Aspects of land drainage development in Ireland over the last twenty-five years

L.F. Galvin

An Foras Taluntais, Kinsealy Research Centre, Dublin 17, Ireland

1 Introduction

The total land area of the Republic of Ireland is 6.89 million ha. Of this 1.18 million ha are occupied by woods, bogland, rocks, water, urban areas etc. The remaining 5.71 million ha are utilized for agriculture. In Table 1 the land use and drainage status of the utilized agricultural land are outlined. These data indicate that over 90% of this land is under grass: dairying and beef production are the major enterprises.

Table 1 Land use and drainage status of agricultural land in the Republic of Ireland (million ha)

Arable crops	0.50		
Hay and silage	1.25	Dry mineral soil	3.35
Pasture	2.96	Wet mineral soil	2.00
Rough grazing	1.00	Peat land	0.36
Total	5.71		5.71

Table 1 also shows that 2.36 million ha (over 40% of the utilized agricultural land) is in need of drainage. Some of this has been drained over the last 38 years but as outlined in Table 2, approx. 65% of the wet land still needs drainage.

Table 2 Estimated area and drainage status of wet land (million ha)

	Wet soil (permeable)	Impervious soil	Peat land	Total
Total wet land	1.20	0.80	0.36	2.36
Drained (1948-'85)	0.70	0.35	0.07	1.12
Not yet drained	0.50	0.45	0.29	1.24
Needs re-draining (estimate)	0.14	0.14	0.02	0.30
Total area in need of drainage	0.64	0.59	0.31	1.54

1.1 Rainfall

Excess rainfall is a major factor in Irish agriculture and leads to many problems, especially in the wetter regions of the west. As outlined in Table 3, the annual rainfall in the west ranges from 1 000 to 1 600 mm. Potential evapotranspiration (PE) is 360-390 mm (annual) and 310-340 mm (April-September). The normal April-September rainfall is 400-650 mm but in a wet summer (1985) the April-September rainfall ranged from 600 to 850 mm which is considerably in excess of the PE.

Table 3 Rainfall and PE data for the Republic of Ireland (mm)

		East	West
Rainfall	Annual	700–1 200	1 000–1 600
	April-September	350– 500	400– 650
	April-September(1985)	450– 550	600– 850
PE	Annual	420– 470	360– 390
	April-September	370– 410	310– 340

1.2 Drainage

In a survey of land drainage problems and installations in Ireland (Galvin 1969), it was found that seepage and springs (38%), impermeable soil (31%) and high watertable (24%) were the major drainage problems in the country.

The wet permeable soils, affected by a high watertable are usually drained in the conventional manner using a drainage coefficient of 10-12 mm/day. For soils affected by artesian seepage or springs detailed investigations are required to greater than normal depths to determine the position of the various soil layers especially the more permeable ones. Considerable progress has been made in the development of investigative techniques and in the design of drainage systems for seepage problems (Mulqueen and Gleeson 1981). The solution usually requires deep drains to maximize the drainage potential of the free-draining layers. These soils respond well to drainage and the installations generally have high benefit/cost ratios.

The impermeable soils, especially those of a plastic nature, give rise to major problems. Under conditions of high summer rainfall and relatively low evaporation (Table 3), substantial moisture deficits rarely occur and trafficability problems can arise for both animals and machinery. Because of this, these soils are totally unsuitable for tillage and need intensive drainage for grass production and utilization. In many cases the primary objective in draining these soils is for the survival of the farmers concerned rather than a boost to production.

Peat land has as wide a range of permeabilities as mineral soil and is affected by similar drainage problems. Although the total area drained is relatively small, the design of suitable drainage systems is somewhat complicated especially where the depth of peat varies.

2 Drainage of peat land

2.1 Peat types

Irish peat lands can broadly be divided into two major categories, blanket bogs and raised bogs (Hammond 1979). The blanket bogs cover extensive areas along the western seaboard and the higher hill and mountain regions where the annual rainfall averages 1 250-1 600 mm.

The raised bogs are mainly located in basin-type hollows in the central plain of Ireland, where the rainfall is approx. 850 mm. In contrast to the blanket bogs which are relatively uniform in composition, the raised bogs generally display a distinct sequence of peat types through the profile. The physical properties of the various peat types vary considerably (Galvin 1976).

