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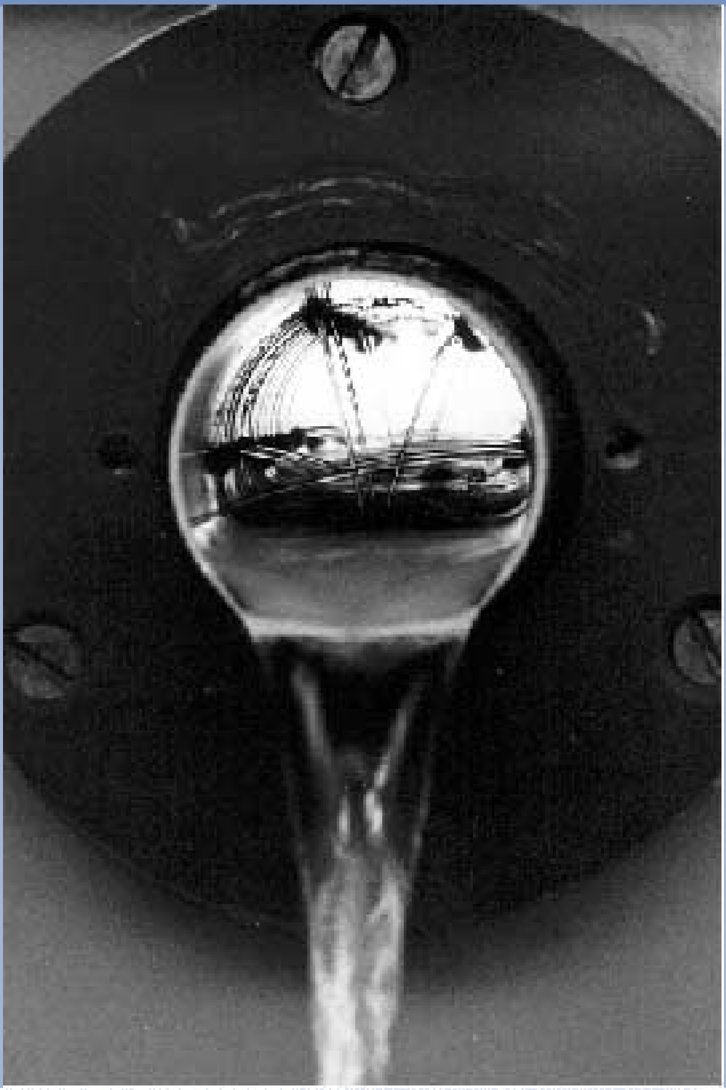
Materials for subsurface land drainage systems



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by
L.C.P.M. Stuyt
ALTERRA, Green World Research
Wageningen, The Netherlands

W. Dierickx
Department for Agricultural Engineering
Merelbeke, Belgium

J. Martínez Beltrán
Water Resources, Development and Management Service
FAO Land and Water Development Division

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Foreword

Reliable subsurface drainage systems for groundwater table and salinity control are needed to maintain or enhance the productivity of irrigated lands and to contribute to the rural development of lowlands in the humid tropics. In addition, they continue to be important as a means of groundwater table control in some areas of the temperate zones. The selection of appropriate materials (i.e. pipes and envelopes) and their adequate installation and maintenance are essential for the proper and lasting performance of subsurface drainage systems. This was acknowledged in FAO Irrigation and Drainage Paper 9, *Drainage Materials*, published in 1972. At that time, the expertise concerning drainage materials came mainly from projects located in the temperate zones of northwestern Europe and the United States. Since then, valuable experience has also been gained in tropical countries that may be useful and, as such, should be made available to the professional communities. In the past two decades, substantial developments have been made in drainage engineering, specifically concerning installation techniques and materials. This progress has been achieved as a result of a great number of research projects and practical experience, also from irrigated lands. Hence, there was a need to update FAO Irrigation and Drainage Paper 9.

Field engineers and contractors who are in charge of new drainage projects need practical guidance for the selection and installation of drainpipes and envelopes. The selection of drainage materials, however, depends upon various factors, of which availability, durability and cost are of paramount importance. A procedure is required which allows engineers to predict whether the installation of envelopes is needed. Guidelines for selection must also consider the required specifications of the materials. In addition, guidelines must be available to help contractors in their assessment of whether or not available materials comply with the required specifications.

The purpose of this Paper is to provide this practical information to drainage engineers and contractors. The Paper is based on the current knowledge of water flow into drainpipes and envelopes, their properties and applicability. It also contains guidelines to assess the need for envelopes and for selection of the most appropriate envelope material, as related to local conditions. Guidelines for installation and maintenance of drainage materials as well as specifications and standards for such materials, which may be used in tender documents for implementation of subsurface drainage works, have also been included. In addition, it contains practical guidelines for the implementation of laboratory and field investigations to evaluate the performance of drainage materials.

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List of symbols

Symbol	Description	Dimension
A	Area of cross-section (m^2)	L^2
C_u	Coefficient of uniformity	-
CEC	Cation Exchange Capacity (meq/100 g)	-
c_o	Cohesion (Pa)	$ML^{-1}T^{-2}$
D_x	Particle diameter of the x% size of the granular envelope material (µm)	L
D_5	Particle diameter of the 5% size of the granular envelope material (µm)	L
D_{15}	Particle diameter of the 15% size of the granular envelope material (µm)	L
D_{30}	Particle diameter of the 30% size of the granular envelope material (µm)	L
D_{50}	Particle diameter of the 50% size of the granular envelope material (µm)	L
D_{100}	Particle diameter of the 100% size of the granular envelope material (µm)	L
d	Internal pipe diameter (cm)	L
d_e	Envelope thickness (cm)	L
d_x	Particle diameter of the *x*% size of the soil material (µm)	L
d_{10}	Particle diameter of the 10% size of the soil material (µm)	L
d_{15}	Particle diameter of the 15% size of the soil material (µm)	L
d_{50}	Particle diameter of the 50% size of the soil material (µm)	L
d_{60}	Particle diameter of the 60% size of the soil material (µm)	L
d_{85}	Particle diameter of the 85% size of the soil material (µm)	L
d_{90}	Particle diameter of the 90% size of the soil material (µm)	L
dh	Small increment in hydraulic head (m)	L
dl	Small increment in length (m)	L
dr	Small increment in radial distance (m)	L
EC	Electrical Conductivity ($dS\ m^{-1}$)	$T^3I^2M^{-1}L^{-3}$
EC_e	Electrical Conductivity of a soil paste saturated with water up to the liquid limit ($dS\ m^{-1}$)	$T^3I^2M^{-1}L^{-3}$
EC_s	Electrical Conductivity of the soil solution at field capacity ($dS\ m^{-1}$)	$T^3I^2M^{-1}L^{-3}$
EC_{gw}	Electrical Conductivity of the groundwater ($dS\ m^{-1}$)	$T^3I^2M^{-1}L^{-3}$
EC_{iw}	Electrical Conductivity of the irrigation water ($dS\ m^{-1}$)	$T^3I^2M^{-1}L^{-3}$
ESP	Exchangeable Sodium Percentage	-
H	Height of sand model tank (m)	L
h	Head loss (m)	L

Symbol	Description	Dimension
h_e	Entrance head loss (m)	L
h_h	Horizontal head loss (m)	L
h_r	Radial head loss (m)	L
h_t	Total head loss (m)	L
h_v	Vertical head loss (m)	L
h_{ap}	Approach flow head loss (m)	L
I_p	Plasticity index of the soil	-
i	Hydraulic gradient for flow in soil	-
i_c	Critical hydraulic gradient	-
i_f	Hydraulic failure gradient	-
i_{ex}	Exit gradient	-
K	Hydraulic conductivity (m d^{-1})	LT^{-1}
K_e	Hydraulic conductivity of the envelope (m d^{-1})	LT^{-1}
	Hydraulic conductivity of the loosened soil in the drain trench (m d^{-1})	LT^{-1}
K_h	Horizontal hydraulic conductivity of the soil (m d^{-1})	LT^{-1}
K_r	Radial hydraulic conductivity of the soil (m d^{-1})	LT^{-1}
K_s	Hydraulic conductivity of the soil (m d^{-1})	LT^{-1}
K_v	Vertical hydraulic conductivity of the soil (m d^{-1})	LT^{-1}
K_{ap}	Hydraulic conductivity of the approach flow zone (m d^{-1})	LT^{-1}
k_M	Reciprocal parameter of Manning's roughness coefficient (m$^{1/3}$ s^{-1})	L$^{1/3}$T^{-1}
L	Drain spacing (m)	L
	Length of a sand model tank (m)	L
LF	Leaching Fraction	-
n	Manning's roughness coefficient (s m$^{-1/3}$)	T L$^{-1/3}$
	Factor of concentration of the irrigation water in the soil	-
O_{90}	Pore diameter of the 90% opening size of the envelope material (µm)	L
p	Ratio of full to sectorial radial flow	-
Q	Discharge (m^3 s^{-1})	L^{3}T^{-1}
q	Specific discharge (m d^{-1})	LT^{-1}
r	Radius of a circular equipotential (m)	L
	Distance from drain center (m)	L
r_e	Radius of the soil-envelope interface (m)	L
r_o	Radius of the ideal drain (m)	L
	Outer drain radius (m)	L
r_{ef}	Equivalent or effective radius (m)	L

