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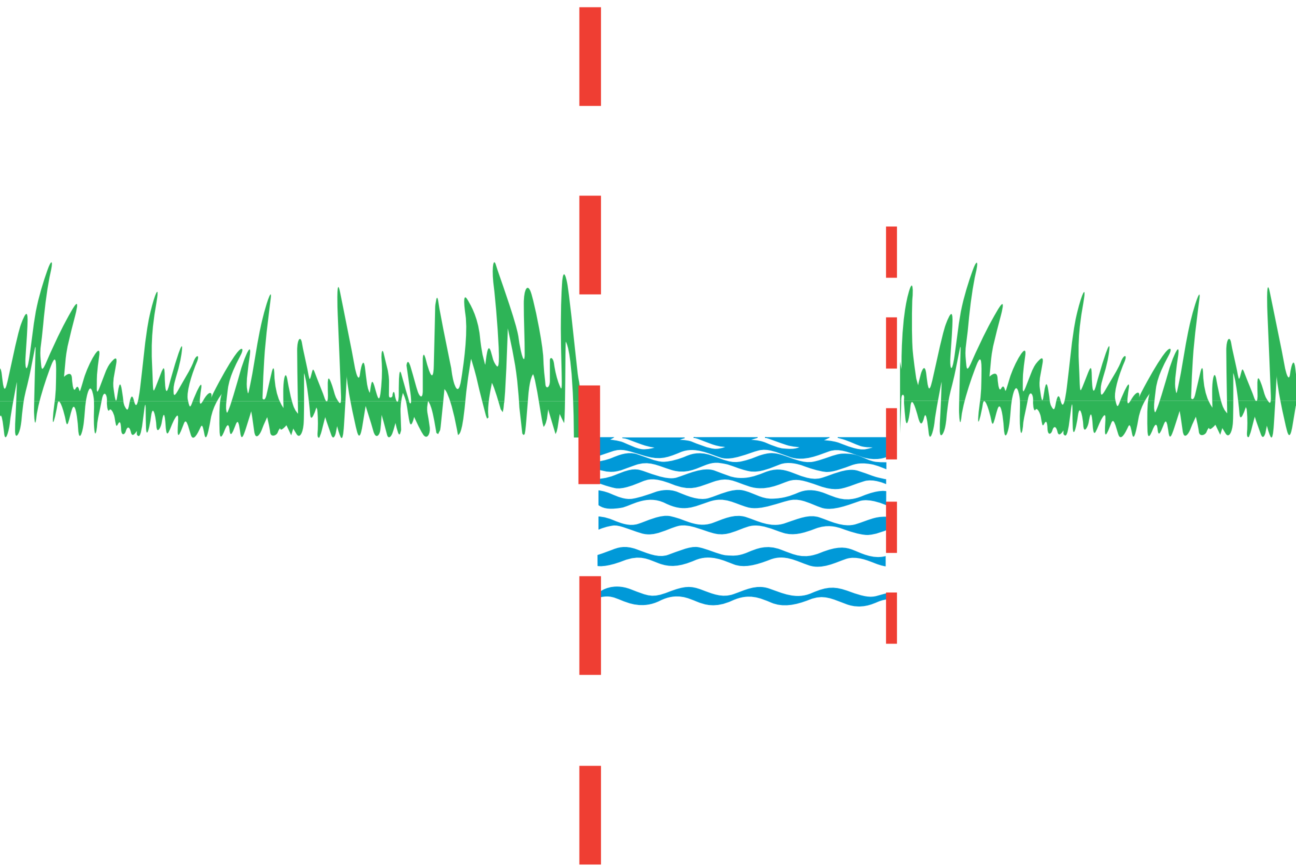
Subsurface Drainage Practices

Guidelines for the implementation, operation and maintenance of subsurface pipe drainage systems

By H.J. Nijland, F.W. Croon and H.P. Ritzema



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Guidelines for the implementation, operation and maintenance of subsurface pipe drainage systems

By H.J. Nijland, F.W. Croon and H.P. Ritzema[1]

[1] With the support of the following drainage experts: Dr. Safwat Abdel Dayem, Dr. Muhammad N. Bhutta and Dr. K.V.G.K. Rao.

This book is published in the Alterra-ILRI Publication Series. The main characteristic of this series is that the books are "practical" in the sense that they can be used in the day-to-day work of those professionals (mostly engineers) who are involved in irrigation and drainage.

Nijland, H.J., F.W. Croon and H.P. Ritzema, 2005. *Subsurface Drainage Practices: Guidelines for the implementation, operation and maintenance of subsurface pipe drainage systems.* Wageningen, Alterra, ILRI Publication no. 60, pp. 608.

Keywords: subsurface drainage, planning, organization, implementation, operation, maintenance.

ISBN 90 327 0340 4

NUR 910

This publication can be ordered by paying € 40,- to bank account number 36 70 54 612 by name of Alterra Wageningen, IBAN number NL 83 RABO 036 70 54 612, Swift number RABO2u nl. Please refer to ILRI Publication 60. This amount is including tax (where applicable) and handling costs.

The aims of Alterra-ILRI are:
- To collect information on land reclamation and improvement from all over the world;
- To disseminate this knowledge through publications, courses, and consultancies;
- To contribute - by supplementary research - towards a better understanding of the land and water problems in developing countries.

Preface

Drainage of agricultural lands is an instrument for production growth, a safeguard for sustainable investment in irrigation and a tool for conservation of land resources. In global terms, drainage in the developing countries is still far of being adequate or sufficient. Out of the 1500 million ha of cropped lands (irrigated and rainfed) of the world, only about 14% is provided by some form of drainage. The total area in need of artificial drainage can be roughly estimated by 300 million ha mainly in the arid and tropical humid zones of the developing countries. Projections of crop production to meet the food and fibre needs of the world during the next 25 years shows that drainage should be improved in at least 10 -15 million ha which would imply investing at least € 750 million annually. It is expected that one third of this area will be provided with subsurface drainage systems.

Subsurface drainage is a form of drainage that was widely introduced in Europe and North America in the twentieth century. In the developing countries, Egypt stands as the country with largest area provided with subsurface drainage (about 2.5 million ha). Countries such as Pakistan, China, Turkey and India however are also providing subsurface drainage to large tracts of their irrigated lands. The world experience in subsurface drainage over the past decades provide a wide range of lessons learned and offers great opportunity to identify best practices. Although the technological advances and the scientific research offered a lot of innovations to subsurface drainage, organizational and institutional aspect of drainage project proved to be equally important for achieving the development objectives. Most of this knowledge and experience however is hidden in the so-called "*grey literature*" (unpublished reports) and in the mind of few experts who have not got the chance to integrate this vast experience and offer it to the next generation of projects. The purpose of this handbook is to made this knowledge and experiences readily available.

This handbook focuses on the construction process of subsurface pipe drainage systems. It includes a discussion of planning, organisation, and installation techniques and contains guidelines and relevant information for improving the quality of pipe drainage installation. The emphasis is on lessons learned from past experiences and how new projects can benefit from these experiences. The handbook is meant for operational managers, field and office staff of drainage organisations, both public and private, involved in the planning, installation and management of pipe drainage systems.

