas the water cannot get away until drains are installed in the soil. The depth, spacing and size of such drains can be designed from information on soil permeability, rainfall and depth of the soil profile.

Springs and seepage

The basic property of a spring is that it is caused by water emerging from the ground under pressure. Seepage is essentially the same as a spring. In this case the water also is under pressure but it does not emerge at a point but is forced up through the soil over a wider area. The important difference between water table and springs is that high water table is caused by rain falling on the site. Springs or seepage are caused by water coming up from below under pressure. This pressure is usually caused by rain entering ground elsewhere at a higher elevation and making its way underground to finally emerge at the spring or seepage line. Ideally these problems are dealt with by digging deep drains to intercept underground flow, thus relieving pressure.

Impermeable soils

Wetness in impermeable soils i.e., soils with low hydraulic conductivity, is due to the fact that the soil pores are too small to allow water to flow freely through them. They are also so small that they remain full of water even after normal drainage has finished. The usual means of draining such a soil is to instal a very intensive drainage system and also to disturb the soil in such a way as to produce cracks in it through which water can flow more freely. Both aims can usually be achieved by mole draining, subsoiling or installing gravel filled mole drains.

Interaction Between Soil Factors and Weather

As we have seen above, the main mechanism by which water leaves soil in winter is by natural or artificial drainage or through surface runoff. When rain stops, the amount of moisture in soil reaches a state where it is in equilibrium with the force of gravity within about 48 hours. The soil is then considered to be at "field capacity" and the amount of moisture retained varies very much, but is a distinct characteristic of each soil type. In summer, the main mechanism by which water leaves soil is through evapotranspiration. This includes direct evaporation from the soil surface and also the water that moves through plants into the atmosphere.

A small amount of evapotranspiration takes place in winter but it is greatly exceeded by rainfall. In summer, evapotranspiration *exceeds* rainfall for several months in most areas, soil moisture drops below "field capacity", and soils develop a *moisture deficit*. This is probably the ideal time to apply farm wastes to avoid runoff, but it is also the time when farmers are extremely busy at other activities such as silage cutting.

Fig. 1 shows mean monthly evapotranspiration and rainfall data for 4 different weather stations and it can be seen that while rainfall differs greatly between the east and

