Developments in subsurface drainage techniques

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Introduction

Subsurface drainage is the technique of controlling the watertable by means of almost horizontal systems of open-jointed or perforated pipes installed at a certain depth in the ground or by 'mole' drains, which are unlined circular channels constructed in the ground. Water flow in these artificial channels occurs by gravity.
The term subsurface drainage is used to differentiate it from surface drainage, which is the removal of excess water by shaping the land so as to make the water flow over the surface to furrows, ditches, or waterways. Ditches can also, to a certain extent, serve to control the watertable, but their use for this purpose is being superseded by underground drains because of such disadvantages as loss of land, hindrance for farming operations and overland traffic, and heavy maintenance requirements due to prolific weed growth or instability of banks. Their use is nowadays mostly restricted to the disposal and transport of water, and sometimes to its storage.
Subsurface drainage systems were first applied on a large scale in the temperate zones of the world, especially in North America, Europe, and the Soviet Union. In the last decades the technique has also been introduced in arid and semi-arid zones, in combination with the introduction or improvement of irrigated agriculture.
In Europe, until some 25 years ago, drains were laid exclusively by hand. The pipes used were short clay ware or concrete pipes. A narrow trench was dug, accurate to the required depth and grade (Figure 1), the last few centimetres of soil being removed with a gutter-shaped scoop to form a proper bedding for the pipes.
To avoid soil disturbance around the pipes, a man would stand beside the trench and use a hook with a long handle to lay the pipes.
Drain installation by hand required 230 to 300 manhours per 1000 m of drain and was thus very labour intensive. It is therefore not surprising that efforts were made to mechanize the installation of subsurface drains. Drain installation was first mechanized in the U.S.A. in the 1920's, but it was not until the 1950's that it was introduced in Europe.
The mechanization of drain pipe laying in The Netherlands was greatly promoted by a number of factors:
- the large expansion of new agricultural areas to be drained
- the need for larger field sizes and better trafficability required by the modernization of agriculture in areas poorly drained by ditches and furrows
- the steady increase of wages and the growing scarcity of experienced labour.

The introduction of machines for pipe drain installation led to the appearance of specialized drainage contractors, working on a price per unit basis and therefore keen to further improve the



Figure 1.
Subsurface drain installation by hand (1952).
(By courtesy of Government Service for Land and Water Use).

technique. We shall now briefly review these developments that took place in the last 25 years.

Drainage machines

Trencher drainage machines

The first drainage machine to be used successfully in The Netherlands was a Buckeye imported from the U.S.A. in 1954. It had an open digging wheel with scoops and a trench box with a shoe to shape the trench bottom. The pipes slid down a chute and were laid in position by a man standing on the machine or walking alongside. The trench was thus excavated entirely by the machine, but pipe laying was still largely manual. The application of cover material, if used, was a separate operation. With the machine an average capacity of 140 m drain per hour could be obtained.

In the mid-fifties some Howard digging wheel machines, imported from Britain, were also used. The chute was constructed in such a way that the pipes automatically slid into position as the machine moved forward. With these machines, which were smaller than the Buckeye, an average of 70 m drain per hour could be obtained. Their depth range, however, was not entirely adequate for Dutch conditions.

The first drainage machines manufactured in The Netherlands were built onto a farm tractor (Figure 2).

As experience was gained with these machines, it was found that they could excavate the trench and lay the pipes with as much accuracy as pipes laid by hand.

Within the next few years various improvements were incorporated (Figure 3):

- the digging wheel was replaced by a digging chain with knives, which allowed a lighter and more compact construction of the machine and resulted in higher laying capacities
- a hydraulic control system was applied to regulate the digging depth
- the machine was no longer built on to a tractor, but on a special frame provided with long and wide tracks.

By 1958, some 80 drainage machines were in use in The Netherlands. When clay tiles were laid by these machines at the usual depth of 1.2 m and the usual trench width of 20 to 25 cm, capacities of 250 to 300 m per hour were normal. A crew of

