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DRAINAGE OF A HILLSIDE SEEP IN CO. CAVAN

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ABSTRACT

The drainage of a hillside seepage arising from a perched water-table was examined and measured. A drain installed to control the seepage was not well located as an interceptor drain and only partially penetrated the upper permeable stratum. As a result, the drain only controlled the seepage over one-ninth its length. Even where the drain appeared to be well located, large amounts of water underflowed it. Downhill from the drain the water-table rose above drain level as a result of high radial resistance. It is concluded that interceptor drains and ditches should penetrate into the impervious clay to intercept all downhill flow and that the drain or ditch should be located just uphill from the seepage boundary.

INTRODUCTION

Hillside seepage problems arising from perched water-tables are common on the freer draining drumlin hills such as those of Co. Cavan. Seepage can arise as a result of a reduction in the land gradient or in the depth to impervious layer, or a combination of both. Drumlin hills are about 80 ha in area and rise with variable slope from about 50 to 110 m above ordnance datum (O.D.). Slopes vary from 0 to 9% on the tail of the hill through 9 to 35% on the steep body to 0 to 9% on the crest of the hill The depth to essentially impervious clay subsoil is also variable as noted by Kilroe, Seymour and Hallissy (1). They found depths of 18 and 40 cm common on the crests and lower slopes respectively of drumlins at Ballyhaise, Co. Cavan. Later, Lee and Ryan (2) found that a soil sequence could be mapped on the hills at Ballyhaise; in general Gleys were found on the crest and tail slopes, while moderately well-drained brown podzolic soils were found on the steep slopes. This sequence of soils was recently re-examined, and gley soils on the slopes and tails of hills were found to be associated with seepage zones. The main cause of the seepage was a rise in the level of the clay layer near the soil surface and also in some areas a reduction of the land gradient. Downslope, dry and seep zones could alternate as often as five times. Neither of the papers (1, 2) refer to hillside seeps nor are they mentioned in the recent Soil Survey Bulletin (3).

Hillside seepage zones are easily discernible on the lansdcape. Seepage forces result in a swampy condition and if the forces are strong they can result in soil slips. In neglected pasture fields, seep zones show up as rushy patches. In heavily fertilised pasture fields at Ballyhaise College, seep zones show up in winter as areas growing tall straggling creeping bent grasses with winter whitening in a background of green pasture of meadow grasses. In practical farming, hillside seeps create great inconvenience and danger from wheel spin and bogging in of farm machinery. There is also a reduction in grass growth along with a prevalence of rushes and other weeds. Moreover, swampy zones may play a big role in the transmission of liver fluke disease.

Interceptor drainage is the standard method of dealing with hillside seepage (4). The main factors of importance are the location, depth and type of interceptor drain. Most analyses of the drainage of hillside seepage are based on Dupuit-Forchheimer assumptions (4, 5, 6, 7). Schmid and Luthin (8) solved the Boussinesq equation for a hillside drained with fully penetrating parallel ditches. Model tests (6, 7) showed that the solution is valid for slopes up to 30%. Selim and Kirkham (9, 10) derived analytical expressions for the flow of groundwater through hillsides of both constant and arbitrary slope. In particular, they describe the movement of water down a saturated hillside and upward out of the soil at a ponded seepage zone in a hillside where the permeable layer becomes constricted downhill.

This paper describes the drainage of a hillside seepage arising from a perched water-table only.

EXPERIMENTAL

A hilly farm on the outskirts of Killeshandra was studied. Figs. 1 and 2 show semisections of two typical hills on the farm. In both hills the seepage zone arises from a major downhill constriction of the permeable topsoil. The profile of the impervious clay (Fig. 2) varies substantially; over a distance of 0.6 metres the clay layer dropped 30 cm at one location in the seep zone. The seep area (Fig. 2) was selected for detailed study since a field drain had been installed near and through it at one point.