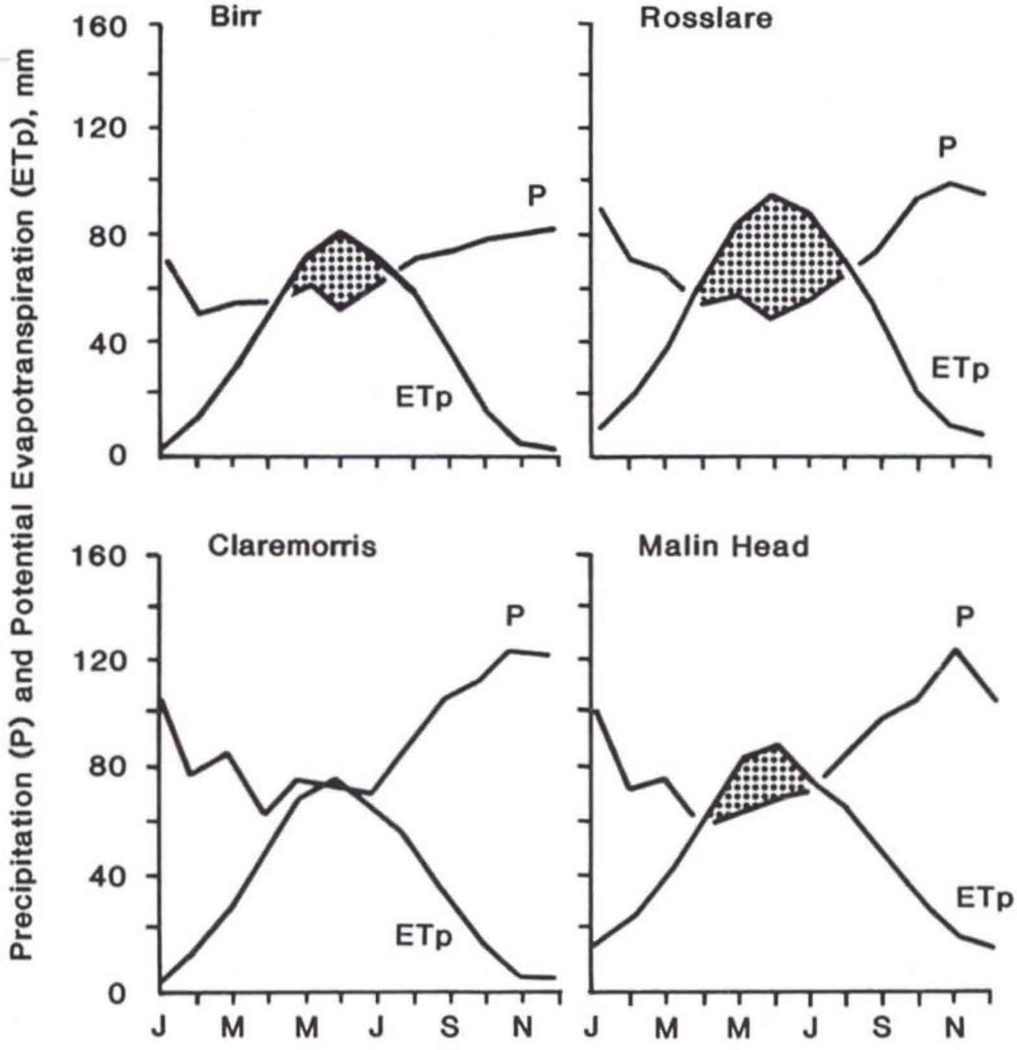

Fig. 1: Mean monthly potential evapotranspiration (ETp) and precipitation (P) data at Birr, Claremorris, Malin Head and Rosslare.

west of the country, evapotranspiration differs little between areas. In effect this means that soils in the west have almost three times more water (i.e. excess rainfall over evapotranspiration) to get rid of by drainage or runoff than soils in the east.

More detailed examination of historical evapotranspiration and rainfall data shows that the average date of first soil moisture deficit in spring varies from about March 30 at Oak Park, Carlow (which is reasonably representative of the south and east), to April 20 at Ballinamore, Co. Leitrim (reflecting the situation in the north and west). However, soil moisture deficits develop for an extended period in February at Oak Park in 5 years out of 20, and on 7 occasions in March. The frequency at Ballinamore is 3 years out of 20 in February and 4 occasions in March. In general lack of soil moisture is not a problem in western and northwestern parts of the country.

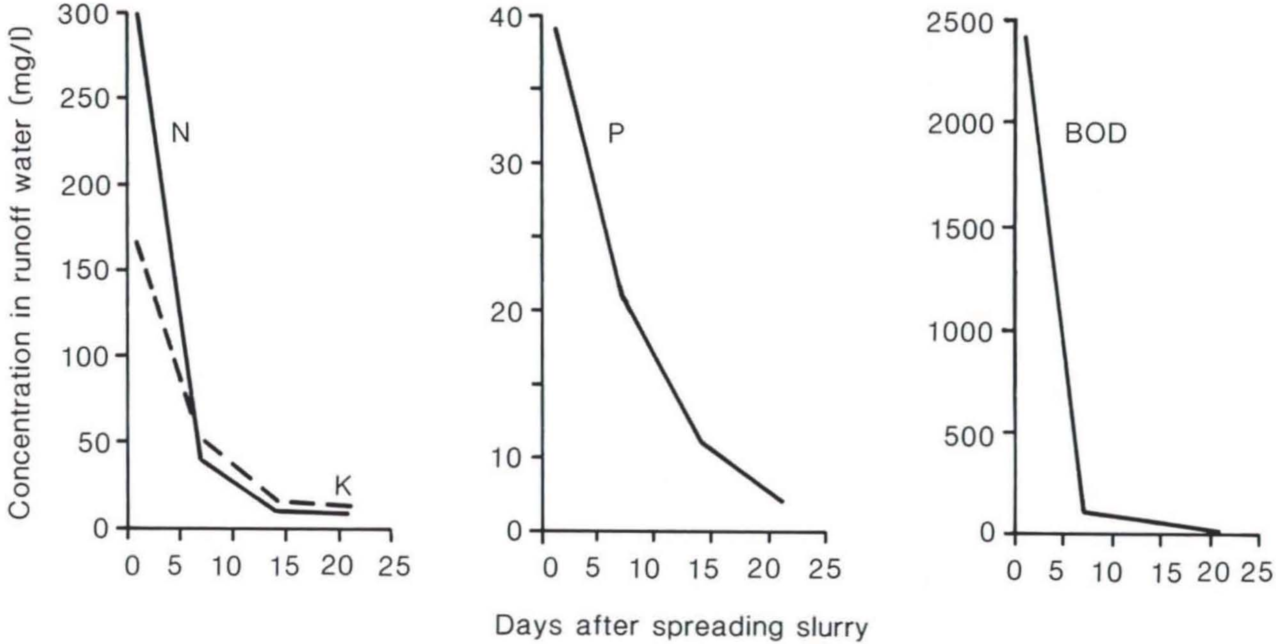

Fig. 2: Concentrations of N, P, K and BOD in runoff water at different time intervals after spreading pig slurry at 3.6 t DM/ha (35-40 m^3/ha).