Symbol	Description	Dimension
S	Pitch length of corrugated pipe (m)	L
SAR	Sodium Adsorption Ratio ($\mathrm{meq}^{1/2}\,1^{-1/2}$)	$M^{1/2}L^{-3/2}$
SAR_e	Sodium Adsorption Ratio of a soil paste saturated with water up to the liquid limit ($\mathrm{meq}^{1/2}\,1^{-1/2}$)	$M^{1/2}L^{-3/2}$
SAR_s	Sodium Adsorption Ratio of the soil solution at field capacity ($\mathrm{meq}^{1/2}\,1^{-1/2}$)	$M^{1/2}L^{-3/2}$
SAR_{gw}	Sodium Adsorption Ratio of the groundwater ($\mathrm{meq}^{1/2}\,1^{-1/2}$)	$M^{1/2}L^{-3/2}$
SAR_{iw}	Sodium Adsorption Ratio of the irrigation water ($\mathrm{meq}^{1/2}\,1^{-1/2}$)	$M^{1/2}L^{-3/2}$
s	Hydraulic gradient for pipe flow	-
TDS	Total Dissolved Solids ($\mathrm{mg\,l^{-1}}$)	ML^{-3}
W	Flow resistance ($\mathrm{d\,m^{-1}}$)	TL^{-1}
	Width of a sand model tank (m)	L
W_e	Entrance flow resistance ($\mathrm{d\,m^{-1}}$)	TL^{-1}
W_h	Horizontal flow resistance ($\mathrm{d\,m^{-1}}$)	TL^{-1}
W_r	Radial flow resistance ($\mathrm{d\,m^{-1}}$)	TL^{-1}
W_t	Total flow resistance ($\mathrm{d\,m^{-1}}$)	TL^{-1}
W_v	Vertical flow resistance ($\mathrm{d\,m^{-1}}$)	TL^{-1}
W_{ap}	Approach flow resistance ($\mathrm{d\,m^{-1}}$)	TL^{-1}
W_{DS}	Mass of oven-dried soil sample (g)	M
W_{LL}	Mass of soil sample at liquid limit (g)	M
W_{PL}	Mass of soil sample at plastic limit (g)	M
$_*$	Subscript *v* (vertical), *h* (horizontal), *r* (radial), *e* (entry) or *t* (total)	-
α	Flow resistance factor	-
α_e	Entrance flow resistance factor	-
α_h	Horizontal flow resistance factor	-
α_r	Radial flow resistance factor	-
α_t	Total flow resistance factor	-
α_v	Vertical flow resistance factor	-
α_e^*	Flow resistance depending on the sector area with radial flow	-
α_e'	Entrance resistance factor of the drainpipe itself when surrounded by an envelope	-
α_{ap}	Approach flow resistance factor	-
$\alpha_{e,e}$	Entrance resistance factor of both drain and surrounding envelope	-
$\alpha_{(e,e)W}$	Entrance resistance factor of both drain and surrounding envelope according to Widmoser (1968)	-
β	Angle of sectorial radial flow (rad)	-
ϕ	Angle of internal friction or shearing resistance (rad)	-

Symbol	Description	Dimension
κ_e	Hydraulic conductivity ratio of envelope and surrounding soil	-
σ_e	Effective stress of the soil particles or intergranular stress (Pa)	$ML^{-1}T^{-2}$
τ_f	Shearing resistance per unit area (Pa)	$ML^{-1}T^{-2}$
Δh	Increment in hydraulic head (m)	L
Δl	Increment in length (m)	L

Chapter 1

Introduction

HISTORY

When drainage for agriculture began approximately 9000 years ago in Mesopotamia, pipes were non-existent (Van Schilfgaarde, 1971). Subsurface drainage was most likely implemented by gravel and stones, or permeable, voluminous substances like e.g. bundles of small trees and shrubs tied together in the bottom of a trench. The first drainpipes are approximately 4000 years old; they were discovered in the Lower Indus River valley (Ami, 1987). In Europe, the first subsurface drainage systems were installed at the beginning of the Christian era. Subsurface drainage, however, was more or less forgotten in the centuries that followed.

Drainage systems reappeared in England around the year 1544 when the Dutch began to export to England the skill of their engineers, who were respected ‘drainers’ and ‘dykers’. The first Dutchman to undertake drainage work in England was Cornelius Vanderdelf, later followed by other famous engineers like Cornelius Vermuyden and Joos Croppenburgh, in the beginning of the 17th century (Chapman, 1956). Soon afterward, ridge tiles were introduced as drains in Scotland and on the European mainland. Ridge tiles must be regarded as the predecessors of tiles, hence the name. The general stages of development were simple horseshoe drains, horseshoe drains on sole plates, flat-bottomed D-shaped drains, and finally round pipes. The invention of the tile extruder in England in 1840 strongly enhanced the rate of land drainage in Europe. Nearly two centuries ago, pipe drainage was introduced in the United States. During the subsequent period, clay tiles were machine manufactured and laid by hand. Around 1960 mechanical installation became widespread. The introduction of perforated plastic pipes for drainage in the 1960s increased the effectiveness, efficiency and economics of installation.

Drainpipes have been made from wood boards or box drains, bricks, and horseshoe shaped ceramic tile, circular clay tile, concrete tile, bituminized fibre perforated pipe, perforated smooth plastic pipe to corrugated plastic pipe. Currently, corrugated pipes are frequently used, although clay and concrete pipes are still used as well. Their application is determined by economic factors in the region concerned.

Some significant developments in agricultural drainage are summarized by Schwab and Fouss (1999). The following first applications are, in chronological order:

- Installation of the first drain tile in the United States (l835).
- Invention of a tile extruder in England (1840).
- Manufacturing of the first drainpipe from sand and cement in the United States (l862).
- Use of trenching machines (1880).
- Introduction of smooth PE pipe in the United States (1948).
- First application of smooth, rigid PVC pipe in The Netherlands (1959).
- Introduction of the first flexible PVC pipe in Germany (1963).

- Installation of the first corrugated, flexible PE pipe in the United States (1965).
- Development of drain ploughs (1969).
- First standard for PE corrugated pipe, i.e. ASTM F405 (1974).
- Drafting of a standard for prewrapped envelope in The Netherlands (1981).
- The first draft ISO standard for corrugated PVC pipes (ISO/DIS 8771, 1985).
- Introduction of draft EN standard for PVC corrugated pipes (CEN/TC155/WG18, 1994).

More historical data concerning drainage materials may be found in Weaver (1964) and Van Someren (FAO, 1972).

CONTEMPORARY DRAINAGE MATERIALS

Contemporary drainage materials may be classified into drainpipes and their accessories, envelopes and auxiliary drain structures. Design criteria for drainpipes are now well established and unambiguous, both with respect to pipe size, geometry and perforation pattern, as well as to pipe material.

When a subsurface drain is installed, some soils may require measures to protect the drainpipe from soil particle entry. Due to the drag force of the water, soil particles or aggregates may be carried into the pipe through the perforations in the pipe wall. This process can never be prevented completely, but it may substantially be slowed down, or stopped by use of external porous material around the pipe. The porous device, designed to do this is called 'drain envelope', but has often erroneously been referred to as a 'drain filter'. The functioning of a filter is such that it retains soil material as a result of which it may become blocked or clogged, or causing the surrounding soil to become clogged. A good 'drain envelope', on the contrary, restricts sediment inflow, provides material of high hydraulic conductivity and structural stability close to the drain, and does not clog with time.

The design of *conventional* envelopes is not a major problem. These envelopes, which belong to the *first generation of envelopes*, consist of gravel, broken shells or loose organic materials like peat litter. Design criteria for mineral granular envelopes have gradually been developed in the United States (Willardson, 1974). Sound design criteria for traditional granular drain envelopes (gravel and coarse sand) are available and have been applied successfully in practice (Terzaghi and Peck, 1961).

In many areas, properly graded gravel envelope material is scarce or non-existent, and then it constitutes the principal cost of drain installation. Moreover, handling and placement of gravel envelopes around the drainpipe is a difficult operation, leading to high installation costs. This has led to a search for lightweight substitutes for gravel envelopes.

Alternative envelope materials were usually composed of organic fibres such as those found in crop residues. Peat envelopes, already mentioned, were applied successfully for many years and were traditional in areas where gravel was expensive. In further attempts to bring down the cost of drainage systems and to simplify mechanical installation, the *second generation of envelopes*, namely cover materials in strip form, gradually replaced loose organic materials. A roll of such a strip could be carried on a trencher and rolled out over the pipe as it was being installed. The first materials produced in strip-form were fibrous peat, flax straw and coconut fibres. Meanwhile, high quality peat litter, a traditional envelope, became scarce, prompting a search for alternatives. In the 1960s, strips of glass fibre sheet were also used, being affordable and easy to handle.