The soil on the hillside is variable. On the crest there is a pseudogley varying in extent downhill. The pseudogley only extends 36 m downhill while in an adjacent transect 20 m east (not shown), it extends 120 m downhill. Downhill the pseudogley is followed by a brown podzolic soil, a seepage water gley, a brown podzolic, a seepage water gley and a brown podzolic to a lake. The depth of topsoil (A_1 horizon, clay loam to sandy loam) varies from 15 cm on the hill top through 36 cm on the brown podzolic to 20 cm on the seepage zone. Underlying the topsoil is a gritty tight clay on the crest pseudogley, and clayey fine sand to fine sand with coarse sand lenses on the brown podzolic. Flow in these fine sands was virtually all through cracks while the matrix has slow hydraulic conductivity. Moderate to rapid inflow of water through

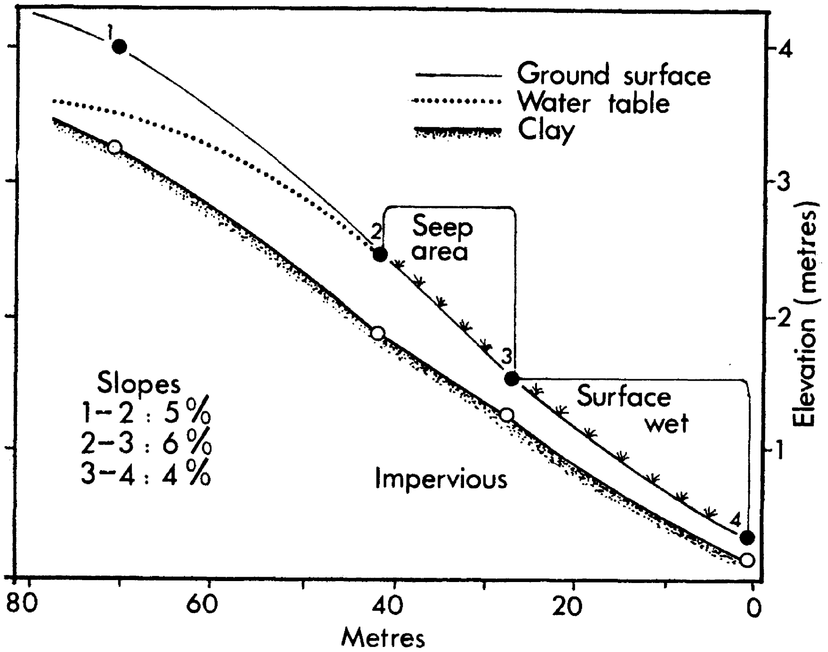

Fig. 1: A semi-section of a Killeshandra hillside showing the gradual constriction of the permeable layer and the occurrence of a seep zone

soil cracks was observed in numerous test pits carefully excavated. It was planned to measure hydraulic conductivity of the fine sand layer (the predominant flow medium) but this was abandoned when the nature of the flow was determined. The impervious clay layer is a tight, firm, overconsolidated gritty clay with a bulk density of 2.3 g/cm^3; it is plastic and strongly cohesive. The hydraulic conductivity is estimated in the order of 1.10^{-6}m/hr and the clay is effectively impervious.

The hillside had been drained the previous year, i.e., 1973, by mole drains discharging into piped collector drains with a gravel overlay (Fig. 3). Although the mole drains caused considerable cracking in the brown podzolic they failed through structural collapse in the seep zones and were ineffective in drying them. In these zones the plastic cohesive layer was too deep to be intercepted by mole drains with inverts at 45 cm depth.

The collector drain with an invert depth of 69 cm penetrated about two-thirds to nine-tenths the depth of the permeable layer. It consisted of a 50 mm plastic tube laid on a sand bed and overlain with permeable gravel to within 36 cm of the adjoining