This handbook has been compiled based on experiences with the development and implementation of pipe drainage techniques and systems over a period of approximately 50 years in four continents. The manual has been written under the responsibility of the Alterra-ILRI, International Institute for Land Reclamation and Improvement by Ir. Henk Nijland of the Netherlands Ministry of Transport, Public Works and Water Management, Ir. Frank W. Croon of Croon Consult, formerly of Arcadis Euroconsult and Ir. Henk Ritzema of Alterra-ILRI, based on the experiences of the authors and their organisations in the implementation of subsurface drainage systems in many parts of the world. As the reference material is not readily available for most readers, the authors have prepared a bibliography with a brief description of the most important published background information.

The contents of the handbook could not have been realised without the direct contribution of the following drainage experts:

Name	**Post/Company/Organisation**
Dr. Safwat Abdel Dayem	Drainage Adviser, The World Bank, Washington, USA
Dr. Muhammad N. Bhutta	Director, International Waterlogging and Salinity Research Institute/ IWASRI, Lahore, Pakistan
Dr. K.V.G.K. Rao	Drainage Adviser, Hyderabad, India

Next to these direct contributions the techniques and methodologies described in this book are based on the knowledge and experiences of the following persons, who have indirectly contributed to the content:

Name	**Company/Organisation**
Ir. F. P. A. C. van Berkom	Alterra-ILRI, Wageningen, The Netherlands
Ir. J.C. Cavelaars	Formerly at Arcadis-Euroconsult, Arnhem, The Netherlands
Ir. J.P. Driessen	Formerly at Arcadis-Euroconsult, Arnhem, The Netherlands
Ing. G. Harmsen	Wavin Overseas, Dedemsvaart, The Netherlands
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Ir. J. Vos	Formerly IJsselmeerpolders Development Authority, Lelystad, The Netherlands
Ing. J. de Weert	Formerly at Larenco, The Netherlands
Mr. H. Koppert	Steenbergen Holland Drain, Klaaswaal, The Netherlands
Mr. W. de Waard	Steenbergen Holland Drain, Klaaswaal, The Netherlands

Beside these people, we like to thank the following staff who contributed to the preparation of this handbook:

Language editor	Mrs. Ninette de Zylva
Drawings	Jos Rietstap Vormgeving
Design and Layout	Graphic Design & DTP team, Alterra

Furthermore this publication could not have been printed without the financial support of:
- Department of Science and Knowledge Transfer, Ministry for Agriculture, Nature and Food Quality, The Netherlands;
- Institute for Inland Water Management and Waste Water Treatment (RIZA), Lelystad, The Netherlands, Ministry of Transport, Public Works and Water Management, The Netherlands;
- Arcadis Euroconsult, The Netherlands;
- Homburg Drainage Machinery, The Netherlands;
- Horman Drainagefilters, The Netherlands;
- Steenbergen Holland Drain, The Netherlands;
- Mastenbroek, UK.

We want to thank everyone who was involved in the production of this book. It is our belief that their combined efforts will facilitate the further introduction of pipe drainage in the world and through this contribute to a better, more sustainable, use of the world's precious land and water resources.

Wageningen, January 2005

Ir. Henk Nijland
Ir. Frank W. Croon
Ir. Henk Ritzema

Contents

Preamble

Implementation of pipe drainage systems

Over the past decades land drainage has evolved as a mature technique to control water logging and salinity and to reclaim agricultural lands. Where drainage has been applied it has proven to be a technically and economically feasible methodology to increase yields and consequently the income of farmers. As a secondary effect it safeguards the productivity of the soil and protects the environment from deterioration.

Of the different drainage methodologies such as open drainage, well drainage and pipe drainage[2], pipe drainage is the most advantageous solution for large areas in the world. Applied on a large scale, it can effectively solve the drainage problems at relatively moderate costs with a minimum of interference to agricultural practices and existing infrastructure. Maintenance of properly constructed pipe drainage systems has proven to be far less problematical than maintenance of other forms of drainage.

The background and theories of drainage and the effects have been amply described in the available literature, for instance ILRI Publication no. 16 *Drainage Principles and Applications* (see the bibliography for more background information). The theories are well known and generally well understood, yet the implementation of pipe drainage for water logging and/or salinity control is still not common knowledge. Furthermore, although the various aspects of the implementation are described in the literature, starting up the routine implementation remains a rather time-consuming and complex process during which small mistakes can have disastrous and costly consequences.

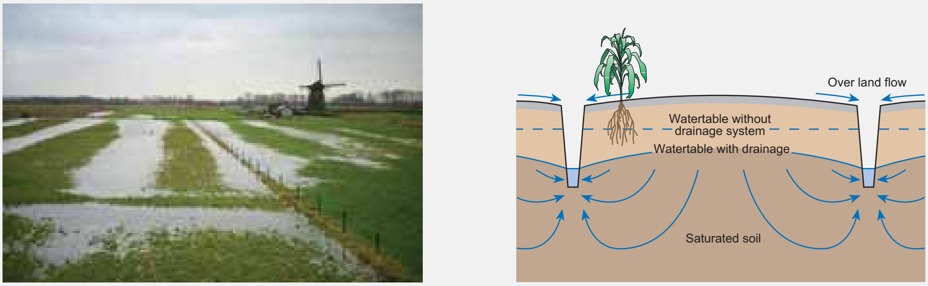
This handbook serves as a guideline for those who have a role in the process of implementing (pipe) drainage systems. Aspects and experiences of the implementation process of pipe drainage systems are summarised in Part I of this handbook. Part II presents the details of the construction of drainage systems and is specially meant for the people working in or with the construction, like contractors or specialised entities, field engineers and supervisors. Finally, Part III presents case studies from various countries describing available information on the introduction of pipe drainage systems in Egypt, Pakistan, China, India and the Netherlands.

[2] In the literature pipe drainage is often referred to as "tile drainage". Please consult the glossary for the definitions used in this handbook.

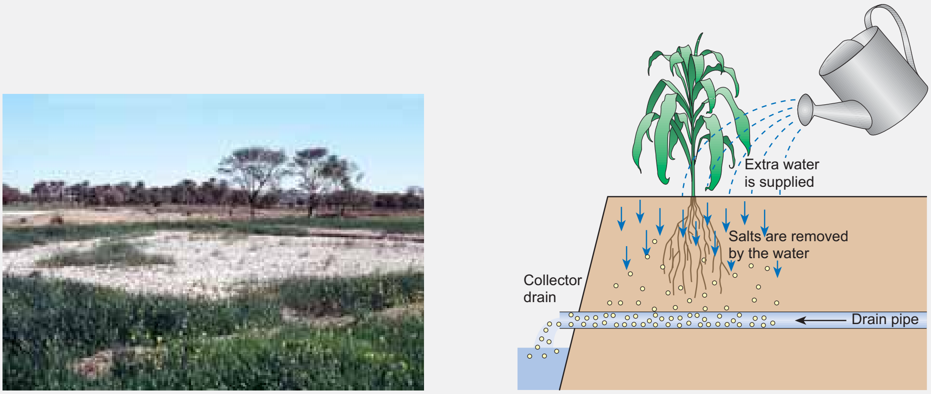
Objectives and effects of agricultural drainage

The overall objective of agricultural drainage, as part of agricultural water management, is to enhance crop growth and to maintain the soil productivity. The immediate objectives of agriculture drainage are (Figure 1):

- To remove excess surface and subsurface water;
- To remove excess soluble salts with the (excess) water from the drained soil profile;
- To maintain groundwater levels at a desired level.



a.



b.

c.