2.2 Drainage systems

The total area of peat that has been drained is relatively small (Table 2). The main drainage emphasis has been on the more permeable cut-over basin peats and on the shallow to medium-depth (300-600 mm deep) peats overlying permeable subsoils. Some drainage has also been carried out on deep and shallow blanket peats.

2.2.1 Deep peat (> 1 m)

Where the peat is permeable (often the case with cut-over raised bogs), conventional drainage systems are installed. It has also been found very beneficial to grade the bog surface to provide uniform surface slopes (Galvin 1972).

For draining deep blanket peat, closely-spaced shallow drains are required (Galvin and Hanrahan 1967). Grubb and Burke (1979) developed an improved tunnel plough for this purpose which excavates and extrudes a band of peat (380 mm high x 280 mm wide) at a depth of 800 mm. Although developed for agriculture the machine is now used extensively for forestry drainage. The aeration provided in the large tunnel encourages prolific root development resulting in far greater tree stability and improved growth.

2.2.2 Peat (< 1 m deep) over a permeable subsoil

Where the peat is permeable, conventional drainage is used. Impermeable peat is usually separated from the permeable subsoil by an iron pan. In such situations, the peat is reclaimed by ploughing to a depth of 70-150 mm below the iron pan. This has the dual effect of breaking the pan to allow free drainage through the permeable subsoil and of providing a peat/subsoil mix at the surface to improve trafficability.

2.2.3 Peat (< 300 mm deep) over an impervious subsoil

This material is usually reclaimed by ploughing to a depth of 50-70 mm below the bottom of the peat and installing mole drains at a depth of 500 mm. The moles provide drainage channels and the deep crack system while the ploughing develops the upper crack structure for increased infiltration. The ploughing also provides subsoil at the surface for trafficability improvement.

2.2.4 Peat (300-1 000 mm deep) over an impervious subsoil

Where the peat is greater than 300 mm deep, the drainage potential is lessened mainly because moles cannot be installed in combination with deep ploughing. In those situations, collector drains are provided and the area is ploughed to a depth of 80-150 mm below the base of the peat. The soil is generally left for one year to dry and ripen after which it is back-bladed and cultivated. This system uses the plough furrows as drainage channels and it is therefore essential to provide continuous well-formed furrows. However, as the drainage effectiveness of the furrows may disimprove with time, this type of reclamation is questionable.

3 Drainage of impermeable soil

For the drainage of impermeable soils, a combination of soil disruption and closely-spaced (1.3-2 m) drainage channels is required. The effectiveness of the system depends on the size and type of cracks formed during disruption and on the permanency of these cracks and of the drainage channels. Irish glacial tills are usually overconsolidated and crack well if disrupted under dry conditions. Mole drains, gravel moles and ripping (or subsoiling) are used as soil disruption cum drainage techniques (Galvin 1982).

Mole drains are quite effective where the soils are stable. However, in many Irish soils, the moles deteriorate completely after a relatively short period (1-3 years). Similar deterioration problems arise in relation to the stability of the disruption channels formed during ripping and subsoiling.

In the early stages of channel deterioration the overall drainage effectiveness is not reduced to any great extent because the channel capacity at close spacing, exceeds the discharge requirements. However, progressive channel and crack deterioration coupled with occasional channel blockages can give rise to reduced channel flow and higher watertable levels. If land is intensively grazed during wet periods under those conditions, poaching damage occurs and the cycle of deterioration escalates rapidly. In those situations, the gravel mole system (Mulqueen 1985) has proved very successful. Apart from the fact that a stable channel is provided, the improved crack system provided by the wider leg of the gravel mole plough is also most beneficial (Galvin 1983).

4 Pilot drainage schemes

During the 1975-78 period agricultural advisors operating the farm modernisation scheme requested assistance in the development of effective drainage systems for a variety of heavy impermeable soils in the west of Ireland. At that stage because of financial constraints it was not possible to install instrumented drainage trials. However, pilot trials were installed on a number of typical farms in particular localities (and soil types), beginning in East Clare (Galvin and McGrath 1977) and extending to the other areas later. Invariably 0.5-1 ha plots of mole drains, gravel moles, ripping and an undrained control were installed and farmed commercially. The condition of the moles and ripping was monitored by excavation and examination and by taking polyurethane casts over a period of 1-4 years. By that time the moles and ripping had deteriorated substantially on all but one site (the moles lasted for 8 years on this site). The extent and serious nature of the deterioration is typified by the situation that developed on the Cree site.