Soon after the introduction of corrugated pipes in 1962, the use of cover materials in strip-form was abandoned. In Europe, fibrous organic envelopes were developed which could be wrapped around corrugated pipes prior to installation. Pipe and envelope could then be installed as a composite product, namely a wrapped drain. This reduced the installation costs by roughly 50 percent.

While the use of organic envelopes has become widespread, their proneness to microbiological decomposition was a disadvantage. Therefore, the youngest *and third generation of envelopes*, synthetic envelopes, has gained popularity quite rapidly. Their application is commonplace in North America and Europe, and is growing fast in countries like Egypt, Pakistan, and India. Synthetic envelopes are either strips of geotextiles wrapped around the drainpipe, or loose synthetic fibre wrappings. Most loose synthetic fibre wrappings are manufactured from recycled material, like polypropylene waste fibres from the carpet industry.

PROBLEMS WITH DRAINAGE MATERIALS

Installing drains in the traditional way, which is by manual labour, cannot be easily done under adverse conditions such as shallow groundwater tables or general wetness. This restriction usually prevented poor drainage performance and ensured a long service life for manually installed systems. Since the introduction of mechanization the installation speed has risen drastically and control of the quality of the work (e.g. grade line accuracy) became more difficult, particularly after the introduction of the flexible corrugated pipe. Installation under adverse conditions also became possible and proved hard to monitor, because contractors and constructing agencies try to keep their machines working as long as possible, due to the high fixed costs of installation machinery. The introduction of laser grade control in 1965 greatly improved the precision of installation.

The mechanization of drain installation as well as the introduction of new types of drain envelopes has led to cost reduction on the one hand, but also to hitherto virtually unknown problems. Some of these problems were introduced by drain installation in very wet soils, and by the introduction of new types of envelopes not suitable for use in all types of soils.

Application of a drain envelope largely depends on physical soil properties. In practice however, availability and cost strongly affect the selection process. Notably in arid areas, where drainage systems are installed for the control of waterlogging and salinization, the need to find affordable alternatives for potentially excellent yet expensive gravel envelopes has become increasingly urgent. The considerable research and practical experience gained from the 1960s to the late 1980s have provided guidelines for envelope design and for selection of materials for different soils.

SCOPE OF THIS PUBLICATION

The objective of this new FAO Irrigation and Drainage Paper on *Materials for subsurface land drainage systems* is to assess and discuss the existing knowledge on drainage materials. The emphasis in this publication is on drainpipes and envelopes. It contains guidelines for design, selection and installation, and standard specifications to be used in tender documents for implementation of subsurface drainage works. Maintenance of drain lines is discussed as well. An effort has been made to seriously investigate the existing criteria, and to detect their similarities and contradictions. This investigation has lead to a set of practical application criteria for envelope materials.

The current knowledge on drainage materials and their suitability should be appealing to, and applicable by engineers and contractors. This is not a ‘drainage materials handbook’ for drainage specialists. It is an *application* guide, primarily developed for the benefit of design engineers and contractors.

In this publication the following issues are covered:

- a review of existing subsurface drainpipes and some auxiliary structures (Chapter 2);
- an evaluation of the properties and suitability of drain envelopes for specific applications as derived from observations in pilot areas and from analogue simulation in laboratories (Chapter 3);
- an analysis of the existing knowledge on water flow into envelopes and drains (Chapter 4);
- guidelines to assess the need for envelopes, and to select the most appropriate envelope material, depending on local conditions (Chapters 5 and 6);
- guidelines for installation and maintenance of drainage materials (Chapter 7);
- the need for research on drainage materials (Chapter 8); and
- a review and assessment of existing standards and specifications for drainpipes and envelopes which are currently used (Chapter 9 and Annex).

Chapter 2

Drainage pipes, accessories and auxiliary structures

DRAINPIPES

For many years, clay and concrete pipes were predominantly used until the introduction of smooth plastic drainpipes around 1960. Soon afterwards corrugated plastic pipes came into common use.

Clay, concrete and plastic pipes give satisfactory results if they meet quality standards and are properly installed. Collector pipes are made of concrete or plastic. Pipes that are manufactured from the latter type of material are not yet competitive for diameters exceeding 200 mm. However, perforated corrugated plastic collectors, wrapped with a sheet envelope, may be installed comparatively easily if the surrounding soil consists of quicksand or has other “quick” properties. Once installed, the collector can act as a drain, cancelling the quick condition of the soil and facilitating the connection of laterals and/or the installation of manholes.

In theory, there are valid considerations to select specific types of drainpipe. In practice, selection is mostly based on cost comparison and on local availability. In addition, the following observations may be relevant (Schultz, 1990):

- If all types of pipe are available, the use of corrugated plastic pipes has distinct advantages (Section *Plastic drainpipes*).
- If pipes are not locally available, local manufacture of concrete pipes is the most straightforward and the easiest to implement. It requires less skill than manufacturing other types of pipe, and is already economical on a small scale. Plastic pipes occupy an intermediate position: local manufacturing from imported raw material is indeed possible for reasonably large quantities.
- Plastic pipes are particularly suited for machine installation. They have the advantage that their performance is the least affected by poor installation practice.
- The manufacturing cost of small diameter pipe (i.e. < 100 mm) is usually of the same order for clay tiles, concrete tiles and plastic. For large diameter pipes, however, concrete is usually the cheapest and plastic the most expensive.

Clay tiles

Clay tile may be either porous or glazed. Pipe sections are abutted against each other and water enters through the joints. The porous type usually has butt joints, but it may also have flanges (also referred to as ‘collars’ or ‘bell joints’). The latter type of tile is more expensive, and the extra cost is only justified in very soft soils. Good quality pipes are adequately baked and are free from cracks and blisters. Clay tile with cracks or other visible shortcomings and badly formed pipes should not be used.

Standard drainpipe sizes are 50, 65, 75, 80, 100, 130, 160, and 200 mm inside diameter. In the United Kingdom, the nominal minimum size is 75 mm inside diameter, which has a generous capacity to carry water, and thus diameter is rarely a significant design consideration when using clayware pipes for laterals. The wall thickness varies from 12 to 24 mm, and may be expressed as $0.08d + 8$ mm, where d is the inside pipe diameter in mm. Current clay tiles have lengths of 300 or 333 mm, yet in some countries greater lengths are available. In Germany, clay tiles were provided with longitudinal grooves at the outside wall, facilitating water flow alongside the drain in combination with envelope materials.

Clay tile is very durable and highly resistant to weathering and deterioration in aggressive soil conditions e.g. in soils containing sulphates and corrosive chemicals. It can be used in almost all circumstances. Clay tile is lighter than concrete and has excellent bearing strength. It is however fragile (especially the German grooved type), and must be handled with care. Clay tiles require a good deal of manual handling, although manufacturers have improved this by various methods of bulk handling.

Manufacturing of clay tiles requires a great deal of skill and a well-equipped plant. The major quality features are straight joints, absence of cracks and homogeneity of the raw material (well-mixed clay). The maximum water absorption rate after being immersed in water for 24 hours should be less than 15 percent of the weight of the tile. The weight of 1 000 tiles should exceed certain minimum values, e.g. 1 400 kg for 60 mm diameter pipe and 2 000 kg for 80 mm diameter pipe.

In some areas, clay and concrete tiles are still laid manually in a hand dug or mechanically excavated trench. These pipes may be covered with bulky materials or with ‘envelopes’ in strip form.

Clay tiles should be installed in such a way that a perfect alignment between individual pipes is obtained. The maximum gap between individual pipes may not exceed 3 mm, except for sand where it should be not more than $2d_{85}$, i.e. the particle size for which 85 percent of the soil particles on dry weight basis have a smaller diameter.

Concrete tiles

Concrete tile has been used on a large scale, e.g. in Egypt, Iraq and other countries. It is used if clay tile is not available, or if greater diameters must be applied. Concrete pipes are used mostly in medium to large sizes, with inside diameters of 100, 150 and 200 mm and up, and section lengths of 0.60, 0.91, 1.22 and 2.40 m. Tile over 300 mm inside diameter is usually reinforced. Butt joints are common.

The manufacture of concrete tiles is much simpler than that of clay tiles. Pipes should be well formed, finished, free from cracks and chips, and properly cured.

Concrete pipes should be used only when soil and groundwater analyses have established that conditions are suitable for their use. Pipes made with ordinary cement are liable to deteriorate in acidic and high sulphate soils, and by water carrying certain alkali salts or other chemicals. Concrete pipes should not be used at locations where industrial waste or house refuse has been collected. Special high sulphate-resistant cements and high density concrete should be used to resist chemical attack (e.g. by acids or sulphates).

Concrete pipes may disintegrate slowly from weathering, and are subject to erosion from fast flowing water carrying abrasive material. However, under a wide range of conditions, a permanent installation is lasting and justified.

Plastic drainpipes

The main advantage of plastic pipes over clay and concrete pipes is their low weight per unit length, greatly reducing transportation cost. An additional cost-saving factor is the reduced need for the labour, required for installation.

