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Leaflet

72

Forest Drainage Schemes

D. A. Thompson

CONTENTS

FRONT COVER Draining of deep peat in Nant-y-Gwair, Blaencwm, above the Rhondda Fawr (*19603*)

FOREST DRAINAGE SCHEMES

by D. A. Thompson

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INTRODUCTION

It has long been recognised that one of the main problems on a large proportion of soils being afforested in Great Britain is excessive soil water. The solutions adopted were based on agricultural practices and consisted of a system of open drains. Over the years, argument and experimentation have revolved around the depth and spacing of drains for different soil types. At the same time forest ploughing has evolved from the need to suppress weeds and provide a turf into which the tree could be planted, to the point where plough furrows give very intensive drainage of the upper layers in soils. This leaflet is concerned with open ditch schemes superimposed on ploughing and commonly called cross-draining.

SITE FACTORS

Soil Types

In the simplest terms forest soils can be subdivided into three groups which will be referred to as imperfect, impeded and impervious soils. Imperfect soils (brown earths and podsols) are more or less freely draining, permitting water to percolate rapidly from the surface down to a water table below. Impeded soils (iron pan and indurated soils) are freely draining down to a compacted, indurated or cemented layer commonly found between 30 and 60 cm depth. If this layer is disturbed by cultivation the depth of freely draining soil is increased. Impervious soils (non-indurated gleys and deep peats) consist of relatively impermeable material usually unaffected by cultivation.

During prolonged periods of rain, water infiltrates the surface and percolates down to a water-logged zone. In imperfect, freely draining soils the water-logged zone will be a relatively deep ground water table. But percolation through compacted, indurated, cemented or relatively impermeable layers is slow and for this reason a zone of water-logging can occur above such layers in impeded and in impervious soils. In water-logged soil, water moves down any slope. When a water-table exists close to the surface rainfall may quickly raise it and thereby increase the down slope flow. It follows that at the foot of any slope serious water-logging close to the surface is more likely in impeded and impervious than in imperfect soils.

Present recommendations for ploughing imperfect, freely draining soils are concerned only with providing a weed-free planting site. Similar objectives determine ploughing requirements for impeded soils but with the added demand for disturbance of soil down to or beyond 60cm. Disruption of compacted layers is expected to allow more rapid movement of water down the soil profile. No such improvement can be expected on impervious soils and the recommendation is to plough furrows 60cm deep which will induce movement of water from the upper layers of the soil. Because shallow rooting is expected, the widest platform between furrows is preferred to encourage stability. For this reason double mouldboard ploughing is recommended.

Topography

Changes in slope affect the rate of flow of water through soil, consequently at the foot of a slope the water table may be close to the surface. (see Figure 1). However, changes in slope usually correspond with changes in soil types, thus imperfect, freely draining soils are often found on steeper slopes and impervious soils on gentler slopes. Such changes exaggerate differences in water table depth. Where the water table emerges at the surface there is usually a recognisable seepage line. Change in slope may coincide with the emergence of a geological stratum of impervious material. (see Figure 2). Where such a stratum may be found emerging on steeper slopes it may be the cause of springs and flushes (see Figure 3).

LAYING OUT A DRAINAGE SCHEME

Objective

Forest drainage schemes are no longer expected to lower water tables in the traditional draining sense. Previous recommendations (Henman, 1963) that close spacing between deep drains will lower water tables sufficiently to permit deeper rooting have been found unsound. On impervious soils, water accumulates in plough furrows and on all sites topographical and geological features will cause excess soil water in certain places. The drainage scheme should be designed to take water from both situations.

Roads and Rides

Before a drainage scheme is begun roads and rides will have been laid out and ploughing done. Roads and rides have two effects on a potential drainage scheme; first, it is often necessary to have drains on either side of a road and secondly, there will be a limited number of culverts into which drains can be led. Ideally, only pre-existing watercourses should cross roads and rides.

