NEW ZEALAND AGRICULTURAL
ENGINEERING INSTITUTE

FIELD DRAINAGE GUIDE

PROJECT REPORT P/16

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ACKNOWLEDGEMENT

The final impetus for the writing of this bulletin came from a visit by Professor G.O. Schwab of Ohio State University to the New Zealand Agricultural Engineering Institute in 1976. During his visit we were conducted on a number of field trips throughout the country by agricultural engineering advisory staff of the Ministry of Agriculture and Fisheries. The opportunity to talk with advisors and farmers in the field situation provided an invaluable source of information.

1. INTRODUCTION

The N.Z.A.E.I. Field Drainage Guide is intended to be a readily available source of design information for farm advisors, contractors, farmers and others involved in agricultural drainage. The emphasis is on subsurface drainage because this is an area where the available information is often difficult to locate and confusing. The technical standards required in subsurface work are higher than for surface drainage and mistakes are not only costly but also not easily rectified.

This booklet is not a comprehensive treatise on agricultural drainage and for this kind of information on New Zealand conditions the reader is referred to "The Draining of Farm Lands" by A.W. Hudson, H.G. Hopewell, D.G. Bowler and M.W. Cross[(1)]. It is presumed that the need for drainage has been established and that a suitably skilled drainage contractor is available. The information presented herein is an attempt to link these two.

Drainage is by no means an exact science. Wherever possible the physical reasons for particular recommendations are given so that the designer can make a judgement on the consequences of departing from the guidelines. In some drainage situations local experience and practice may appear to conflict with methods presented in this guide. In such cases, proven successful practice must be allowed to reign with due regard for the physical reasons behind the apparent anomaly.

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(1) Bulletin No. 18, Massey University, Palmerston North, New Zealand.

2. SURFACE DRAINAGE

Surface drainage is itself a subject of considerable breadth and only a few points can be noted here which may have an impact on the design of a subsurface system. The types of surface drains referred to in this section are the relatively shallow drains and methods of landforming used for removing surface water from the field. The large open drains required as outfalls for subsurface drains or as main arterial drains are often constructed and maintained by a local authority and are outside the scope of this guide.

Removal of surface runoff via subsurface drains is expensive in comparison with a few shallow surface channels. However, surface drainage is successful only if maintained regularly. In practice the farmer needs to have some form of ditcher which can be attached to a tractor with similar effort to that required for other pieces of cultivation equipment.

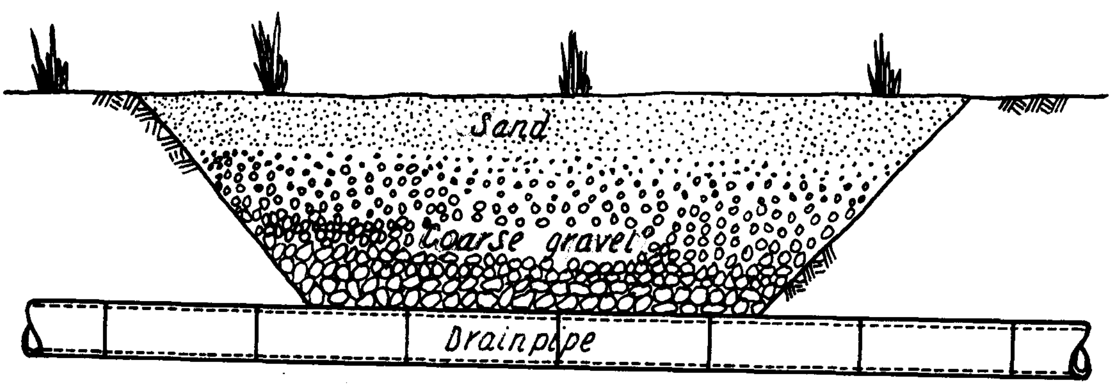

Figure 2.1 Blind inlet for entry of surface water to a subsurface drain.

The possible purchase and use of a ditching implement should be considered as an alternative to a greater intensity of subsurface drainage when surface water is a significant problem.

Where surface runoff must be routed through subsurface drains such as in depressions with no surface outlet additional flow capacity should be allowed for in the design. This is especially important in mole drainage (see 3.2) where overloading the collector drains can cause failure of the mole channels.

The entry of surface water to the subsurface drain can be facilitated by gravel backfill up to the topsoil (see 5.1) or a blind inlet as shown in Figure 2.1. Design of a surface inlet should provide some means of preventing the entry of silt into the subsurface drain.

3. TYPES OF SUBSURFACE DRAINAGE

3.1 DRAINAGE OF DEEP PERMEABLE SOILS

When the soil is sufficiently permeable to a depth of at least 1 - 2 m the soil water can move throughout the soil mass to a drainline as shown in Figure 3.1. Drains in this situation are sometimes called relief drains and they lower high water table conditions caused by precipitation or irrigation water.

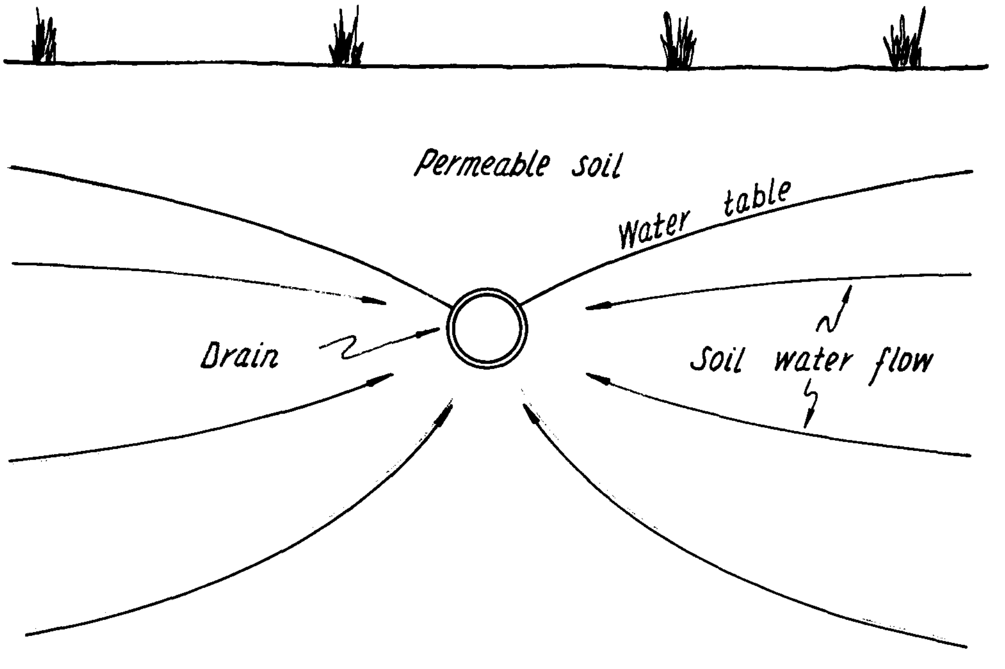

Figure 3.1 Flow of soil water in permeable soils.

3.2 MOLE DRAINAGE

For soils which are not sufficiently permeable for drainage to occur as described in 3.1 some form of soil treatment such as mole ploughing or sub-soiling (3.3) may be required. If the sub-soil is suitable at the 400 - 500 mm depth (discussed in Chapter 6) then a mole plough drawn through the soil will leave a moulded drain channel and form a crack structure in the soil. Soil water can then move through the cracks to the mole channel and eventually to a pipe drain collector via a permeable connector as shown in Figure 3.2.

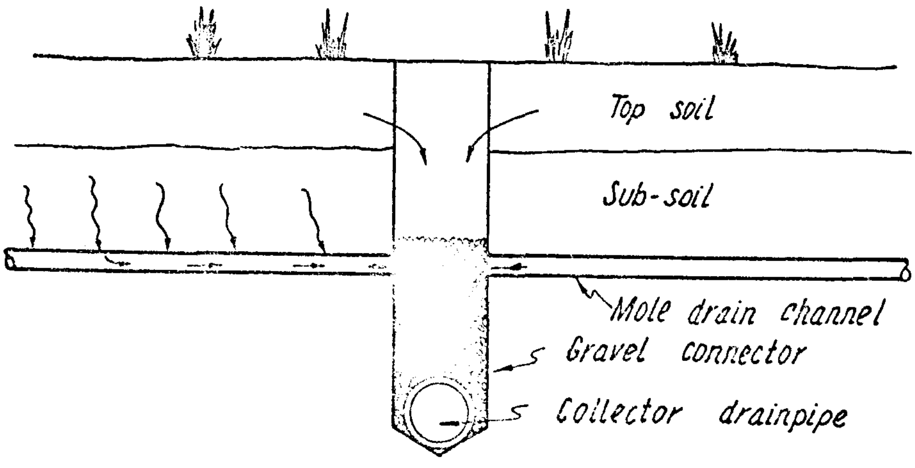

Figure 3.2 Flow of soil water in mole drainage.

3.3 SUBSOILING

A subsoiling implement may be used to obtain improved drainage in certain conditions:

(a) Where drainage of a soil is impeded only by a thin impermeable layer such as a cultivation pan then a subsoiler can be used to break the impeding layer. This is useful only if good drainage conditions occur beneath the pan.

(b) A subsoiler can be used to obtain an improvement in soil permeability due to shattering of the soil structure. This operation is usually carried out under much drier soil moisture conditions than mole ploughing. Sub-surface channels, similar to mole channels (see 3.2), may be formed and these can be useful if the direction of subsoiling is similar to that for mole ploughing. The life of this soil structure improvement will depend on the soil type and subsoiling should be regarded as a cultivation technique rather than a permanent soil treatment.

3.4 INTERCEPTOR DRAINS

In the previously described drainage situations the source of excess soil water was assumed to be precipitation or irrigation water which infiltrates over the whole problem area. However much of the wet land in New Zealand is wet because of soil water movement downslope from adjacent higher land. This lateral movement of water can be intercepted by a drainline across the direction of flow as shown in Figure 3.3.

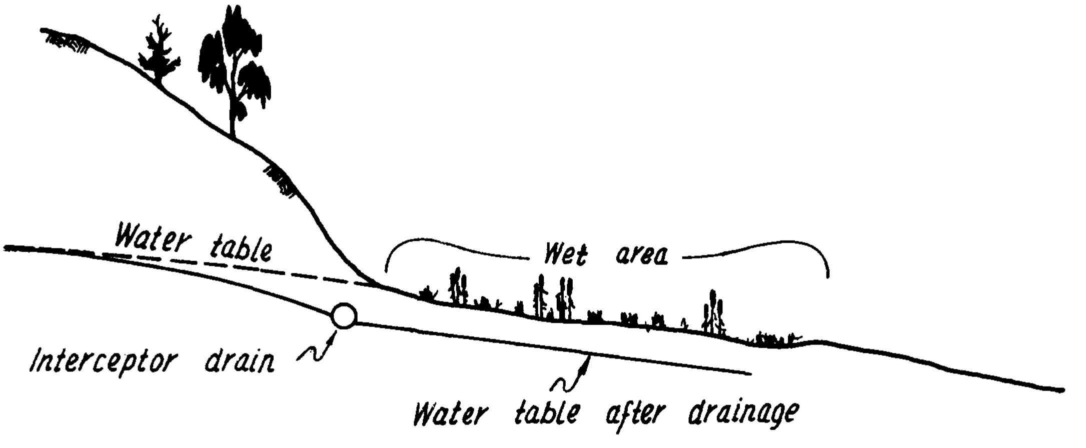

Figure 3.3 Interceptor drain.