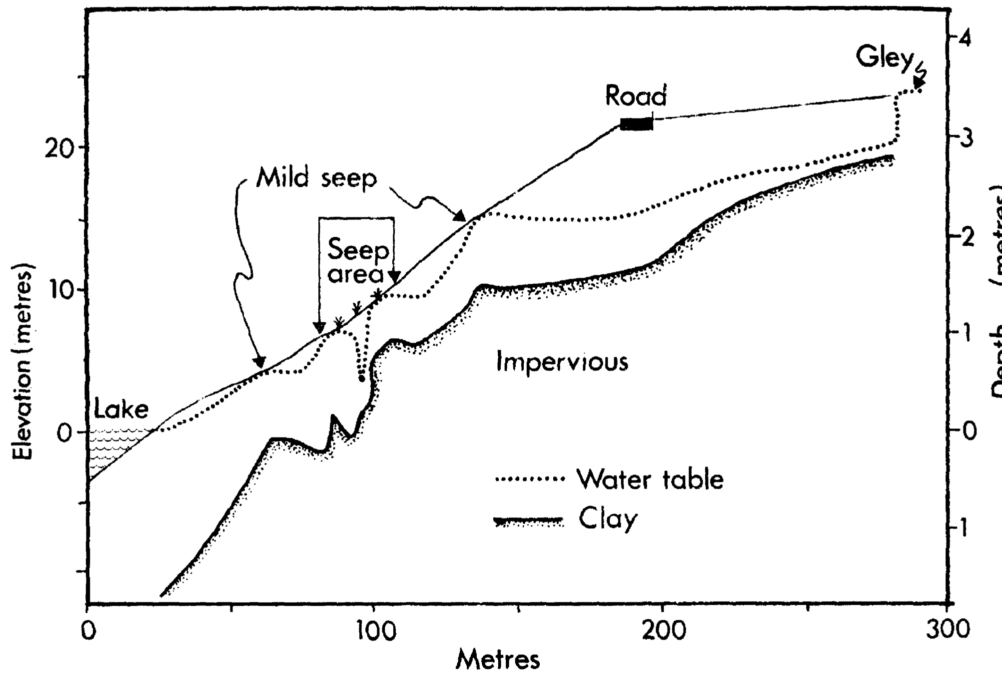

Fig. 2: A semi-section of a Killeshandra hillside showing the very uneven nature of the impervious clay layer and the occurrence of seepages

ground surface. The collector drain was placed at an angle of 5° to the contour to give a gradient of 9%. The drain was too low to intercept the seepage area for 42 m from its outfall or four-ninths its length and too high over another four-ninths (Fig. 3). It seemed to be reasonably effective over about one-ninth its length as judged on the ground.

The following measurements were made:

1. Infiltration capacity by double ring flooding infiltrometer on the brown podzolic area. Measurements were taken after overnight wetting of the ground.
2. Piezometric heights at various depths and intervals from the collector drain.
3. Water-table levels at two directly uphill transects through the collector drain where the drain was a) too far down the hillside to intercept the seep and b) reasonably effective in intercepting the seepage.
4. Discharge measurements from the drain.

RESULTS

Infiltration capacity

Some typical infiltration curves are shown in Fig. 4. The geometric mean of the measurements was 13.5 mm/hr. Measurements in adjacent fields gave means of 17.4, 12.1 and 7.2 mm/hr. Very high values were found over and adjacent to some mole drains; high values measured were 77.0 and 63.3 mm/hr. These values show that infiltration capacity is high on the body of the slope and that direct surface run-off is practically unimportant as a source of flow augmentation to the seepage zone. At a nearby station (Ballinamore) the average hourly rainfall intensity in rainy spells is 1.1 mm and intensities in excess of 5 mm/hr are extremely rare. If the small head of ponded water employed (20 to 50 mm) is ignored, the vertical hydraulic conductivity may be taken as $1.4.10^{-2}$m/hr.

