INFILTRATION RATE ASSESSMENT OF SOME MAJOR SOILS

END OF PROJECT REPORT

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SUMMARY

Landspreading of fertilisers and wastes require an evaluation of the risk of overland flow in order to minimise risks of polluting rivers and lakes. Infiltration capacity measurements offer a practical means of indexing runoff risk. The objectives of this study were to assess the spatial and temporal variability of infiltration capacity and to assess the capacity of some major Irish soils.

Infiltration capacity was measured using double ring infiltrometers at freely drained (8) imperfectly drained (1) and poorly drained (1) sites. The first series was performed for one day in summer. Eight years later a second series was conducted for two days in winter and summer at the same sites. On average six replicates were required in summer and fourteen in winter to estimate the mean with 50 percent precision. Capacities were reasonably stable between years but there was a significant difference between seasons. Capacities in summer were about 3.5 times the winter values. Except on the poorly drained soil the infiltration capacity exceeded or equalled the five year return rainfall rate indicating a very small risk of overland flow in summer. In winter the capacity at three sites, including freely drained sites, were less than 2.5 mm hr^{-1} indicating a significant general risk in winter.

INTRODUCTION

Infiltration is the process by which water enters the soil. It separates water into two major hydrologic components - surface runoff and sub-surface recharge. The assessment of runoff risk has assumed an increased importance because of concerns about the associated pollution hazards. Accurate determination of infiltration rates is an important factor in reliable prediction of surface runoff. As environmental impact statements (EIS's) are concerned with long range effects it is essential that the infiltration data on which they are based should be reasonably stable over decades. For planning purposes it is essential to know the stability of infiltration data under Irish conditions and whether the infiltration capacity of individual soils is adequate to cope with the anticipated hydrologic loads.

The objectives of the investigation were to evaluate (1) the infiltration capacity of the dominant component of major soil associations and (2) the reliability of infiltration tests.

The mathematical and physical analysis of the infiltration process developed by Phillip (1957) separates the process into two components - that caused by the matric potential force (suction) and that caused by gravity.

The early stage is dominated by soil suction which for a specific soil is determined by the moisture content. This component tends to vanish at large times and the infiltration rate becomes equal to the field saturated hydraulic conductivity. Thus as infiltration progresses the influence of the initial soil moisture content decreases and eventually becomes negligible (Phillip, 1957).

An ideal infiltration curve, based on theoretical analysis, is illustrated in Fig. 1. A given soil ends up with the same infiltration rate whether the soil was initially dry or moist. Rainfall or irrigation at rates greater than the infiltration capacity will result in surface runoff. The steady infiltration rate represents the minimum capacity as the soil can absorb additional amounts of water in and on the soil. The steady infiltration rate is a conservative design criterion and its use for predicting risk of runoff includes ample safety margin. The steady infiltration rate is a function of the pore configuration of the soil. Soils in Ireland derived from shale, sandstone or limestone containing little or none of the swelling clay mineral montmorillonite are the predominant soils in Ireland (Gardiner and Radford, 1980) and consequently the steady infiltration rate should remain stable over time unless the soil structure is altered by animal or machine traffic.

MATERIALS AND METHODS

Sites

Measurements were made at ten sites. These were chosen to represent the dominant component of major soil associations located mainly in the south and east of the country (Fig. 2). These sites were originally used in a study of the transfer of Radiocaesium from soils to crops after the Chernobyl incident. Infiltration measurements had been conducted at these sites in summer 1988. Repeat measurements were made in 1995 or 1996 and, except at Clonroche, were located in the same field as near as possible to the original site. At Clonroche an alternative site on the same soil series was selected following the sale of the original site.