Natural Watercourses

Slopes will often be greater than 3° and in such cases it is necessary to identify a natural water course which will be used to take water straight downhill. They are defined in Appendix II but

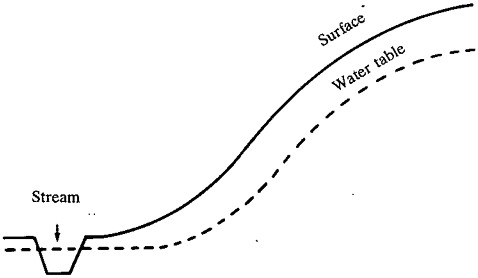


Figure 1

The relationship between the surface and water table with changes in slope on similar soil.

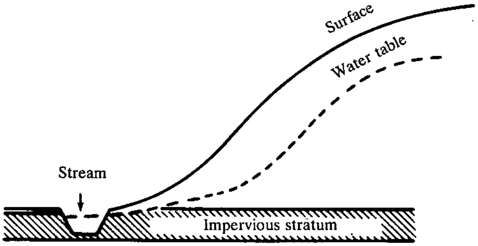


Figure 2

The effect on the water table of an impervious stratum at the foot of the slope.

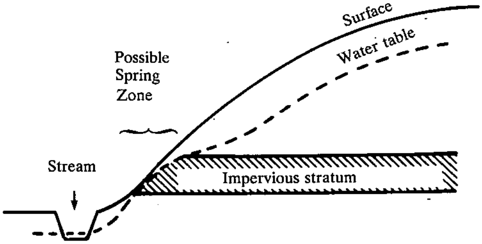


Figure 3

The effect on the water table of an impervious stratum part way down a steep slope.