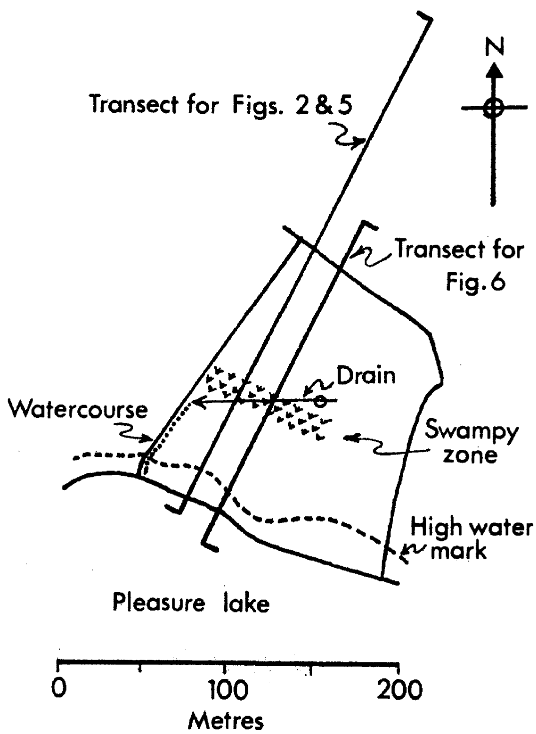

Fig. 3: A site plan showing seep zone, drain location and position of transects

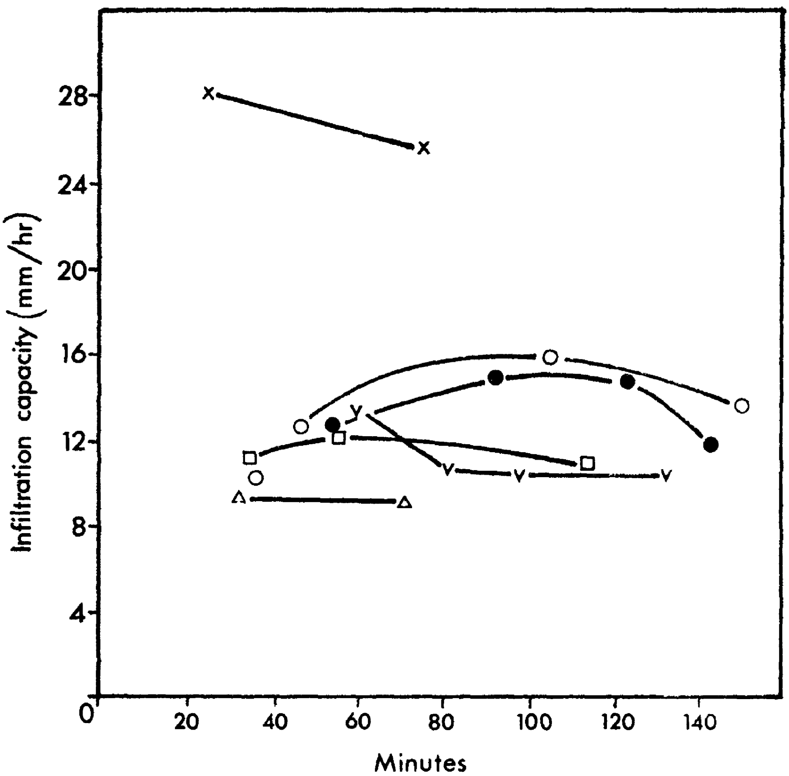

Fig. 4: Some typical infiltration curves after over-night wetting of the ground

TABLE 1: Piezometric heads (cm below soil level) during wet and dry spells at various distances from the drain

Distance uphill from drain (m)			6[a]				12			18	
Elevation (m)			0.0				0.8			2.0	
Depth to impervious layer (cm)			73				69			46	
Piezometer depth (cm)	30	60	75	90	108	60	75	90	60	75	90
Dry weather	33	29	31	27	33	47	55	77	—	74	77
Showery weather	23	23	27	22	29	41	47	47	74	68	72
Wet weather	4	+2[b]	2	0	4	7	9	23	23	22	25

[a] Uphill periphery from seep area
[b] 2 cm above ground surface

Piezometric heads

Piezometers were installed at 6, 12, 18 and 24 m uphill from the collector drain and at various depths at each point. Measurements during dry and wet spells showed that the water-table was essentially static at each point (Table 1) with practically zero deep seepage. This established that the clay subsoil was acting as an aquiclude. The head for the piezometer at 6 m and 60 cm depth consistently rose above ground level in wet weather and would appear to validate the theoretical deductions of Selim and Kirkham (9, 10). The piezometers at 12 m and 90 cm depth and at 24 m and 135 cm depth showed a slow but steady increase in head and behaved differently to the remainder.