The classification, drainage and texture characteristics of each site are given in Table 1. Soil Association 14 is represented by two sites at Clonroche and Dundalk; the latter is a stony phase. Most of the sites are well or moderately well drained reflecting the preponderance of free drainage in the more intensively utilised agricultural areas in the region. The Castlecomer site, an impermeable Gleysol, was anticipated to represent soils of high runoff-risk while the Kilcock site represents the transition between the free draining soils and the permeable Gleysols. Textures of the free draining sites range from sandy loam to loam in the A horizon and from sandy loam to clay loam in the B horizon. Structure of the A horizon was moderately well developed at most (8) sites; the structure at the Dundalk site was strongly developed and was weakly developed at Castlecomer. All sites were under grassland and at the initial test were not trampled to any significant extent. However the Birr site was trampled by sheep after the summer test and prior to the winter test.

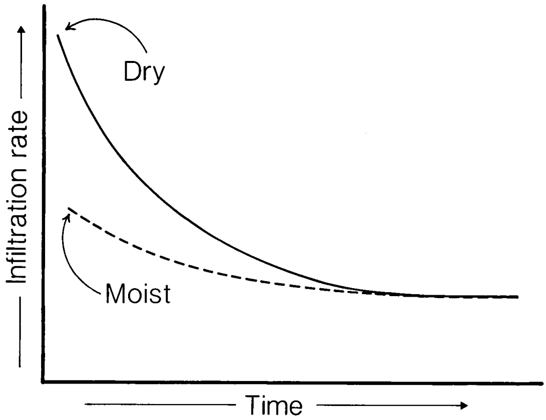

Fig 1: Ideal infiltration curves

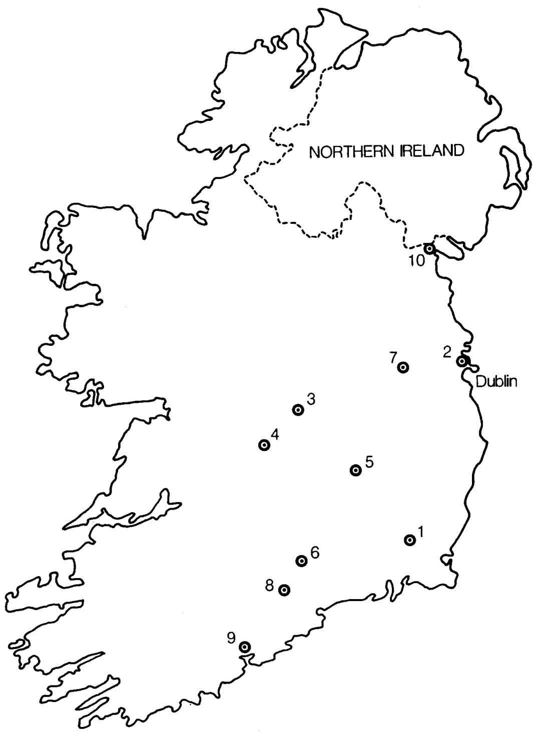

Fig. 2. Location of sites.

Table 1: Classification, drainage and texture characteristics of sites								
Site No.	Name	Association[1]	Drainage Class	Texture		Bulk density kg/l	Moisture Content % saturation	
				A horizon	B horizon		Summer	Winter
1	Clonroche	14	Well	Loam	Clay loam	0.97	88	100
2	Kinsealy	38	Moderate	Loam	Clay loam	0.95	53	100
3	Birr	30	Well	Sandy loam	Sandy loam	1.16	39	100
4	Gurteen	31	Well	Loam	Loam	1.05	78	100
5	Castlecomer	22	Poor	Clay loam	Clay loam	0.61	74	100
6	Clonmel	34	Well	Loam	Clay loam	0.85	75	100
7	Kilcock	40	Imperfect	Loam	Clay loam	0.92	31	92
8	Cappoquin	6	Well	Loam	Loam	0.92	76	100
9	Midleton	13	Well	Loam	Loam	1.13	14	100
10	Dundalk	14	Well	Loam	Stony loam	0.99	37	99

[1]Gardiner and Radford (1980)

At each site the initial moisture content at 0 - 60 mm depth was lower in summer than in winter (Table 1). In winter the surface was field saturated except at Clonmel and at Kinsealy.

In summer all sites were unsaturated to varying degrees. Bulk density was low at all sites and was mostly less than one. This is attributed to the abundance of grass roots at the surface. It indicates that compaction by machines or animals was negligible.