CHAPTER 4

Runoff Risk of Irish Soils

A great deal of research on runoff has been carried out by the National Agricultural Research Agency (originally An Foras Taluntais, now Teagasc). These studies took place in different locations, on a variety of soil types and were subject to different climatic conditions, but the results of all studies were in broad general agreement and the main findings were as follows:

The most important factor affecting the concentration of nutrients in runoff water, was the number of days which elapsed between the date of slurry or fertiliser spreading, and the occurrence of rainfall which caused the first runoff. If prolonged rain, causing runoff, occurred within the first few days after spreading on poorly drained soil, the concentrations of BOD, N, P and K were all very high, and total losses of BOD, N, P or K could be as high as 20% of the amount applied. In one experiment more than 50% of fertilizer N was lost because of heavy rainfall within 24 hours of spreading.

If the runoff did not take place until a week after spreading, the concentrations of all parameters were markedly lower. These results are well demonstrated in Fig. 2. The most notable feature is the very rapid drop in BOD concentration which shows that landspreading is a very effective way to reduce BOD. The "bad news" is that P concentration drops relatively slowly with time, and continues at a low level (2-3 mg/l) for several weeks.

The effect of soil type was through the influence of soil permeability on the volume of runoff. Studies carried out over four years at Johnstown Castle, where mean annual rainfall was 1093 mm, showed that an average of 210 mm was lost annually in runoff from an impermeable gley soil, compared with 50 mm lost in runoff from a moderately well drained loam. When runoff occurred soon after spreading, nutrient concentration in the runoff water was proportional to the concentration of the soluble components in the material spread, and was remarkably similar in both soils.

Where soils with drainage problems are properly drained, the volume of runoff water is likely to be greatly reduced. It is important to point out that results of field experiments indicate the conditions under which *potential* runoff losses take place. In practice, at catchment level, there are many opportunities for nutrients in runoff water to be absorbed especially if the water passes over fields with low soil fertility before reaching a watercourse. Similarly, when runoff water flows into a ditch, soil sediment in the ditch may absorb soluble P from the water.

By now it should be clear to the reader that there is a *potential* for loss of nutrients to waterways through runoff, and that understanding the drainage properties of soils and avoiding times when heavy rainfall is expected soon after spreading slurry or fertilizers, is the key to preventing this runoff occurring.

A number of attempts have been made both in this country and abroad to link together soil and meteorological data to help farmers to reduce pollution risk on their farms. Most emphasis has been placed on winter rainfall and on the water retention capacity of various soil associations. The most serious obstacle to progress in this matter has been the lack of soil physical data.

Runoff-Risk Ranking of Irish soils

In order to classify the potential runoff risk of Irish soils, Gleeson has prepared a map (Plate 1, centre pages) in which he shows 8 different categories of soils with different runoff risks. He attempts to define whether those with high runoff risk are likely to be due to impermeable soils, seepage or high water tables. It cannot be over emphasised that *this map is intended as a general guide only*. There will always be great variation within any area. In fact even at farm level, most farms have dry fields and wet fields *which only the farmer knows, from experience*. The responsibility therefore rests with the farmer, to check the weather forecast before applying either slurry or fertilizer, especially to his poorly drained fields, to ensure that the oncoming weather will not cause runoff which would wash nutrients or organic matter into surface waters. *It should also be noted that many Irish soils have extremely good natural drainage and have almost no runoff risk at any time.*

The following is the detailed legend for Plate 1, outlining the runoff risk ranking for 8 categories of soil (T. Gleeson, 1992):

1. **Persistently wet soils in high rainfall areas**:– Climatic Peats, Peaty Gleys, Peaty Podzols. These soils are mainly in mountain areas with strong slopes or in low level blanket peat areas. They have high watertables due to underlying impervious pans, layers or bedrock. There is usually strong seepage down slope. Runoff is frequent with intense rainfall. Few soils are drained.

2. **Soils or very low hydraulic conductivity (< 3 mm/day in the subsoil)**: – Occasional runoff where not drained or where natural drainage aquifers are not present within about 1m of surface. They occur mainly in Upper Carboniferous Limestone Shale areas with deep deposits of till.

3. 3a **Soils where seepage is locally prevalent on wet lower slopes**:– These soils are mainly on undrained hill slopes in sandstone, granite and shale areas.
   3b **Soils of low hydraulic conductivity**: – as in 2 above but less severe.
   3c **Soils with moderately low hydraulic conductivity and some down-slope seepage**:– These soils occur mostly on slopes with deep sandstone or basalt tills and on slopes with shaley limestone and calcareous mud tills.