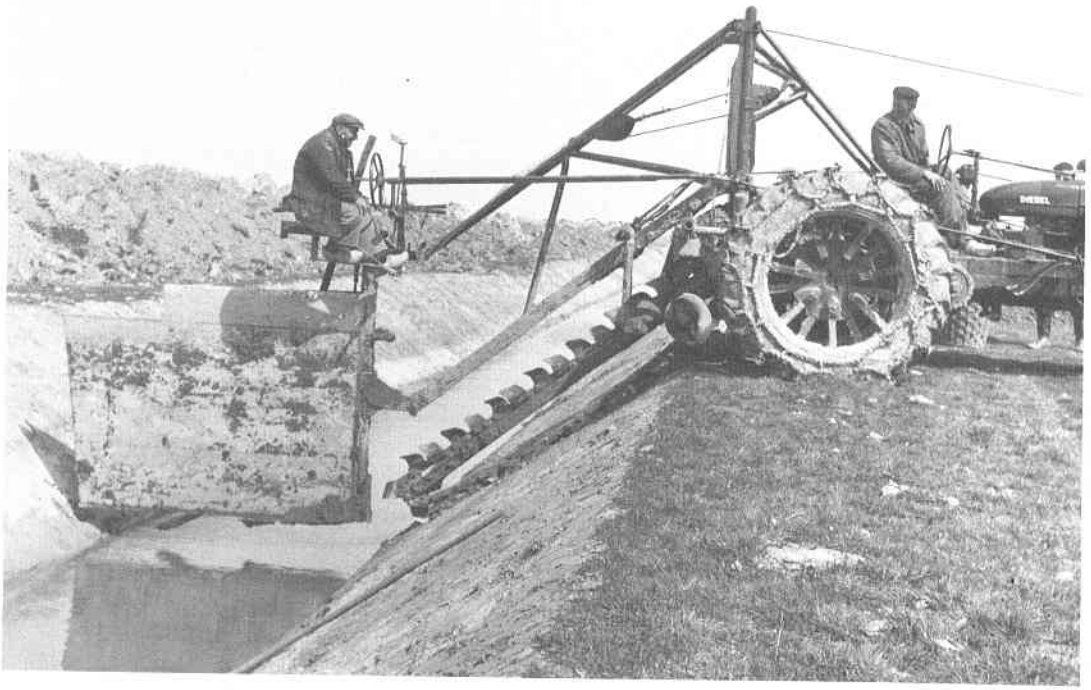
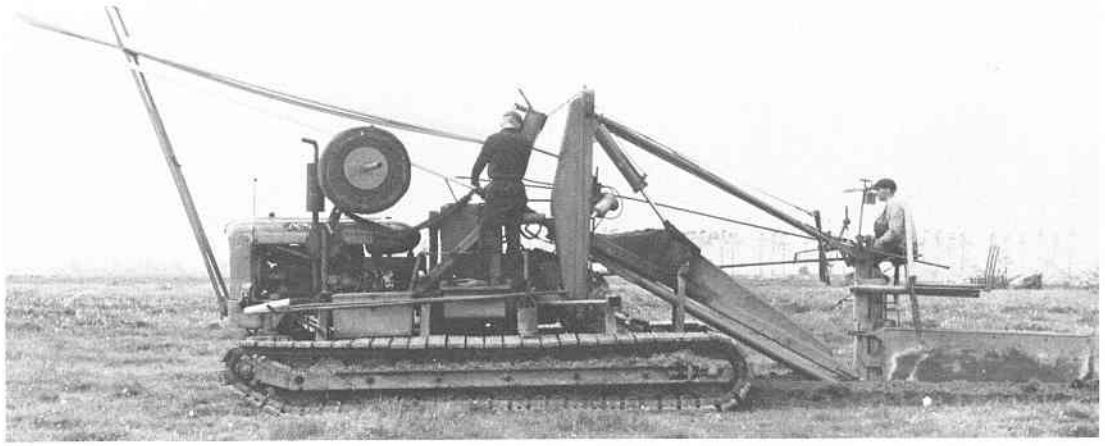


Figure 2.
Early model drainage machine (1958) using digging chain with knives (van den Ende).
(By courtesy of Government Service for Land and Water Use).

Figure 3.
Drainage machine installing smooth plastic pipe wrapped on the machine with peat litter band, 1967 (Draiëntie). Flat digging chain type, see also Figure 4a. (By courtesy of Government Service for Land and Water Use).



7 men was required for this operation so that the labour input was 25 to 30 manhours per 1000 m drain. These machines can be characterized as 'flat' digging chain type; they have the trench box connected to the machine frame by a parallelogram construction (Figure 4a).
With this system the angle of the digging beam varies according to the working depth. These machines are most efficient at working depths of up to 1.4 m in soft soils, which are the predominant conditions in The Netherlands.
The success of the drainage machines in The Netherlands led manufacturers to build machines for export as well. This greatly stimulated the adaptation of the machines for a wide range of working conditions: hard and stony soils, working depths of up to 2.5 m for arid irrigated lands, and the application of a gravel pack around the drain pipe. This led to the development of 'steep' digging chain type machines (Figures 4b and 5), which have the trench box connected to the machine chassis by an intermediate frame.
While trenching, the digging beam is at an approximately constant angle of 60° with the horizontal, irrespective of working depth. Other adaptations consisted of increased engine power up to 200 hp, adjustable width between the tracks (narrow for transport, wide for digging), and the track frames flexibly connected to the machine chassis for movement over uneven ground.