The Cree pilot scheme which included moles, gravel moles, ripping, piped drains spaced at approx. 15 m and a control was installed in 1977. The initial results on all the disruption plots were very good. The moles, gravel moles and ripping maintained good watertable control over the first year while the piped drainage plot and control were quite wet. However, during 1978 and 1979 the monitoring showed that the moles and the ripping channels were deteriorating rapidly. This was borne out by increasing surface wetness and trafficability problems. The early summer of 1980 was dry and there was no difficulty in harvesting the first silage cut. However, the breakdown in drainage coupled with the wet weather in June, July and August of 1980 forced the farmer to postpone the second silage cut until September. At that stage he harvested the gravel moled plot without difficulty but failed completely to travel on any of the other plots. He was compelled to cut these plots with a rotary mower and use a buck-rake to remove the grass. During this process extensive surface damage occurred on all but the gravel moled plot. The farmer subsequently gravel moled the whole area.

The major advantage of these pilot schemes was that they were operated by farmers with whom other farmers in the neighbourhood and on similar type soils in other areas could relate. The Cree site which was visited by many groups of farmers and members of the advisory services demonstrated, in a very clear cut manner, the disastrous results of a drainage breakdown during a wet summer and the contrast between effective drainage and poor drainage. Some farmers and advisers who had visited the site in 1978 and 1979 were amazed at the deterioration that occurred during 1980 and realized after explanation that it was the culmination of a cycle of deterioration that began very early in the life of the moled and ripped plots. These farmers examined the condition of moles installed on their own land and became far more discerning in their selection of drainage systems for future farm developments.

5 Experimental trials

5.1 Field trials 1980-1984

In 1980/81 under a project, partly funded by the EEC, a number of instrumented drainage trials were installed (Galvin 1983). The drainage techniques under test combined soil disruption with channel formation and included:
- Mole drains spaced at 1.3 m;
- Gravel moles spaced at 1.3 m;
- Gravel moles + ripping. The gravel moles are spaced at 2.6 m with intermediate ripping (also spaced at 2.6 m);
- Ripping spaced at 1.3 m;
- Control (undrained).

Summary of results

The following is a summary of the results which are discussed in more detail (Galvin 1983; Galvin 1986a; Galvin 1986b). Data from the Kanturk site which are typical of the type of breakdown that occurred generally, are shown in Figures 1 and 2.
- Mole drains
  On many sites the moles failed after relatively short periods (1 to 3 years). On those sites the watertable control was quite effective during the early part of mole collapse but became less effective as the deterioration increased;
- Gravel moles
  The gravel moles have generally given good results where they have been installed