4. **Basin and cutover peats and adjoining alluvial flat areas**:– These soils, when not drained, have frequent high watertables. Because they are generally flat, considerable ponding will occur before any run-off occurs.

5. **Soils on drier lower hill slopes with occasional seepage and wet hollows in wet weather.**

6. **Mainly dry soils in low rainfall areas**:– Runoff risk from wet hollows and occasional seepage down-slope in prolonged wet weather only.
   6a **Soils at bottom of slope of undulating topography.**
   6b **Heavy soils of shaley limestone origin.**
   6c **Soils in occasionally wet hollows in flat to gently undulating topography.**

7. **Dry soils with virtually no runoff risk.**
   7a **Permeable soils on morainic sands and gravel**
   7b **Permeable limestone soils with shallow till cover; some with poor aquifer protection.**

8. **Soils on thin till cover and poor aquifer protection:–**
   No runoff risk.

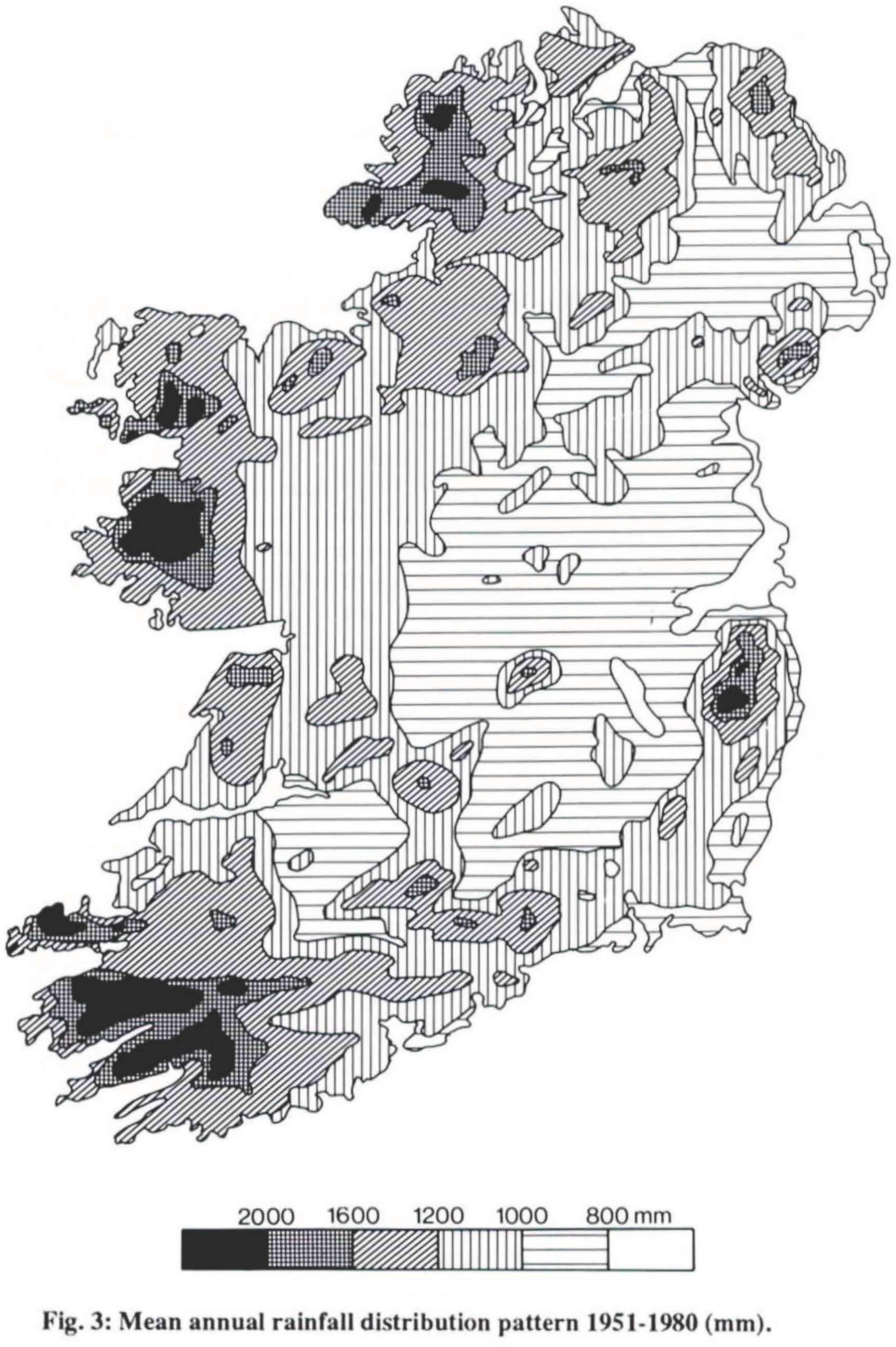

Fig. 3: Mean annual rainfall distribution pattern 1951-1980 (mm).