The zone of influence of an interceptor drain is small in the uphill direction but theoretically infinite in the downhill direction. However this is usually not the case in practice because further inflow to the soil water may be occurring apart from what is transported laterally. A further interceptor may be needed or relief drains (as in 3.1) may be installed to handle all other water apart from laterally moving "foreign water". The presence of impermeable barriers and other formations can contribute to drainage problems which appear to be very complex viewed from the surface. An example is shown in Figure 3.4.

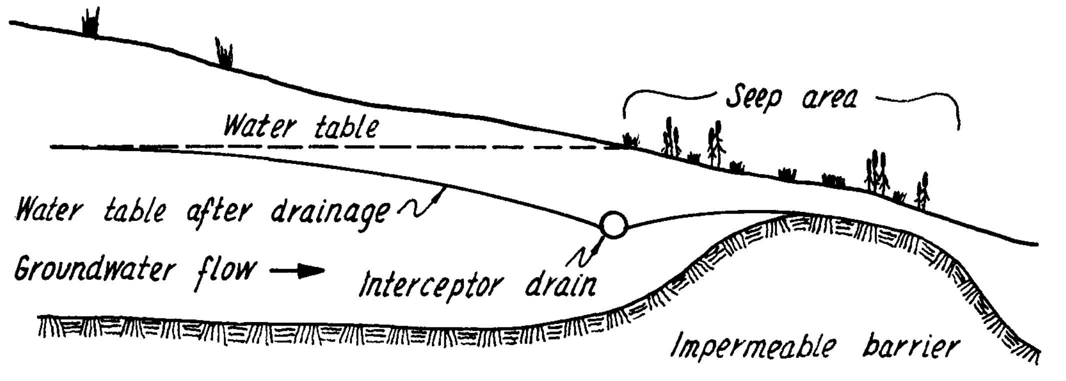

Figure 3.4 Wet area caused by an impermeable barrier.

3.5 ARTESIAN DRAINAGE

Groundwater under pressure in a permeable formation can supply water continually from below to the overlying soil causing a high water table or even springs and surface flooding. The cause of the artesian pressure is usually that groundwater in a confined aquifer is being supplied from higher areas. The geological structure can be very complex and the drainage problem can be solved locally in two ways:

(a) Installation of relief drains to remove the water faster than it rises through the soil profile.

(b) Use of pressure relief drains or wells to remove water from the permeable formation and thus reduce the pressure causing upward flow to the soil.

A combination of these methods may be required as shown in Figure 3.5 especially if precipitation fed soil water must be drained as well.

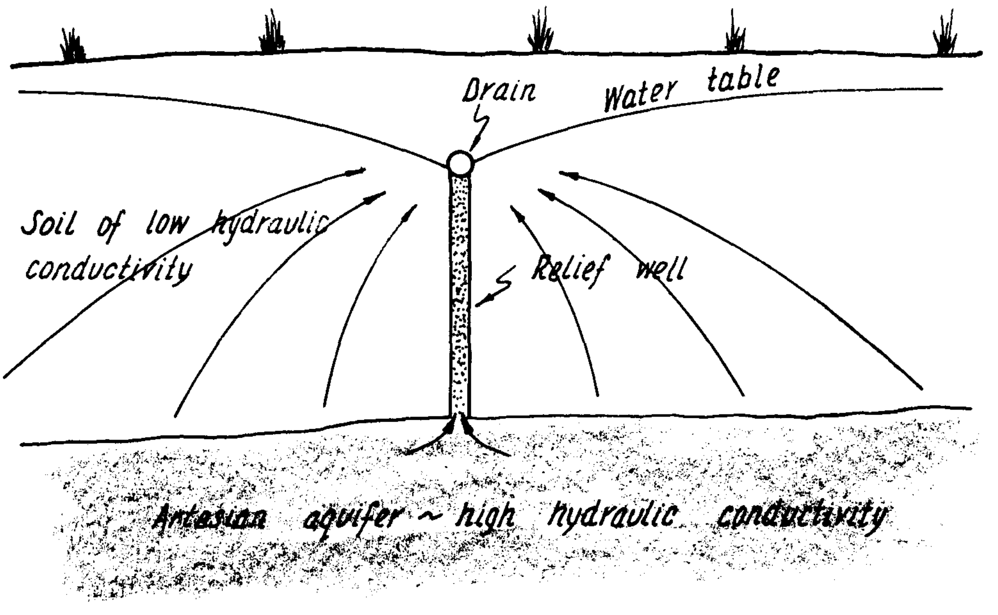

Figure 3.5 Artesian drainage.

4. DESIGN OF SUBSURFACE DRAINAGE

A fundamental principle of all drainage design is that even small drainage systems must take into account possible future extensions and improvements as well as the drainage of adjacent areas.

4.1 OUTFALL

The discharge of drainage water is covered by the Water and Soil Conservation Act 1967. The appropriate local authority, such as the Catchment Board, should be contacted for information on the requirements and restrictions in force for the area of concern.

An outfall to the drainage scheme may be by gravity or pumping to an open drain. Drainage wells or soakpits connected to an aquifer may be considered but the possibility of pollution will be a determining factor for the water authority.

The requirements of an outfall are:

(a) Sufficient capacity - this is determined from the maximum capacity of the drainpipes entering the outfall. This required capacity is in addition to any other requirements, for example, surface runoff entering an open drain.

(b) Depth - the outfall must be deep enough so that the required pipe gradients and minimum depth of soil cover over the pipes are maintained throughout the drainage scheme. Prolonged flooding of the outlet pipe should not occur. Flooding for a few hours during a storm is acceptable.

4.2 LAYOUT OF DRAINLINES

When planning the layout of a drainage scheme it is very important that underground services are located such as power cables, water pipes, gas pipes in order to avoid accidental damage from trenching operations. If possible, old drainlines should be located so that these can be dealt with as described in 7.7.

4.2.1 Random layout

The random type of drainage pattern can be used in the following situations:

(a) For drainage of isolated wet spots in a field.

(b) In undulating fields the laying of drainlines along the hollows may be necessary where:

(i) Mole drains drawn across the field require collector drains in the hollows.

(ii) Surface runoff which collects in the hollows can be removed by subsurface drains where surface drainage is not possible.

(iii) The undulations in the field may be too large to permit the use of a regular drainage pattern (see 4.2.2) in deep permeable soils.

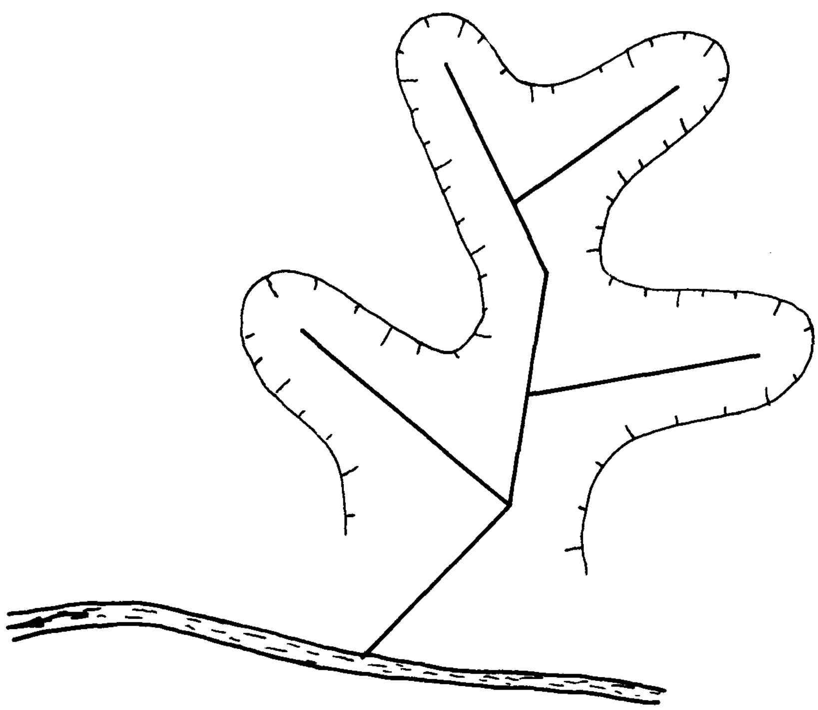

Figure 4.1 Random layout.

4.2.2 Regular layout

Two examples of regular drainline patterns are shown in Figure 4.2. The layout pattern is determined by the slope of the land, required drainline gradients, location of outfall and the use of mole drains. Situations for this layout are:

(a) In mole drainage the regular layout may be used in fields with a constant slope and no undulations large enough to cause reverse grades in mole drains drawn over the collector drains.

(b) For drainage of deep permeable soils a regular pattern is usually desirable in order to obtain uniform effective drainage. Deviation from a regular layout is usually necessary only when the ground contours would cause excessive trenching depths or insufficient soil cover over the drainlines.

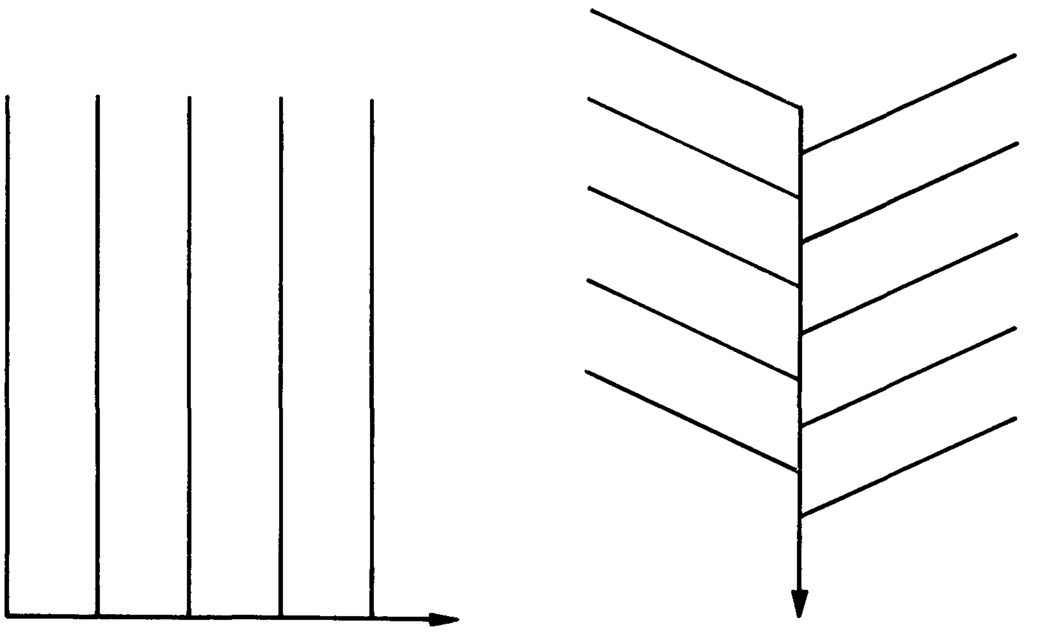

Figure 4.2 Regular layout.