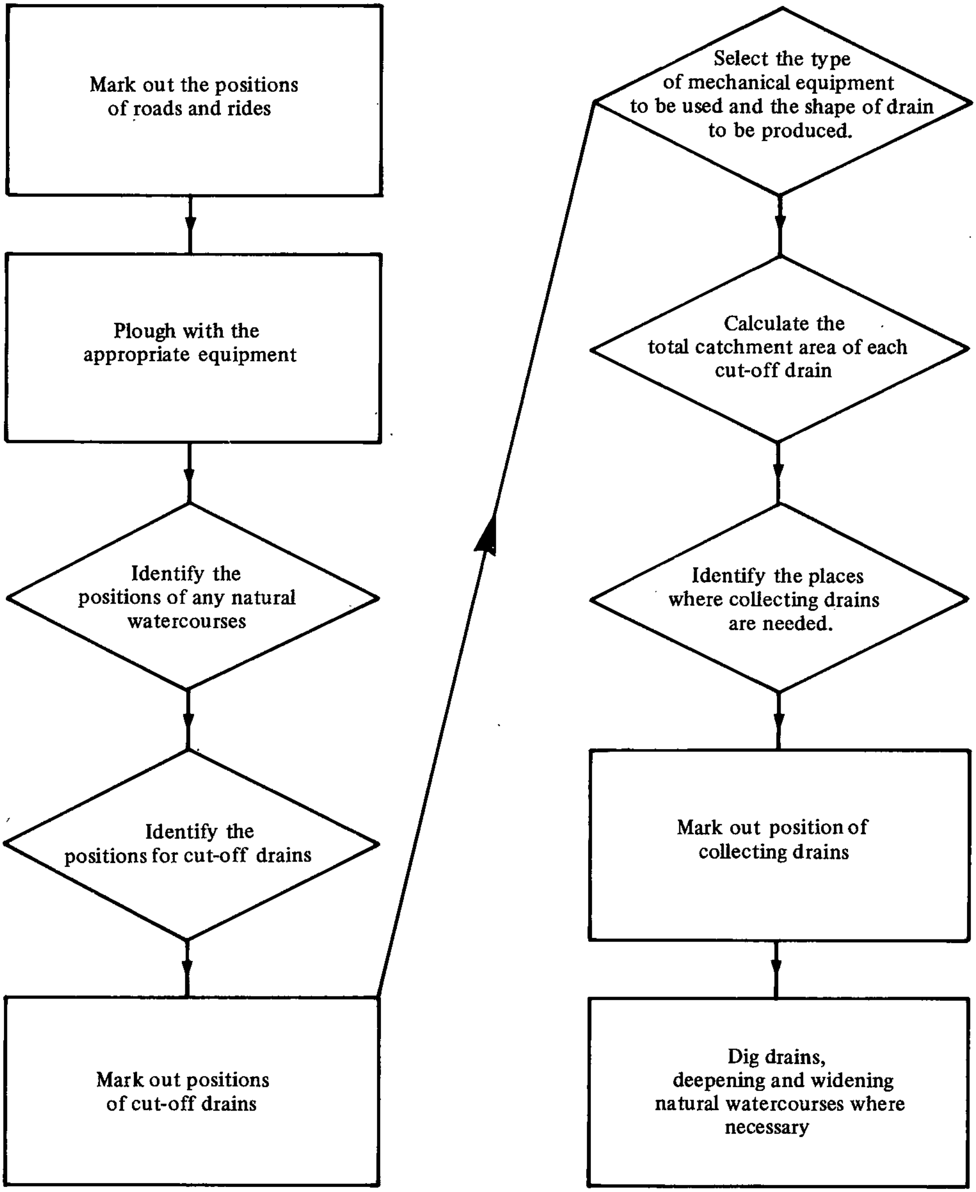


Figure 4. The order of decisions and operations in laying out a drainage scheme

it is important to recognise the implication behind this definition because a certain degree of erosion or gullying can occur which should be anticipated.

At the head of a stream there is usually insufficient water to cause rapid deepening of the watercourse. This condition changes downstream and the stream bed may be eroded down to bedrock. Finally even the bedrock may be eroded. Erosion damage occurs during peak flows. In each catchment the peak rate of flow of water to a stream varies according to the nature of the soil, but as a general rule this rate of flow is increased by ploughing and draining. Therefore it follows that during the first few years, ploughing and draining will increase the rate of erosion of the stream bed.

Where a new drain is cut straight down the slope, great erosion damage can be expected in comparison with damage caused by using natural watercourses to carry water downhill. But damage to the natural watercourse will depend on how well it is developed. For example, a stream running over bedrock will suffer only slight damage to its banks in comparison with a stream running over till which may erode quite rapidly with increased peak flows.

Cross Drains

It is usual in forestry for open drains to be called *cross-drains* because they cross the ploughing and slope. Two forms of cross-drains may be identified, *cut-off drains* and *collecting drains.* As a general rule all cross-drains should run towards the head of the valley when draining on slopes; this gives the shortest length of drain for a given catchment area.

Cut-off drains

The purpose of a cut-off drain is to intercept ground water where the water table tends to be close to the surface and thereby prevent soils down the slope becoming excessively wet. In the case of a hollow the cut-off drain prevents ponding. Inevitably, cut-off drains will also collect water from plough furrows. The positions for cut-off drains should be easily identifiable once ploughing has been carried out. On fairly level topography, the hollows from which water cannot escape must be linked by the shortest lengths of drain possible to the nearest watercourse. On sloping topography great care must be taken to place the cut-off drain in the correct position, not above or too far below any seepage zones, at the same time maintaining a sufficient gradient to the drain to allow water to flow away. The design of drain to be used is explained later.

Collecting Drains

Collecting drains merely collect water from plough furrows and their purpose is to reduce the amount flowing straight downhill and entering cut-off drains. Collecting drains are not required at set intervals as has been general practice in the past. They are laid out after the cut-off drains at positions required by the limitations in capacity of the drains used. For example, if the maximum capacity of the drain type used is equivalent to that of a 5 ha catchment and a cut-off drain is planned that will collect from 8 ha, then a collecting drain will be placed above the cut-off drain to reduce its catchment to below 5 ha.

LIMITATIONS TO THE USE OF OPEN DRAINS

There are three limitations to the use of open drains — economic, the gradient of a drain and those imposed by the drainage machinery.

Economic limits

Once water is collected in an open channel, whether plough furrow or cross-drain, it becomes a liability and its disposal must be carefully considered. The economic benefits from a drainage scheme are twofold, first the increased yield of timber associated with crops standing longer on aerated soils and secondly the avoidance of costly damage caused by uncontrolled run-off. As a general rule the cheapest drainage scheme is required, but that specification must be modified where damage to landscape, fishing, neighbouring land or streams is a risk.