Smooth plastic pipes were made of rigid polyvinyl chloride (PVC) and were provided with longitudinal slits to permit water entry. Smooth plastic pipes have never found a widespread use because they were rapidly superseded by corrugated pipes, that became available in 1963. They were so successful that they gradually started to replace clay and concrete pipes. This process is still continuing in various countries. The corrugated shape of the wall makes the pipe not only flexible, but also more resistant to compression than the smooth pipe, for the same quantity of raw material.

The introduction of corrugated pipe was a milestone in the history of agricultural drainage. This flexible pipe is very well suited for mechanized installation. Hence, the installation costs are significantly reduced. In addition, corrugated pipe has facilitated the development of trenchless installation techniques.

The switch from clay and concrete pipes to corrugated plastic pipes was expected because corrugated plastic pipes were advantageous, viz.:

- Light weight makes handling easier, even for great lengths.
- Long, continuous length eases handling, gives less alignment problems, and reduces stagnation of pipe supply resulting in a high installation rate for drainage machines.
- Flexibility and coilability facilitate handling, transportation and installation.
- Greater and more uniformly distributed perforation area, facilitating access of water.
- Easy wrapping with envelope materials.
- Safer implementation without too wide joints or misalignment.
- Less labour intensive and consequently lower labour cost for manufacture, handling, transportation and installation.
- Inert to all common soil chemicals.

Corrugated pipes also have disadvantages, compared to clay and concrete pipes:

- Vulnerability to deterioration from UV-radiation when exposed to sunlight for long periods, especially if made of PVC.
- Increased brittleness at low temperatures.
- Increased deflection risk at high temperatures and excessive stretch during installation.
- Lower deflection resistance under permanent load.
- Risk of collapse under sudden load, e.g. by trench wall caving or stones.
- Smaller transport capacity for the same inner diameter because of corrugation roughness.
- Not fire resistant.
- Not easy to relocate in the field with a tile probe without damaging the pipe.

Corrugated plastic drains are made of PVC, high-density polyethylene (PE) and polypropylene (PP). Preference of one of these materials is based on economic factors. In Europe, corrugated drains are mainly made of PVC except for the United Kingdom, where they are made of PE and a minority of PP. In the United States and Canada, most drainpipes are made of PE, largely because of the low price of the raw material. Good quality pipes can be made of both PVC and PE although these raw materials have different physical properties:

- The lower stiffness of PE means that pipes may be easily deformed under load, especially at temperatures approaching 40°C, and if they are subjected to longitudinal stress.

- PVC pipes are more susceptible to UV-radiation and become brittle at exposure; storage of unprotected pipes in the open should therefore be avoided.
- PVC pipes are more brittle at low temperatures than PE pipes; PVC pipes should not be installed at outside temperatures below 3°C because the risk that cracks will be formed is too high.
- PVC softens at 80°C and drainpipes will deform when exposed to such temperature. Especially in arid and semiarid areas, special care shall be taken to prevent such storage conditions.
- PVC has some environmental disadvantages: it forms hydrochloric acid when burnt.

In northwest Europe, PP pipes have been introduced for agricultural purposes. They are not widely used, but they are quite suitable for application in greenhouses, because they are heat resistant and tolerate disinfection of soils by steam vapour.

European pipe sizes usually refer to outside diameter. Standard outside diameters are 40, 50, 65, 80, 100, 125, 160 and 200 mm. Larger diameters are available as well. *North American* pipe sizes refer to inside diameters, which are 102, 127, 152, 203, 254, 305, 381, 457 and 610 mm. The inside diameter is normally 0.9 times the outside diameter. Corrugated plastic pipes of not too large a diameter (up to 250 mm) are delivered in coils. Larger diameter pipes are supplied in lengths of 6 m.

Water enters corrugated pipes through perforations, which are located in the valleys of the corrugations. Elongated openings or ‘slots’ are common, yet circular openings may be found as well. The perforations may have a diameter or slot width usually ranging between 0.6 to 2 mm. The length of the slots is approximately 5 mm, but sawn slits of larger diameter pipes may be longer. The perforations should be evenly distributed over the pipe wall, usually in at least four rows with a minimum of two perforations per 100 mm of each single row. In Europe, the perforation area should be at least 1200 mm^2 per metre of pipe.

Machine installation of corrugated plastic drainpipes is very straightforward. Smaller diameter pipes are usually carried on a reel on the machine and wound off while the installation proceeds. Larger diameter pipes are mostly laid out in the field and guided through the machine. A thorough control of the pipes and a careful installation is nevertheless always necessary to prevent pipe damage and longitudinal stretching. Regular quality control of corrugated plastic pipes is very important. The impact of sudden loads, simulating trench wall caving on the pipe at temperatures corresponding to the ambient installation temperature should be part of a testing programme.

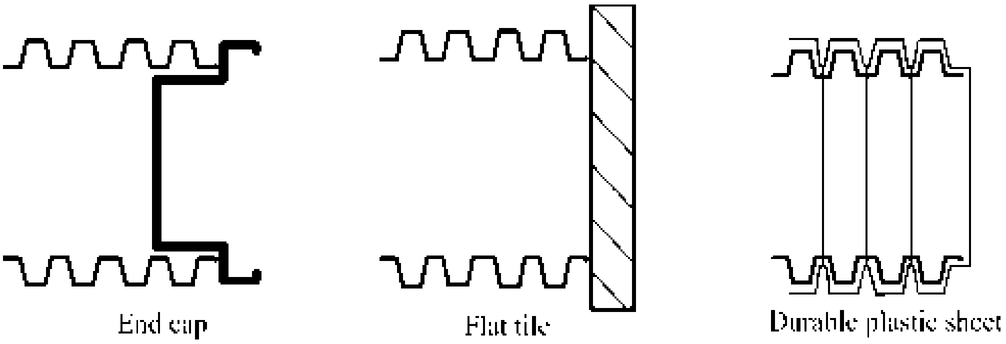
PIPE ACCESSORIES

Subsurface drainage systems require accessories and special structures such as pipe fittings (couplers, reducers, junctions, end caps), gravity or pumped outlets, junction boxes, inspection chambers (manholes), drain bridges, non-perforated rigid pipes, blind inlets, surface inlets, controlled drainage or subirrigation facilities, and cleaning provisions. Some fittings are made by pipe manufacturers, others are manufactured by specialized companies, and others are fabricated on the spot.

End caps

End caps prevent the entrance of soil at the upstream drain-end opening. They can be made of the corresponding pipe material but any other durable flat material can be used for this purpose as well (Figure 1).

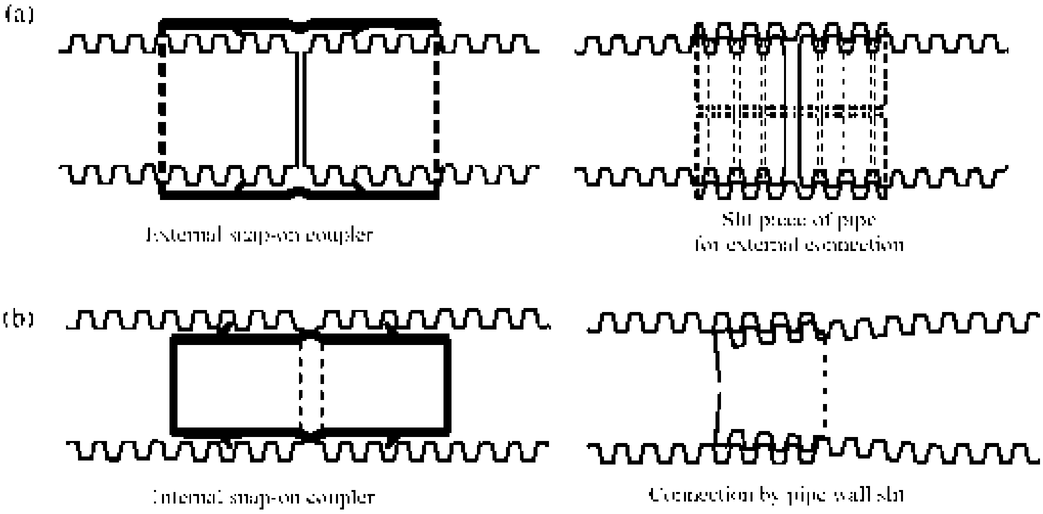
FIGURE 1
End caps



Couplers

Corrugated pipes generally have external ‘snap-on’ couplers to connect pipes of the same diameter. Alternatively, a piece of pipe of the same diameter that is split for easy placing around both pipe ends, and firmly wrapped with tape or wire to keep it in place during installation, can be used instead (Figure 2a). Internal couplers (Figure 2b) can be used with the trenchless technique to prevent separation of connected pipes when passing through the pipe feeder device (Schwab and Fouss, 1999). Pipes can also be connected internally by making a slit in the end of the upstream pipe and forming a cone that is pushed into the end of the downstream pipe. Such connections are not very reliable and do impede the discharge of water and suspended solids.