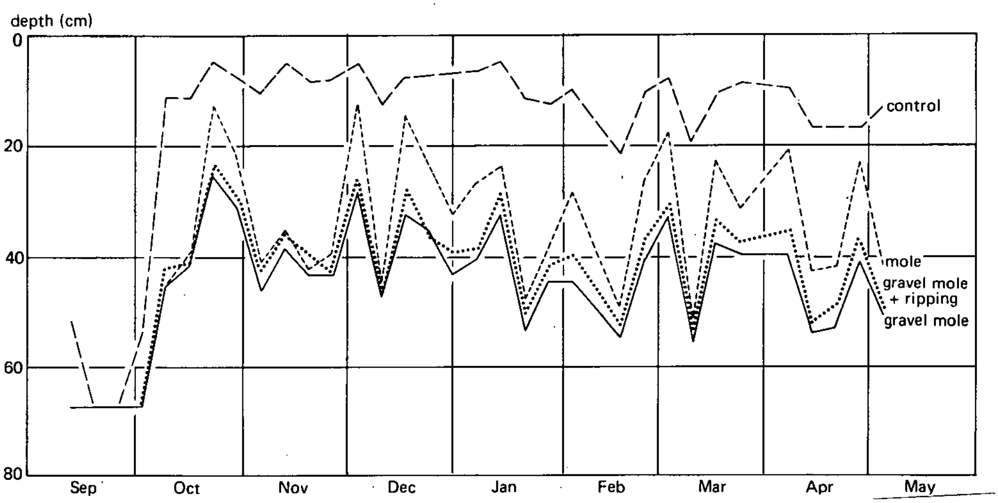

Figure 1 Waterlevel fluctuations at Kanturk 1982-83

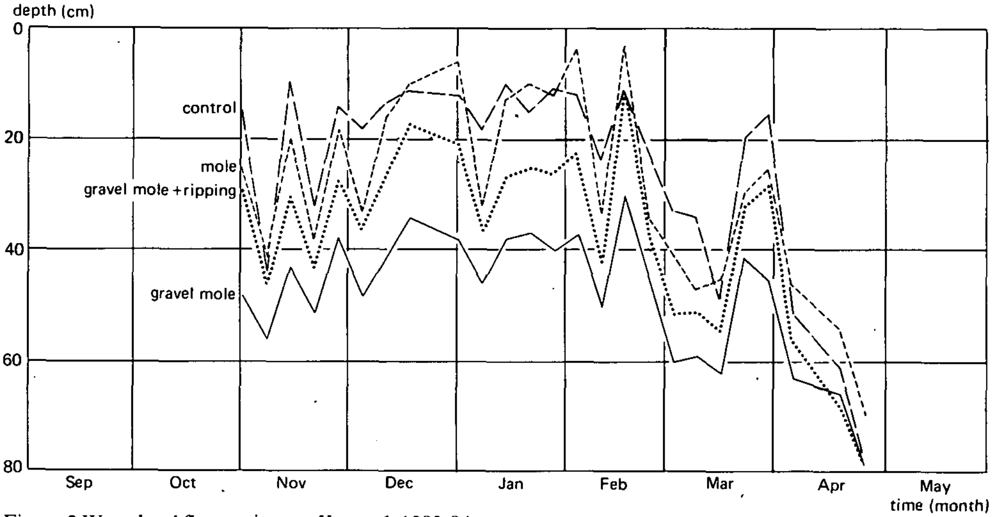

Figure 2 Waterlevel fluctuations at Kanturk 1983-84

under suitable conditions so that adequate soil cracking was attained. No problems have been encountered in relation to the clogging of the gravel channel. The effectiveness of the system is therefore directly related to the cracking developed during installation and to the preservation of that crack structure;

- Ripping
  Ripping has generally performed in a manner somewhat similar to mole drains. The cracking developed during ripping (using the gravel mole machine) is generally better than that developed by the mole plough but the channel formed is less stable;
- Gravel mole + ripping
  This system was installed in an effort to reduce expenditure and was based on the premise that if the soil profile to the depth of installation were completely cracked, the water could discharge through the gravel moles at 2.6 m centres. In practice it was found that the soil was not completely cracked between adjacent gravel moles but that each gravel mole and rip channel controlled the watertable within its own sphere of influence. As the rip channels deteriorated the watertable control also deteriorated. This system is more effective than moles or ripping in unstable soils but is not as effective as gravel moles installed at 1.3 m centres.

5.2 Shallow moles

Shallow moles (at a depth of approx. 300 mm) were installed at the Kilmaley site in an attempt to improve the upper crack structure over moles, gravel moles and ripping which had been installed under unsuitable soil water conditions (Galvin 1986b). It was envisaged that the shallow moles would collapse very quickly due to the shallow depth of installation and that the effect of shallow moling would be limited to a general loosening and improvement in crack structure over the existing disruption channels (moles, gravel moles etc.). However, the shallow moles did not collapse quickly and were still operating very efficiently 14 months after installation. At that stage they were disrupted by subsoiling because the efficiency of the shallow moles in removing rainfall was masking the relative effectiveness of the other drainage systems. This experience and some further experimental work have shown that shallow moles have a reasonable life-span even in unstable soils and that they are very efficient in removing rainfall quickly. They are unlikely to be as effective as moles installed at the standard 450-500 mm depth in controlling watertable at sufficient depth to prevent poaching. However, they should prove very effective as an ancillary system to moles or gravel moles installed at the standard depth. Furthermore the system is relatively inexpensive and can be installed with a light tractor. It can therefore be repeated at regular 2-3 year intervals by farmers without much difficulty.