4.2.3 Interceptor Drainlines

Interceptor drains for controlling seepage should lie across the direction of groundwater flow within the limits imposed by the required pipe gradient for adequate flow capacity.

4.3 SPACING OF DRAINLINES

The recommendations for spacing in the following subsections are for the situation where drainpipe flow is not limiting. In the case where, because of the drain layout, the design pipe flow (as described in 4.5) would be exceeded the spacing is obviously controlled by the number of drainlines required to carry the discharge.

4.3.1 Spacing of drains in permeable soils

The spacing between parallel drains depends on the rate of removal of water (the drainage coefficient, see 4.5), the allowable water table height, the hydraulic conductivity of the soil and the depth of an impermeable layer (any layer which has a hydraulic conductivity less than one tenth of that of the soil above it). This situation is shown in Figure 4.3.

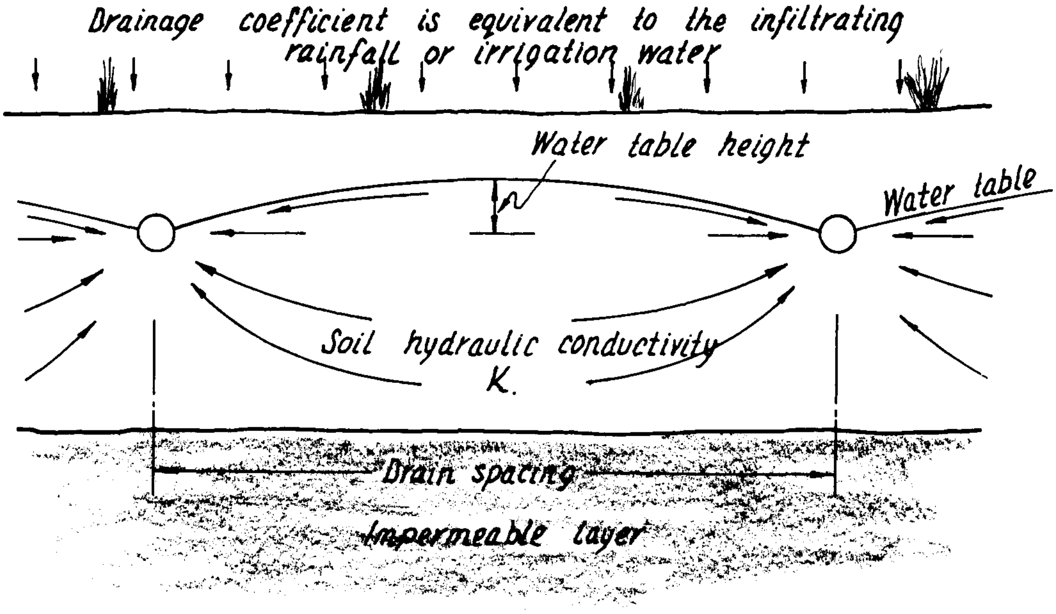

Figure 4.3 Spacing of drains in permeable soils.

There are several mathematical formulas for determining the required drain spacing but the use of these is hampered by the difficulty of making field measurements of the hydraulic conductivity which are representative of the actual soil behaviour.

A nomograph for one of these formulas is given in Appendix D with some indication of its possible applicability.

In the absence of any local experience a drain spacing of 40 m is recommended. This value is not too large for permeable soils and allows for subsequent halving of the spacing to 20 m if a higher level of protection is found to be required. The designer may have to modify the spacing to fit in with existing fencelines or orchard layout and opportunities may arise for variations in spacing which would give information for further development of the scheme.

4.3.2 Mole drainage collector spacing

The mole drains are usually drawn at 2 - 3 m spacing (approximately one tractor width). The spacing of the collector drains is determined by the recommended length of mole drain between collectors. The recommended lengths given in Table 4.1 depend on the slope for reasons which are presented in 6.2. These values are not precise and where there is local experience to justify a different length then this should be taken into account.

TABLE 4.1

Surface slope	Length of mole drains between collectors
0 - 1 percent	40 - 60 m
1 - 3 percent	60 - 80 m
3 - 5 percent	80 -100 m

The presence of hollows or gullies would control the position of collector drains so that mole drains could not flow into a low area without a suitable outfall. On undulating country this factor overides any consideration of regular drain spacing.

4.3.3 Artesian drain spacing

For a uniform soil overlying an artesian aquifer the drain spacing depends on the pressure in the aquifer and its distance below the surface, the depth of drains and the required control on water table height. This situation is shown in Figure 4.4.

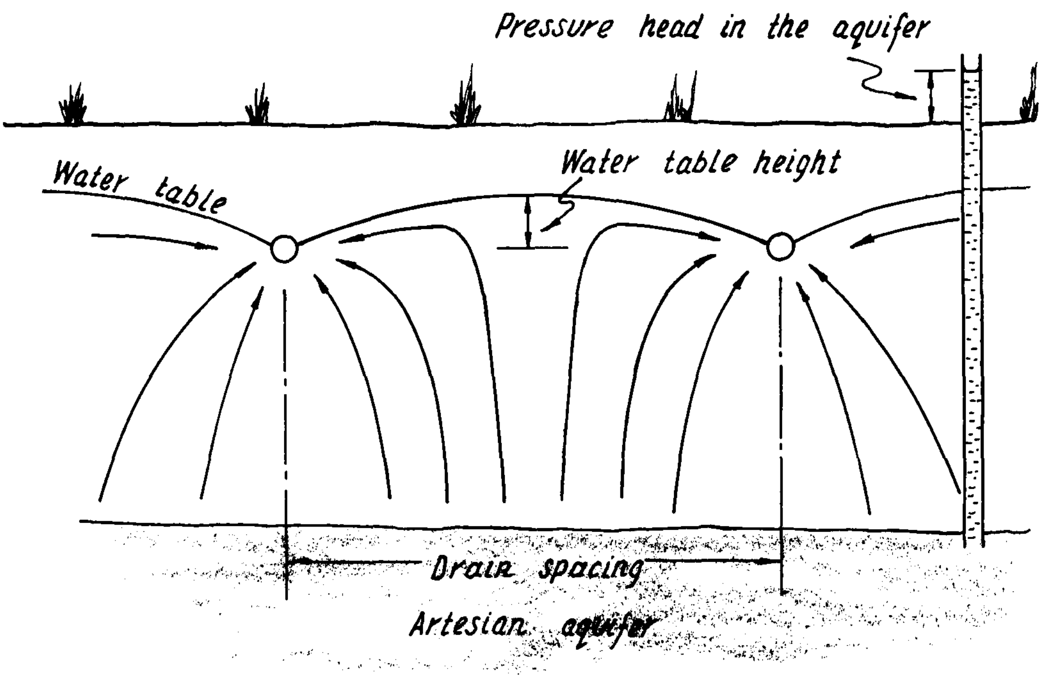

Figure 4.4 Factors which control artesian drain spacing.

The spacing does not depend on the hydraulic conductivity of the soil because the conductivity controls both the supply of water from the aquifer and its removal by the drains. In many cases the soil overlying the aquifer is not uniform but there are soil layers of low hydraulic conductivity which dissipate much of the aquifer pressure as the water flows upwards. This situation can be treated as drainage of a deep permeable soil with a larger drainage coefficient (see 4.5.4).

This means that a spacing of 40 m can be used if no other experience is available. The required spacing decreases with increasing aquifer pressure and a spacing which is too wide can lead to wet areas or other damage to crops between the drainlines. The aquifer pressure can vary with the rainfall in the source areas which supply the aquifer. This fact together with the non-uniformity of the soil makes it difficult to specify a precise design procedure.

The non-uniformity of the soil often occurs in such a way that there are localised areas of higher conductivity which allow the artesian water to find an easier path upwards to cause wet spots, springs, or ponded water on the surface. A regular grid of drains may not be the best solution in these situations as a few well placed drains which "capture" the springs or seepages can be more effective.

4.4 DEPTH OF DRAINS

The depth at which subsurface drainpipes are laid depends on the type of drainage problem, the available trenching machinery and hence the cost. The minimum soil cover is given in section 7.5 as 600 mm so that the minimum depth to the bottom of the trench is 600 mm plus the outside drainpipe diameter.

4.4.1 Permeable soil drainage

In deep permeable soils the same degree of drainage can theoretically be obtained by increasing the depth for increased spacing between drainlines. In practice this kind of trade-off is not usually worthwhile because trenching costs increase rapidly with depth. Drain depths of 0.9 - 1.25 m are commonly used with the higher value being used in orchard drainage.

4.4.2 Mole drainage

In mole drainage the pipe drain acts as a collector for the mole drains and needs to be a sufficient distance below the mole channel so that there is no possibility of damage to the pipe from the mole plough. In order to allow for variations in the ground surface a minimum distance of 150 mm between mole channel and top of collector pipe is reasonable. For the common moling depth of 450 mm the 600 mm minimum soil cover controls this depth.

4.4.3 Interceptor drains

The amount of water 'captured' by an interceptor drain laid across the direction of groundwater flow is proportional to the depth of the drain below the watertable, provided there is no 'bridging' of flow over the top of the drain (see 5.2). If the drain rests on the impermeable barrier then all the flow can be intercepted (theoretically). It is therefore worthwhile placing interceptor drains as deep as that determined by the requirements of the drainage situation. Since the watertable downstream of the drain is lowered to about the same depth as the drain (see 3.4) this requirement may determine the pipe depth.

4.4.4 Artesian drainage

This is a situation where deep drains are worthwhile. If drains can be laid in the artesian aquifer they are very effective in relieving pressure. However this may be too costly and the use of relief wells connected to drainpipes should be considered.

4.5 DRAINAGE COEFFICIENT

The drainage coefficient is an equivalent depth of water over the area to be drained which must be removed in 24 hours.

Example

drainage coefficient = 15 mm/day
area to be drained = 5 ha

Design discharge from the outfall is:

$$5 \times 10,000 \times 0.15 \text{ m}^3/\text{day}$$

$$= \frac{5 \times 10,000 \times 0.015 \times 1000}{86,400} \quad \ell/\text{sec}$$

$$= 8.7 \ \ell/\text{sec}$$

This calculation can be carried out by means of the chart in Appendix B. The drainage coefficient concept is discussed more fully in Appendix A but recommendations are given in the following sections for values to be used in the various types of subsurface drainage.

4.5.1 Drainage coefficients for permeable soils

For the drainage of permeable soils the flow capacity of the drainlines must be sufficient to allow the removal of excess soil water before damage occurs to the crop. The rate of removal of water is controlled by the hydraulic conductivity of the soil and the spacing and depth of the drains. The drainage coefficient is used to check that pipe capacity is not a limiting factor.