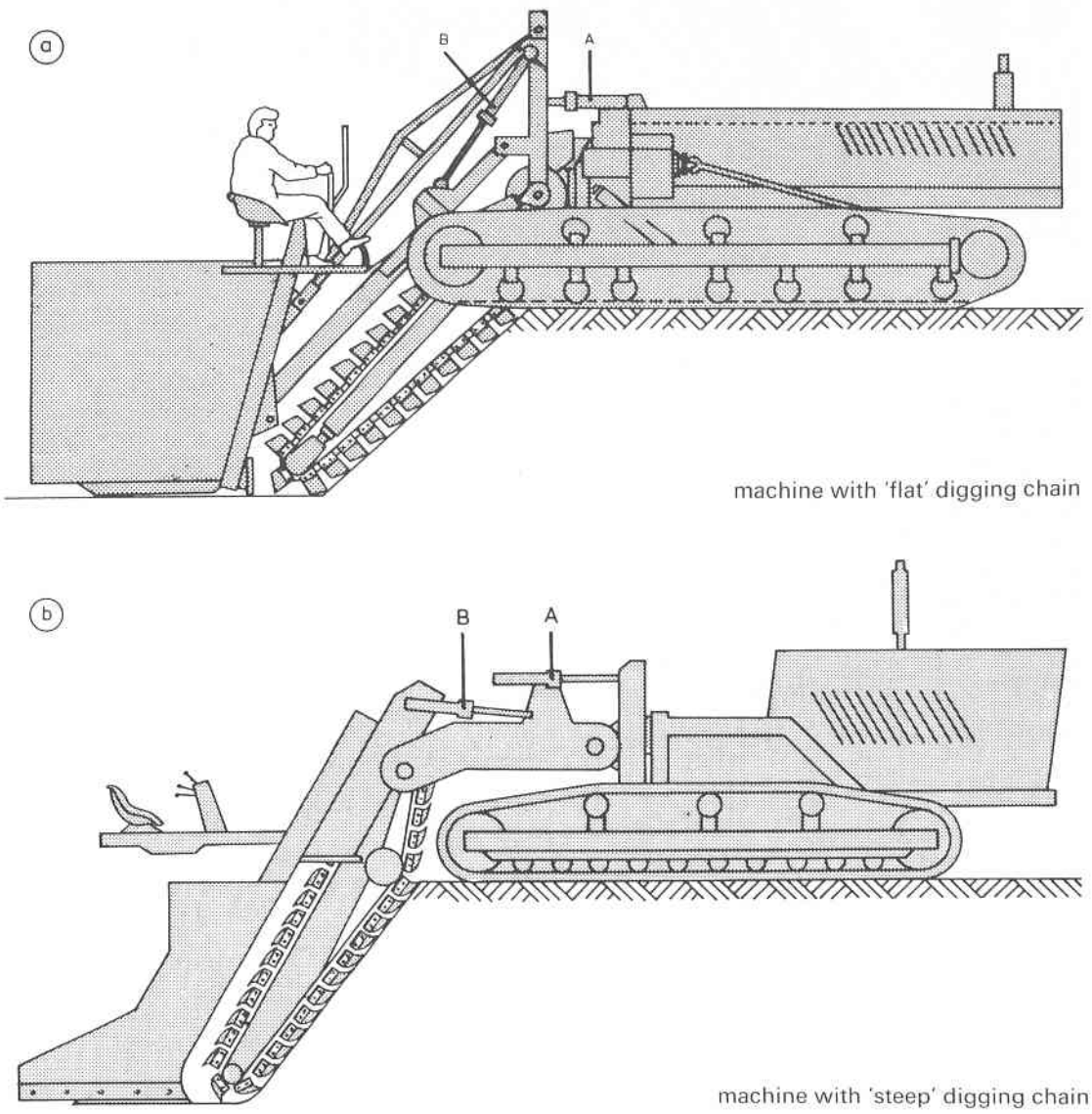


Figure 4.
Two main types of trencher drainage machines. Principle of depth regulation: while trenching, the shoe rests on trench bottom and the lifting cylinders A are in float position; depth is regulated by expanding or retracting cylinders B.



Figure 5.
Laser equipped drainage machine installing corrugated PE pipe, 1977 (U.S.A.). Steep digging chain type, see also Figure 4b. (By courtesy of Steenbergen Hollanddrain).

Trenchless drainage machines

An entirely different development is the trenchless drainage machine, also called drain plough. Trenchless drainage evolved from mole drainage, which is another form of subsurface drainage, although one not practised in The Netherlands. Mole drains are circular channels pulled in the soil by a mole plough. This technique is widely applied in heavy clay soils with a low hydraulic conductivity as, for example, in the United Kingdom (BAILEY 1979).

The invention of flexible drain pipe (which will be described later) made it possible to use the mole plough principle for pipe laying. With the trenchless machine a hollow blade is pulled through the ground and the drain pipe is guided into position through the blade. Several makes of trenchless machines are used in Europe, northeastern U.S.A. and Canada. The blade is manufactured as an attachment to a heavy crawler tractor or as an integral part of the drainage machine (Figure 6). On most types the working depth does not exceed 1.5 m.

The shape of the blade has been much improved in recent years. It is generally curved forward with a flat front so as to lift up the soil rather than push it aside, in order to create the space needed for the drain pipe and to reduce the traction required to pull the blade through the ground. The main advantage of the trenchless technique lies in its greater working speed and less wear and tear (fewer moving parts in the ground), and consequently a lower cost per metre of drain installed. Trenchless machines require a relatively dry topsoil for the crawler tracks to find enough grip to develop the high traction power to pull the blade through the ground. This requirement may limit the suitable working period for the trenchless machines. Some machines are equipped with winch traction to reduce slip.