Figure 1 Objectives of drainage are: (a) to remove excess water, (b) to control salinity and (c) to maintain the watertable at a desired level

Drainage systems are man-made systems that are only implemented when natural drainage is insufficient for a satisfactory form of agriculture. Areas with limited natural drainage requiring artificial drainage are usually located in coastal plains, river valleys and inland plains where in the humid regions rainfall exceeds evaporation, or in arid regions where the (inevitable) inefficient use of irrigation water has caused water logging and secondary salinisation. Pipe drainage systems have proved to be an essential and relatively cheap method to restore the productivity of agricultural lands, especially in arid and semi-arid zones. These agricultural (pipe) drainage systems can be used for:

- Reclamation of new land with a groundwatertable and/or soil salinity that is too high;
- Controlling groundwater levels at desired depths and soil salinity at desired levels;
- Restoring the productivity of water logged and/or salinised lands to their potential levels.

Under specific conditions, these systems also create conditions under which:

- Accessibility to the field for (mechanised) farm operations is better assured;
- More crops per year can be grown;
- A larger range of crops can be grown;
- Higher value crops can be cultivated.

Finally, secondary benefits of agricultural drainage systems are:

- Facilitation of sanitation: lowering of groundwater levels in an area will facilitate the sanitation of houses and/or population centres;
- Health improvement: lowering groundwatertables and removing stagnant water can under specific conditions control malaria, bilharzias etc.;
- Improvement of access and trafficability of an area: lowering groundwatertables and removing surface water will improve the general accessibility in an area;
- Improvement of environmental conditions: lower groundwatertables and reduced salinity in an area will stop or reverse environmental deterioration.

The costs of pipe drainage systems vary from place to place depending on the local physical and economic conditions. Generally speaking, the cost of large-scale pipe drainage systems fluctuates between € 750 and € 1500 per ha.[3]

The need for drainage

Drainage plays an essential part in food production while safeguarding the investments in irrigation and conserving land resources. During the second half of the 20th Century, drainage was implemented in about 150 million hectares of under-producing and naturally waterlogged or salinised lands, mainly in Europe, North America, Middle East and to a lesser extent Asia. This resulted in important improvements that contributed to a considerable increase of food

[3] In this handbook all prices are in euro (€ 1.00 = US $ 1.00) in 2002 prices except when stated otherwise.

production. Drainage has also contributed to agricultural intensification and diversification and as such has made the agricultural sector more competitive and financially sustainable. In global terms, however, drainage is still far of being adequate or sufficient. Out of the worldwide 1500 million ha of cropped land (irrigated and rainfed), only about 14% is provided with some form of artificial drainage (Figure 2a). Consequently large parts of existing agricultural land still suffer from inadequate drainage and/or salinisation, e.g. in arid and semi-arid areas some 20 to 30 million ha suffer from irrigation induced degradation resulting in water logging and high soil salinity.

To be able to feed the growing world population and to banish hunger from the world, food production needs to be doubled within 25 years. The majority of this increase will have to come from investment in improved irrigation and drainage practices in existing agricultural areas (Figure 2.b). This includes the reclamation of areas that are already equipped with irrigation facilities, by using piped subsurface drainage systems and improved water management, which can relatively cheaply restore these areas to their full production potential. To fulfil this task, it is estimated that drainage is to be improved on at least 10-15 million ha.

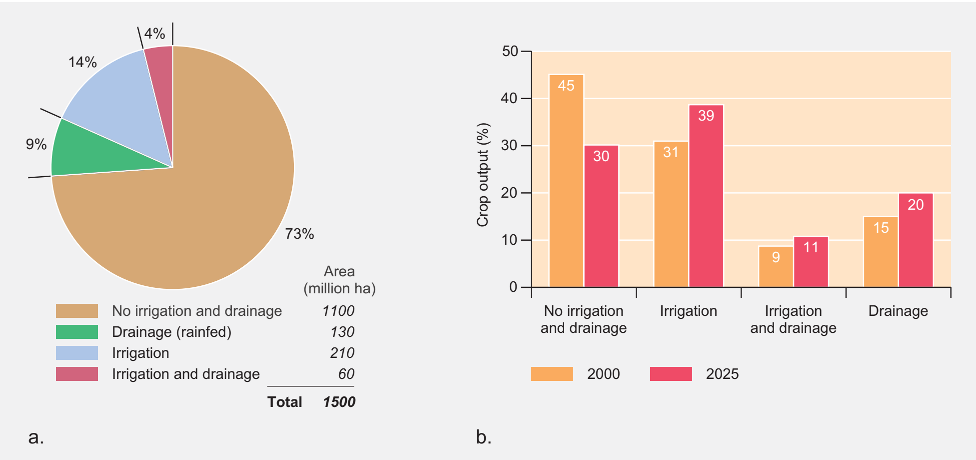


Figure 2 Drainage plays an essential part to sustain food production: (a) Worldwide agricultural areas equipped with and without irrigation and/or drainage systems, and; (b) Agricultural output (crop yield) from agricultural land with and without irrigation and drainage facilities now (2000) and in 2025 (Source ICID Statistics, 2003)

History of pipe drainage technology

Subsurface drainage has a long history, the oldest known systems date back some 9000 years in Mesopotamia. Drain pipes were already in use some 4000 years ago in the lower Indus Valley and bamboo pipes were used as drains in ancient times in China.

Pipe drainage in modern times started in the United Kingdom in the 17^{th} Century in the form of trenches filled with bushes or stones. The first clay pipes were produced in 1810, followed by concrete pipes a few decades later. Starting around 1940, the prevailing empirical knowledge of drainage and salinity control gained a solid theoretical footing. A breakthrough in pipe drainage technology also occurred in the 1940s when rigid plastic pipes were introduced followed by corrugated PVC and PE pipes in the 1960s. Nowadays, corrugated PE or PVC is considered to be the preferred standard.

Mechanised installation developed rapidly from the 1940s onwards (Figure 3). Nowadays, highly effective drainage machines that install the drain pipes in trenches (trenchers) with almost perfect depth and grade control are on the market. Moreover, trenchless drainage machines that were developed after the 1970s have proved to be very cost effective for the installation of corrugated PVC pipes to relative shallow depth. Laser technology for semi-automatic depth and grade control has, in the meantime, become standard for mechanised installation.