Where infiltrating rainfall is the only source of excess soil water the drainage coefficient can range from 10 mm/day for low rainfall intensity climates such as Southland up to 25 mm/day for areas where prolonged high intensity rain can occur or in situations where a higher level of crop protection is desired.

A method proposed in the U.K.[1] is to remove 60 percent of the five-day design rainfall in the five day period. Thus a five-day rainfall of 100 mm would require a drainage coefficient of

$$\frac{0.6 \times 100}{5} = 12 \text{ mm/day}$$

The application of this method in New Zealand has not been tested but it may be a useful design check.

4.5.2 Mole drainage coefficient

The rate of movement of soil water through mole drained land to the collector drains is more rapid than for permeable soil drainage. It is not possible to control this rate by varying the collector spacing (this is determined by the mole channel slope as described in 4.3.2) and the collectors must have sufficient capacity to prevent prolonged backing up of water in the mole channels.

Peak flow rates equivalent to a drainage coefficient of 40 mm/day have been recorded from mole-drained pasture. It is recommended that a design rate of 25 mm/day be used for mole drainage schemes.

4.5.3 Interceptor drain capacity

The capacity of interceptor drains is usually expressed as a flow per unit length of drainline so that the size of pipe and distance between outfalls can be calculated. In practice it is difficult to give design figures for flow because the slope, thickness and especially the hydraulic conductivity of water bearing layers can vary over such a wide range. It is more practicable to dig a short length of trench to the required depth and thus obtain an estimate of the required flow capacity. (The flow is proportional to the length of drain).

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(1) "The Relationship between drainage rate and rainfall". MAFF Field Drainage Experimental Unit Technical Bulletin 74/5

4.5.4 Artesian drainage coefficient

The rate of movement of water from an artesian aquifer into the overlying soil depends on the pressure in the aquifer and the hydraulic conductivity of the soil. The presence of thin impermeable layers and localised permeable spots can give great variation in the degree of wetness over an area. This makes the estimation of pipe capacity almost impossible and the designer should make allowances for future additions to the drainage system if required. The artesian aquifer pressures during an exceptionally wet season may increase very much above normal and cause new springs or wet areas to form. If poorly drained strips appear between drainlines the problem may require closer drain spacing rather than increased pipe size (see 4.3.3).

For situations where layers of low conductivity impede the upward water movement the situation behaves in a similar way to the drainage of deep permeable soils. The drainage coefficient in this case must take into account the two sources of water (rain and artesian water) and values in the range of 20 - 50 mm/day would be appropriate.

4.6 DRAINPIPE SELECTION

The selection of a suitable drainpipe to carry the required flow can be made by means of the chart in Appendix B. The chart can be entered by using the required capacity and the pipe gradient or by using the drainage coefficient, area drained and pipe gradient. This stage of the design is really a check that the chosen drainpipe can carry the flow. It is important to note that the chart is not to be used for determining drain spacing as this is dependent on soil properties. Spacing may be decreased if insufficient capacity is available but never increased in order to 'load up' the drainpipe.

5. PERMEABLE BACKFILL

One important decision to be made in the design of subsurface drainage is whether to use artificial backfill in the trench. Gravel is probably the most commonly used material but straw, peat moss, brushwood have been used and may still have a place.

The uses of permeable backfill are:

(a) As a permeable connector between mole drains and the collector drain.

(b) To provide a permeable path to an interceptor drain in order to prevent the groundwater flow 'bridging' over the top of the drain.

(c) As an envelope around the drainpipe to improve the hydraulic efficiency.

(d) As a protection against silting of the drainpipe.

These purposes sometimes overlap but each will be discussed more fully.

5.1 MOLE DRAINAGE CONNECTOR

As shown in Figure 5.1 gravel (or a similar permeable material) can be used to connect mole drains to the collector drain. The connection is effected simply by drawing the mole

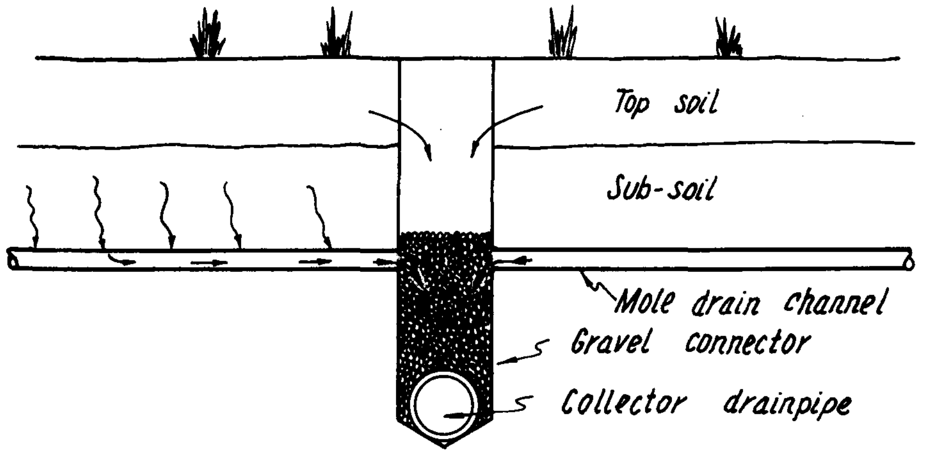


Figure 5.1 Mole-tile connector.

plough across the drainline. The trench width should not be too wide in order to conserve the amount of backfill material required. A minimum trench width of 150 mm is sufficient when gravel is used. Many mole drainage schemes are installed with only topsoil backfill or use a 'sandwich' of straw as a connector. However it is generally recognised that the mole drains will last longer with a good outfall (see 6.2).

5.2 BACKFILL FOR INTERCEPTOR DRAINS

In 4.4.3 the point was made that the effectiveness of an interceptor drain is reduced if groundwater flows above the drain and is not captured. This effect can be reduced to a large extent by backfilling the drain with gravel to provide a permeable path for water down to the drain. The depth of permeable fill should be at least up to the undisturbed watertable level.

5.3 IMPROVEMENT OF HYDRAULIC EFFICIENCY

In the drainage of permeable soils the movement of soil water towards the drainline is impeded by the convergence of flow to the drainline and in particular to the joints in tile drains (almost all movement of water into a tile drain goes through the joints <u>not</u> through the porous tile). This impedance to the flow decreases as the diameter of the drainpipe increases. A gravel envelope around the pipe (Figure 5.2) increases the effective diameter of the pipe and provides a permeable path for

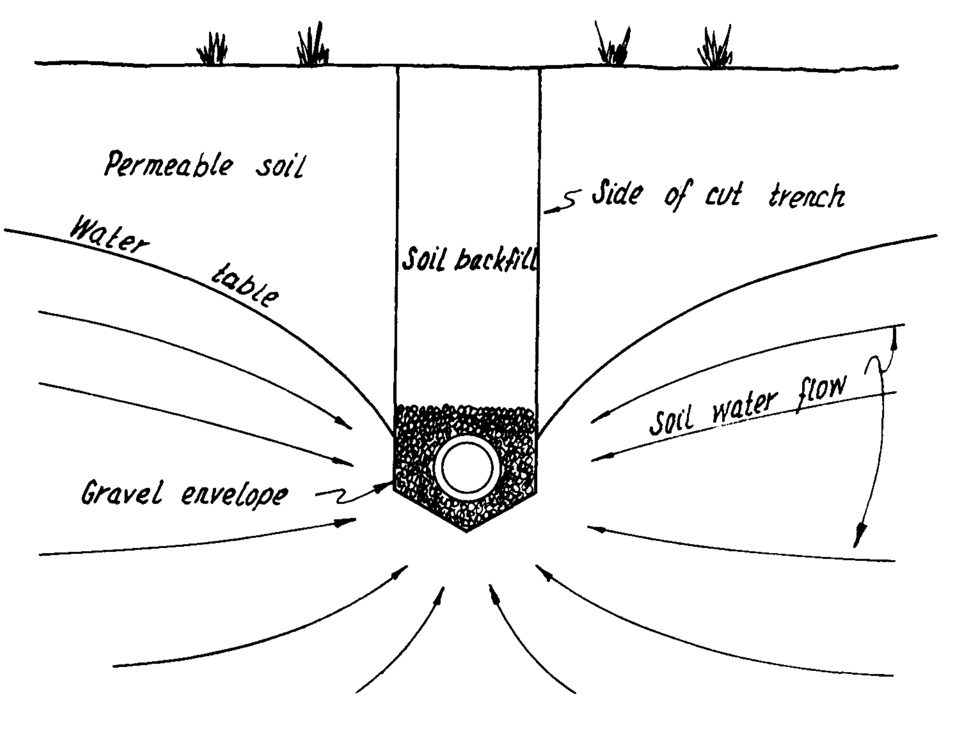


Figure 5.2 Gravel envelope.

soil water to the nearest tile joint. The effect of this hydraulic improvement is that the spacing between drains can be increased. In deep permeable soils this improvement is estimated to be up to 100 percent, that is, the spacing can be doubled. In the shallower soils in New Zealand a 50 percent increase would be feasible. On the basis of cost the use of gravel for this purpose alone would seldom be justified.

Research has shown that a gravel envelope around the top and sides of the drainpipe is almost as effective as the full surround and would usually be easier to place.

5.4 PREVENTION OF SILTING

Artificial backfill can be effective in preventing the entry of soil particles into the drain but the cause of the soil movement needs to be considered. There are two cases:

(a) Soil migrates downwards under the influence of gravity and water so that there is a continual supply of particles to enter the joints or slots in the drainpipe. Almost any material will help to prevent this movement. The use of brushwood, moss and straw backfill is quite old. For permeable soil drainage a strip of polythene on top of the drainpipe is effective as the soil water enters the drainpipe through the sides and bottom. In this situation gravel is not necessary if its only purpose is to prevent the downward movement of soil into the drain.

(b) In some soils which contain fine sands the hydraulic gradient in the soil water flow near the drain is sufficient to carry soil particles into the drainpipe. The process involved is similar to the formation of quicksands and the soil particles which enter the drain are not removed by the normal water flow in the drainpipe. This process can be prevented by an envelope of gravel which contains a selected range of particle sizes. This graded gravel acts as a filter to prevent movement of the problem soil. A single size gravel envelope will often be effective because of the reduction in hydraulic gradient due to an increase in effective drain diameter as described in 5.3.

Various types of alternative filter materials such as fibreglass and coconut fibre are used in several overseas countries and the designer who is confronted with a problem soil should seek further information on available filters.

6. MOLE DRAINAGE

6.1 SOILS SUITABLE FOR MOLE DRAINAGE

There is at present no rigorous system for classifying soils suitable for mole drainage nor are there suitable field tests of sufficient reliability.

It is usually necessary for the subsoil to contain some clay but the required percentage can be as low as 15 percent if other factors are suitable (such as particle size and clay chemistry).

Appendix C contains the results of a survey on the suitability of various soils in New Zealand for mole drainage. The survey records the experiences of farm advisors involved in agricultural drainage.