5.3 Field trials 1984-1986

The 1984-86 field trials which are expected to continue beyond 1989 are designed to simulate normal farming practice as realistically as possible. Three major systems are being tested: moles, gravel moles and an undrained control. Each system is installed on two plots one of which will be shallow moled at 2-3 year intervals to relieve compaction and improve hydrological efficiency. The project is being installed at two sites (Kilmaley and Laragh) and there are two replications on each site: twelve 0.25 ha plots per site.

The plots will be grazed continuously and grass production, grazing days and ground conditions will be monitored. Hydrological measurements include continuous water flow recording (Talman 1979) and watertable measurements on a number of maximum-reading piezometers (Davies 1969). These piezometers are read at 2-3 days intervals and the ground scoring is recorded at the same time. The collector drains and disruption treatments were installed at the Kilmaley site in August 1984. It was re-seeded in August 1986 and will be grazed in 1987.

The collector drains were installed at Laragh in July 1985 but the disruption treatments have not yet been installed due to unfavourable weather and soil conditions. However, sacrificial moles were installed at the full 450 mm depth on the mole and gravel mole plots in September 1986 at a time when the soil conditions were too wet for adequate shatter. It is hoped that the moles will speed up the drying process on these plots during the early part of 1987 and thereby improve the effectiveness of the shatter achieved during the installation of the moles and gravel moles.

5.3.1 Kilmaley measurements

Piezometric measurements at Kilmaley during 1984-85 and 1985-86 indicate that all the drained plots are giving effective watertable control throughout the year, whereas the watertable on the undrained control is at or near the ground surface for extended periods. There has been no major fall-off in the effectiveness of any of the drainage treatments over the two-year period. This is borne out by the SEW(30) figures in Table 4 which show no major increase in SEW values on any of the drainage treatments. The flow hydrographs confirm that no major breakdown has occurred as yet even though site excavations and surface observations indicate that moles have deteriorated substantially in places.

Table 4 SEW(30) figures for Kilmaley 1984-85 and 1985-86

	1984-85	1985-86
Control	3,188	4,802
Shallow moles	1,005	1,093
Gravel moles	160	177
Moles	467	477

This was evident during re-seeding (August 1986): small areas randomly distributed through the mole drained plots were wetter and softer than the general drained area. Observations carried out by excavation and examining the moles and shallow moles have shown that the deep moles contain substantial quantities of slurried soil and appear to be failing by unconfined swelling. Occasional total blockages were encountered but in the majority of moles examined, the channels were still capable of transporting water. The shallow moles are in a better condition and contain comparatively little slurry. There was evidence in some of the shallow moles that the complete roof had dropped down without collapsing leaving an elliptically-shaped channel (width greater than height). This is typical of the disturbance that occurs when moles are installed slightly above the critical depth. Continued hydrological observations and production data from Kilmaley and Laragh should provide basic information on the cost effectiveness of the various disruption systems.

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Drainage development in Belgium

W. Dierickx
National Institute for Agricultural Engineering, Merelbeke, Belgium

J. Feyen
Department of Land Management, Catholic University of Leuven, Belgium

1 Introduction

Subsurface drainage is widely applied in Belgium in the low lying, flat agricultural lands and the valley bottoms for better crop production, trafficability and workability. The scientific design for drain spacing is mainly based on Dutch knowledge and experience, and due to the geographical and climatological similarity the same drainage criteria as proposed in the Netherlands are accepted.

Not only from the design point of view, but also the materials and equipment used to install subsurface drains are strongly controlled by the changes in drainage technology in the Netherlands. Most of the pipes installed in Belgium are imported either from the Netherlands or West Germany. Some 25 years ago Belgium started to produce clay pipes to compete with the bulk volume imported. Since the introduction of corrugated plastic tubing those small plants disappeared soon, and only since 1984 Belgium is producing small diameter corrugated pipes, used as field laterals. Recently this industry has the capacity to wrap the pipes with envelope materials. Up to now, the larger diameter pipes are still imported. Most of the Belgian contractors use drainage machinery manufactured in the Netherlands. In addition it can be stated that, due to the proximity of the Netherlands, being Belgiums northern neighbour, quite a volume of drainage work is being done by Dutch contractors.

Summarizing it is a fact that drainage development in Belgium has been strongly influenced by the changes in drainage technology in the Netherlands, primarily due to the geographical situation of both countries and in the second place due to the world leading role Dutch scientists have played in field drainage.