Measurement of Infiltration

The method of measurement was chosen to simulate as far as possible the practical conditions encountered in environmental impact assessments.

Infiltration rate was measured with a double-ring infiltrometer (Plate 1) with inner diameters of 280, 300 or 320 mm and outer diameters of 540, 560, or 580 mm. The slight variation in diameter allowed nesting of cylinders during transport. Rings were 25 mm deep and were made from 12 gauge shovel steel with sharpened bottom edges. The outer rings were reinforced by welding a mild steel band (50 mm x 6 mm) to the top driving edge. An oak beam 1.5 m x 200 mm x 140 mm was placed across the cylinder which was driven into the ground to a depth of 50 mm using a 7 kg sledge hammer. Grass was cut to near soil level and a pad was placed inside the inner ring to prevent puddling. The inner and outer edges were tamped to seal possible cracking. Six double-ring infiltrometers were set up at each site. Water was transported to the site in an 1100 l tank and was added periodically to the cylinders using 25 l drums. Generally the water level was kept at or above 5 cm depth; the difference in height between the inner and outer rings was kept to a minimum. The amount of water required per site, on day one in summer varied from 300 l at Castlecomer to 3,500 l at Cappoquin; a smaller amount, 100 l to 2,500 l was required on day two. The rate of fall in the water level in the inner cylinder was measured at 1, 5, 10, 15, 30, 45 and 60 minutes and at 30 minute intervals thereafter. The test was conducted for one day in the first series of measurements and on two consecutive days in the second series. The duration of the tests was from 4.5 to 7.5 hours in winter and from 6.5 to 8.5 hours in summer.

Attempts to obtain undisturbed soil samples from the inner cylinder, after completion of the infiltration measurements, were unsuccessful due to compression of the saturated soil. Ten soil samples, 60 mm deep were obtained at random from the area between the infiltrometers. These were bulked for the determination of gravimetric moisture content. To estimate the initial soil moisture tension a minimum of twelve undisturbed samples was obtained from the site using 50 x 50 mm stainless steel cylinders.

Plate 1: Double ring infiltrometer

RESULTS

Variation within Sites and Sampling Requirement

Intra-site variation in steady infiltration rates was substantial and varied widely between sites. In summer, year 2, the coefficient of variation (CV) ranged from 0.14 at Cappoquin to 0.84 at Kinsealy. The mean CV for all sites was 0.45 and was similar to that found in year 1 (CV = 0.44) Intra-site variation was much higher in winter. The mean CV for all sites was 0.7; the CV ranged from 0.43 at Clonmel to 1.05 at Midleton.

The spatial variation in summer is similar to the variation in field saturated hydraulic conductivity (CV = 0.5) found in glacial till soils (Diamond, 1984). The similarity is to be expected as the steady infiltration rate is theoretically equal to the mean vertical hydraulic conductivity of the profile (Bouwer, 1986). Estimates of the number of observations required to estimate the mean infiltration rate of a site at three levels of precision are shown in Table 2. As the variation tends to be greater at lower infiltration rates the levels of precision are defined as a proportion of the mean viz 1, 0.4 and 0.2 times the mean. On average six replicates are required in summer and 14 in winter to estimate the mean rate of a site with 50 percent precision (CV = 1 x mean). In summer this rises to 40 at twenty percent precision and to 158 at ten percent precision. Some individual sites had extraordinarily high sampling requirements e.g. Kinsealy which required over 500 observations for ten percent precision. In winter the number of observation required for a given level of precision was higher than in summer. In general about twice as many are required in winter (Table 3). With six replicates the 50 percent precision level was achieved at seven sites in summer and at only two sites in winter. The large numbers of replicates required, even on homogeneous soil areas, make the attainment of greater than 50 per cent precision impractical. The sampling requirements of a particular site are not predictable. Six should be adequate for most sites comprising a single soil series and phase. Additional measurements should be made as indicated by the variance. Land areas comprising more than one soil unit will require a corresponding increase in the number of observations.