The construction of mole drains is a relatively inexpensive operation and it should be tried on any heavy land which is to be drained. This possibility should be considered at the initial design stage.

6.2 PHYSICAL CONDITIONS REQUIRED FOR MOLE DRAINS

It is generally recognised that the primary cause of the collapse of mole drains (neglecting the effect of soil type and construction faults) is loss of soil strength due to saturation of the soil around the mole channel especially at the top and sides of the channel. In order to avoid this saturated state the mole channel must not become overloaded during operation thus developing positive soil water pressure in the top and sides. After flow has ceased the channel should not have pockets of water left in it. The constructional requirements for these conditions are:

(a) A good outfall. Most mole drains have a collector drain as an outfall (see 3.2) and a gravel connector provides a free flowing path to the collector drain. Hand-augered connections between mole drain and collector have been used but require considerable labour. Less porous connectors such as earth backfill lead to a greater possibility of the mole channel filling with water and thus shortening its life.

(b) The mole channel should not have any reverse grades as these are points where positive soil water pressures develop and water and silt are trapped after flow has ceased. In practice this means that mole drains should not be drawn through any hollow deep enough to cause the mole plough to reverse grade unless there is a collector drain in the lowest part of the hollow. Alternatively some land smoothing may be required to fill in small depressions.

(c) The maximum length of a mole drain is dependent on the slope (see 4.3.2). This is because the steeper slopes permit a higher flow and thus a higher inflow into the mole channel. The inflow is directly proportional to the length. In situations where the slope decreases along the mole drain the channel length should be decided by the least slope in order to avoid overloading the channel.

(d) The collector drains and outfall of the whole drainage scheme must be designed so that water does not back up into the mole drains. This means that the collectors must have sufficient flow capacity and possible flooding of the outfall should be checked for its effect on water levels throughout the scheme.

6.3 CONSTRUCTION OF MOLE DRAINS

It should be the aim of the designer to plan the collector drain layout in such a way that the ploughing of the mole drains is simplified, that is, preferably all parallel within any one paddock. The direction of the moles should be specified on the drainage plan.

The spacing between mole drains is usually 2 - 3 m.

The mole plough should be adjusted to run at the depth of the densest clay layer. This is commonly at about the 450 mm depth in many New Zealand soils.

The desirable moisture condition of the soil is field capacity in the subsoil with the topsoil dry enough for good traction. These conditions are usually best met in the spring and the continued drying of the soil into summer helps the formation of cracks in the clay. Mole ploughing at other times of the year when the soil is not saturated nor very dry can still be beneficial but there is a lower probability of having the warm dry weather afterwards which helps in the development of the crack structure in the soil and possibly a chemical hardening of the channel walls.

Mole ploughs require a large drawbar pull for successful operation. Even under good conditions a 50 - 60 kW wheel tractor is near its limit of traction. A crawler tractor is much more suitable for this work.

A typical rate of mole ploughing is approximately 0.5 ha/hour.

6.4 THE LIFE OF MOLE DRAINS

It can be seen from the foregoing section that the life of a mole drain depends on a number of factors apart from the soil type. Reports of lifetimes of two to 25 years have been noted. Mole ploughing is probably best considered as a cultivation practice which, under good conditions, should be carried out at five to seven year intervals. On less suitable soils it may be required at one to two year intervals.

7. CONSTRUCTION STANDARDS

This chapter deals with the construction of subsurface drainlines. The construction of mole drains is covered in Chapter Six.

7.1 MATERIALS

7.1.1 Clay tiles

The specifications for clay tiles are given by the New Zealand Standard:

'Clay Field Drainpipes' NZS 1824:1963.

A rough field check on tile quality can be made by striking the clay pipe with a small metal object such as a coin. A ringing tone is an indication of good quality. Any cracked or distorted pipes should be rejected.

7.1.2 Concrete drainpipe

Concrete drainpipes should be manufactured according to the New Zealand Standard:

'Precast Concrete Drainage Pipes' NZS 594:1961.

7.1.3 Plastic drainpipe

The New Zealand Standard for plastic drainpipe of both the rigid and corrugated type is:

'Performance requirements for plastic pipe for use as light duty sub-soil drains' NZS 7650:1975.

7.1.4 Wooden drains

Wooden box drains for peat drainage (see 7.10) should be constructed of ground treated timber.

7.1.5 Gravel backfill

All gravel used in contact with subsurface drains should be clean, durable and contain no fines (preferably no particles smaller than coarse sand, that is, none less than 0.2 mm).

Some recommended ranges of gravel size for specific purposes are as follows:

(a) For gravel connectors in mole drainage any size or mixture of sizes in the range 5 - 50 mm are acceptable. The lower size limit excludes coarse sands because of the very high permeabilities required for good mole drain outfalls. Gravel larger than 50 mm can deflect the mole plough when it is drawn through the connector.

(b) When gravel is used as an envelope around plastic drainpipe it should support the pipe so that the full strength can be developed (see 7.2.2(b)) and there should be no sharp objects which could damage the plastic wall. For naturally graded gravels the acceptable size range is from coarse sand to 40 mm. For single size gravels a maximum size of about 15 mm is preferred.

7.2 INSTALLATION OF DRAINPIPE

7.2.1 Trenching

Apart from the use of the trenchless method (see 7.2.4) the pipe trench is best dug by a trenching machine which is designed for laying agricultural drains. Such a machine will have grade control and a pipe chute which guides the drainpipe onto the carefully formed bottom of the trench. Attachments for continuous blinding (the careful placing of soil adjacent to the pipe) and backfilling may also be provided. If a proper agricultural trencher is not available then some of the alternatives are:

(a) A backhoe excavator. The bottom of the trench will have to be hand finished to grade. The buckets normally fitted to these machines are often too wide for agricultural drainage because of the excessive amount of gravel which would be required if it is used. If possible a narrow bucket of about 200 mm width should be used. The use of this width in heavy soils will require a spoil ejector and preferably no sides to the bucket.

(b) The industrial chain-type trencher can be used but again these machines do not dig to grade. The bottom will need hand finishing and loose material removed from the bottom of the trench.

(c) In places where hand digging of trenches is required the labour can be minimised by the use of the proper tools. Use of the drainage spade gives a narrow trench which can be graded to a good bottom finish and laid with pipes without the need for anyone to get into the trench. The use of the proper pipe handling and bottom finishing tools can also reduce the labour involved in the use of backhoes and other non-agricultural trenchers and permit the use of narrow trenches.

If a trench is dug below grade and needs additional filling only small gravel, not loose soil, should be used to provide a firm pipe bed.

If possible, trenching should not be carried out under wet soil conditions because the consequent smearing of the sides of the trench can impede the flow of soil water to the drain and pipes should never be laid in slurry conditions. If drains must be laid in saturated soils then the trench should be dug below grade (beginning at the outfall of course), allowed to drain and the bottom laid with pea gravel up to grade level before laying the pipes.

7.2.2 Pipelaying

(a) Clay or concrete pipe

These pipes are in short lengths (usually 300 or 600 mm) and soil water enters the drain at the joints between the pipes. The bottom of the trench should be rounded or grooved to prevent the pipes rolling sideways. In peat or other soft ground the pipes can be laid on wooden planks to prevent settlement.

There are various recommendations about the size of the gap between tiles when laying by hand but with the use of trenchers with tile laying chutes the only practical method is to keep the tiles touching as they are laid. The normal roughness of the tile end face allows sufficient space for water entry.

The tiles should be blinded before backfilling. This means laying some of the backfill material (gravel or topsoil for example) between the pipe and the trench walls so that the pipe is properly supported before backfilling with the larger fractions of material can move the pipe or leave large pieces of material in such a way as to cause concentrated loading of the pipe. Some modern agricultural trenchers have a blinding attachment which scrapes a small amount of soil onto the pipe as it is laid.

(b) Plastic pipe

The single most important property of plastic drainpipe is that its ability to withstand heavy loads depends entirely on the fact that any load on top of the pipe causes it to flex slightly and transfer the force to the soil around the sides. If there is no soil (or gravel) around the pipe it will probably collapse. This behaviour is in contrast to rigid clay tiles which support loads by virtue of their own strength. Thus it is most important that:

(i) The bottom of the trench is formed to the shape of the pipe or alternatively has V-shaped groove of angle 90° - 120°.

(ii) Careful blinding of the pipe with soil or gravel is essential to the development of soil support from the sides. The blinding should cover the pipe in order to protect the plastic from the impact of large lumps of soil during backfilling. The blinding must be carried out as the pipe is being laid to prevent the pipe from rising off the trench bottom due to residual stresses from coiling of the pipe.

Care must be taken not to stretch plastic pipe when laying as this will reduce the strength. This is especially true if the pipe has been lying in the hot sun. During frosty weather some care should be taken in uncoiling plastic pipe as some plastic materials may crack at low temperatures.

7.2.3 Backfilling the trench

Any special materials such as polythene strip and filters should be placed during the laying and blinding of the pipe.

If a gravel connector (for mole drainage) is being used the trench is filled with the gravel to within the specified depth from ground surface (commonly 300 mm for mole depth of 450 mm).

There is usually not much choice about whether the subsoil or topsoil is returned to the trench first as both are thoroughly mixed by most trenching machines.

Backfilling should not be carried out if the soil is in a saturated condition nor should heavy applications of irrigation water be made in an attempt to settle the backfill rapidly. Natural settlement of the backfill is preferable. The purpose of these precautions is to restrict entry of soil into the drainpipe and loss of permeability near the drain. Soil from a poorly drained soil which has been dug by a trenching machine often has little structure left. Sometimes straw is placed over the drain and even on top of the gravel connector to provide temporary (for several years) protection for the drain.

7.2.4 Trenchless drainlaying

The foregoing recommendations on trenching, pipe laying and backfilling can be superceded by modern drainlayers which carry out all these operators in one pass. Inspection of the finished drainline is very difficult and careful operation and materials handling is required. This is especially true when laying clay tiles as a large gap between adjacent pipes can cause rapid siltation of the drain.

7.3 GRADE CONTROL

The laying of drainpipe to the correct grade is necessary for the following reasons:

(a) To maintain the design pipe flow.

(b) To avoid siltation of the drainpipe due to ponds left after flow has ceased or decreases in flow velocity due to changes of gradient.

Where changes of grade are required the designer must avoid the development of positive or negative pressures in the pipe.

7.3.1 Minimum grades

The recommended minimum grade is determined by the velocity of flow required to remove any soil particles which enter the drainpipe. This velocity is expressed in terms of full pipe flow and thus the required grade can be obtained for a particular type of drainpipe from the chart in Appendix B.

Recommended velocities are:

Small risk of silting, or clay particles and fine silts	0.2 m/s
Where coarse silts to fine sands could enter the pipe	0.5 m/s

For 100 mm clay tiles the flow chart gives grades of 0.1 percent for the lower velocity and 0.34 percent for the higher velocity.