The functioning of drains installed with the trenchless technique depends very much on the changes in soil structure brought about by the passing of the blade. Above a certain critical depth, heaving and fissuring of the soil takes place, but below that depth, deformation or compaction will occur. This may reduce the hydraulic conductivity of the soil in the vicinity of the drain pipe and hamper the entry of water. Further, because of the speed of installation, depth and grade control appears to be still a weak point. It is not yet clear under which conditions trenchless drainage is more favourable than drainage with a trenching machine (SPOOR 1979; REEVE 1979; NAARDING 1979; EGGELSMAN 1979; OLESON 1979; CROS et al. 1979).

Depth and grade control

The depth and grade of the drains laid by machine was initially controlled by means of sighting targets installed before the drain-laying operation was performed. The machine operator kept a sighting bar on the machine in line with the

targets by moving the depth control switch as required.
In recent years, an automatic depth control system that makes use of a laser light beam has been introduced. This laser system, developed in the U.S.A., consists of a command post mounted on a tripod in the field and a receiver and control unit mounted on the machine. The command post emits a laser beam which is rotated in a plane that can be tilted according to the required drain gradient (STUDEBAKER 1971). When the laser beam hits the receiver unit at too low a point, the solenoid valve of the depth regulating cylinder is automatically actuated to make the machine dig deeper; when the beam hits at too high a point, the machine digs shallower.
With fast working trenchless machines, it may happen that the great inertia and friction forces cause a considerable delay between the signal of the receiver and the subsequent depth correction by the machine. This may lead to inaccurate drain gradients and even counter slopes. The result may be air entrapment in the drain pipe, causing it to function poorly. So far this phenomenon has received little attention and requires further investigation.

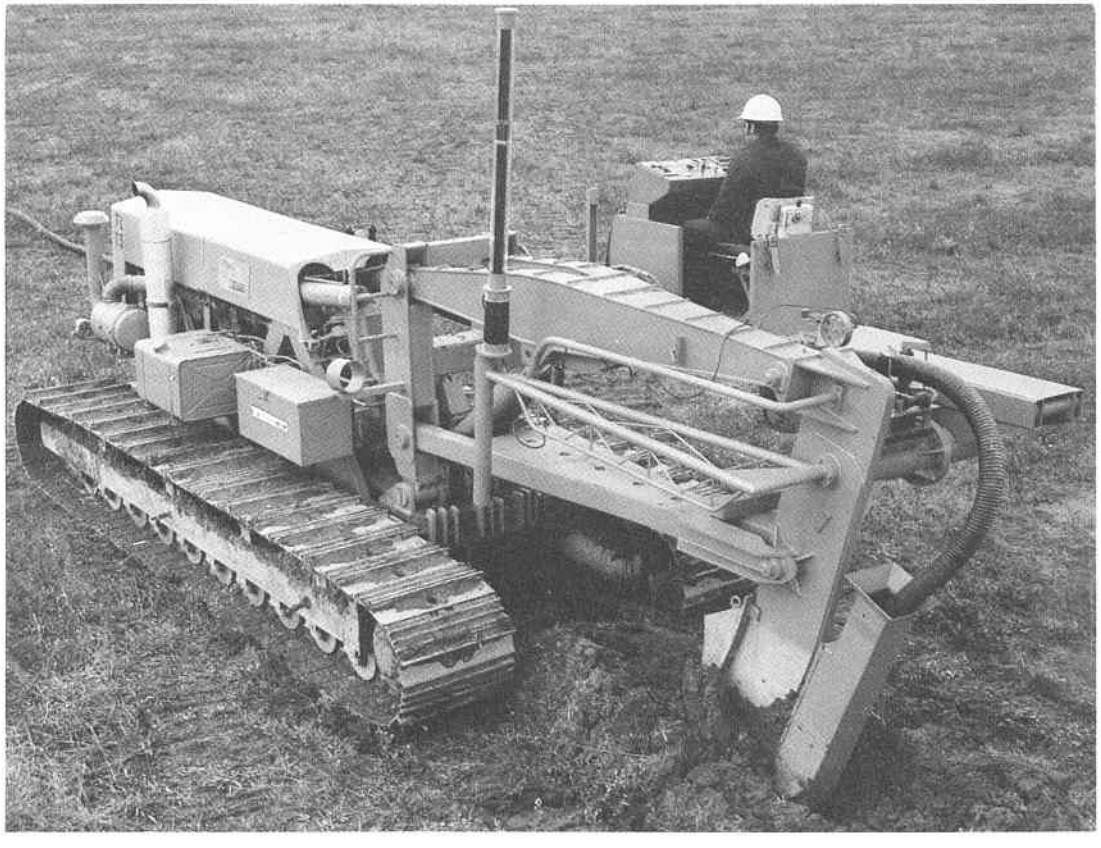


Figure 6.
Trenchless drainage machine, 1978 (U.S.A.).
(By courtesy of Barth Holland).