FIGURE 2
Couplers

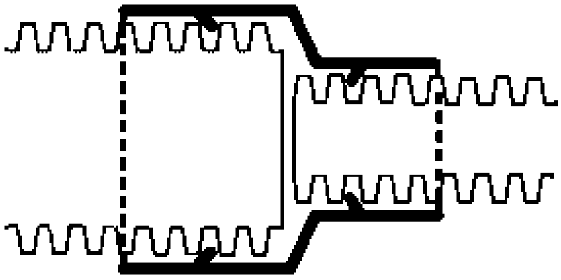


Reducers

Reducers connect two pipe ends of different diameters (Figure 3).

Pipe fittings

FIGURE 3
Drainpipe reducer



A wide range of pipe fittings, made of various raw materials, is commercially available for all kinds of pipes. Fittings for clay, concrete and corrugated plastic pipes are generally made by the various pipe manufacturers and therefore they are mostly not interchangeable.

Cross, T and Y-pieces connect laterals or collectors with collectors (Figure 4a). Many fittings are fabricated with multiple sizes at the ends (Figure 4b) facilitating the connection of various sizes of collectors and laterals (Schwab and Fouss, 1999). The end sides of the fittings are cut off, or adapted by removing some parts in the field to attach to the appropriate diameter. Simple connections with elbows and T-pieces on top of the collector are nowadays used to connect laterals with collectors (Figure 4c).

PROTECTION STRUCTURES

Drain bridges

The undisturbed natural soil in which the pipes are laid normally has enough strength to support the pipe. However, when the drain crosses a soft spot where the soil has not yet settled, e.g. a filled-in former ditch, drain bridges should be used to maintain the level of the drain during settlement of the soil. Drain bridges can be made of timber blocks on which the drain is laid or of a continuous length of solid, rigid pipe (see Section *Rigid pipes*) surrounding the drain (Figure 5).

Rigid pipes

Drainpipes can be connected to or slid into a rigid, reinforced concrete, plastic or coated steel pipe where they have to cross a road, a waterway, a gutter, unstable soil (see Section *Drain bridges*), a row of trees to prevent roots from growing into the pipes, or other obstacles (Figure 6).

INLETS

Blind inlets

Blind inlets are intended to drain stagnant pools, while sediments are intercepted. They consist of a trench above a drain that is filled with porous material (Figure 7). Durable material, such as stones, gravel and coarse sand is preferred as trench backfill. The gradation may vary from finer material at the surface to coarser with depth, although the trench can also be filled with one suitable porous material. The advantage of blind inlets is the initial low costs and the lack of interference with tillage operations. However, in general the use of blind inlets has been unsatisfactory because they tend to clog at the surface with fine soil particles and other sediments.