Gradients

Flow of water in a drain which has a too gentle gradient will be too slow to carry any sediment and therefore be more liable to induce silting up and blockage than a drain with a steeper gradient. But a too steep gradient increases the risk of damage to the drain by erosion. A gradient of 3° is considered to give sufficient flow velocity to avoid silting but not enough to cause significant erosion for most forest soils in Great Britain.

However, the risks of silting and erosion are related to volume and flow rate of water in the drain. Usually the risk of erosion is less near the source of a drain than near its exit. Therefore over its length the gradient of a drain can start at 6-7° at the source but must drop to 2-3° at the exit.

It is inevitable that water in a drain or plough furrow will contain sediments at some time during a year. For this reason it is recommended that drains are stopped short of lakes, lochs or reservoirs if these are the destination for the water carried. If water from drains is allowed to spill over the natural surface it is usually slowed down and any sediment carried will tend to be deposited. When this happens infrequently, sediment becomes secured by growth of ground vegetation through it.

Machinery

Each type of draining equipment; plough, backacter or digger, produces a particular depth and shape of drain. The profile and specification of drains produced by each major type of draining equipment are given in Appendix I. The depth and shape of a drain determines its capacity for carrying water and consequently the area of its catchment. Carrying capacity is also related to spacing and this is explained in Appendix I.

The direction of draining is determined by the ability of the draining equipment to traverse ploughing and side slopes. In many instances machines cannot work across ploughing except at an angle close to 90°. In most cases a tracked vehicle can straddle plough furrows but draining may be impossible due to the severe swing and tilt of the towed, wheeled plough. Wheeled tractors often cannot work under those conditions. Similarly on steep side slopes working becomes difficult if not dangerous.

MAINTENANCE

Purpose

The purpose of a drain maintenance programme is to release blockages. Serious blockages, apart from collapsing sides which should be very rare, occur in two forms; an accumulation in the drain of dead grass or other ground vegetation and accumulation of brash during thinning or felling operations. The latter can be anticipated so that appropriate maintenance is carried out when required. But the former is more haphazard and is aggravated by the fact that as the tree crop develops closed canopy, so the quantity of water reaching the ground is decreased and consequently flow in drains is reduced. Since one reason for having drains at 3° gradient is to facilitate self-cleaning this action becomes less effective as the crop gets older.

It is not the purpose of a maintenance programme to deepen or widen drains (see Remedial Drainage Work). Releasing blockages however is preventive and is justified because of damage which will occur to root systems by flooding and to the landscape by erosion should the drain overflow. Once water is impounded in a drain it becomes a liability and should be treated as such.

Timing of Maintenance Work

During crop establishment light reaches the bottom of open drains and vegetation may take root there. This vegetation usually causes the accumulation of debris. Therefore, during this crop phase, maintenance is concerned with keeping the drain bottom clean. It will be normal to clean drains during the first five years after planting and again just after closure of canopy. Thereafter, only thinning or felling should create a need for further maintenance, but if the establishment phase is protracted an extra cleaning may be required between five and ten years.

Maintenance of Existing Schemes

The forest manager, having identified the crops and areas which require drain maintenance, may be faced by an enormous programme should every drain have to be cleaned, and careful selection is needed to ensure the work is most cost effective.

A quick and simple method is to observe the outflow from each cross-drain into natural watercourses or main drains. Drains discharging large quantities of water may need little maintenance work because they are normally self-cleaning, but there are greater risks of damage should these drains become blocked. Drains discharging little or no water will obviously have a low priority for maintenance; but it should be remembered that if the drain is blocked, water may be finding an alternative route off the area. A discharge rate between these two extremes presents the most difficult decision for the forester. The rate of flow will not be sufficient for adequate self-cleaning therefore blockage is more likely; at the same time maintenance work is not associated with large drainage benefits.

In using discharge rates as a guide, it should be remembered that outflow depends on rainfall; since any drain will carry rain falling directly into it, a rough principle is to observe discharge one day after significant rainfall. Furthermore since the amount of water carried increases down a drain, less maintenance may be required towards its source. Good sense is needed in deciding where to stop cleaning along a drain.