Drain pipes

Apart from the technical development of the drainage machines, the introduction of entirely new drainage materials has also contributed greatly to simplifying drainage operations, increasing installation capacities, and reducing costs. Whereas 25 years ago all subsurface drains in The Netherlands were made of either clay or concrete, these materials have now almost entirely been superseded by plastic.
The first experiments with thin-walled smooth plastic pipes started in 1959. They were of rigid polyvinylchloride with perforations in the form of longitudinal saw splits. Considerable research was done on required wall thickness, area of perforations, entry resistance for the flow of water into the pipes, and hydraulic capacity. The pipes were first applied in land drainage projects in 1960, and their use increased rapidly in subsequent years (van SOMEREN 1965; Figure 7). Their main advantage was the low weight per unit length, which greatly reduced the transport costs to the field and made transport in the field largely unnecessary because sufficient 6 m lengths of pipe for an entire drain line could be carried on the machine (see Figure 3). The simplified pipe handling meant that the machine crew could be reduced by two men, thereby lowering installation costs.
Since 1967 the smooth-walled plastic pipe has

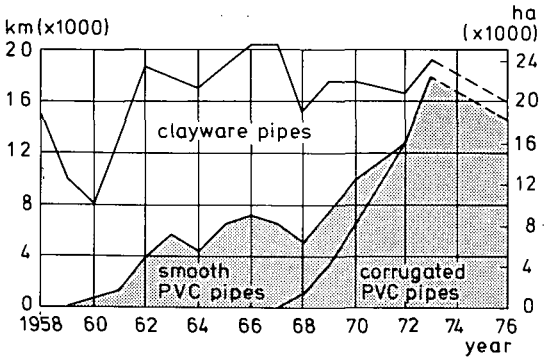


Figure 7.
Subsurface field drainage installed in The Netherlands, period 1958–1976.

gradually been replaced by corrugated PVC pipe. The corrugated form of the wall makes this pipe more resistant to deformation for the same quantity of PVC material, yet it remains flexible, which is a great advantage for pipe laying by machine. The corrugated PVC pipe, which has small perforations in the valleys of the corrugations, is manufactured in a series of diameters, ranging from 50 to 200 mm and is delivered in coils of different lengths. Individual lengths of corrugated pipe are joined by means of connecting sleeves of a screw type or with a few hooks that click behind the corrugations of two pipe ends, so that a strong connection can be made.

The introduction of corrugated plastic pipe has virtually eliminated the possibility of too open joints and misalignment of pipes. Installation by machine is very straightforward. Coils of the smaller-diameter pipe are usually carried on a reel on the machine and wound off as installation proceeds (see also Figure 12). The larger diameters are mostly laid out on the field and guided through the machine (see Figure 5). In The Netherlands, with a crew of 3 or 4 men, installation rates of about 600 m pipe per hour have become normal, resulting in a labour input of 4 to 7 manhours per 1000 m of drain.

In the U.S.A. plastic drain pipes are mostly of polyethylene (PE) instead of polyvinylchloride (PVC), largely because of the lower price and the ample availability of the raw material for PE in the early stages of development. Polyethylene has the advantage of preserving its quality at low temperatures, whereas PVC tends to get brittle and must be very carefully handled when temperatures are below 0 °C. A disadvantage of PE is that it has less stiffness than PVC so that it may lose its resistance to deformation when under pressure, especially in hot weather and when subjected to longitudinal stress. To minimize stretch of the pipe during installation some machines in the U.S.A., are fitted with a power feed mechanism to push the pipe into the pipe guide at the appropriate speed (JOHNSTON 1979).

Envelope materials

In the early subsurface drainage projects in Europe, the drains were often covered with a layer of organic materials to facilitate the inflow of groundwater and to prevent soil particles of the loose trench backfill from entering the pipes. The traditional materials used were sieved fibrous peat, wood chips, sawdust, straw from cereal crops, and heather bushes. The handling of these materials, however, was laborious, and the materials were not always available in the quantities required.

In its early days mechanical installation of drain pipes was not always successful, even though the drains were covered with the traditional materials. The poor results obtained were due to working under too wet soil conditions, installing drain pipes in new areas of unstable soils where no previous experience existed, and using plastic pipes whose outer diameter was small compared with that of the usual clay pipes. These problems initiated large-scale investigations in the laboratory, using model tanks, and in the field, making experiments with new organic and synthetic materials.

With the progressing mechanization of drainage work a search began for materials that could be produced in band form. A roll of such band could be carried on the machine and placed over the pipe during installation (see Figure 3). The first bands produced were made of the traditional organic materials: fibrous peat, flax straw, and later also coconut fibre. In the early sixties, a thin non-woven glass fibre sheeting was widely used. It was economical, and could easily be handled on the machine, to cover or even surround the pipes. Nowadays, however, its use is no longer recommended, except in some light-textured soils, as it tends to get clogged with fine soil particles and is very sensitive to choking by chemical or bacteriological deposits of iron compounds.