CHAPTER 5

Meteorological Conditions and Runoff

Precipitation in Ireland is mostly associated with frontal rainbelts and to a lesser extent with unstable, showery airflows. While individual depressions may cause heavy rain anywhere in the country, the west and north usually receive most. The northwest also experiences longer periods of rain - on average frontal rainbelts give about 5 hours of rain in the northwest (being closest to the Atlantic depressions) compared with 2 hours in the southeast. Rainbelts returning from the Irish Sea occasionally reverse the normal pattern producing heaviest falls and longest durations in the east and midlands.

Rainfall Climate

Regional distribution

The average annual rainfall map of Ireland may appear to be very complex but much of the complexity is due to topography - average rainfall is always greater on mountains. For this study rainfall is simplified into five categories (Fig. 3). If the high rainfall associated with mountains of east Munster and Leinster is allowed for, a strong increase from east to west is clearly seen. Within the high rainfall regions, however, some areas such as parts of north Kerry and Limerick have relatively low rainfall amounts.

Month to month variation

Even under average conditions, rainfall amounts vary greatly from month to month. Normally much less precipitation occurs in the spring and summer months compared with the autumn and winter months. There are pronounced regional differences however; April is driest at Claremorris, while at Roche's Point both April and particularly June are dry.

Variation from year-to-year is a regular feature of precipitation. Some months, however, show greater year-to-year variability being very wet in some years and very dry in other years. The months which have the greatest inter-annual variability are February in the midlands, east and north; April in the south and May in the west. For example, the mean annual rainfall for February at Johnstown Castle between 1968 and 1991 was 82 mm, but in 1986 it was as low as 6 mm, while in 1977 it was 191 mm. Field conditions vary greatly depending on the weather pattern of a particular month. If a winter month, e.g. February, has the possibility of low rainfall in some years, it may be unwise to totally prohibit land spreading of slurry in that month. Grass growth and nutrient uptake commence in February in most parts of the country and farmers should be able to take advantage of dry spells and suitable soil conditions to spread slurry, *provided they check the weather forecast* to ensure that heavy rain, which would cause runoff, is not imminent.

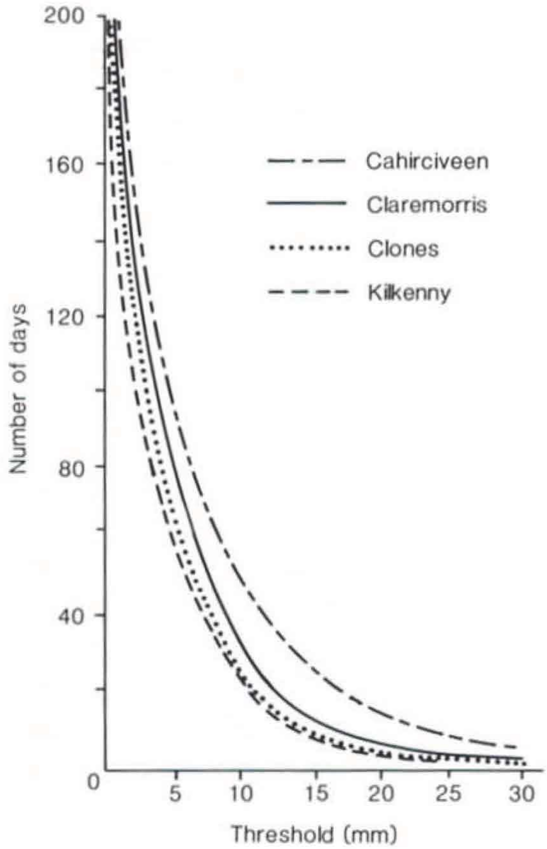

Fig. 4: Annual frequency of occurrence of days with rainfall of varying threshold values (ranging from 0.2 mm to 30 mm) at Cahirciveen, Claremorris, Clones and Kilkenny.

Occurrences of Heavy Rain

Very wet days

As the possibility of run-off is increased following a spell of heavy rain, the climatic risks may be gauged from the regional variation in the frequency of 'very wet' days. For this purpose the mean number of days with 10 mm or more rainfall are given for a representative number of stations in Table 3. On an annual basis, for example, the number of such occasions is 31 at Claremorris, 22 at Kilkenny and 17 at Casement Aerodrome in Dublin. These wet days mostly occur in the five month period September to January.

Table 3: Mean number of days with 10.0 mm or more at specified stations for period 1960-1984.