Water-table levels

Water-table tubes were inserted at a depth of 1 m. Since the main objective was to establish the performance of the partially penetrating drain, the tubes were installed at spacings of 0.5, 1, 2, 3, 3.5, 7.5, 12 and 14.5 m uphill and downhill from the drain. The piezometers at 6, 12, 18 and 24 m uphill of the drain functioned as additional

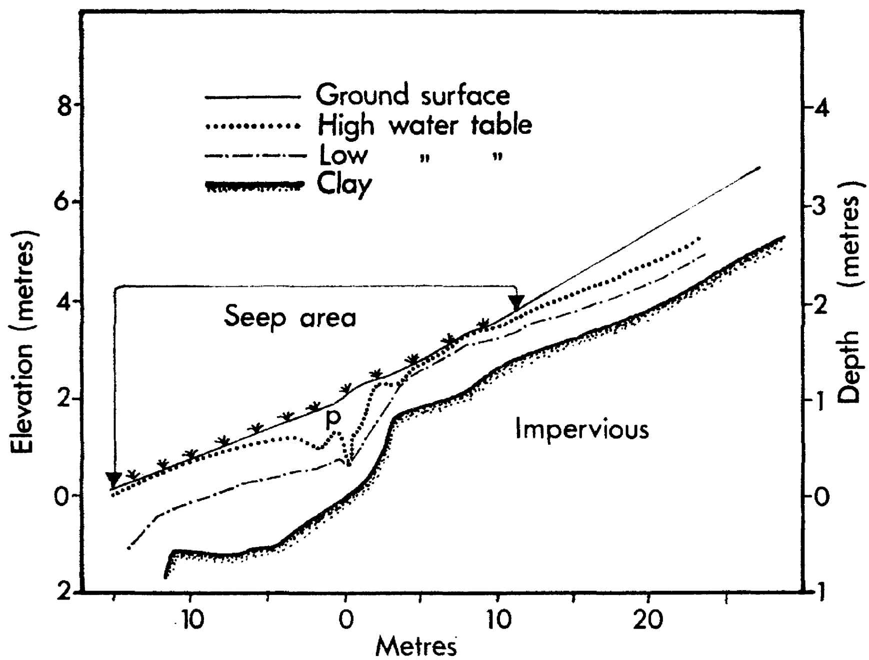

Fig. 5: Effect of the drain on water-tables where the drain was too low downhill to intercept the seepage

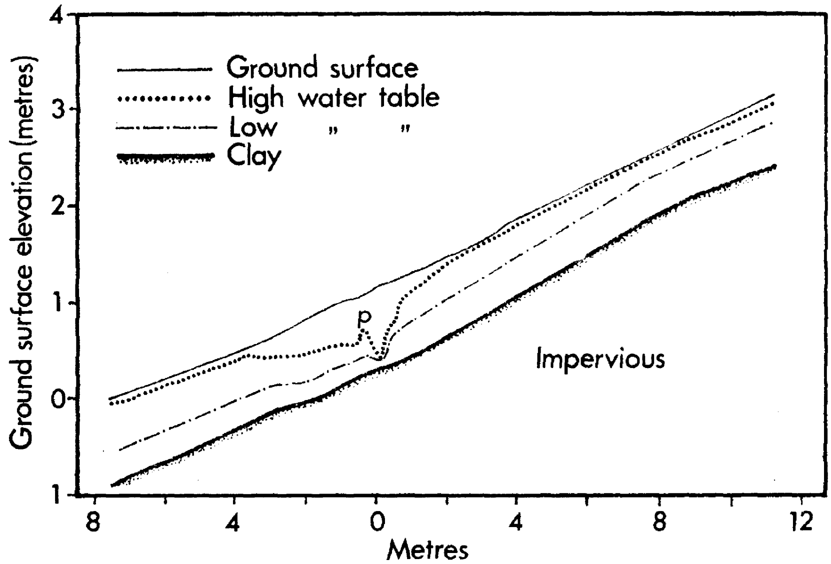

Fig. 6: Effect of the drain on water-tables where the drain seemed reasonably effective

TABLE 2: Comparison of piezometric heights and water-table in an adjacent tube (cm below soil surface)