7.3.2 Maximum grades

Recommendations on maximum grades are made because experience has shown that tile drains on grades of greater than two percent in some soils have failed due to erosion of the soil around the pipe caused by turbulent flow at the pipe joints. Lateral drains can usually be designed to have grades of less than two percent but main drains may have to be laid on steep grades. Where the grade exceeds two percent in sandy soils, four percent in silt loam or six percent in clay one or more of the following protective measures should be taken:

(a) Since the soil next to the pipe is critical the use of clay binding around the pipe allows the use of the six percent maximum grade.

(b) Wrap the pipe joints with tar paper or other durable protective material.

(c) Seal the pipe joints or use continuous pipe.

Where the steep section of drainline joins a section at a smaller grade pay particular attention to the construction practices described in 7.3.3.

7.3.3 Changes of grade

Two types of grade change are shown in Figure 7.1.

If the pipe is flowing full then pressures are lowered near point A which can lead to soil being sucked into the pipe and pressures are increased near point B which can cause blowout of the drain.

At increases of grade a breather pipe (as at point A) allows air into the drain thus relieving the suction. On decrease of grade a relief pipe (at point B) allows water to rise and spill over the top if necessary.

These precautions are not required if the pipes never run full.

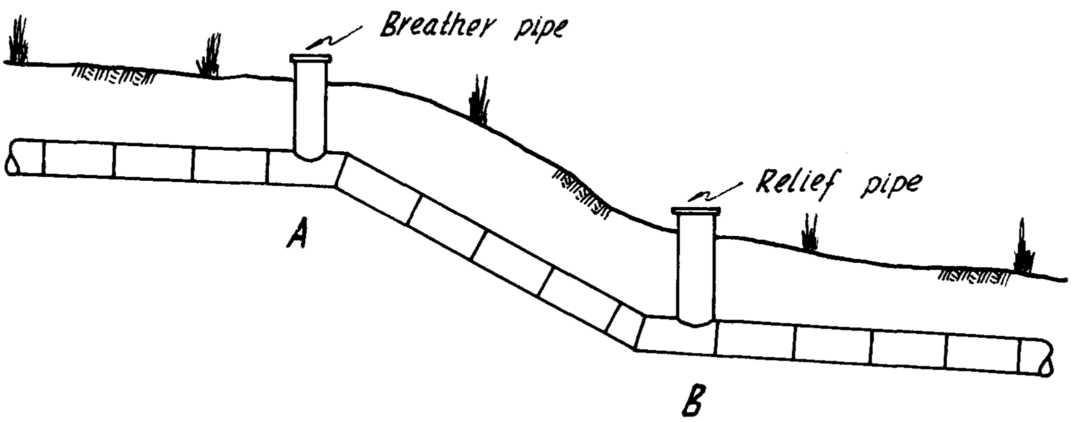


Figure 7.1 Changes in drainpipe gradient.

An alternative is to use a smaller diameter pipe (preferably continuous, see 7.3.2) on the steep section. Its flow capacity on the steep grade should be about equal to the capacity of the larger pipe on the smaller grade.

7.3.4 Accuracy of grade control

The desirable accuracy of grade is as follows:

(a) There should be no reverse grades.

(b) Deviation of the constructed grade from the design grade line should not exceed 15 percent of the internal pipe diameter.

(c) These allowable deviations should be gradual over a distance of not less than ten metres.

In spite of the foregoing requirements it must be understood that drain pipe laid in almost any fashion will drain waterlogged ground. The efficiency with which drainage occurs and the life of the drain depends on good construction practice. However there may be situations where emergency subsurface drainage is required, drain life is of small importance and careful construction is difficult. In these circumstances some degree of drainage can still be obtained.

7.4 JUNCTIONS AND CHANGES OF DIRECTION

The horizontal changes of direction in a drainline are usually limited in radius of curvature by the type of trenching machine used. For curves dug by hand the gaps between tiles on the outside of the curve should not be large enough to admit soil. Plastic pipe (in the corrugated form) does not have this problem. Manufactured bends are best used for acute direction changes.

Manufactured junctions should be used where lateral drains join the mainline. The angle between the pipes (for example, Y-junction or T-junction) is not important as far as flow efficiency is concerned.

Junction boxes can be used where the laterals join the main line at different levels (Figure 7.2).

These structures, although costly, act as silt traps and provide an inspection and maintenance point in the drainage system.

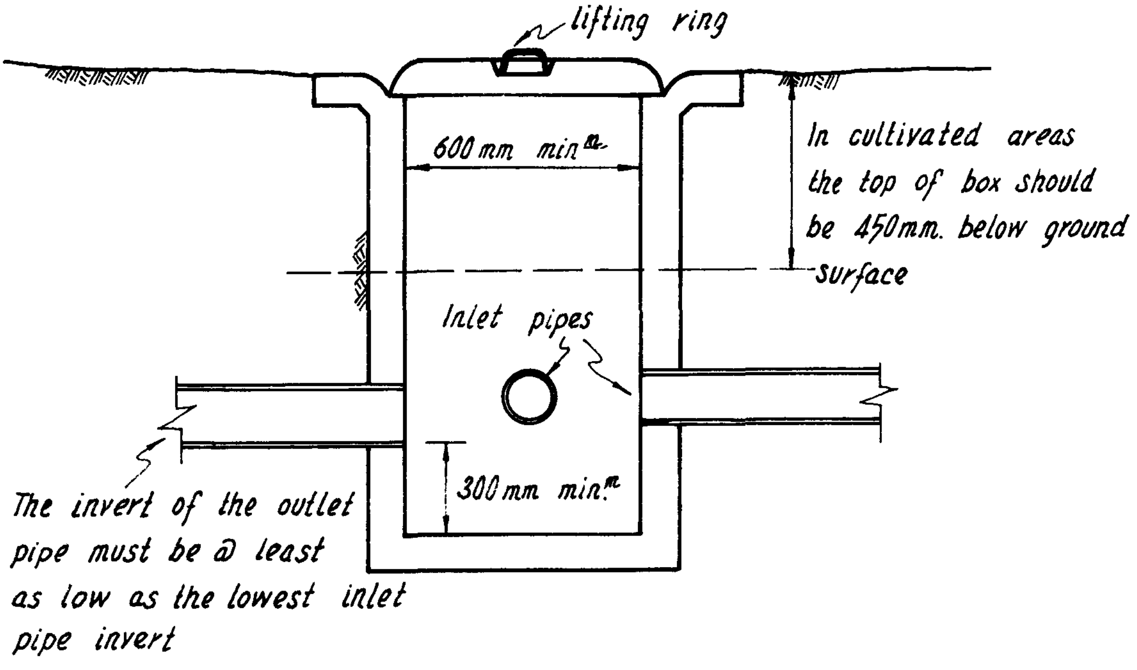


Figure 7.2 Junction box.

7.5 MINIMUM COVER OVER DRAINS

In order to avoid damage to the drainpipe from traffic loading and cultivation no part of a subsurface drain should be less than 600 mm below the ground surface.

7.6 BACKFILL LOADS ON DRAINPIPE

The backfill load on a pipe in a trench depends on the soil type, width and depth of trench. For the usual range of agricultural trenches, that is, up to 450 mm wide and 2 m deep the soil loading is not critical. For greater widths or depths or large diameter pipes, engineering advice should be sought.

7.7 CONNECTION TO OLD DRAINLINES

Agricultural land which needs drainage quite often has the remnants of former subsurface drains which have failed due to various causes. The presence of these old drains can intensify the problem by collecting water in one part of the paddock and piping it to another part where a pipe blockage causes a small spring to form. Where possible the old drainpipes should be connected to the new system by means of a gravel connector as in mole drainage (see 3.2). This can be done by dumping gravel in the trench where the new drainline crosses an old one. The old drainline should never be directly connected to the new pipe because silt may be transported into the drain and cause its premature failure.

7.8 DRAINPIPES NEAR TREES

There should be no tile joints or perforated pipe within 30 m of water loving trees such as willows and poplars. For other trees or where drain flow is infrequent during the growing season this distance can be reduced to 15 m. This restriction does not apply to orchard drainage where drainflow is infrequent. Continuous seepage into orchard drains may give problems however and deep drainage outside the orchard may have to be considered to remove this seepage. (This would be in addition to the normal orchard drains).

Drains within the aforementioned distances from trees should be of continuous unperforated pipe.

7.9 OUTFALLS

The outfall for a subsurface drain may be an open ditch or the sump of a pumped outlet, or a combination of both. In suitable areas the use of a drainage well can be an economical solution.

7.9.1 Gravity outfall to an open ditch

The last three metres of drainline at the outfall should consist of continuous rigid pipe of at least the same diameter as the drainpipe.

The backfill should be well tamped around and over the pipe. Any porous backfill material should be discontinued above the outfall pipe.

Some attention should be paid to the possibility of the outfall being flooded by high water levels in the ditch. Long periods of flooding should be avoided because the drain may silt up due to low flow velocities when the pipe is full and the discharge is small.

Short periods of flooding - such as during storm events - are permissible if the following precautions are taken:

(a) Water levels should never rise high enough to cause flooding of mole drains.

(b) The saturation of soil backfill and subsequent rapid drainage can cause soil to enter the drain unless there is some means of protection such as polythene strip on the top of the drain pipe or gravel backfill is used.

Construction of the outfall should take into account the cleaning operations required on the open ditch and thus need to be well marked or built in such a way as to resist damage or blockage from ditch cleaning machinery.

Prevention of erosion damage from stock and entry of small animals into the pipe are factors to be considered.

7.9.2 Drainage wells

Where a gravity outfall is not available one possibility which has been used in New Zealand is the disposal of drainage water down a well into a suitable aquifer. Pumping rates of wells in the same formation and drawdown information give some idea of the capacity of the formation to accept the water. Because of the risk of pollution to well users the advice of the local water authority must be sought.

7.9.3 Pumped outfalls

Where it is not possible to obtain a gravity outfall or a drainage well for a subsurface drainage system then a drainage pump may be considered. The detailed design is not within the scope of this monograph but the following points should be considered when an initial assessment is carried out.

(a) Whenever a very long pipe main or open ditch is required to provide a gravity outfall the construction costs may be high enough for the alternative of a pumped outlet to be a better solution.

(b) In order to minimise pumping costs as much water as possible should be diverted through gravity outfalls. This usually means taking special care with surface drainage.

(c) Drainage pumps do not run continuously and thus some storage is required. Where electric motors can be used they can be operated automatically at 5 - 10 cycles/hour (a pump cycle is a period of pumping followed by the period when the storage is being refilled). The storage required is usually a sump constructed of concrete, concrete blocks or a large concrete pipe.

When internal combustion engines are used they are usually manually started no more than twice in 24 hours. The storage required is thus very much larger and usually consists of a long open ditch which provides the outfall for the subsurface drains.

7.10 SUBSURFACE DRAINAGE OF PEAT

The subsurface drains in peat are only part of what should be a carefully designed water control system which aims to prevent the peat drying out as well as providing a suitably drained soil for agriculture.