After the introduction of the corrugated plastic drain pipe, a technique was developed to prewrap these pipes with an envelope material in the factory. Prewrapping not only means great handling efficiency – the prewrapped pipe is coiled and installed through the machine in the

same way as pipe without an envelope – but it also provides a complete mantle around the pipe. Since most of the groundwater enters a drain from below, the advantage of a complete envelope is obvious, the more so in soils whose stability is poor. The materials most used at present are coconut fibre and fibrous peat (Figure 8), but it is expected that the trend for further developments in envelope materials will move in the direction of synthetic fibre fabrics (KNOPS and DIERICKX 1979).

Even the proper selection of pipe and envelope materials does not always guarantee that the drains will function properly. Investigations in The Netherlands have convincingly proved that a decisive factor for successful subsurface drainage lies in favourable soil moisture conditions at the time of installation. Particularly detrimental is backfilling the excavated trench with soil that is wet because of a high watertable or because of rainfall during installation. If the soil structure in the vicinity of the drain deteriorates through smearing, kneading, compaction, or sedimentation, this will greatly hamper the flow of water into the drain. It is therefore advisable to install drains under relatively dry field conditions and when the watertable is below drain level.

A drain envelope is not required under all circumstances. Cohesive soils with a clay content of about 25 per cent or more present no stability problems and are not particularly sensitive to structural deterioration under wet laying conditions. Drains in such soils can be laid without an envelope (KNOPS et al. 1979).

In irrigated arid and semi-arid areas, coarse sand and gravel, found locally, is widely used as envelope material. If well graded from medium coarse sand to fine gravel, ranging in size from about 0.25 to 20mm, this material provides an effective and durable envelope. It is used in fine-sandy, silty, and dispersive soils, and in unstable subsoils, especially when the watertable is high.

In irrigated areas it is often not possible to select a favourable period for drain installation because the watertable tends to remain high throughout the year. In such circumstances, a gravel pack around the drain pipe is still the best way to prevent soil particles from being washed into the pipe immediately after installation. Because of the large quantities of gravel required and the high costs of transporting and handling this heavy material, a gravel envelope can constitute a substantial part of the total cost of drainage. The gravel is nowadays applied under and over the drain pipe through a hopper and ducts on the drainage machine. The handling of the gravel is often the limiting factor for the speed of the drain-laying operation, although this problem has been alleviated in recent years by the introduction of self-unloading gravel trailers. These fill a gravel hopper on the drainage machine which

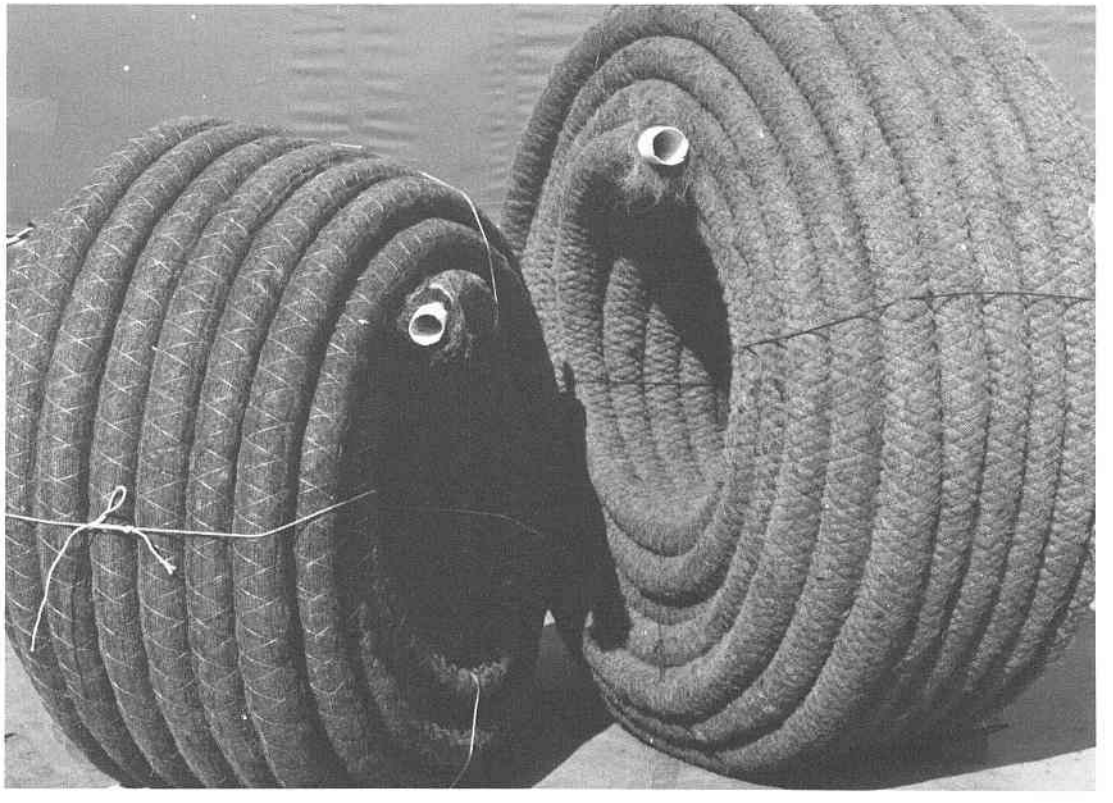


Figure 8.
Corrugated PVC drain pipe, prewrapped with fibrous peat (left) or coconut fibre (right).