The necessary envelop material around the field drains originally consisted of locally available materials like stones, gravel or straw. In arid areas the technique for the use of granular envelopes has been further developed to such a degree that effective granular envelopes can be designed for most soils. In practice, granular envelopes are often expensive, installation is cumbersome and error prone and requires almost perfect logistic management during installation. Moreover, gravel cannot be used when installation is done with trenchless equipment. Alternatively pre-wrapped envelopes of synthetic material have been under development for some decades. Pre-wrapped envelopes made of artificial fibre are presently almost universally used in Europe, in some areas of the United States and in Egypt. Since the specifications of envelopes are very soil specific and soils are rather variable, the specifications and effectiveness of envelopes have to be proven in field trials in the areas where they are to be applied.

Drainage systems and drainage methods

In humid regions the primary goal of agricultural drainage is to lower the water content of the rootzone to provide adequate aeration following excessive rainfall or irrigation. A secondary goal is to provide site access and trafficability for timely planting and harvesting. Under these conditions open drainage systems are the most common, but dictated by agricultural practices, more and more in combination with subsurface drainage to lower groundwater levels quickly after rainstorms or at the end of the rainy season.

In arid and semi-arid regions the primary goal of agricultural drainage is to remove the accumulated salts from the rootzone and to control the secondary salinisation by lowering groundwater levels. These goals can be achieved by both pipe and open drains, in most cases pipe drains are the most practical solution.

There are field drainage and main drainage systems. The field drainage system controls the groundwater level in the field and removes the excess rain or irrigation water. The main drainage

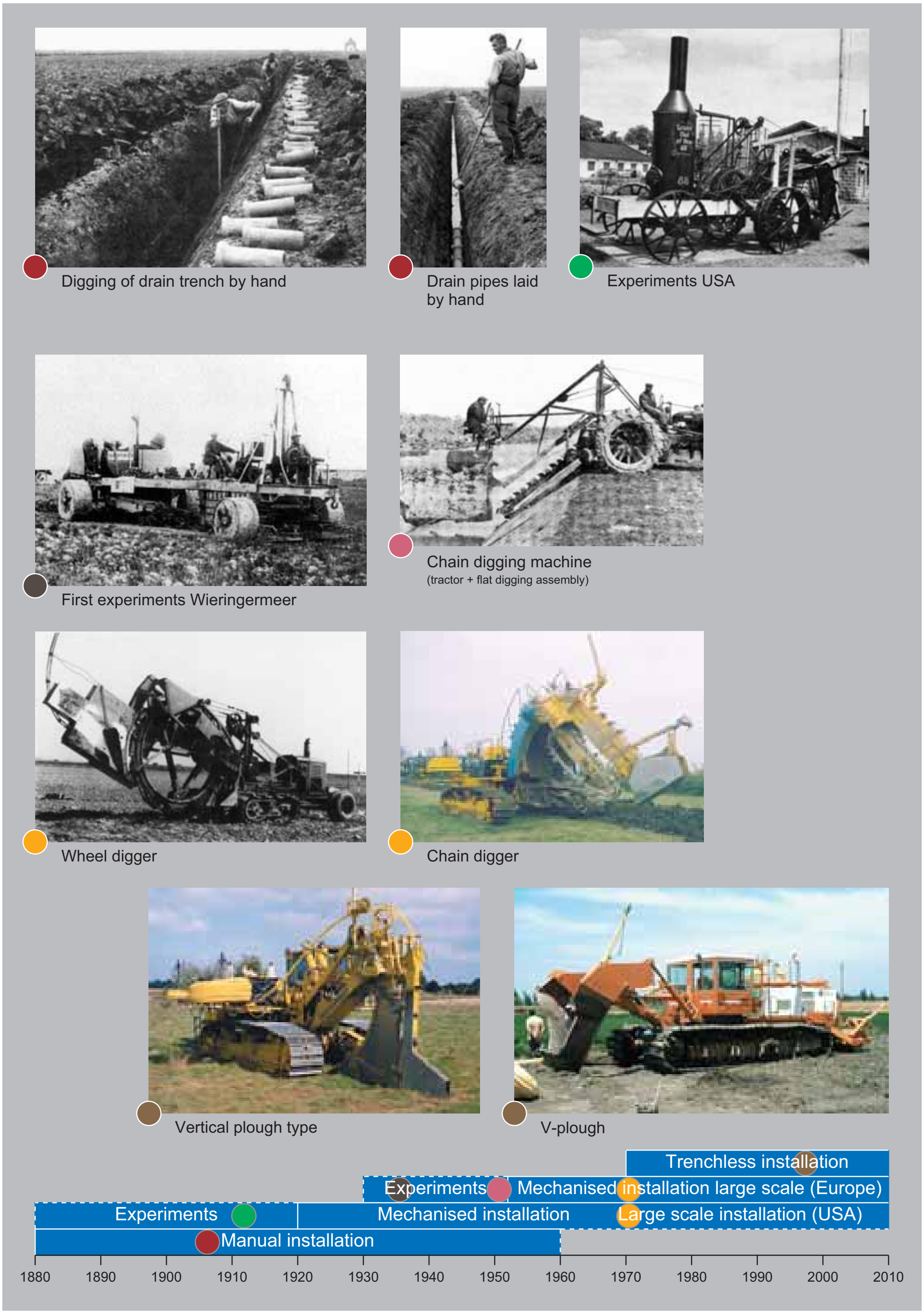


Figure 3 History of mechanised installation of subsurface pipe drainage systems

systems convey the water to the outlets of the drainage basins. Field drainage systems can be either surface or subsurface drainage systems. Surface drainage systems are applied when overland flow or water ponding occurs on the soil surface (Figure 1a). Subsurface drainage systems are usually applied when there are problems with excessively shallow watertables and/or secondary salinisation (Figure 1c). There are four types of subsurface drainage systems (Figure 4):

- Tubewell drainage (vertical drainage, also called well drainage);
- Mole drainage (horizontal drainage);
- Open drainage (horizontal drainage, also called ditch drainage), and;
- Pipe drainage (horizontal drainage, also called tile drainage).

Tubewell drainage systems

A tubewell drainage system consists of a network of tubewells to lower the watertable, including provisions for running the pumps, and surface drains to dispose of the excess water. Tubewell drainage is used in areas with a high soil permeability and preferably fresh groundwater that can be reused for irrigation. The system is operation and maintenance intensive and requires a continuous diesel or electrical power supply.

Mole drainage systems

A mole drain is an unlined underground drainage channel, formed by pulling a solid object, usually a solid cylinder with a wedge-shaped point at the end, through the soil at the proper slope and depth, without a trench having to be dug. Mole drainage is applied only under very specific conditions, mainly in stable clayey soils. The effect of mole drainage is a rapid removal of excess water from the surface layers, rather than at controlling the watertable as such. The mole drains have a life span of only a few years and have to be renewed frequently.

Open drainage systems

An open drain is a channel with an exposed water surface that conveys overland flow as well as subsurface flow. Open drains combine surface and subsurface drainage functions. The main disadvantages of open drainage systems are: (i) land loss; (ii) interference with the irrigation; (iii) splitting-up of the land into small units; (iv) hampering (mechanised) farming operation; and (v) relatively frequent maintenance requirements.