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Athlone O.P.W.	2	1	1	1	1	1	2	2	2	3	2	2	22
Ballinacurra	4	3	2	2	2	1	2	2	3	3	3	3	31
Ballyshannon	3	1	2	1	2	2	2	3	3	3	3	3	27
Belmullet	3	2	2	1	1	2	1	2	4	3	4	3	27
Birr	2	1	1	1	1	1	2	2	2	2	2	2	19
Carndonagh	4	2	2	2	1	2	2	2	3	4	4	4	31
Casement Aerodrome	2	1	1	1	1	1	1	2	2	2	2	2	17
Claremorris	4	2	2	1	1	2	2	3	3	4	4	4	31
Clones	2	2	2	1	1	1	1	2	2	3	3	2	22
Cuilcagh Mtns.	7	5	6	3	5	4	3	5	6	7	7	8	66
Delphi Lodge	10	7	7	5	6	5	5	7	8	10	10	10	88
Dublin Airport	2	1	1	1	1	1	1	2	2	2	2	2	19
Dundalk	3	2	2	1	1	2	2	2	3	3	3	3	27
Glenties Hatchery	6	4	4	2	3	2	3	3	5	6	5	5	48
Kilkenny	3	2	1	1	1	1	2	2	3	3	2	3	22
Knockaderry Resv.	4	3	3	2	2	1	2	2	4	3	3	3	34
Malin Head	3	2	2	1	1	1	1	2	3	3	4	2	26
Mallow (Hazelwood)	3	3	2	1	1	1	2	2	2	2	3	3	25
Markree Castle	4	2	2	1	2	2	2	3	3	3	4	3	30
Mullingar	3	1	1	1	1	2	1	2	3	3	3	3	24
Portuma O.P.W.	2	1	1	1	1	1	2	2	2	2	3	2	19
Roches Point	4	3	2	2	2	1	2	2	3	3	3	3	29
Rosslare	3	2	2	2	1	1	1	2	3	3	3	3	27
Roundwood	5	3	3	2	2	1	1	2	4	4	4	5	38
Shannon Airport	2	2	1	1	1	2	2	2	3	3	3	3	24
Slivermines Mtns	7	4	4	4	3	2	3	4	5	5	6	7	54
Valentia Observatory	6	4	4	2	2	2	2	3	4	5	5	5	45

Frequency of various daily rainfall amounts

The frequency of occurrence of days with rainfall of varying threshold values (ranging from 0.2 mm to 30 mm) is shown in Figure 4. Of the four stations given in the figure, and for any given threshold value, the frequency varies considerably with the location of the station. (When considering a threshold value, the frequency refers to daily rainfall equal to or exceeding a particular amount). For example, days with 10 mm or more precipitation occur twice as often at Cahirciveen as at Kilkenny. It is clear from the figure that for all stations the number of days with 10 mm or more rainfall is quite low compared with the frequent occurrences of low rainfall days.

Hourly rainfall

Short bursts of heavy rain, such as occur in unstable thundery situations, can also be the cause of runoff because the infiltration capacity of the soil may be exceeded. The relative frequency of short-term heavy rainfall events is shown in Table 4 in terms of occasions of hourly rainfall (between exact hours) of 5 mm or more. It can be seen that there are relatively few of these occasions in spring. They mostly occur in summer, especially in August/September and are often associated with thundery bursts of rain, but many soils still have a moisture deficit at that time and runoff is unlikely.

Table 4: Number of occasions in 20 years, 1958-1977, when rainfall between exact hours was 5 mm or more

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Malin Head	3	6	4	1	6	8	12	23	17	21	14	11	128
Belmullet	9	5	3	0	4	15	14	26	23	27	17	9	153
Claremorris	13	1	3	3	10	23	25	31	31	26	14	9	189
Clones	3	3	4	3	10	20	15	34	21	18	7	6	145
Mullingar	9	2	0	7	5	15	21	20	20	18	18	7	139
Birr	8	1	2	6	8	9	15	23	14	27	4	7	124
Shannon Airport	10	3	4	5	7	18	14	28	22	23	11	9	155
Kilkenny	7	8	2	5	9	8	22	23	31	22	11	8	156
Dublin Airport	8	0	1	2	9	18	20	20	38	23	12	8	161
Rosslare	21	8	6	4	13	19	25	39	41	38	38	20	272
Roche's Point	22	8	3	4	13	11	25	42	43	42	23	13	249
Cahirciveen	46	24	22	13	6	30	19	28	60	58	40	44	391

Frozen Ground

The condition of frozen ground in winter (mostly December to February) may seem opportune for the carrying of heavy field traffic, especially during a prolonged harsh spell. From a study of records over 25 years, widespread frozen ground conditions of 10 days or more have occured once in six years but at the regional level, such conditions occurred once in three years. The spreading of organic waste on such occasions may seem to provide a short term solution, but can be a risk to pollution subsequently. If a thaw sets in abruptly with the onset of a spell of heavy rain (sometimes augmented by melting snow) runoff can occur.