Where there is a high density of drains in an area it is probable that they will be carrying less than their capacity. It is in these circumstances that decisions are most needed to determine which drains are to be cleaned and which not. All drains unless altered along the lines described in the section on Remedial Drainage Work should be looked at before deciding not to clean them.

REMEDIAL DRAINAGE WORK

Purpose

Any particular form of remedial work may have one or both of the following purposes; first, to improve the efficiency of the drainage scheme by conducting water from an area to reduce risks to crop and landscape and second, to reduce maintenance requirements. All remedial work is a form of new investment and should be properly justified.

Deepening and Widening Drains

There are two reasons for deepening and widening a drain. First, if the quantity of water in the drain is expected to increase either because its length is being extended or another drain is to be led into it and if remedial work is not done, nature may take its course and the drain will be eroded by increased flow and thereby enlarge its capacity but with attendant risks downstream. Secondly, the existing drain may fail, for lack of depth, to act as a cut-off: deepening may be cheaper than cutting a new drain a few metres away.

Reduction in the number of active drains

If it is considered that a particular drain no longer warrants maintenance, it is advisable that an attempt be made to divert water at frequent intervals out of this drain into a drain which is to be maintained. On ploughed ground this would involve using furrows to conduct water down the slope every 10 to 20 metres. On unploughed ground incipient natural watercourses can be used for this purpose.

New Drains

Only where there is a clear need for cut-off drains or a severe risk of erosion damage can new drains for remedial purposes be justified before felling. Explanation of the cut-off drain function is given on p.6. It is possible that need for a new cut-off drain becomes apparent only after drainage by plough furrows and water loss via trees has caused the surface to sink to some degree. This is particularly the case with raised bogs.

Erosion damage may result from too few drains to carry run-off or, more likely, from drains having a too steep gradient. Correction is difficult because the existing drain erodes below the normal depth of draining and is therefore difficult to intercept. As a general rule water should be tapped from such a drain using new collecting drains at intervals from the highest point to the place where gullying has begun.

Restocking Areas

Restocking areas will fall into two categories, those which have been freshly ploughed and those not. Ploughing through stumps and brash very often disturbs existing drains so much that they may have to be remade. But in general the rules are the same as for areas of ploughed afforestation ground.

Where ploughing has not been done a previous drainage scheme may exist. Clear-felled sites offer an opportunity to lay out drains which were difficult to do while the crop was growing. During the establishment phase of the second rotation there will be an increased run-off down any existing drains. New drains should be confined to cut-off drains placed in positions not covered by the existing system or to collecting drains to tap water from above existing drains which are eroding because they are too steep.

SUMMARY

1. A drainage scheme carries water, collected by plough furrows in collecting drains or intercepted at strategic points by cut-off drains, to a natural watercourse.
2. A cross-drain is ideally restricted to a gradient of approximately 3° and its capacity sets a limit to the size of its catchment area.
3. Only natural watercourses or incipient natural watercourses should be used to carry water straight down hill.
4. After road and ride side drains are identified and natural watercourses located, cut-off drains and then collecting drains are laid out.
5. Maintenance is the removal of blockages from drains and should be done only on drains carrying sufficient water to be considered active.
6. Remedial work includes deepening and widening of existing drains as well as digging new drains and should be considered as a new investment.

APPENDIX I

ALLOWABLE CATCHMENT AREA FOR CROSS-DRAINS

Introduction

When the forces exerted by water and the particles in it are sufficient to dislodge material from the sides and bottom of a drain, active erosion is taking place. The magnitude of these forces during erosion depends on the shape and roughness of the drain, the soil type and texture, but particularly on the velocity of water.

Critical velocity is the maximum velocity before serious erosion occurs; this may also be called *permissible velocity* since it is usually damage which designers are trying to avoid. As well as drain shape and roughness, velocity is determined by the slope of drain and the volume of water in it. And finally the volume of water derives from the amount of rainfall in a period of time. A *critical storm* is one which delivers the maximum volume of rain on the catchment compatible with permissible velocity. It follows that the size of catchment area is determined by the critical storm and permissible velocity.