Pipe drainage systems

A pipe drain is a buried pipe (regardless of material, size or shape) that conveys excess groundwater to control the watertable at a desired depth. Pipe drainage systems are installed in the soil below the plough layer (normally > 0.70 m depth) and therefore have the advantage of not interfering with the farm operations. The land can be farmed right over the drain and there is no loss of farming area. Maintenance requirements are minimal if the systems are properly constructed. If overland drainage flows occur, shallow open drains are additionally required.

Subsurface pipe drainage systems can be divided into: (i) singular and (ii) composite systems. In a singular pipe drainage system, the field drains are buried perforated pipes that discharge

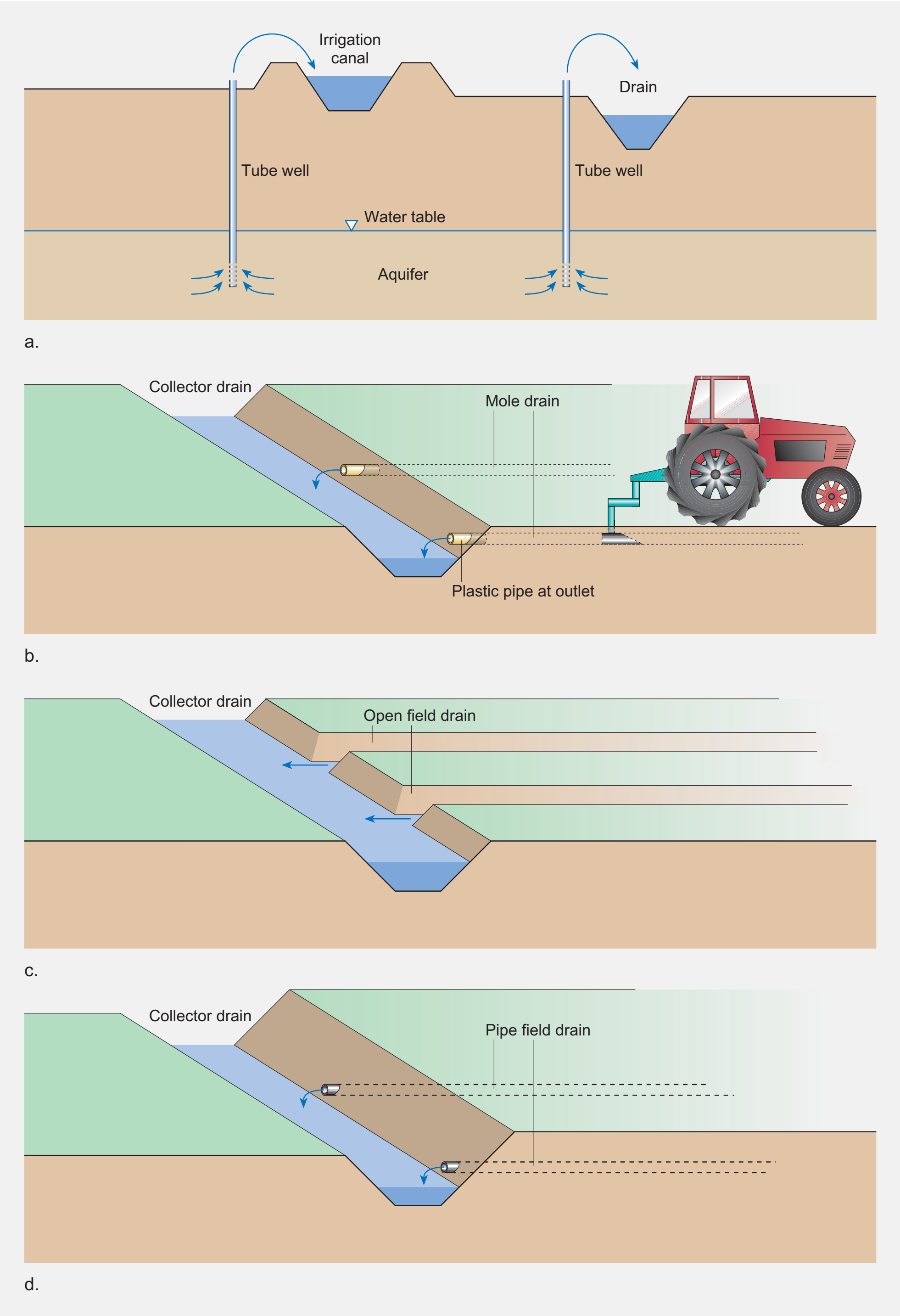


Figure 4 The four types of subsurface drainage systems are Tubewell drainage (a), Mole drainage (b), Open drainage (c) and Pipe drainage (d)

into open collector drains (Figure 5a). In a composite pipe drainage system, the collector drains also consist of closed or perforated pipes that in turn discharge into an open main drain either by gravity or by pumping. The collector system itself may be composed of sub-collectors and a main collector.