FIGURE 4
Pipe fittings

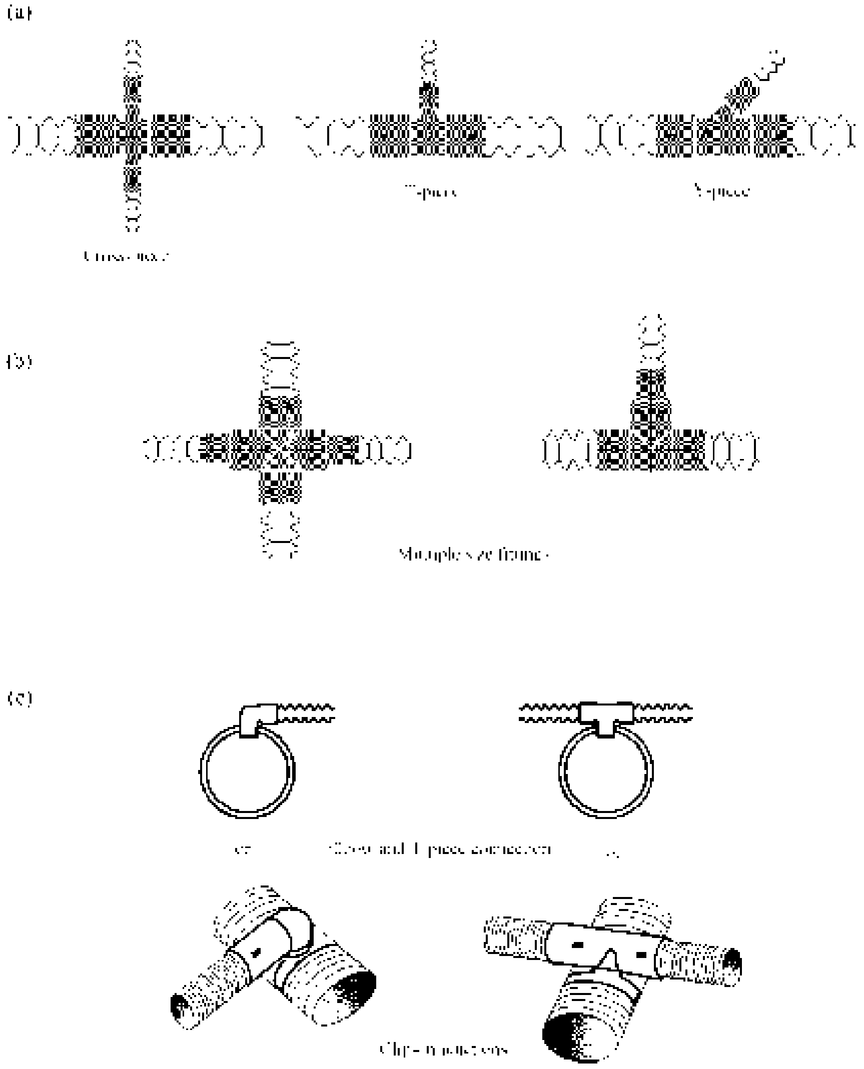


FIGURE 5
Drain bridge

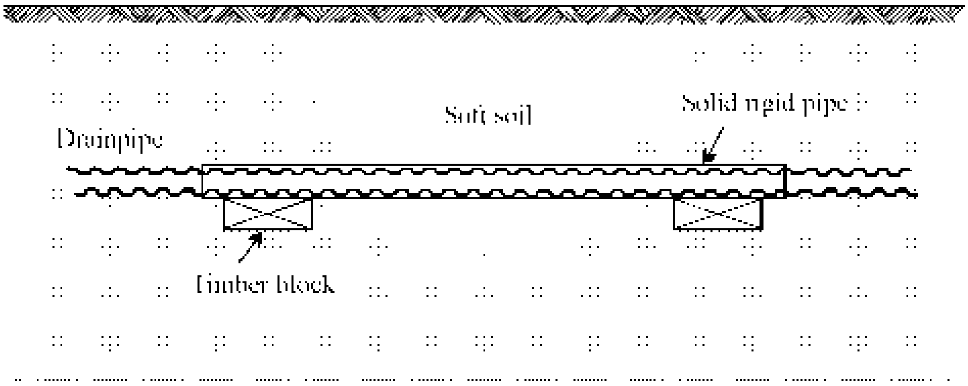


FIGURE 6
Use of rigid pipes to cross a road, a waterway or a row of trees

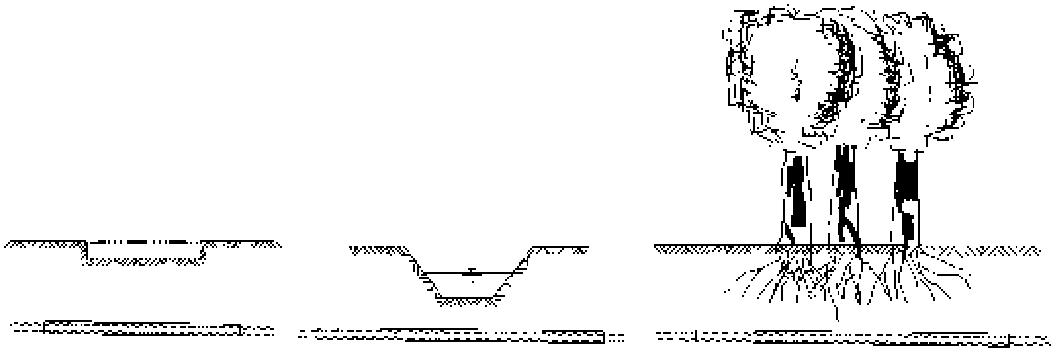


FIGURE 7
Blind inlet

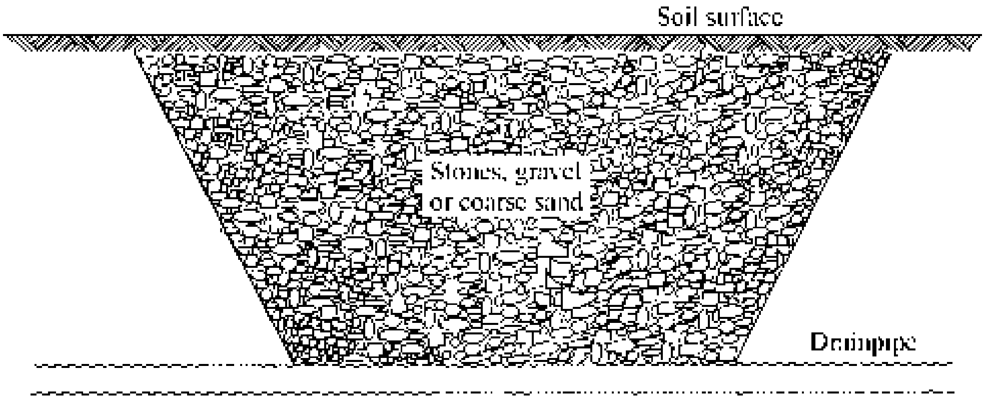
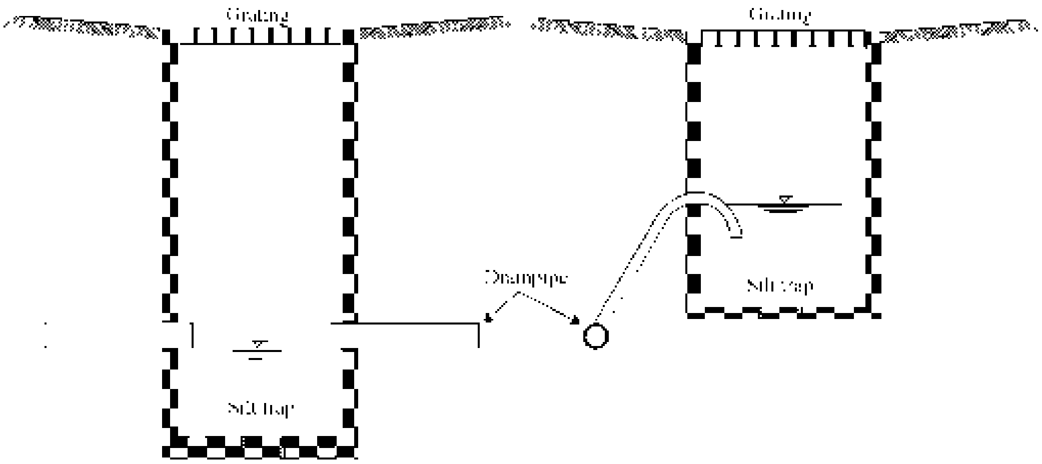


FIGURE 8
Surface inlets



Surface inlets

Surface water inlets are incidentally used to evacuate surface water from localized areas through the drainage system when the construction of ditches is not feasible or impractical. A proper silt trap is essential to prevent or reduce drain siltation. The open inlet can be in the collector line although it is better located next to the collector and connected to it with a siphon (Figure 8) as a safeguard against poor maintenance. Surface inlets are usually made of masonry or cast-in-place concrete, but concrete and rigid plastic pipes can also be used. A metal grating is usually installed to restrict the entry of trash and waste.

CONNECTION STRUCTURES

Junction boxes

Junction boxes are used where two or more drains (laterals and/or collectors) come together or where the diameter or the slope of the collector changes. They can be pre-casted (Figure 9a) or made of masonry or cast-in-place concrete, but also rigid plastic or concrete pipes can be used for this purpose. Junction boxes can be combined with a silt trap and extended to the soil surface (Figure 9b). The bottom of the silt trap should be at least 0.30 m below the bottom of the inlet of the downstream pipe. The invert of the entering laterals should be positioned at least 0.10 m above the top of the leaving collector to further sedimentation in the silt trap. Blind junction boxes will not hinder field works. The lid should therefore be situated at a minimum depth of 0.40 m below soil surface. They can be exposed if inspection and occasional cleaning is required. With the lid at the soil surface, the junction box is not so very much different from an inspection chamber, yet it hampers field works.

The position of blind boxes and covered manholes (see Section *Manholes*) should be well documented. Nevertheless, finding them is often difficult. If they do not contain steel components, a lid with steel bars should be installed on top of the structure in order to facilitate easy location with a metal detector.

Manholes

Inspection chambers or manholes differ from junction boxes with a silt trap in that they provide for ready access if drains require inspection and cleaning. The material can be concrete or masonry, but also redwood has been used successfully (Luthin, 1978). Deep inspection chambers are constructed with a number of reinforced concrete rings. They should be sufficiently large and must be provided with metal rungs fixed in the wall to allow a man to descend to the drain lines (Figure 10a). Since the lid of manholes is usually above the soil surface, they are objectionable because of their interference with farming operations. To meet this objection a capped manhole, with the top at least 0.40 m under the soil surface, can be installed with the inconvenience that the top of the manhole has to be dug out for each inspection (Figure 10b).

OUTLETS

Gravity outlets

The outlet of laterals and collectors must be protected in case of gravity discharge of the water into an open drain system. The outlet should be reliable since malfunctioning affects the performance of the entire drain or drainage system. The outlet of laterals and smaller collector

FIGURE 9
Junction boxes

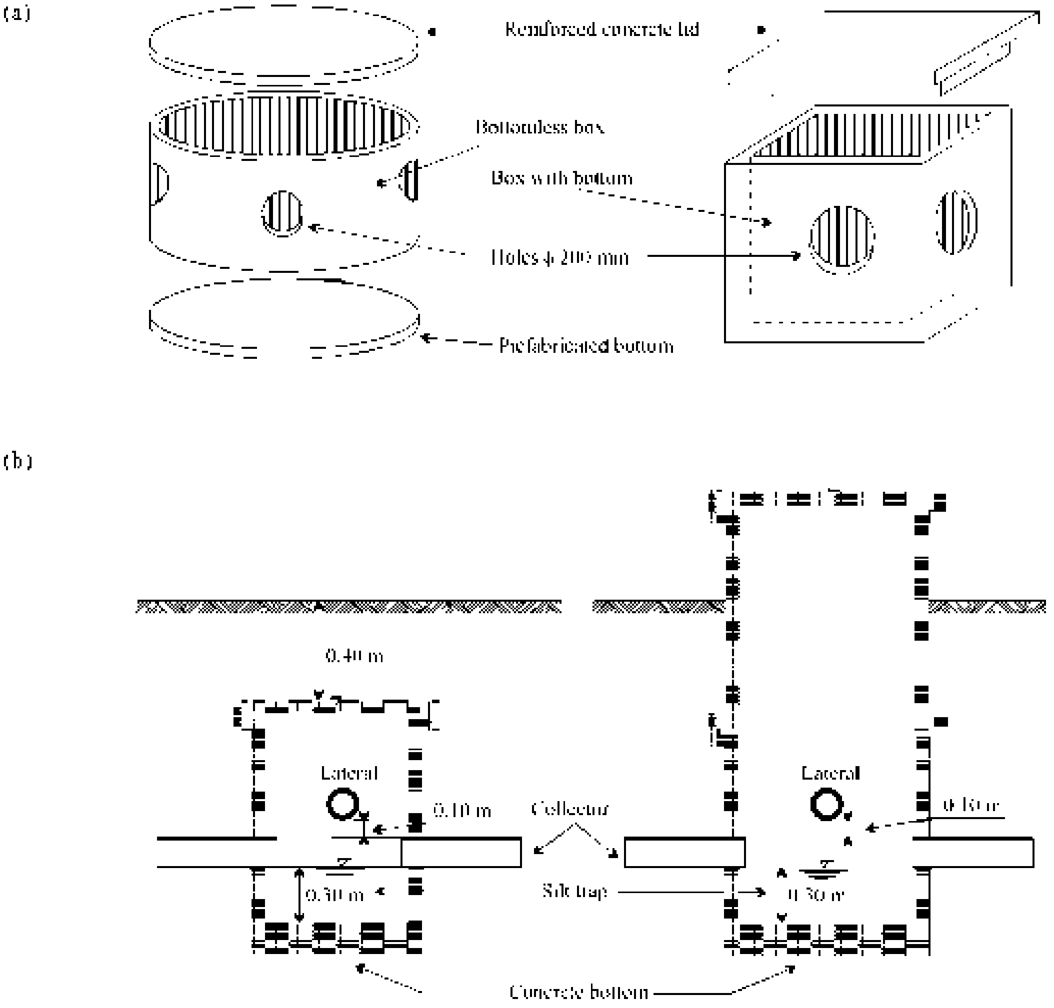
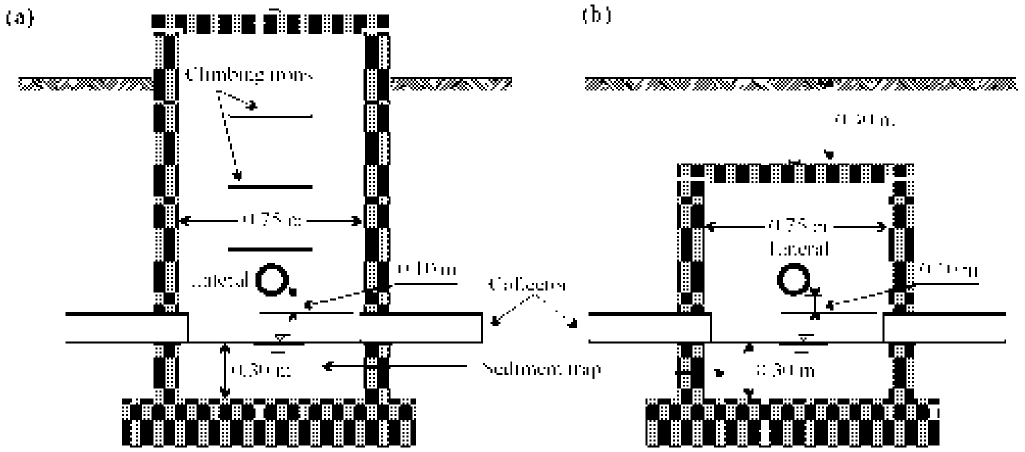