2 Analysis of the area drained and prospects for the future

Most of the drainage activity in Belgium is directly or indirectly supervised by the Nationale Landmaatschappij, which main task is the re-allocation of farm land. Within the re-allotment projects executed by the Nationale Landmaatschappij subsurface drainage is installed where the low productivity of the soils is due to high watertable conditions or poor drainability of the profile. According to their information the total area drained in re-allotment schemes amounts to 23 000 ha by the end of 1984. In 1985 about 1500 ha was drained and it is estimated that the area drained in future will be in between 1 500 and 2000 ha per year. The rather low intensity with which the area potentially suited for drainage is drained, is due to the current economic recession and the introduction of production quota's by the EC policy. The distribution of the areas drained through the Nationale Landmaatschappij are given in Table 1.

Table 1 Areal distribution of the drained land in Belgium

Province	Drained area (ha)
West-Flanders	9,801
East-Flanders	6,966
Brabant	2,809
Antwerp	572
Limburg	97
Luxembourg	793
Liège	58
Namûr	1,751
Hainaut	145
Total	22,992

(Source: Nationale Landmaatschappij)

Information about privately installed subsurface drainage is very scarce. Some sources estimate the total drained area installed between 1960 and 1977, including the land area drained by the Nationale Landmaatschappij, at 49 000 ha. Assuming a yearly growth since then of about 1500 ha some 60 000 ha should have been drained by 1984. According to previous hypothesis the land drained by the Nationale Landmaatschappij should only represent about 1/3 of the total land area drained. This seems to be rather small, because the already drained zones in the re-allotment areas are generally negligeable.

The size of the provinces are not that different to explain the differences per province in area drained in Table 1. The main reason for the relative large area drained in both West- and East-Flanders is the specific land use, which is mostly arable land. In the province of Antwerp and Limburg to the contrary, most of the sandy soils with shallow watertable are used as pasture, now gradually being converted for the production of fodder maize. Notwithstanding the current slow trend in drainage activity in Flanders, where only about 10% of the drainable land is drained, it is expected that interest in subsurface drainage will increase due to an increased interest in the growth of field vegetable crops used for fresh consumption and canning industry. The expansion in the sandy region will depend mainly on the long term effect of the milk quota measure on farm activity.

The area drained in the southern part of Belgium, so-called Wallonia, is small in comparison with the area drained in the northern part of the country. This can be explained by the difference in geology, topography and land use. The arable soils, where mainly the field crops winter wheat, sugar-beets and barley are grown in rotation, are composed of deep permeable loam with the watertable beyond the influence of the root zone. The plateau soils in the far south are used as pasture land or covered by pine forest. The drained soils are mainly meadows in the valley bottoms eroded by the numerous meandering rivers. Here the lay-out of the drainage network is strongly influenced by local topography, and consists primarily of single lines of pipe draining wet patches in the field.

Generally it can be stated that with a yearly growth in drained area of about 1500 ha and an expected life-time of 25 to 50 years, the effectively drained area in Belgium will never exceed 20 to 35% of the 300 000 ha, being the total area in Belgium which needs drainage.

3 Drainage criteria

An important aspect concerning drainage systems is the ability for the designer to determine the appropriate dimensions because it is those which count for the quality of the installation as well as the economic acceptability of the investment. Notwithstanding theoretical insights and practical relationships concerning models for unsaturated and saturated flow, that describe the infiltration and drainage processes, and models for the approximation of the discharge process of simple and more complex drainage units, have become available, drainage design in practice is mainly based on the application of Hooghoudt's equation. The reasons for the wide use of this equation are probably its simplicity and effectiveness. The equation involves the selection of two parameters only, rainfall intensity (q) and watertable depth (H) at mid-drain spacing. Last parameter determines together with the drain level (d) the steady height (h) of the watertable above drain level. Commonly applied values for these parameters are represented in Table 2. They originate from field experiences and research work performed in the Netherlands.