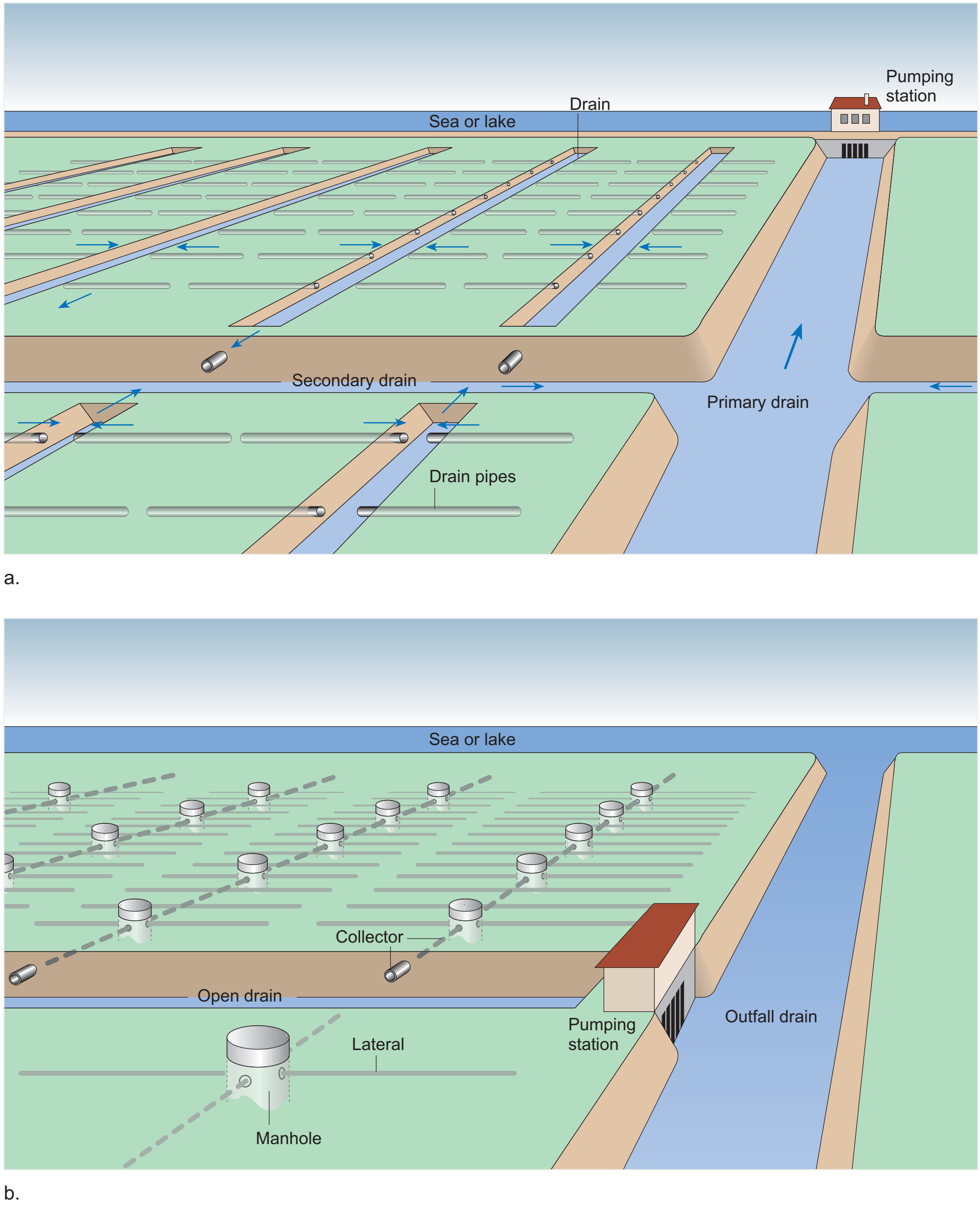


Figure 5 Subsurface drainage system can be: a) single subsurface drainage system, for example The Netherlands, or b) composite subsurface drainage system, for example Egypt

The structure of the handbook

This handbook focuses on the construction process of subsurface pipe drainage systems. Since the construction process is part of the total implementation process, a description of the implementation process is also included. Because there is already a wealth of manuals and literature available on parts of the implementation process (see Bibliography), the authors have tried to avoid any duplication. Wherever relevant, references to existing sources are made provided that they are easily accessible.

This handbook is organised as follows:

Part I: The Implementation of pipe drainage systems: the process
Part I describes the process to be followed for the implementation of subsurface pipe drainage systems. This part is meant for all people concerned with part or the whole process of the implementation of subsurface pipe drainage systems. Part I aspires to give guidelines for carrying out all the required activities; it also provides suggestions for decisions for the implementation mode and how these can be prepared. Part I focuses on drainage systems that are implemented with important governmental participation and/or financing.

Part II: The Implementation of pipe drainage systems: the construction
Part II is a guideline for the actual installation of subsurface pipe drainage systems. It is chiefly meant for those who are involved in the actual construction process.

Part III: The Implementation of pipe drainage systems: Case histories
Part III presents the salient features of the history and present practices of the implementation of and the start up of the implementation process of pipe drainage systems in various countries, such as Egypt, China, India, Pakistan and the Netherlands. This part is intended as reference. The most relevant experiences in these countries have been used to compile Part I and Part II.

Part I

Implementation of subsurface drainage systems: the Process

Part I describes the process to be followed for the implementation of subsurface pipe drainage systems. This part is meant for all people concerned with part or the whole process of the implementation of subsurface pipe drainage systems. Part I aspires to give guidelines for carrying out all the required activities; it also provides suggestions for decisions for the implementation mode and how these can be prepared. Part I focuses on drainage systems that are implemented with important governmental participation and/or financing.

I.1 Implementation Process for Subsurface Drainage Systems

I.1.1 Main steps and players in the implementation process

This chapter discusses the implementation process of subsurface drainage projects. Proper planning is essential because drainage usually involves substantial long-term investments of capital and other costs. In the implementation process, four main steps can be distinguished, i.e. (Figure 6):

- Step 1: Policy preparation and decision-making;
- Step 2: Technical, organisational and administrative preparation;
- Step 3: Actual implementation: field investigations, design, planning & budgeting, tendering and construction;
- Step 4: Handing-over and operation & maintenance.

Numerous stakeholders are involved in the implementation process, i.e.: the farmers who are the main beneficiaries, the government, planning and implementation authorities, drainage contractors, suppliers of drainage materials and machinery, each with their own specific interest. For each step, however, one authority will have the overall responsibility: the national or regional government in the policy and decision-making process, a planning authority in the preparation, a implementation authority for the actual implementation and of course the farmers or their representatives to operate and maintain the system.

The importance of the different steps depends on the extent of the development of the subsurface pipe drainage in the country concerned and on how the country is organised. In a country where pipe drainage is a routine matter, the national government has probably already got a

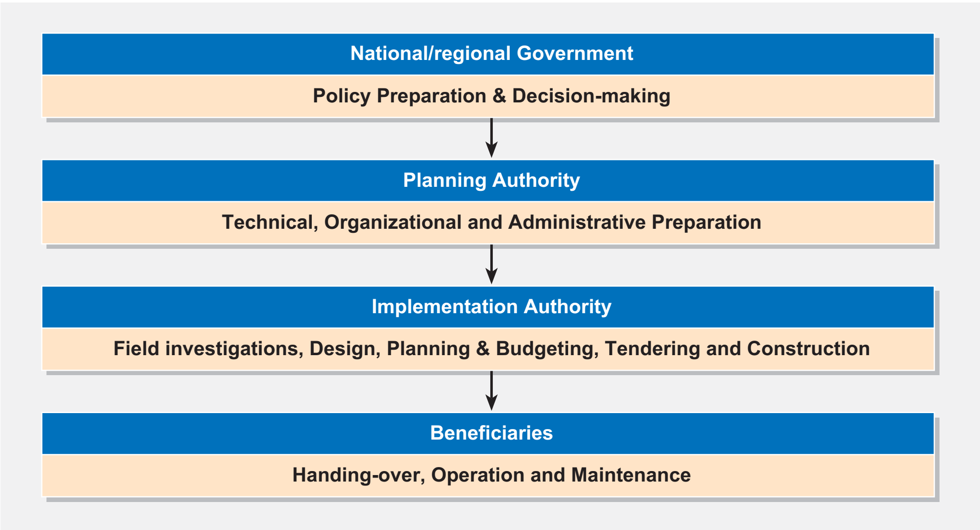


Figure 6 The main steps and responsible organisations in the drainage implementation process

standard policy or national plan and does not need to be involved with each individual project. The planning authority only determines the limits of the projects and the financing, whereas the implementation authority is responsible for the tendering or for giving the order to design and construct the systems. In a country where there is no pipe drainage tradition and no existing "drainage industry" each element of the implementation has to be developed from scratch: information on all aspects of the systems has to be collected and crucial choices about alternative possibilities must be made. If there is a well-developed private sector in a country, the private sector will or may be involved in the development and/or implementation process. Failing this, vital decisions will need to be made as to whether the whole development and implementation process should be carried out and/or developed by and for government entities, or whether the private sector should be invited to participate and if so to what degree. The four main steps of the implementation process are discussed in the following sections.