CHAPTER 6

Weather Information and How Farmers Can Use It

Although the Farm Development Service of the Department of Agriculture and Food and the Agricultural Advisory Services have provided technical advice on waste control structures for many years, in 1987/88 a new initiative was taken by the National Agricultural Advisory Service (then ACOT, now Teagasc) involving an intensive nationwide campaign to educate all farmers about the pollution potential of farm wastes. This campaign involved more than 300 seminars, practical demonstrations and open days and many events were organised in cooperation with the farming organisations.

Environmental education was also introduced into the curriculum for the Certificate in Farming, which is taken by two out of every three new entrants to farming. It is estimated that since that time, farmers, to their credit, have invested about £300 million in upgrading their pollution control facilities. This work was greatly assisted by more attractive grants made available by the Department of Agriculture and Food under the "Control of Farmyard Pollution Scheme" from autumn 1988 onwards.

Hopefully, most farmers now realise the pollution potential of the materials they handle, and that the biggest contribution they can make is to ensure adequate waste collection and storage facilities. The next phase of the educational programme is now under way with the objective of raising farmers' awareness about the less obvious, but highly damaging, pollution which results from the nutrients which reach waterways due to soiled water escaping from open yards and dungsteads or through runoff from land after spreading of slurry or fertilizers.

Using Weather Forecasts for Day-to-Day Decisions

Weather data and weather forecasts can be very helpful to farmers in making management decisions which could greatly reduce pollution from agriculture, and a few examples are given below.

Silage effluent

1. Wet weather prior to silage cutting time will mean that the silage contains high water content, which will result in large volumes of silage effluent - as much as 1,000 litres (220 gallons) per 100 tonnes of silage. Farmers must ensure that facilities are in place to collect *all* of the effluent and that junctions are properly aligned to channel the effluent to the collection tank. Collection tanks must be emptied regularly and not allowed to overflow.
2. Warm dry weather prior to silage cutting may mean that only small volumes of effluent are produced. However, warm dry weather will mean high water temperatures, low oxygen, and low flow in the rivers. These conditions are ideal for rapid bacterial growth so that even very small amounts of silage effluent will cause a fish kill by deoxygenation under these circumstances.

Slurry or fertilizer spreading - Avoid runoff

Farmers normally check that soils are sufficiently dry to take machinery for spreading either fertiliser or slurry without causing wheel marks. This precaution will ensure that the soil has some soakage capacity so that slurry will not runoff during actual spreading, provided recommended rates 33-40 m^3/ha (3000-3500 gals/acre) are not exceeded. However, it is very important that farmers should also check *the weather forecast before spreading to ensure that heavy rainfall is not expected within the first few days* as this could cause runoff of nutrients from both slurry and fertilizers especially if spread on poorly drained soils. It would be wise for farmers in catchments of sensitive lakes or reservoirs, to spread their P fertilizer in summer, when runoff risk is low.

Nitrate leaching

1. Nitrogen fertilizer spreading. Farmers should always try to match fertilizer applications to crop growth patterns. This means applying the bulk of the N fertilizer in the first half of the growing season, with smaller applications later in the season. If there is a prolonged drought in July/August, no further N should be applied until the drought ends. No fertilizer should be applied after the first of September. These precautions help reduce nitrate leaching.
2. Slurry spreading in autumn/early winter. Slurry applied to coarse free-

draining soils at the end of the growing season may contribute to nitrate in groundwater. It is better to apply slurry, as much as possible, during the growing season so that there are only small amounts to be spread at the end of the grazing season.

Toxic chemicals

The weather forecast may include an alert that conditions are suitable for the spread of plant pathogens. If farmers decide to spray crops with appropriate pesticides they should be careful to avoid any spillage of chemicals into water through overflow of spraying equipment or careless disposal of containers, as these chemicals are very poisonous and may contaminate public water supplies and/or kill fish.

Availability of Weather Forecasts

The Meteorological Service provides detailed weather forecasts six times daily on national television and four daily on national radio (as well as several other shorter forecasts on regional and local radio). Telephone recorded forecasts with 3-day outlooks are available on a regional basis and these are updated three times daily. Forecasts are also given in the daily and weekly national and provincial press.