Table 2 Design criteria for rainfall intensity and watertable depth at mid-drain spacing

Land use	Discharge rate $q(mm.d^{-1})$	Watertable depth H(m)	Watertable head h(m) for d = 1 m*	Ratio h/q(d)
Pasture	7	0.3–0.4	0.7–0.6	100–85
Field crops	7	0.4–0.5	0.6–0.5	85–70
Vegetables	7	0.6–0.7	0.4–0.3	70–60

* d = drain level of 1 m below surface

The h/q ratio is considered as the drainage criterion for steady state drainage equations; the lower its value, the closer the drain spacing. In the case of a non-steady state approach the drainage criterion is specified by the required recession rate of the watertable at mid-drain spacing within a given period. The design criteria as specified in Table 2 are typical for the wet conditions in winter which approach nearly steady state. Evapotranspiration is negligeable and the rainfall is fairly uniform distributed in time. In addition it can be assumed that by the end of November soil water has been replenished, so that storage variations are minimal. To solve under those conditions Hooghoudt's equation the following soil information is required: the saturated hydraulic conductivity of the soil profile below the watertable and the level of the impervious layer. Last information is either derived from the soil map on scale 1/20 000, which is almost entirely published for Belgian territory, or from local field investigations. Traditionally the hydraulic conductivity is determined in situ with the auger hole method. Distinction is thereby made in the determination of the saturated hydraulic conductivity above and below drain level. The number of observation holes for the determination of the hydraulic conductivity varies according to the project size and the heterogeneity of the soil pattern. For small projects, from 10 to 15 ha, 3 to 5 auger holes are made.

Subsurface drainage originally was planned to control the watertable depth during the winter period. Nowadays more and more attention is paid to keep the water content of the plough layer below a critical threshold value for satisfying workability and trafficability of the soil during late harvest period and early spring, when sowing and preemergence treatments are carried out. Drainage systems designed for those periods are often called off-season drainage systems and the criteria specified in Table 2, typical for winter conditions, do not hold. For off-season drainage preference is given more and more to criteria for the non-steady state approach. The criteria are a depth criterion for the watertable at mid-drain spacing and a frequency of exceedance during harvest or seeding time. The watertable depth is defined in relation to the threshold value of the water content of the top layer. Those relations which are soil dependent, are found empirically. If the non-steady state approach is used in the design phase, the designer calculates the watertable elevation during the critical period for different drain levels and drain spacings. The drainage intensity which meets the specified criterion is normally installed.

Other problems encountered in drainage design are the likelihood of change in land use when the economical conditions are favourable, and the parcelling of the land. The fields of a farmer seldom are united in one block. The only way to test various geometric variants is with the aid of an interactive computerized design approach. In that way it becomes feasible to make a design tailored to the exploitation and at the same time optimally integrated in the main drainage system. Under the conditions that the land use is likely to change it is preferable to use the most stringent design criteria.

4 Drainage materials and machinery

The formerly used clay pipes are, in Belgium at least, completely replaced by corrugated plastic tubes. Smooth, rigid plastic pipes have not been used to a great extent at all. The corrugated plastic tubes used as field laterals have an outside diameter of 50 mm, equal to the inside diameter of the clay pipes. In spite of their smaller dimension it has been experimentally proven that corrugated tubes are more effective than clay pipes due to the more uniform pattern of perforations. In flat areas the laterals are normally oriented to use the available field slope and the main or collector lines are oriented parallel to the natural water ways. As a consequence of field size, field slope and nominal diameter of the laterals, their length is restricted to 150 and 200 m. Collector drains have diameters up to 200 mm and their length is in principle unrestricted. In practice too long collectors are avoided by junction boxes.

The main envelope material used in the past was coconut fibre, but flax straw was also successfully applied. Glass fibre sheet and glass wool were also used but their susceptibility to blocking and clogging, especially in soils with a high clay and/or silt content or rich in organic dust or where iron deposits occur, has cancelled their use as a drainage envelope. Other materials have been experimented, but for one or another reason they have never been accepted by designers or contractors. Under certain profile conditions coconut fibre and other organic envelopes can decay very rapidly. For those conditions, loose synthetic fibre envelopes are recommended. A newly applied envelope material is a mat of polypropylene fibre, a waste product of the carpet industry. The mat should meet following specifications: a mean thickness of 6 mm and a minimum thickness of 5 mm; a mean weight of at least 450 $g.m^{-2}$ and a minimum weight of 400 $g.m^{-2}$; the 90% pore size diameter as a mean of 5 replications should be in between 600 and 1000 micron, whereby each individual pore diameter should not deviate more than 25% from the mean. The only disadvantage of this synthetic envelope is its price, which is far higher than the price of coconut envelopes.