Figure 9.
Drainage machine installing corrugated PVC pipe with gravel surround, 1977. Gravel supplied from self-unloading gravel trailer (Iraq). (By courtesy of Steenbergen Hollanddrain).

lays the pipe and applies the gravel at the same time (Figure 9).
A great deal of research on the textural requirements for gravel filters has been done in the U.S.A. (BOERS and van SOMEREN 1979).

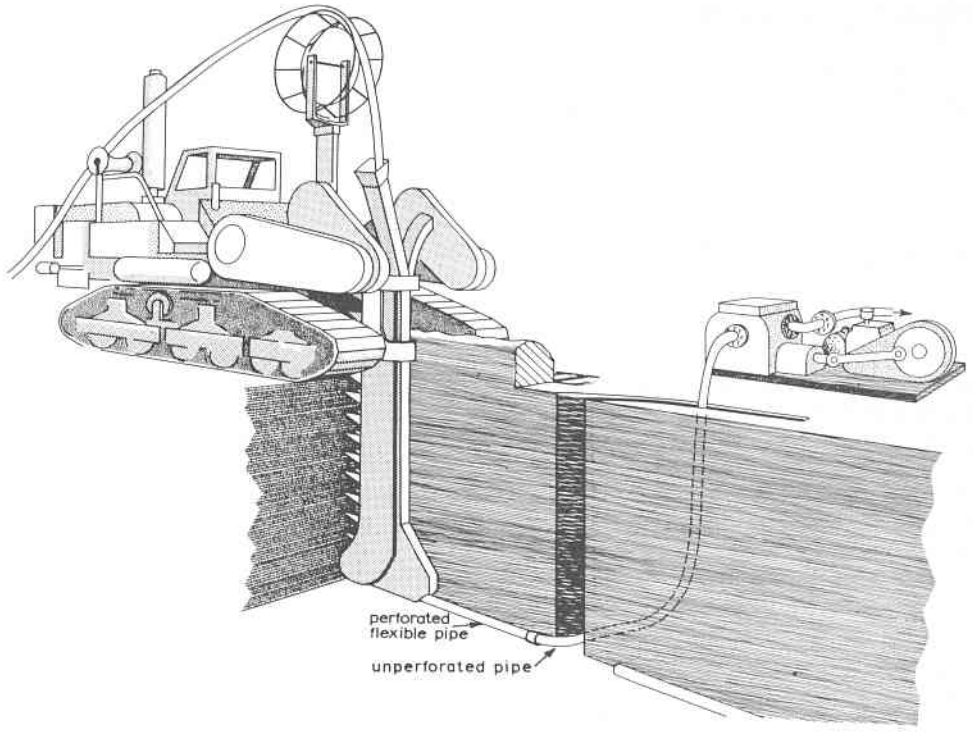
Collector drain construction

The drainage system preferred in The Netherlands, as in other flat low-lying areas, is a singular system in which the individual pipe drains discharge into a ditch, the ditch acting as a collector drain that transports the water to a disposal point. Elsewhere, in arid and semi-arid areas under irrigation, but also in temperate humid areas where more slope is available, there is a tendency to install composite drainage systems, in which the pipe drains discharge into a collector pipe. Because of their large diameter, collector pipes are usually made of concrete, the price of large diameter plastic pipe not being competitive. They are installed with sealed joints, or are open jointed with a gravel surround. Under favourable soil conditions they can be installed with a heavy duty trenching machine in much the same way as ordinary pipe drains (Figure 10). When the size of the project does not warrant the use of a special machine, they are laid by hand in a trench that has been excavated either manually or by a multipurpose hydraulic backhoe excavator.
In unstable subsoils where 'quick' conditions arise due to a silty or fine sandy soil texture and a high watertable, serious difficulties are encountered in collector pipe laying. It is hardly possible to prepare a firm trench bottom and the trench walls do not stand up long enough to allow the pipes to be laid properly.
A new technique developed in The Netherlands in the last decade can overcome such problems. The technique, 'horizontal wellpointing', was initially developed for gas pipeline construction through high watertable areas to lower the watertable locally in a strip along the alignment of the pipeline. In this way the unstable 'quick' condition can be eliminated and the trench can be dug in the normal way. Of course, the use of this technique adds to the cost of the collector drain, but for really difficult situations there appears to be no acceptable alternative.
The technique consists of bringing into the ground a length of corrugated plastic drain pipe, prewrapped with a filter material and connected to a piece of blind pipe without perforations protruding above the ground. The blind pipe is connected to a vacuum piston pump that sucks up the water entering the perforated pipe, which thus functions as a horizontal well (Figure 11). The length of this pipe may vary from 30 to 80 m, depending on the depth below the original watertable and the hydraulic conductivity of the



Figure 10.
Heavy duty drainage machine installing concrete collector pipes, 1975 (Morocco). (By courtesy of Barth Holland).