The radio broadcast at 7.55 am on RTÉ Radio 1 gives a forecast for up to 5 days ahead and *the farming forecast on RTÉ 1 on Sunday (14.15 hours) gives one for a week ahead, and in particular relates the weather conditions to a wide range of farming activities*. While the Sunday farming forecast gives farmers an opportunity to plan their activities for the week ahead, the daily forecasts can be used to check before proceeding with a particular task on a particular day.

The computer forecasts from the European Centre and Medium Range Weather Forecasting (ECMWF) and the many advances made in a wide range of technology, including satellite cloud pictures, radar images now enable the Meteorological Service to routinely provide forecasts up to five to seven days ahead. While the accuracy of the predictions usually decreases as the forecast period increases, nevertheless weather forecasts show a considerable level of skill up to four days or more.

Useful outputs of the ECMWF predictions are rainfall amounts. In this way approaching weather systems which are likely to give considerable precipitation over the country can especially be

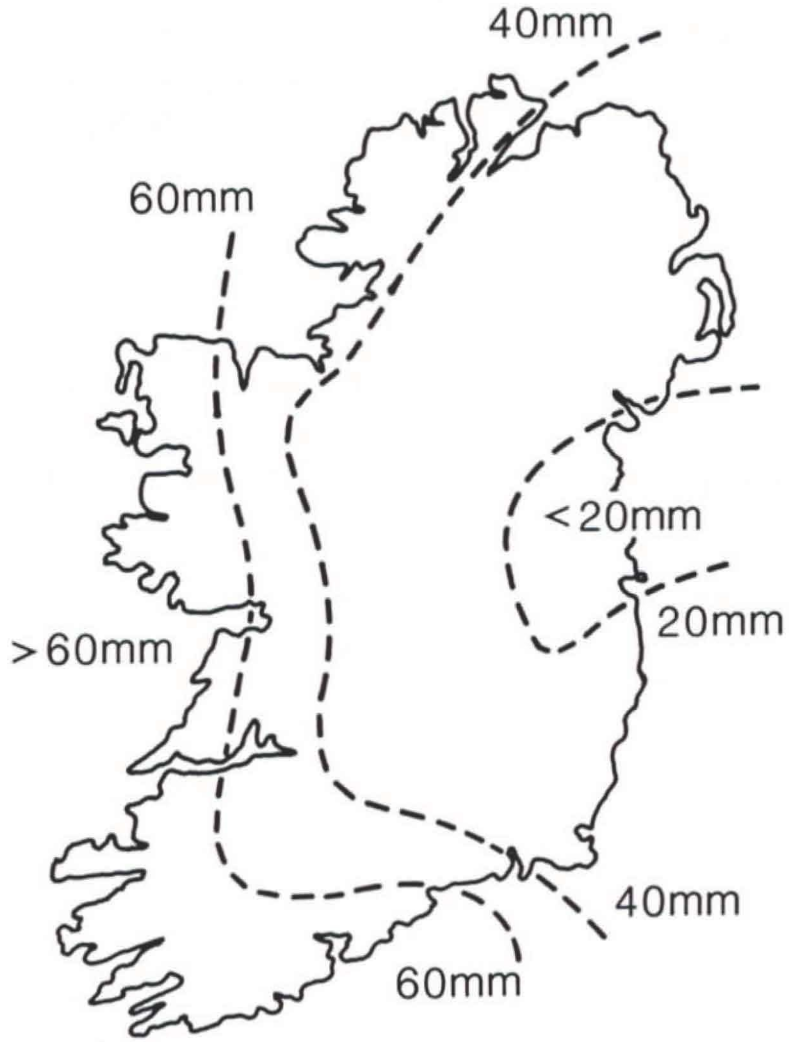

Fig. 5: Example of the type of forecast given on TV, showing predicted regional variations in the total rainfall amount forecast for seven days (25 mm = one inch).

highlighted for farmers. Figure 5 shows a typical prediction giving regional variations in the total rainfall amount forecast for seven days. While weather forecasting still contains an element of uncertainty, nevertheless, the regular issue of such information should help farmers plan activities, e.g. the spreading of slurry and fertizsers. This would be true especially where the current field conditions are suitable for the task but where the weather in subsequent days could lead to considerable runoff.

Conclusion

Current and forecast meteorological conditions, as well as the climate and soils of an area, are important considerations when evaluating potential for runoff. For farmers to manage farm waste disposal, they must take into account all the information at their disposal, not least of which is the meteorological information. It is clear that there are great regional differences in climate and that considerable year-to-year variation occurs. Conditions can sometimes be suitable from January to March for spreading farm waste on land, but because of small evapotranspiration in winter/early spring, large soil moisture deficits are unlikely to develop and runoff can more easily occur with the onset of wet spells in those early months. The weather forecast can be of considerable importance in avoiding farm generated pollution despite the uncertainties which sometimes attach to the information.

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