Storm Rainfalls

The estimated return period for a 25 mm in 1 hour (1 inch in 1 hr) storm is 10 years and for a 38 mm in 1 hour ($1\frac{1}{2}$ inches in 1 hr) storm, 50 years (Plant, 1971). The critical storm to be used for design purposes depends on the risk to be taken that permissible velocity should be exceeded. A risk of slight erosion damage once every 10 years is considered reasonable for newly ploughed forest areas. The rate of rainfall (expressed in mm/h) will vary during a storm which delivers 25 mm in 1 hour and it is more than likely that for a period of 10 minutes rainfall rate will be 75 mm/h. Assuming that rain falling on the most distant part of the catchment will reach the drain exit in 10 minutes, 75 mm/h is the effective critical storm rate with a return time of 10 years.

Calculation of Critical Catchment Sizes

Not all rain falling will find a rapid route to the cross-drain exit. Some will fall on undisturbed ground and will first have to percolate through the soil before entering a plough furrow. It is estimated that on ploughed forest ground a quarter of the rainfall will enter the furrows directly and begin to move off the site. This means that at the height of a critical storm approximately 25 per cent of 75 mm/h will run off a catchment. This is equivalent to 0.0521 cumecs/ha (cu m per second per hectare).

Permissible velocity is determined by the ability of particles on the drain wall to stick together when a force is applied to them. Various calculations have been made based on figures produced by Fortier and Scobey (1926). A velocity of 2.0 m per second is adopted in this leaflet for estimating catchment sizes. By assuming a slope of 3° for all cross-drains and assuming similar roughness, catchment areas for different shapes of drain can be calculated. For each shape the width of drain bottom and side slope are defined and, using the above assumptions maximum depth of water, cross-sectional area of water and quantity of water are calculated. By dividing the maximum quantity of water by 0.0521 cumecs the maximum critical catchment area is obtained.

Example – *Calculation of critical catchment area for draining plough, Figure 5.*

Permissible Velocity $= V = 2.0\,\mathrm{m/sec}$
Slope drain (gradient) $= I = \tan 3^\circ$
Roughness coefficient $= n = 0.3$
Bottom width $= B = 0.3\,\mathrm{m}$
Side slope on drain $= Z = \tan\alpha = 0.45$, where α is angle between drain side and vertical

Hydraulic Radius (R) (Manning's formula)

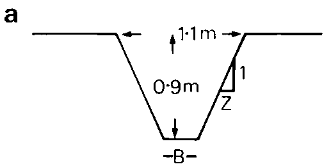
$$R = \left[\frac{Vn}{I^{0.5}}\right]^{1.5} = 0.1342$$

Depth of water at permissible velocity = y (based on a trapezoidal shape)

$$y = \frac{\left[2R(1+Z^2)^{0.5} - B\right] + \left[(2R(1+Z^2)^{0.5} - B)^2 + 4RZB\right]^{0.5}}{2Z}$$