In spite of the availability of a wide range of envelopes, the problems of silting up of drains and clogging due to iron deposits still exist. The mechanism of envelope materials is not fully understood. Particularly with regard to the interaction between soil conditions, clogging and decay of the envelope further research needs to be done. It is still very risky to predict the structural stability of the soil in the trench, the need for envelopes and hence the type of envelope.

Nowadays drainage in Belgium is installed by modern trenching machines with digging chain, and trenchless machines with ripper or V-plough originating from the Netherlands and West-Germany. Where depth regulation in the past was done manually by the machine operator, keeping a reference mark on the digging part of the machine fixed on a sightline visualized by stakes, now only laser equipment is used for depth regulation.

5 Cost evolution of drainage

Information on the cost evolution of subsurface drainage with a regular parallel layout, the laterals discharging into an open collector, was supplied by the Nationale Landmaatschappij from their archives of tenders. The total cost price, expressed in Belgian franc per meter, includes the cost of drain pipe, the envelope and the installation costs. Each of those items represents about 1/3 of the total cost. The prices given in Figure 1 hold for simple drainage systems with coconut fibre or flax straw as envelope and for a minimum project size of several hundred hectares. Drainage investments on request of individual farmers can be expected to be about 50 to 100% more expen-

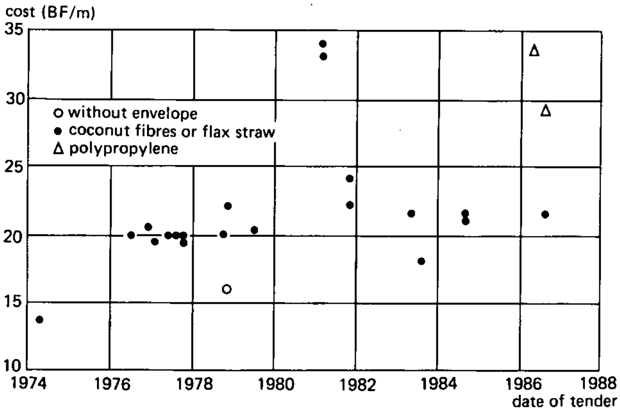

Figure 1 Cost price of parallel drain systems Source: the tender archives of the Nationale Landmaatschappij, Brussels, Belgium

sive. Figure 1 reveals that the unit cost price of parallel drain systems with either coconut fibre or flax straw as envelope did not vary much during the past decade, with the exception of the steep price increase around 1981. Figure 1 illustrates also the effect of envelope material on the total unit price.

During the period covered by Figure 1 the subsidy on drainage works executed within the context of re-allotment schemes decreased from 60 to 45%. Drainage works supervised by the administration of municipalities, polders or 'wateringues' receive a subsidy of 30% if the design is made by an authorized consulting office. Unfortunately it takes 2 years on the average from the start of the project before the drains are installed. Due to the administrative delay and the expense of the consulting office the benefits of the subsidy are often gone before the first drain tubes are installed. As a consequence more and more farmers prefer to drain their land by private enterprise, thereby loosing the grant of the local authorities. In practice most farmers ask a contractor to drain their land without any investigation of the site. Drain spacing and drain depth are based on soil type, land use and local experience. Although the cost per meter pipe almost doubles when installed by private enterprise, the farmer immediately profits from the advantage of drainage.

6 Drainage maintenance

Although maintaining properly designed and installed subsurface drains not difficult, maintenance is frequently neglected in Belgium. Only when severe siltation problems occur, drain pipes will be cleaned by flushing. Broken outlets are seldom repaired, unless waterlogging is hindering normal farming operations. Generally Belgian farmers consider drain pipes as free of maintenance.

7 Conclusions

Drainage development in Belgium has been and will be strongly influenced in future by the evolution of drainage technology in the Netherlands. The obvious reason is the nearby location of the Netherlands and the similarity, in particular for Flanders, of climate, soils, agrohydrological conditions and farming practice. In addition the public funds allocated for drainage research will never allow the development of a typical Belgium drainage profile. The only research being done and receiving international recognition, is the study of envelopes, their short and long term performance. To a lesser extent research has been done with regard to the development of a computer aided design package for use on personal computers. So far a software package for drain design on a main frame computer has been established. It is not expected that in the immediate future new areas in drainage research will be explored.