Some constructional features of pipe drains in peat are:

Peat provides a poor foundation for clay tiles and they are likely to settle out of alignment. Boards mounted on wooden piles have been used to support the tiles. A better alternative is to use plastic drainpipe which is light and continuous. Wooden box drains made of 150 mm x 25 mm planks with chainsaw notches cut through the corners of the box have been used in several peat drainage schemes.

8. APPENDICES

APPENDIX A - DRAINAGE COEFFICIENTS

The concept of a drainage coefficient has become a useful index of the flow capacity required of the ditches and pipes of a drainage system. The drainage coefficient is defined as the depth of water to be removed in 24 hours from the area contributing to the drain flow. The relationship between this coefficient and the agricultural requirements of a drainage system is largely a matter of experience.

If the drainage requirement of a crop could be defined, for example, saturation of the root zone not to exceed 48 hours, then a drainage coefficient could be found such that the total 48 hour rainfall of a specified probability of occurence could be removed in that time. This particular coefficient would include surface and subsurface runoff. The subsurface drainage system would be designed to remove only the water in the soil. For a situation of poor surface drainage or rainfall at less than the infiltration rate of the soil all the rainfall will pass through the subsurface drains. This is not the case where rainfall exceeds infiltration and there is good surface drainage. For a low intensity rainfall climate, studies have been made (notably in England) of the drainage coefficient required in a particular regional climate to meet a specified agricultural drainage need.

Another approach to subsurface drainage design is to specify a particular rate of drawdown of the watertable after the wet season. This of course requires knowledge of the drainable porosity of the soil. The drainage flow capacity for this case is still expressed as a drainage coefficient. In practice the measurement of soil porosity is not simple and experience on a particular soil is more reliable.

If there is any downslope movement of groundwater or artesian water in addition to excess rainfall then the situation becomes very difficult to solve analytically.

Mole drainage systems require a large flow capacity in order to protect the mole channels rather than for a specified agricultural requirement.

For many of the small scale farm drainage schemes in New Zealand the spacing and lengths of lateral drainlines are such that the capacity of available sizes of drainpipe are quite adequate. Flow capacity becomes a critical factor only for pipe mains. If the laterals outfall into an open ditch size is controlled by the depth requirement rather than flow capacity.

The author is reluctant to recommend particular values of the drainage coefficient based on regional, climatic, soil or crop characteristics apart from the guidelines suggested in section 4.5. The drainage coefficient is a useful design index but its value should be based more on experience than any a priori assumptions.

APPENDIX B - PIPE SELECTION CHART

The chart shows the flow characteristics of the two common sizes of clay pipe used in New Zealand and the various types of locally manufactured plastic drainpipe. The designer should check on the availability of any pipe under consideration as manufacturers may change a product or withdraw it completely.

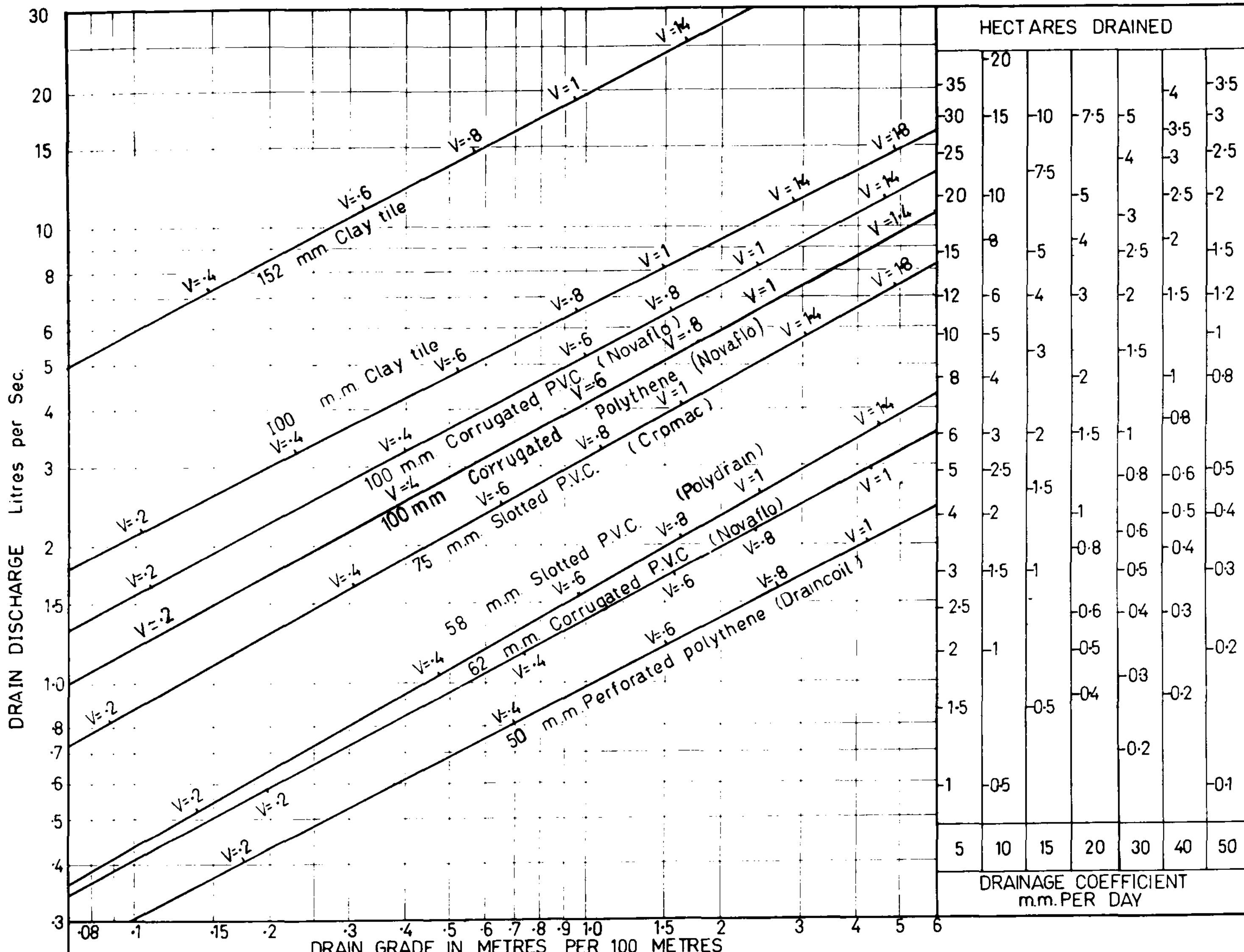
The characteristics for 100 mm and 150 mm diameter clay pipe are derived from the design charts of the USDA Soil Conservation Service.

Data from a U.S. manufacturer of corrugated polythene drainpipe provided the characteristics for the 100 mm corrugated polythene 'Novaflo'.

All the other types of plastic drainpipe were tested by the New Zealand Agricultural Engineering Institute[1] and the relevant flow characteristics derived from these tests.

The brand names of the tested products are given in brackets on the chart but the description of the type of pipe (e.g. 100 mm corrugated PVC or 50 mm perforated polythene) is sufficient identification for brands not shown.

(1) "The Flow Characteristics of Plastic Drainage Pipe Available in New Zealand" NZAEI Project Report No. 10.



DRAIN PIPE DESIGN CHART

NOTES

1. Curves for clay tiles from:

$$V = 92{\cdot}87 \; R^{\frac{2}{3}} S^{\frac{1}{2}} \text{ (m/sec)}$$

USDA Bulletin 854 (converted to S.I. units)

2. Curves for plastic pipe obtained by experiment.

3. Figures V = 2 V = 4 etc. refer to water velocity in the drains (m/sec)

APPENDIX C - SUITABILITY OF SOILS FOR MOLE DRAINAGE

At various times in the history of mole drainage tests have been suggested for determining the suitability of soils for this purpose. The validity of the more simple tests is often questioned because some soils which fail the test appear to be able to be successfully mole drained. The physical and chemical behaviour of soils under the conditions induced by mole ploughing are far from being well understood. Again, local experience of a particular soil is the best guide at present.

In order to obtain some benefit of this local experience for other people involved in drainage the N.Z.A.E.I. carried out a survey among the advisory staff of the Ministry of Agriculture and Fisheries on their experience with mole drainage. The results of this survey are presented on the following pages.

It is hoped that the designer can find among the soils listed one that is sufficiently similar to the soil under consideration so that some judgement can be made on its suitability for mole drainage.

The soil set names and numbers refer to:

"Soils of North Island, New Zealand" Soil Bureau Bulletin (n.s.) 5 for numbers followed by (N).

"Soils of South Island, New Zealand" Soil Bureau Bulletin 27 for numbers followed by (S).

The information in these bulletins has been used to arrange the soils according to the soil type at moling depth (400 - 500 mm). This was done on the basis of soil set names supplied by advisory staff for the N.Z.A.E.I. survey and no distinction was made between soil classes within a soil set e.g. whether it was a silt loam or clay loam. The usual reservations in applying soil survey data to particular localities should be noted.

The remarks listed under the heading "Mole drainage characteristics" represent the opinions of advisory staff. The difficulty of assessing the quality of mole drainage, especially over short time periods, will be apparent from a consideration of the factors described in chapter six.

Soil Type at depth 400-500mm	Soil Set name and reference number. North Island (N) South Island (S)	Mole Drainage characteristics
Sand	Otatara 70 (S)	unsuitable
	Riverton 70a (S)	unsuitable
	Hungahunga 105 (N)	suitable
Sandy loam	Waihou 48 (N)	suitable in some areas
	Horotiu 48a (N)	effective
	Willowbridge 95d (S)	suitable
	Oreti 27b (S)	unsuitable
	Seaforth 99d (S)	unsuitable
	Pigburn 2a (S)	marginally suitable in parts
Sandy silt	Tuapere 98g (S)	unsuitable
Silt loam	Horotiu Te Kowhai complex 48b (N)	effective
	Karaka 72 (N)	fair-rather variable
	Akeake 104 (N)	suitable
	Pukeuri 11b (S)	suitable
	Mairaki 18 (S)	unsuitable
	Waitohi 18a (S)	suitable
	Wakanui 18f (S)	suitable
	Claremont 20 (S)	suitable
	Ashley 20a (S)	unsuitable
	Opuha 21 (S)	suitable
	Hororata 27e (S)	unsuitable
	Kahutara 30dH (S)	suitable
	Chaslands 36a (S)	marginal
	Coopers Creek 89b (S)	variable

Soil Type at depth 400-500 mm	Soil Set name and reference number. North Island (N) South Island (S)	Mole Drainage characteristics
	Dacre 89f (S)	marginal
	Mayfield 96d (S)	suitable
	Mataura 98f (S)	unsuitable
Peaty Silt Loam	Invercargill 86c (S)	marginal
	Manapouri 89g (S)	marginal
Loam	Manawatu 1 (N)	marginal
	Kairanga 2a (N)	suitable
	Acton 97b (S)	unsuitable
Stony loam	Hapuku 34d (S)	suitable
Clay loam	Morton 13c (N)	suitable
	Kokotau 13d (N)	suitable
	Atua 29 (N)	reasonably suitable
	Bideford 29e (N)	reasonably suitable
	Hamilton 83 (N)	suitable
	Topehahae 98 (N)	suitable
	Waitohi 2 (S)	suitable
	Lottery 18e (S)	suitable
	Jordan 25 (S)	suitable
	Temuka 89 (S)	suitable
	Braeburn 89d (S)	suitable
Clay	Warkworth 39a (N)	suitable
	Waikare 45 (N)	reasonable
	Kaipara 101 (N)	suitable
	Hauraki 103 (N)	suitable

APPENDIX D - DRAIN SPACING FORMULA

There is a considerable number of mathematical formulas for calculating the spacing of drains in permeable soils. Their applicability in practice is limited by the fact that it is difficult to obtain meaningful measurements of the hydraulic conductivity and porosity (for the unsteady flow formulas) of the soil. The difficulty arises from the fact that measurements of these properties at a point do not always give a reliable estimate of the overall behaviour of the soil mass. Another problem is that the soil properties can change significantly after the installation of a drainage system or changes in cultivation practices.