I.1.2 Step 1: Policy preparation and decision-making

The first step in the implementation process of a drainage system is the request to a government to start the process. The request comes either directly from the future beneficiaries, most times farmers or an organisation representing them, or from the local authorities or in the form of a national or regional plan. The role of the government or an agency is crucial, since drainage usually requires a regional infrastructure that generally affects more than one landowner. Furthermore, governments (pre) finance all or part of the costs, because of the collective nature of drainage and the benefits that often go beyond the direct interest of the landowners involved. Only in rare cases, i.e. in developed West European countries, USA and Canada and on large estate farms for sugarcane or bananas in developing countries, do private landowners implement drainage systems on their own accord. Even then, the government may play a role as regulator of the quantity and quality of the drain water that may be discharged in to a river or lake. At this stage, the role of the government is threefold (Figure 7):

- Collection of basic information;
- Decision-making;
- Specification for follow-up activities.

Collection of basic information

To arrive at a decision to implement a drainage system and to ascertain the necessary financing thereof, the government needs to have information. Most of the information can be obtained from experiences elsewhere in the country or region. If there is no drainage history in the country, information can be gathered through a feasibility study, which in the case of international financing is usually a requirement anyway. A study such as this will logically provide the following information:

- *The effect of drainage*: An insight into the direct and indirect effects of drainage, i.e. physical, social and economical. To estimate the effects of drainage, an inventory is made of the existing conditions and problems, such as: groundwatertable levels, groundwater quality, soil salinity/alkalinity, irrigation water quality, rainfall and present yields. Then, based on this inventory, an assumption can be made of the conditions that can be created once a drainage system has been implemented as well as the yields that can be expected under those conditions.

- *The cost of drainage*: A general estimate of the cost of the systems in relation to the available budgets, the expected subsidies and the financing available from the direct beneficiaries or other sources. The cost of drainage can be estimated by preparing a detailed analysis of the actions required to implement a drainage system and by estimating the cost of each action. If there is no local drainage industry (private or public) an estimate will need to be made of the investments required for equipment and facilities. In the absence of local references for prices and costs, estimates can be based on known international figures.
- *Impacts of the implementation*: These impacts refer to a positive or negative environmental impact affecting the project area and neighbouring areas. These impacts can include: pollution by the effluent necessitating additional capacity or infrastructure to discharge the effluent; need of future subsidies for operation and maintenance; need of sufficient capacity of services for implementation and/or maintenance; and existing regulations. The anticipated increase in yields and thus benefits, the operation and maintenance requirements, the institutional requirements, the supporting/accompanying measures and the cost of all these need to be estimated. Specialised studies are often required to assess the environmental impact of drainage implementation.

Resulting decision
The above-mentioned information helps the government to formulate a policy, which in most cases consists of:

- A decision to proceed (or not) and a formulation of the conditions;
- If government financing is involved, how this will be done, to what extent and to which governmental budget the costs will be allocated;
- Any accompanying measures to be taken, how and by whom.

Specification of following activities
Following a positive decision the next step is the technical, organisational and administrative preparation of the project. The government normally assigns this activity to a national or regional

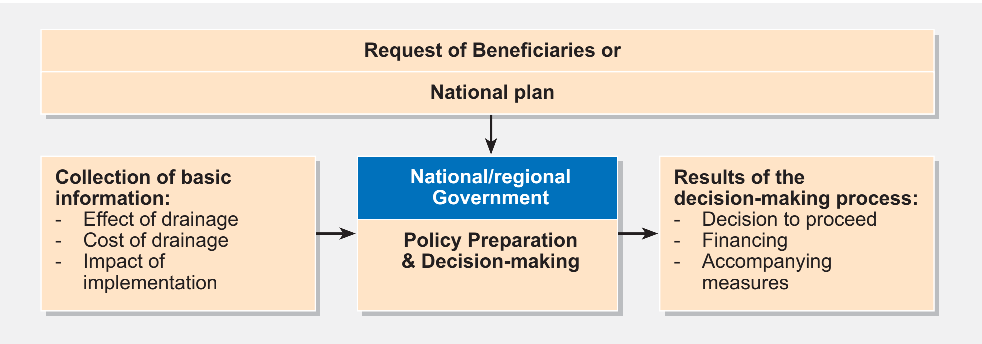


Figure 7 The policy preparation and decision-making process

planning agency or to a special entity. To do this, the required outputs of the project have to be formulated and the preparation activities have to be specified.

I.1.3 Step 2: Technical, organisational and administrative preparation

I.1.3.1 Preparation process

Once the government has given the project the go-ahead and a budget is available, further planning and preparations take place in line with the defined objectives to arrive at a precise and quantified project concept. A specialised entity, here called the Planning Authority, carries out the planning including the procedural, technical and economic preparation. Such an entity is usually part of a ministry, regional government or a special authority within the national government, depending on the internal governmental organisation and the existing experience with the implementation of subsurface pipe drainage systems. The entity responsible for this step may ask for or contract specialised organisations, government departments or companies to carry out part of the tasks.

This step is crucial to making the right choices between the various alternative solutions for the subsurface drainage system, which are not only purely technical in nature but also involve elements of policy, economy, sociology, traditions, assessment of local capacity, the economic relationships in the country, existing privatisation, privatisation policies and existing or desired farmer participation.

Depending on the country's experience with the implementation of drainage, the planning and preparation can be a simple definition of where the desired system will be implemented, the

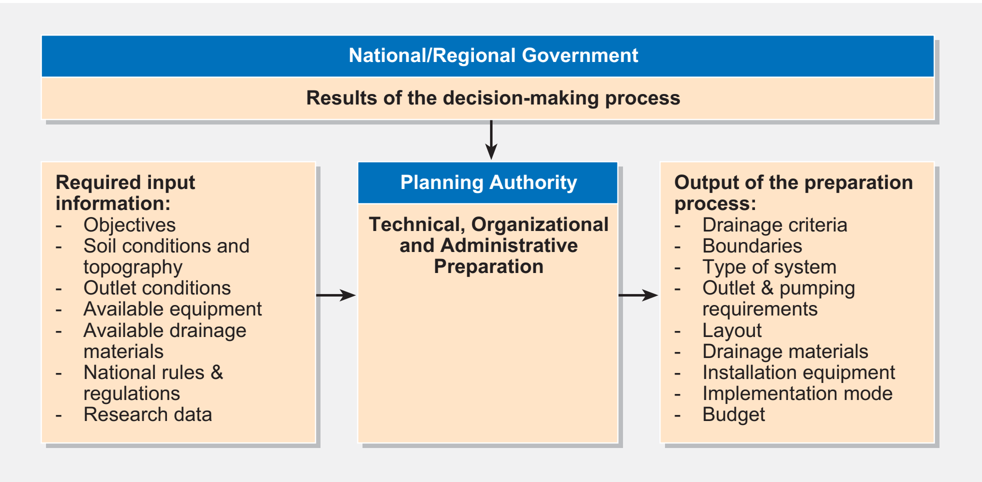


Figure 8 Information requirements and the output of planning and preparation step of the implementation process

budget involved and the authority concerned. If subsurface pipe drainage is new to a country or region, decisions will have to be made on all technical and procedural matters concerning the systems that will be implemented and the methods employed. In exceptional cases the planning can involve experiments, research or pilot areas. The necessary information for taking the appropriate decisions and the resulting output of the planning procedures (Figure 8) are elaborated in the following sections.