FIGURE 10
Inspection chambers (manholes)



drains can be protected with a non-perforated rigid pipe made of plastic, coated galvanized steel, reinforced concrete or other materials. The length of this pipe ranges from 1.5 to 5.0 m, depending on the diameter of the drain pipe, the risk of root penetration from bank vegetation and the danger of erosion under the pipe or at the discharge point. No envelope material (particularly gravel) shall be applied near the outlet and the last few metres of the trench backfill should be well compacted over the entire depth of the trench. The outlet pipe can be connected to, or slid over the drain pipe and at least half of its length should be buried (Figure 11a).

FIGURE 11
Gravity outlets

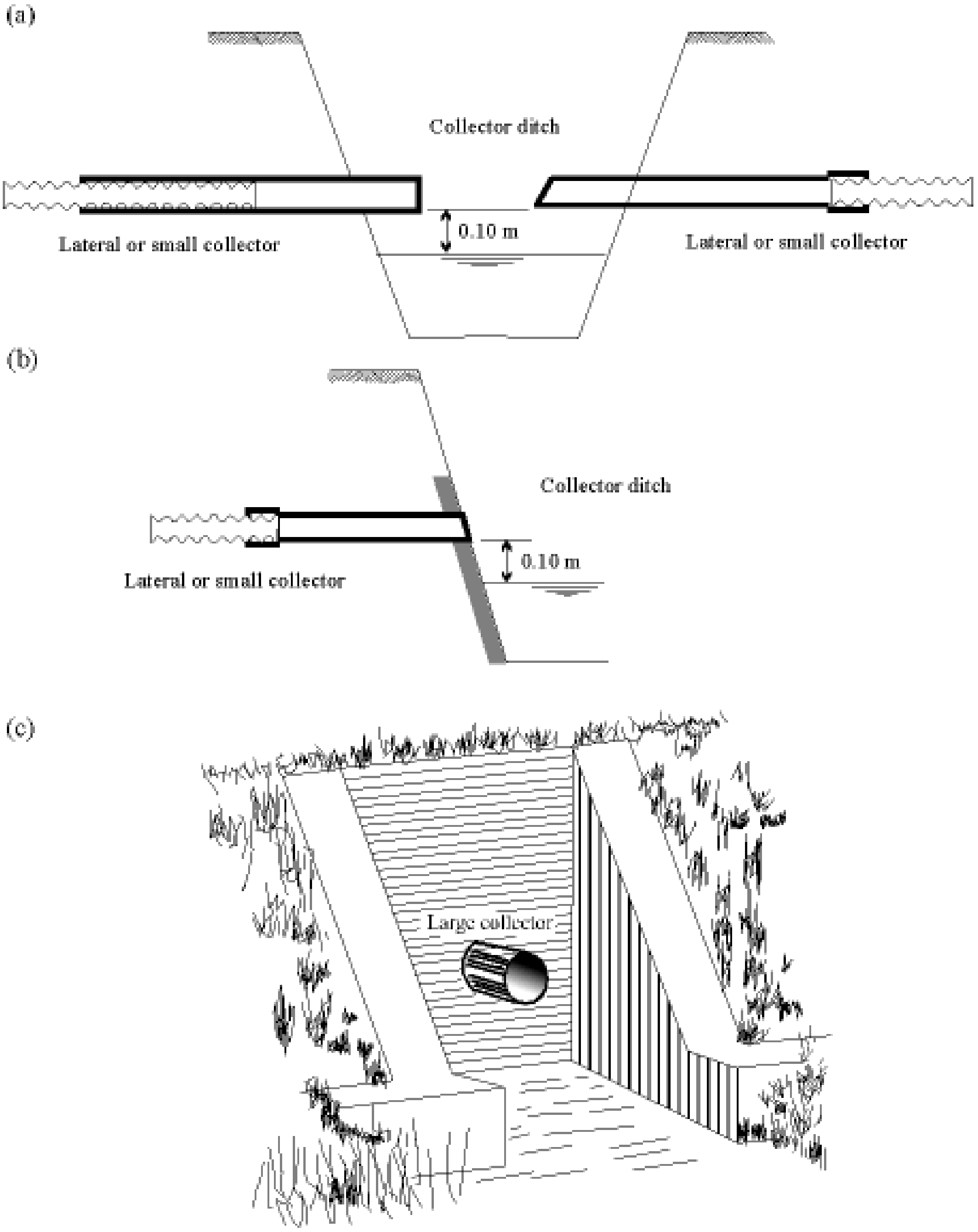


FIGURE 12
Drainage pump sump

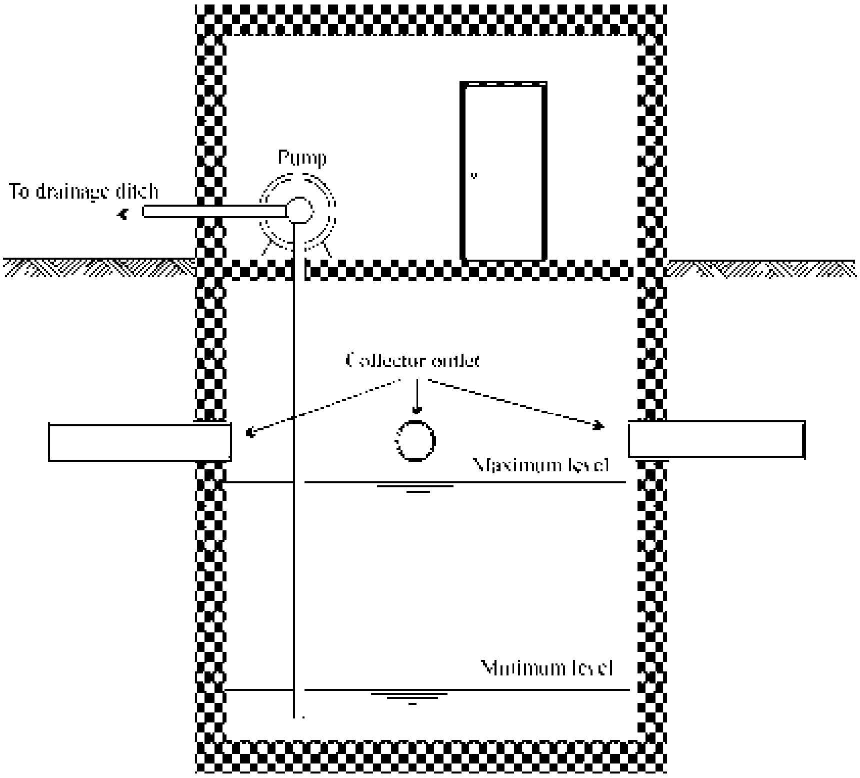
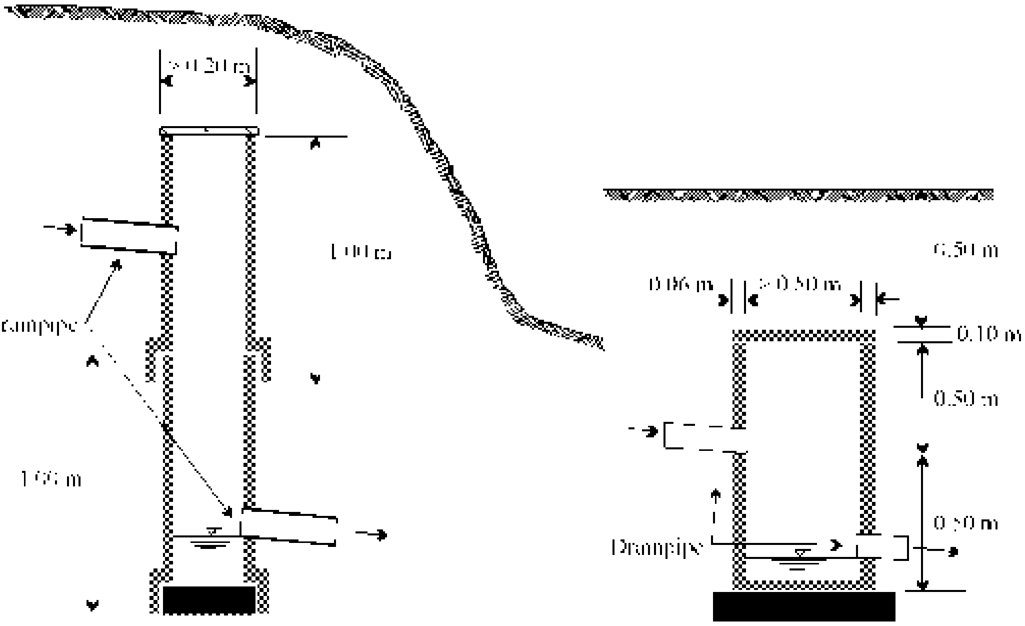


FIGURE 13
Gradient reducers (after Eggelsmann, 1978)



The main function of drain outlets is to prevent erosion of the ditch bank. For this purpose the unperforated end-pipe must reach far enough out to discharge above the water-level in the ditch. Support by a pole or rod may be needed to avoid sagging.