Date	Piezometer	Water-table tube
19.11	16	15
20.11	19	18
25.11	4	7
29.11	10	7
16.12	6	8
8.1	9	10
11.1	22	20

measuring points. Fig. 5 shows the water-table levels for the transect where the drain was located too far downhill to intercept the seepage. It confirms that the drain was indeed too low to intercept the body of the seepage which in wet weather extends to 12 m uphill from the drain. However, the upper boundary of the seep area which is conspicuous in the field is 6 m uphill from the drain. Fig. 5 also shows that the drain which is two-thirds fully penetrating failed to control the water-table downhill from the drain at the level of the drain. The reason for this is the high radial resistance to water entry into the drain. Near the drain, predominantly rectilinear flow down the hillside gives way to predominantly radial flow into the drain and curvilinear flow downhill. The strong curvature of the water-table near the drain (Figs. 2 and 5) indicates high radial resistance. The point P represents the boundary of flow into the drain on the downhill side; downhill from P water flows downhill and uphill from P water flows into the drain. Large quantities of water bypass the drain as a result of high radial resistance.

Where the drain seemed from surface observations to be fairly well placed it was about nine-tenths fully penetrating (Fig. 6). Again radial resistance resulted in water bypassing the drain. P represents the boundary divide on the downhill side of the drain between flow downhill and flow into the drain. High radial resistance is again indicated by the strong curvature of the water-table near the drain (Fig. 6).

Table 2 shows that there was good agreement between the water-table tube and an adjacent piezometer tube.

Discharge

Discharge was measured to derive a quantitative notion of the aggregate hydraulic conductivity and of the radial resistance. While uniform inflow is assumed, there is considerable evidence to suggest that this may not be so. The heterogeneous (cracked) nature of the subsoil, the cracking induced by the mole plough, the presence of numerous sand lenses, and of gravel and stones may all lead to non-uniform inflow. Furthermore, the non-ideal location of the drain and the non-uniform gradient of the clay aquiclude may lead to considerable departure from the assumption of uniform inflow. In spite of the above drawbacks, the drain installation is a useful mechanism for deriving hydraulic information about soil, especially as in this case where a cracked soil has a poorly pervious matrix. This experience is also corroborated by Dutch experience (11).

Discharge from the drain was measured in dry weather in early January when evapotranspiration and direct surface run-off from the seepage zone were negligible. The discharge was 6.48 m^3/day and the drain length was 94.2 m. This gives an inflow rate of 0.0688 m^2/day per unit length of drain. This may now be compared with a computed rate of inflow.

Using Dupuit-Forchheimer assumptions after Donnan (4) the following may be deduced:

$q_u = Kh_u \tan a_u =$ flow per unit soil width upslope from the drain (m^2/day) 1

$q_d = Kh_d \tan a_d =$ flow per unit soil width downslope from the drain (m^2/day) 2,

where K is the hydraulic conductivity in the lateral direction, h_u and h_d are the heights of the water-table above the impervious layer upslope and downslope from the drain respectively and $\tan a$ is the slope of the impervious layer.

The following data were measured where the drain seemed reasonably well located (Fig. 6): $h_u = 0.503$ m; $h_d = 0.351$ m; $\tan a = 0.170$.

From this it follows that $q_u = 0.0855$ K and $q_d = 0.0597$ K m^2/day. Then, computed inflow into drain is 0.0258 K m^2/day. Equating the computed with the value estimated from discharge measurements, 0.0258 K = 0.0688 m^2/day. Then, estimated K is 2.67 m/day.

Where the drain was located too far downslope to intercept the seepage (Figs. 2 and 5), the above relationships could not be applied because of the very uneven nature of the clay aquiclude downslope from the drain and the possible occurrence of two-dimensional flow both downslope and cross-slope into the dish in the clay. The ratio of the estimated lateral or near horizontal hydraulic conductivity to the measured vertical value is 2.67/0.324 or 8.24. This suggests that the soil may be anisotropic if the assumption of uniform inflow is justified.