Figure 11.
Principle of horizontal wellpointing technique for local lowering the watertable.



soil layers. It is usually installed at a depth of between 0.5 and 1 m below the bottom of the trench that is to be excavated.
The special machine used for this purpose has a vertical digging beam, around which the digging chain provided with scoops moves. At the rear side the chain moves downward between protecting side plates, preventing the soil from caving in. Immediately behind the digging chain the corrugated drain pipe is let down through a vertical guide tube, bending to the rear at the lower end. Machines are available that can install the horizontal wells to a depth of 6 m (Figure 12).

Outlook for the future

The technical developments in subsurface drain installation during the last 25 years have been spectacular. They have considerably increased the possibilities of installing drains in large areas of agricultural land within a relatively short time. They have also considerably reduced the labour input and have, as a result, kept the costs of subsurface drainage fairly stable, despite sharp rises in wages and costs of materials. In addition, they have enlarged the possibilities of applying mechanical pipe-laying in irrigated areas where deep drainage is required.
Clearly, developments have been very rapid, and not all the new materials and methods have been adequately investigated and tested before being

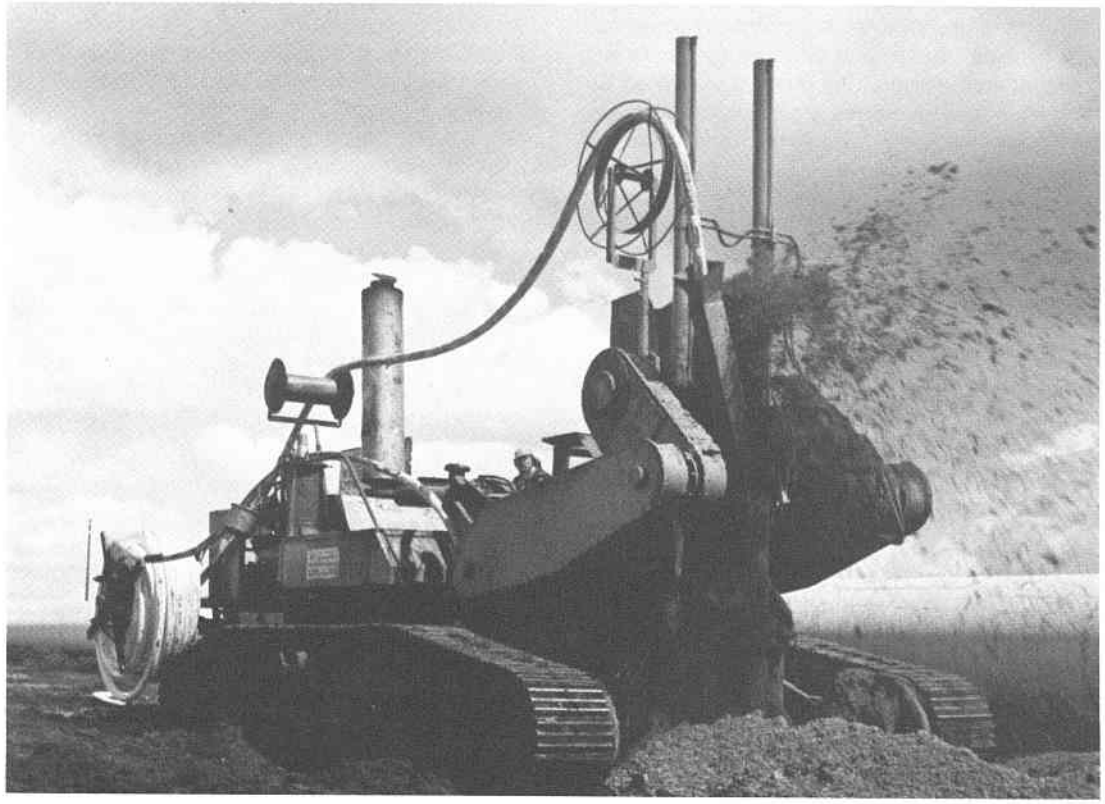


Figure 12.
Horizontal wellpointing machine, 1972. (By courtesy of Reinders-Wessemius).

applied in practice. The trenchless technique needs further perfection, especially with regard to grade control and functioning of the drains. Also the search for new envelope materials needs to be continued.

Nevertheless, it is also clear that subsurface drainage techniques are now available for a wide range of very different conditions. Nor is there any doubt about the need for drainage. FAO (1977), (see also DIELEMAN 1979) estimated that 52 million hectares of irrigated land in developing countries need to be drained in the 1975–1990 period and that some 26 million hectares of rainfed land will profit from the improvement or introduction of drainage. The total cost is estimated at US $ 14,000 million.

In the coming decades, the technique of subsurface drainage will have a vital role to play in increasing and restoring the productivity of agricultural land. In arid regions, it will constitute a key factor in the long-term viability of irrigated agriculture.

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