On the following pages a nomograph[1] for one of these formulas is presented.

This formula is for the steady state situation in which the drainage system is just maintaining the watertable at the required depth for the particular drainage coefficient (see Appendix A).

There are five factors involved:

The drainage coefficient - p
The hydraulic conductivity of the soil - K
Maximum height of the water table above the drains - h
Depth of the impermeable layer from the drains - d
Spacing between the drains - S

For a particular soil type and climate the ratio K/p can be considered to be constant. Thus knowledge of the geometrical properties h, d, S from an existing drainage scheme could be used to find K/p and hence what spacing would be required for the same soil and climate but with a different depth to the impermeable layer or with deeper drains, or for a different watertable level.

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(1) This nomograph has been redrawn from the paper "Tile drainage in the Netherlands" by W.C. Visser, Netherlands Journal of Agricultural Science, Volume 2 No. 2, 1954. The original drawing was by J.H. Boumans from the data of L.F. Ernst.

Example

An existing drainage scheme has a spacing of 40 m between the drains which are laid at a depth of 0.9 m. There is a tight clay layer at a depth of 3 m below the ground surface. The watertable at mid point between the drains is 500 mm below ground during wet seasons. What improvement in watertable depth could be obtained by halving the spacing to 20 m by laying additional drains between the existing ones?

$S = 40$ m
$d = 3 - 0.9 = 2.1$ m
$h = 0.9 - 0.5 = 0.4$ m
$d/h = 5.25 \quad s/h = 100$

These values do not fit on the first nomograph (for $K/p \leqslant 100$) and so the second nomograph is used. A line through $d/h = 5.25$ and $s/h = 100$ gives $K/p = 340$.

For the new spacing $S = 20$ m.

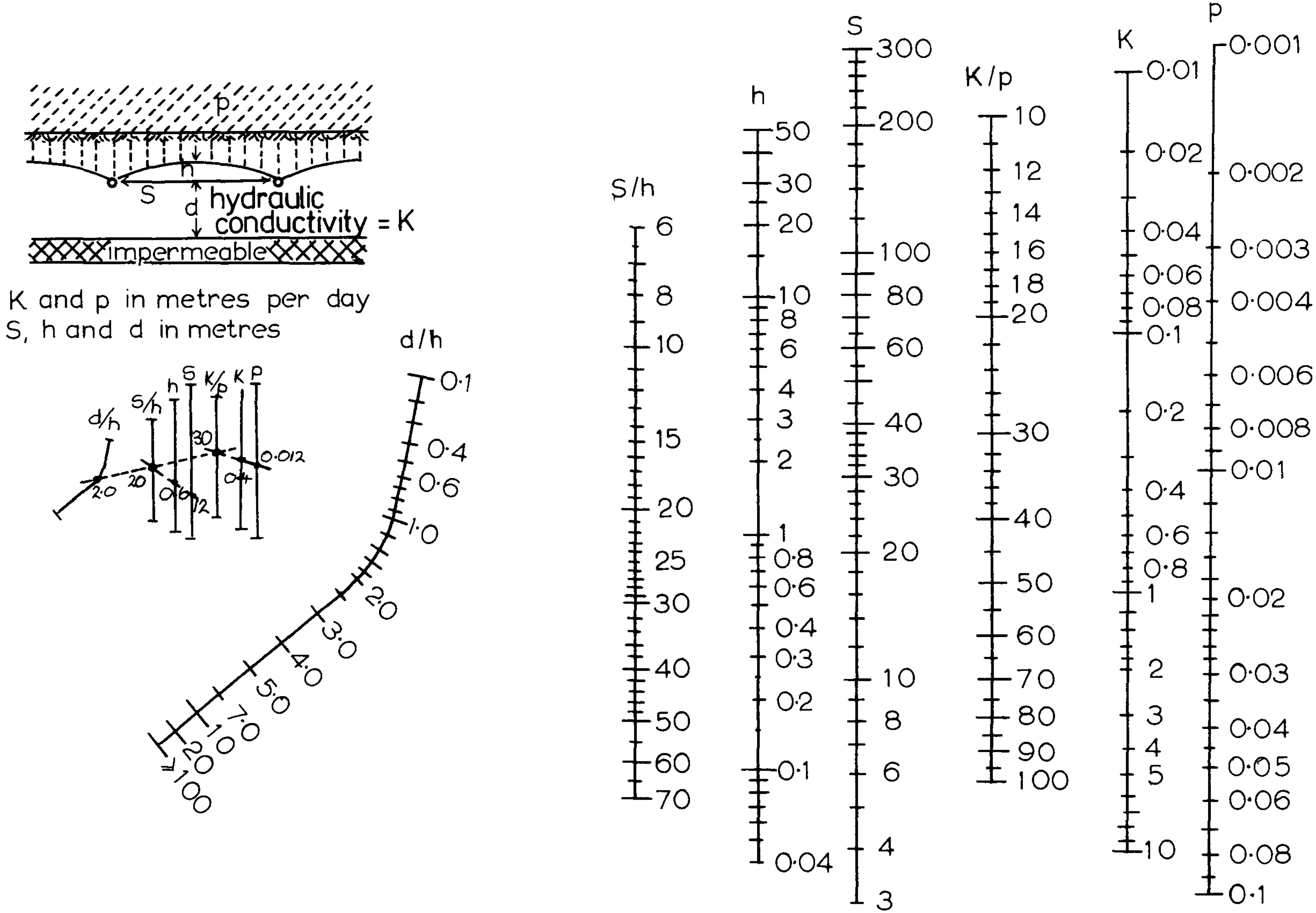
h is to be found so that S/h and d/h are unknown. Thus trial values of h should be used until the line joining $K/p = 340$ and the value of d/h intersects the S/h line at a point which yields the same value of h.

In this example $h = 0.15$ m is found to be satisfactory. Thus the new water table depth at mid point between the drains is:

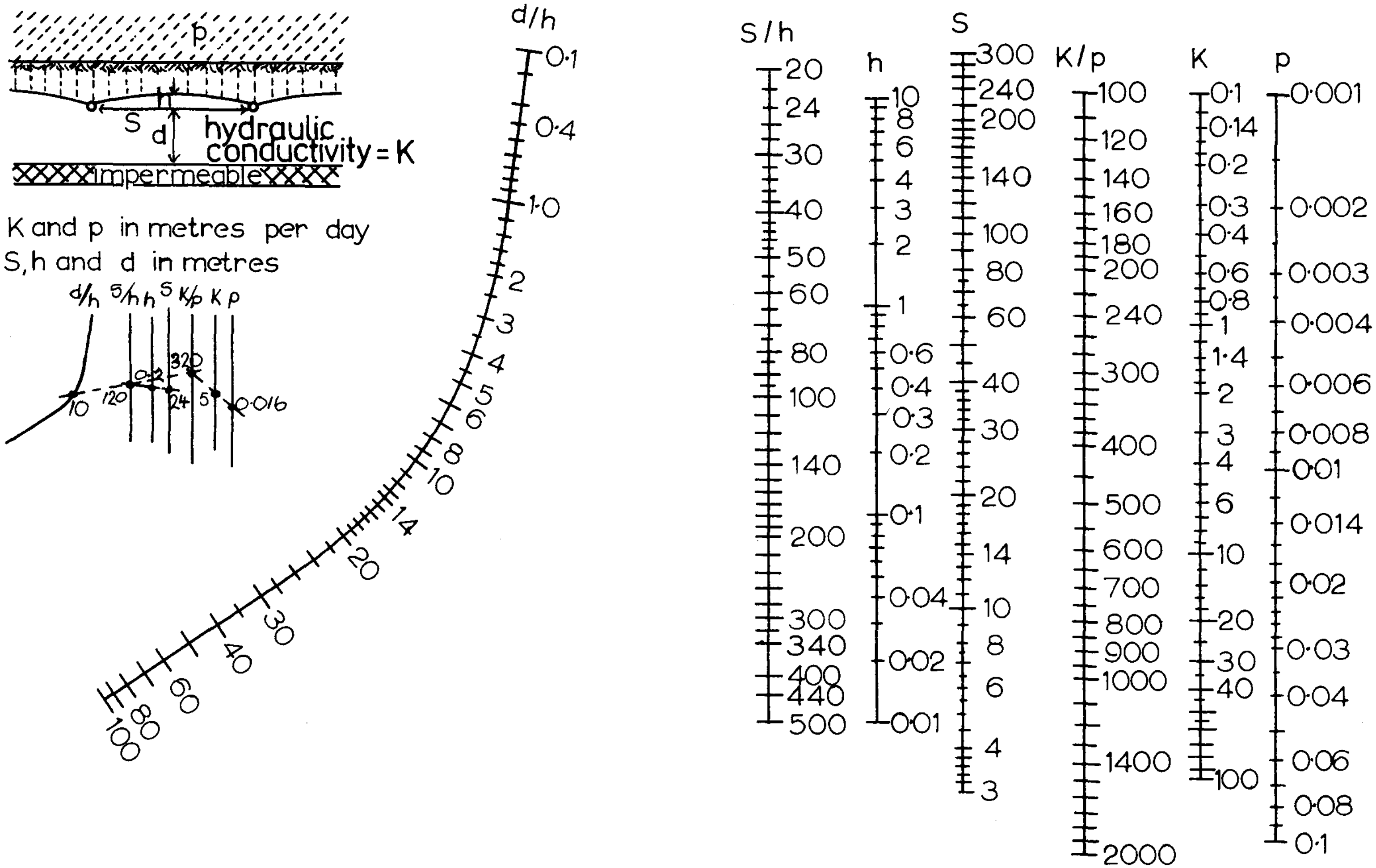
$0.9 - 0.15 = 0.75$ m $= 750$ mm

Hence the improvement is $750 - 500 = 250$ mm.

Nomogram for calculating distances between tile drains when $K/p \leqslant 100$



Nomogram for calculating distances between tile drains when K / p ⩾ 100



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P/2 The Hydraulic Performance of Trough Valves: T.D. Heiler (July 1968) (2nd Edition May 1971) (out of print).

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P/9 The Spinning Disc Distributor Part 2: G.R. Davies (February 1973) (out of print).

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