An estimate of the efficiency of the drain (Fig. 6) in collecting downhill flow can be computed. The fraction of the downhill water collected is independent of the hydraulic conductivity and is q_{dr}/q_u or 0.0258/0.0855 or 0.30. This suggests that the drain is collecting less than one-third the amount of water it should as a result of partial penetration and high radial resistance. Radial resistance also affects the effective distance of water-table drawdown upslope from the drain. If it is assumed that the effective distance of drawdown upslope corresponds with the point where the water-table is 0.9 times its original height, then the measured distance of effective

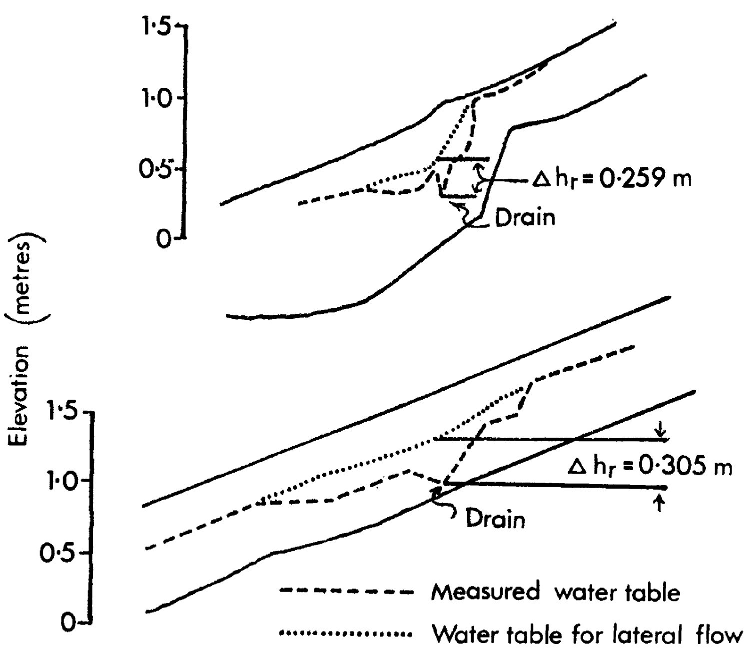

Fig. 7: Measured and estimated water-table elevations used in the calculation of radial resistance

drawdown is 1.6 m compared with a value of 4.3 m computed by the approximations of Donnan (4).

In computing radial resistance on a hillside, the shape of the water-table giving rise to lateral flow only is estimated by hand. While this method gives only a crude and subjective estimate, it is the only method possible because of lack of symmetry in the slope of the water-table. Estimates are derived for the two transects as shown in Fig. 7. For the non-ideal drain location (Fig. 7, top) the estimated radial resistance is 0.259/0.0688 or 3.8 days/m, where 0.0688 is the inflow rate per unit length of drain computed from discharge measurements assuming uniform inflow. The radial resistance where the drain seemed fairly well located is 4.4 days/m computed in a similar manner. While these estimates are crude, they do give a notion of the radial resistance which is known to be high from the shape of the water-table (Figs 5 and 6).

DISCUSSION

The results showed that the location and depth of the drain were the two critical factors which militated against the effective performance of the drain. With high radial resistance and partial penetration, only about one-third of the available water flowed into the drain. Observations at Ballyhaise College with perimeter field ditches on the tail side of fields showed that partially penetrating ditches allowed large quantities of water to underflow them. This water gave rise to numerous seep zones downhill. At one point in a recently excavated ditch, full penetration gave way to partial penetration downslope. Flowing water from the fully penetrating section infiltrated the invert of the partially penetrating section resulting in a dry ditch. This infiltrating water later emerged downhill from the ditch in a seepage zone. At Ballyhaise the depth to impervious clay varies from 60 to 20 cm at a seepy zone. At the tails of fields the depth to impervious layer can vary up to 2.5 m as a result of downhill soil erosion under tillage.

To intercept seepages, both ditches and drains should fully penetrate the pervious layer and into the impervious layer. The depth of ditch penetration into the impervious layer will depend on the expected wetted perimeter and on a consideration of silting and maintenance. In the case of drains, a tube or pipe drain embedded in the impervious layer and with a gravel overlay to the top of the impervious layer is required. Once the location of the drain has been decided on, it is then necessary to produce a profile of the impervious layer so that the depth and gradient of the drain can be designed. Where a grid of drains is required the normograph provided by Schmid and Luthin (8) may be used to determine the spacing.

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