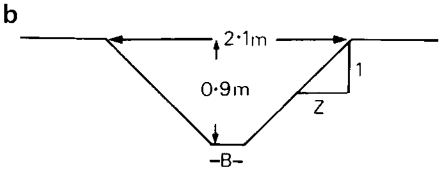
$$y = 0.2929 \text{ metres}$$

DRAINING PLOUGHS



B = 0.3 m
Z = 0.45
Depth of water, y = 0.29 m
Critical Catchment Area = 4.8 ha

DIGGER AND BACKACTER BUCKETS

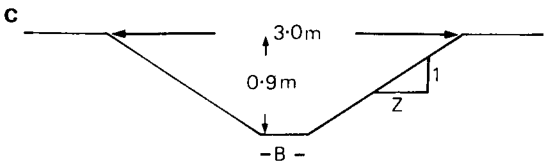


B = 0.3 m

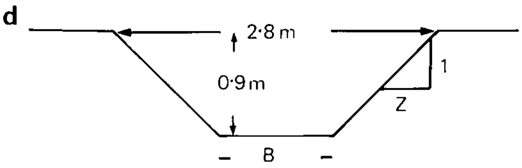
Z = 1.00
Depth of water, y = 0.24 m

Critical Catchment Area = 5.1 ha

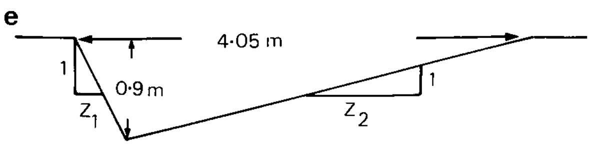
DIGGER BUCKETS



B = 0.3 m
Z = 1.5
Depth of water, y = 0.23 m
Critical Catchment Area = 5.9 ha



B = 1.0 m
Z = 1.0
Depth of water, y = 0.17 m
Critical Catchment Area = 7.6 ha



Z_1 = 0.5
Z_2 = 4.0
Depth of water, y = 0.31 m
Critical Catchment Area = 8.4 ha

Figure 5. Some drain cross-sections with related critical catchment area.

$$\text{Cross-section area} = A = (B + Zy)y = 0.1265\text{m}^2$$

$$\text{Quantity} = Q = AV = 0.2529 \text{ cumecs}$$

$$\text{Catchment Area} = \frac{Q}{\begin{array}{c}\text{Critical quantity}\\ \text{per hectare}\end{array}} = \frac{0{\cdot}2529}{0.0521} = 4.85 \text{ ha}$$

Results

Calculations have been made for the drain profiles given in Figure 5 to demonstrate the variation which might be expected using different types of draining equipment. All the results are meant to be used as guide lines because for any particular site the assumptions used in their calculation may be inappropriate.

As a general rule, changing the slope of drain from 3° to 2° approximately doubles the catchment area. For example, using drain shape 5 (a) the catchment area becomes 9.4 ha and for 5 (e) 15.5 ha. If the permissible velocity changes from 2.0 m/sec to 1.7 m/sec catchment areas should be approximately halved. For example using 5 (a) the catchment area becomes 2.5 ha and for 5 (e) 4.4 ha with a drain slope of 3°.

A critical catchment for a forest drain on a newly ploughed area calculated by the method above from slope and shape of drain, should be small enough to avoid significant erosion damage nine years out of ten.

APPENDIX II

GLOSSARY OF TERMS

Natural watercourse
A channel formed naturally which takes water straight downhill. The natural watercourse is usually situated in a re-entrant relative to the position on a general slope, and the presence of this depression without a clearly defined channel can be taken as an indication of an incipient natural watercourse position.

Cross-drain
An open ditch which crosses ploughing and slope intercepting water, and conducting it to a natural watercourse. The gradient on a cross-drain should be great enough to prevent sediment accumulation yet gentle enough to avoid erosion.

Cut-off drain
A drain sited to lead water arising from topographical features or springs to a natural watercourse.

Collecting drain
A drain sited to collect water from plough furrows.

Main drain
The term previously given to drains designed to collect water from collecting drains and cut-off drains and lead it into a natural watercourse.

Slope or gradient of drain
The angle (in degrees) between the drain bottom and horizontal.

Slope of drain side
The angle (in degrees) between the drain side and vertical.

Depth
The distance (in centimetres) from the original ground surface to the bottom of the drain.

Drain shape
The cross-sectional profile of the drain with particular reference to the width at the bottom and slope on the drain sides.

Drainage intensity
The total length of drains per unit area (metres/hectare).

Catchment area (CA)
The total surface area contributing rainfall to a single channel.

Velocity (V)
The average velocity (metres/second) of water flowing down a drain.

Wetted perimeter (P)
The length of cross-sectional wetted surface for a given depth of water in a drain (metres).

Cross-sectional area (A)
The cross-sectional area of water for a given depth of water in a drain (sq metres).

Hydraulic radius (R)
The quotient A/P

Manning's coefficient of roughness (n)
The coefficient expressing the reduction in velocity of water in a channel caused by surface roughness when using the Manning formula

$$V = \frac{1}{n} R^{0{\cdot}67} \ I^{0{\cdot}5}$$

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