Duration of Tests

Regression analysis shows a significant correlation between the infiltration rates on day 1 and day 2 in summer ($R^2 = 0.754^{xxx}$) and also in winter ($R^2 = 0.770^{xxx}$). The mean value on day 2 was slightly lower, than on day 1 in summer; analysis of variance indicated that the difference was not statistically significant. In winter however, the infiltration rate on day 2 was about half that on day 1 and the difference was statistically highly significant.

The two-day test is necessary in winter as the steady state is not achieved in a single day. An alternative way would be to apply the correction indicated by the regression equation to the day 1 data; however, this is unreliable as the same relationship may not obtain under a different moisture regime. Although on average the difference is small in summer, the two day test is still necessary because of large differences in individual sites such as for example, Birr.

Longterm Variation

The difference in mean infiltration rate between year 1 and year 2 was small (10 mm hr-1) and was not statistically significant ($P < 0.05$). At the nine sites in which measurements were repeated in the same field the mean infiltration rates of sites were significantly related ($R^2 = 0.53^{x}$) on day 1 and very significantly related ($R^2 = 0.70^{xx}$) on day 2. Given the large intra-site variability and that the tests were not performed in exactly the same position in both years, this implies that the soil structure and associated pore configuration were reasonably stable over the eight year period. The low bulk density in year 2 indicates that compaction by animal or machine traffic was insignificant. The long term stability of steady infiltration rates in summer indicates that infiltration rate tests can have a role in the long term prediction of surface runoff.

Seasonal Variation

Infiltration rates were substantially lower in winter than in summer. On day 1 the final infiltration rate was about half the summer rate. The infiltration rate in winter on day 2, which is a better measure of the steady rate, was about one-third of the summer rate. The differences between seasons were statistically very significant ($P<0.001$). Regression analyses did not show a relationship between steady infiltration rate and initial moisture content. The stability of infiltration

Table 2:	Average number of measurements required per site (P<0.05)		
	Confidence Interval (x mean)		
Season	0.2	0.4	1.0
Summer	158	40	6
Winter	353	88	4

rates between years indicates an overall long term stability of soil structure. Seasonal changes in soil structure, especially in the subsoil, are unlikely to be significant. Abrupt changes in infiltration can occur in soils composed of swelling clays. However, in Ireland, the montmorillonitic minerals which form swelling clays are not associated with shales, sandstones and limestones which comprise the parent materials of the sites. Except at Birr, there was no visible evidence of compaction by animals or machines having occurred between the summer and winter tests. There was a clear difference in the initial moisture content between summer and winter and, although regression analysis did not reveal a relationship between infiltration rate and the initial moisture content at the surface, the change in moisture regime from summer to winter is the most likely cause of the large seasonal difference in infiltration rates. In winter the lowest infiltration rate was at the free draining Clonroche soil. The rates were slightly lower at 100 mm depth than at the surface indicating that the low rates were not caused by surface compaction. Pressure head measurements indicated the presence of a perched water table during the later stages of the infiltration test at Clonroche. A perched watertable would impede the downward flow of water and cause slow infiltration. At the other seven free draining sites infiltration rates were higher than at Clonroche (Table 4) and the seasonal change in infiltration rates may not be due to perched water tables at these sites. At Kinsealy, where there was a twofold seasonal change, a piezometer driven to 45 cm indicated unsaturated conditions in winter. The field saturated hydraulic conductivity may be only 0.25 to 0.5 times the conductivity at full saturation.

Influence of Soils

The mean infiltration rate of each site in summer and winter (day 2) are presented in Table 4. Infiltration tests are a poor discriminate of soil properties in winter because infiltration rates are influenced more by hydrologic regime than by soil properties.

In summer four classes are distinguished (Table 4). The Castlecomer site, an impermeable gley was always in the lowest group. Classification of the sites into coarse and medium/fine textured groups showed that the infiltration rates of the coarse group were always at least twice the medium fine group. Although there was some overlap between the groups it seems that infiltration rates above 100 mm/hr are invariably associated with coarse texture whereas values less than 50 mm/hr are most likely to be associated with medium/fine texture.