Sometimes short non-protruding outlets are used in combination with chutes protecting the side-slope of the ditch. These chutes can be halved plastic pipes or cement gutters guiding the stream (Figure 11b). A non-protruding pipe can also be used where there is danger of ice jams.

In spite of many efforts, no adequate solution is yet found to solve the problem of outlet interference with ditch maintenance. Plastic end pipes resist corrosion from chemicals in soil and water but burning off side slopes of ditches as a maintenance measure will be fatal.

Larger collector drains justify the use of a small concrete structure, made of masonry, cast-in-place concrete, or pre-cast segments (Figure 11c). Outlets should be provided with a removable screen to prevent the entry of small animals. Although the outlet into open ditches may be submerged for short periods during storms, they are usually not and should be at least 0.10 to 0.15 m above the water level in the ditch at normal flow (Figure 11).

Pumped outlets

Pumps are used for the discharge of water from a drainage system into an outlet ditch, when gravity outflow is not possible because of insufficient outlet depth. This situation is common with deep drainage systems that are designed for salinity control in arid and semi-arid regions. In other areas they may be needed because of insufficient outlet levels. Collector lines discharge into a storage sump with concrete base, where a float-controlled pump periodically empties the sump (Figure 12). Pumped outlets are more expensive than gravity outlets, not only because of the initial cost of equipment, but also due to costs associated with maintenance and power consumption.

Pumped outlets are equipped with a power unit (either electric motor or diesel engine), and pumps and pipes for lifting collected drainage water to a shallow gravity outlet. Small sumps can be constructed with large diameter plastic, asphalt-coated corrugated steel or concrete pipes while larger sumps shall be made of reinforced concrete rings, masonry or reinforced concrete.

SPECIAL STRUCTURES

Gradient reducers

A gradient reducer may be required in sloping lands to reduce excessive flow velocities in drain pipes and prevent erosion and subsequent water movement through channels formed outside the pipe. They can be made of concrete or plastic pipes, or of masonry or concrete (Figure 13). They are in fact blind junction boxes of great height with the entering pipe near the top and the leaving pipe near the bottom of the box.

Cleaning facilities

Although cleaning of properly designed and carefully installed drainpipes should be exception rather than general rule, there may be circumstances where drains require regular cleaning (e.g. if iron ochre is formed). Cleaning of laterals of a composite drainage system, equipped with blind junctions is possible only after dismantling of some of these connections. The provision

FIGURE 14
Access pipe for cleaning laterals of a composite drainage system (Cavelaars *et al*. 1994)

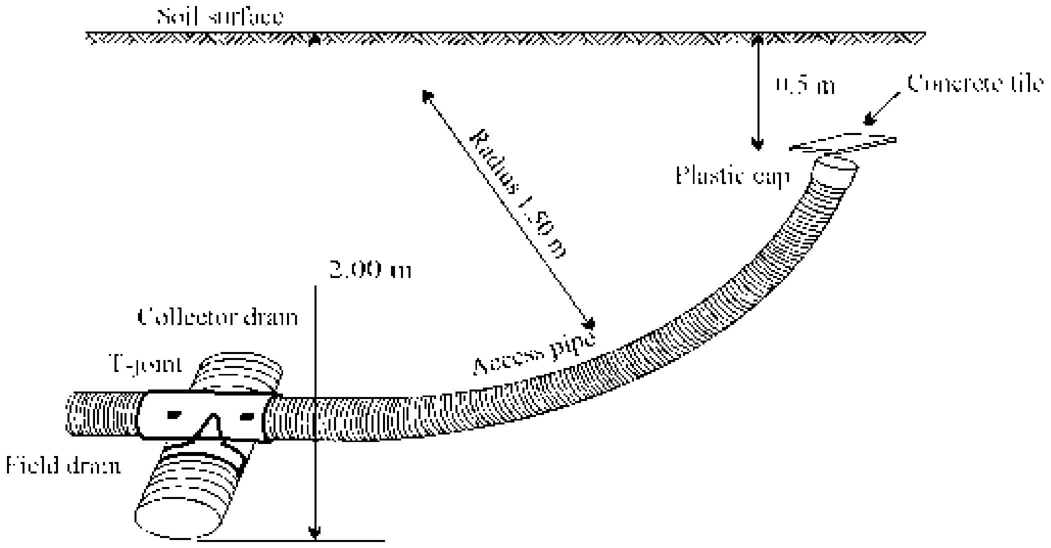
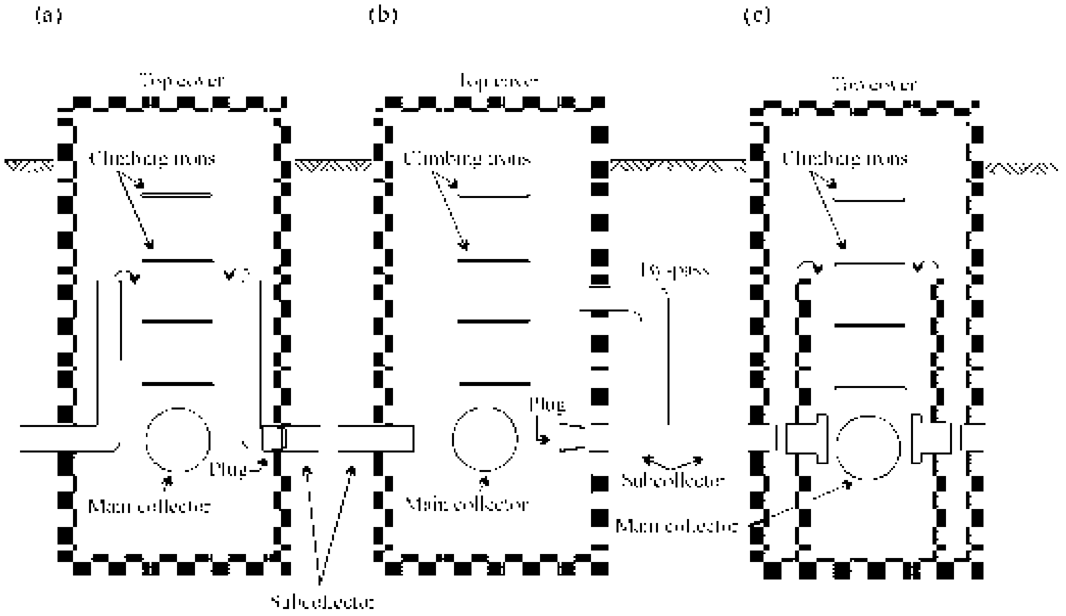


FIGURE 15
Controlled drainage systems: (a) elbow and plug with riser; (b) plug with bypass (after Abdel Dayem *et al*., 1989)**; (c) sophisticated structure with crest board** (after Cavelaars *et al*. (1994); slightly modified)



of special fittings (Figure 14) however facilitates cleaning by flushing without having to excavate and dismantle junctions. A concrete tile with steel bars above the access pipe allows easy retrieval with a metal detector from the soil surface (Cavelaars *et al*., 1994).

Structures for controlled drainage and subirrigation

There can be some reasons to reduce drainage temporarily (e.g. environmental considerations, unwarranted and harmful leaching of fertilizers in winter, supplementary irrigation and special water regimes for rice and other crops). Devices for controlled drainage can be installed in open ditches or on subsurface drains. Unperforated pipes with a length of 5 m, leading drains into or from the control structure, should be used to prevent seepage around the structure. Very simple control tools can be used such as an elbow or plug with a riser (Figure 15a) or a plug with a bypass (Figure 15b). Structures with crest boards are common in open ditches. Very sophisticated structures with crest boards (Figure 15c), floats or electric water level sensors in a sump, either located on the drain line or midway between drains, can be used as well (Madramootoo *et al*., FAO, 1997; Schwab and Fouss, 1999). Simple yet reliable control devices can be made locally, however, with available means. Control structures are made of masonry, cast-in-place concrete or pre-cast segments.

Drainpipes serving both drainage and irrigation purposes are sometimes laid without slope. However, this is not necessary as long as the gradient remains sufficiently small. Automatic controls are required to maintain the water level at the drainage outlets, which serve as inlets for subirrigation systems. Subirrigation should not be practised in arid regions where soil salinity is a potential problem.