Implications for overland flow

Since rainfall is generally intermittent in Ireland the intensity over hourly periods is more appropriate than daily rates to evaluate the risk of overland flow. The expected rainfall, with a return period of 5 years for times of one hour, is less than 18 mm in the lowland regions of the country (Logue, 1975). Obviously the expected rainfall or the maximum liquid application rate should not exceed the infiltration capacity if surface runoff is to be avoided. However the measured values need adjustment to approximate the true infiltration capacity. A derating factor of 0.6 compensates for ring size and ponding depth. In summer the derated steady infiltration rates are at or above 18 mm hr^{-1} at all sites except Castlecomer. This implies that, except on impermeable gley soils, the risk of overland flow in summer is negligible on soils that are wettable and lack visible evidence of abnormal compaction by machines or animals. The steady infiltration rate defines a minimum absorption capacity. At any given time, especially in summer, the soil will be capable of storing additional water both in and on the soil; the amount will depend on the antecedent weather conditions and on micro relief. This reduces still further the actual risk of overland flow.

In winter the infiltration capacity at all sites, except Dundalk, was below the five year return hourly rainfall indicating a risk of overland flow. Four sites, including two freely drained sites, were below 5 mm hr^{-1} and three sites were below 2.5 mm hr^{-1}. The 'Code of Good Agricultural Practice' (DOE, DAFF 1996) recommends that the appropriate rates of application of soiled water by irrigation in sensitive and other areas should not exceed 2.5 mm hr^{-1} and 5.0 mm hr^{-1} respectively. Six sites could cope with the maximum rates but irrigation at these rates in the other sites could result in overland flow. Except possibly the impermeable gleys it is not possible to discriminate between sensitive and other areas in winter based on infiltration tests. The risk is determined by the interaction between weather conditions and hydrologic regime which change with time.

Table 3: Mean steady infiltration rate (mm/hr) by year, season and day

Summer*		Year 1	Year 2	Significance
		69.4	79.5	NS
		Winter	**Summer**	
Year 2**	day 1	42.2	85.2	xxx
	day 2	21.9	76.4	xxx
Significance		xxx	NS	

* - 10 sites

** - 9 sites, excluding Clonroche

Table 4: Mean steady infiltration rate (mm/hr) of each site and grouping by Duncan's Multiple RangeTest

		Year 2, Day 2	
Site	No.	Summer	Winter
Clonroche	1		0.8b
Birr	2	53.7c[x]	11.3b
Burteen	3	114.0b	8.7b
Midleton	4	103.0b	22.0b
Kilcock	5	96.3b	6.0b
Castlecomer	6	5.3d	1.7b
Kinsealy	7	29.0cd	11.7b
Dundalk	8	96.0b	122.0a
Cappoquin	9	160.0a	3.7b
Clonmel	10	30.0cd	10.3b

[x] - Within each season, sites with the same letter are not significantly different ($a = 0.05$)

CONCLUSION

1. Infiltration capacity was reasonably stable over an eight year period and accordingly infiltration tests have a role in assessing the long term risk of overland flow and the associated pollution hazard.
2. There was a pronounced seasonal effect. Steady infiltration capacity in summer was on average 3.5 times the winter rate. Except on an impermeable gley, the infiltration capacity in summer equals or exceeds the hourly rainfall expected once in five years. Consequently the risk of overland flow is very small on freely drained soils in summer. Irrigation rates of 5 mm ha-1 or 2.5 mm hr^{-1} permitted by the Code of Good Practice exceed the infiltration capacity of some soils, including free draining soils, in winter. Consequently there is a significant risk of overland flow in winter.

Substantial variation occurs within sites and the variation is greater in winter than in summer. For 50 percent precision six measurements are in general required on sites composed of a single soil series or phase. A correspondingly greater number will be required on land areas composed of a number of soils. It is recommended that (1) infiltration tests are carried out in summer as tests in winter do not reflect stable soil characteristics and (2) that the tests are performed over two successive days. To assess the risk of overland flow over the whole year additional information will be required on the duration and degree of wetness.

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