I.1.3.2 Required input information

Besides the order to proceed and the budget limitations imposed by the government on the planning and preparation, essential additional information on a number of aspects of the implementation process includes (Figure 8):

- Objectives of the drainage systems;
- Soil conditions and topography;
- Outlet conditions;
- Available equipment;
- Available drainage materials;
- National rules and regulations;
- Research data.

Objectives of the drainage systems
The objectives, such as reclamation of an area, the increase in yield, the reversing of soil deterioration and the control of salinity, have to be well specified because they have a bearing on the system to be installed. The objectives generally accompany the original request to the government or the national/regional plan.

Soil conditions and topography
Existing soil maps and field investigations should preferably be used: detailed soil maps (soil maps: scale 1:50 000 and 1:100 000) with observations to >2 m depth. If these are not available soil information will need to be collected during the field investigations, for instance, in single value maps giving information about soil texture, soil salinity/alkalinity and groundwater fluctuations/groundwater quality (scale between 1: 5 000 and 1: 10 000, the scales normally used to prepare the design of the field drainage system). Information will also be required on the general topography of the area, land use, existing infrastructure, buildings, hydrographical information, etc. (maps scale 1: 50 000 and 1: 100 000). What is important is information about levels preferably with 0.5 m contour lines. If such precise information is not available the areas must be surveyed during the field investigations, in which case contours every 0.2 m are recommended.

Outlet conditions
The outlet conditions for the proposed drainage system(s) must be fully known, including where the drain water can be discharged and to which topographical levels. This will require using hydrographical/topographical data from existing sources, which must be collected if not

available. Hydrographical information should include water levels at outlet and allowable water quality of effluent. The consequences of outlet conditions for the concept of the entire drainage system include:

(i) limits to which a piped drainage system can be applied;
(ii) the required water level of conveyance for open drains;
(iii) whether pumping is necessary;
(iv) where the systems need to be pumped;
(v) possibilities for continuous discharge or whether storage of effluent will be required, and
(vi) feasibility or acceptability of pollution occurring as a result of the drainage effluent (salinity!).

Available equipment

The authority must have knowledge of the available equipment for drain installation together with the capacities and limitations thereof. If there is no specialised equipment available, alternative installation methods must be studied or possibilities to purchase or rent the equipment need to be worked out. Any specialised drainage equipment present in the country needs to be surveyed to ascertain the specifications, location and availability of the equipment. Absence of specialised drainage equipment will necessitate listing of the general specifications of the equipment and investigation of possible sources to purchase, rent or lease equipment. Depending on the mode of implementation, i.e. directly by government entities or by contractors, the future ownership and management of the equipment needs to be determined. This may involve a special feasibility study for the ownership of the equipment, and if it turns out that purchasing the equipment for the project alone is not feasible, subsidies will be needed together with/or guarantees for use in future projects. Installation equipment for subsurface drainage systems is discussed in detail in Chapter I.5.

Available drainage materials

Information about the available drainage materials must be complete, otherwise alternative solutions will need to be worked out. The materials used will influence the design of the systems and the cost and organisation of the construction as well the required installation equipment. An inventory will have to be made of the available materials together with the specifications (pipes, collector pipes, envelope, manholes, sumps, pumps). If no suitable materials are available, general specifications of the materials will have to be drawn up and potential sources to purchase them investigated. A feasibility survey of local production and a survey of potential local producers may have to be carried out. Field trials may be required if there is no knowledge about the suitable envelope materials under the soil conditions in the area and if pre-wrapped envelopes are to be used. Drainage materials are discussed in detail in Chapter I.4.

National rules and regulations

The authority must be well versed with the existing national rules and regulations governing the organisation and infrastructure of rural areas, landownership, cooperatives, water users, pollution control, and the like. This also includes the rules and regulations on financing of the implementation and the participation of beneficiaries. If the private sector is going to be involved it is essential to pay heed to the regulations for contracting to the private sector and tendering when preparing for drainage implementation. National rules and regulations can be obtained from the relevant ministries. If foreign or donor financing is involved the financiers may also have their own individual requirements. International financiers' rules should be included in the financing agreement with the national government, which can be obtained from special publications or web sites. Information about tendering and so forth is given in Part 1 Chapter 2.

Research data

Available research data of drainage pilot projects should be collected. These data will provide valuable information on local specific drainage criteria and suitable technologies for subsurface drainage. To some extent, data collected in pilot areas can also provide a base-line for economic and financial analysis for large scale subsurface drainage development.

I.1.3.3 Output of the preparation process

The output of the technical and administrative preparation process should include specifications on (Figure 8):

- Drainage criteria;
- Boundaries of the areas to be drained;
- Type of system to be installed;
- Outlet and pumping requirements;
- Layout of the system;
- Drainage materials to be used;
- Installation equipment;
- Implementation mode;
- Budget.

Drainage Criteria

Drainage criteria are tailored to the objective of the system. Developing the criteria requires considerable insight into "drainage science" as well as a large amount of basic information including crops to be grown, soil conditions and climate. It calls for professional knowledge from specialised institutes or consultants. In principle, the drainage criteria formulate the depth to which the groundwater level has to be lowered and the capacity of the drainage system, with possible variation over the seasons. If the drainage system has a (temporary) reclamation or rehabilitation function, the compromises for the criteria necessary for reclamation and for the post reclamation period need to be defined. The depth (or level) of the drainage system is calculated from the criterion "depth of groundwater".

Boundaries of the area to be drained

The boundaries of the area to be drained are partly based on the governmental decision (number of hectares to be drained), partly on the present land use, field layout, ownership and existing infrastructure (for instance: no urban area to be included), partly on the soil conditions (certain types of soil can be excluded), and on the topographic conditions (some very low or some very high areas can be excluded). For operation and maintenance purposes it is desirable that the boundaries of drainage and irrigation units coincide, although in practice this is often problematic.

Type of system
The basic information (soil, topography, property and field boundaries and present field layout) and the criteria underpin the choice of the type of system that would be the most suitable (tubewell, mole, open or pipe drainage). The advantages and disadvantages and the requirements of the various systems also need to be carefully taken into consideration when making the decision. In Chapter I.3 layout options for subsurface drainage systems are discussed. Note that in this handbook only pipe drainage systems are discussed!

Outlet and pumping requirement
The location of the outlet in relation to the area to be drained and the (water) level of the outlet location (the drain base) in relation to the level of the fields to be drained, provide an indication of the possibilities for (complete, partial or temporary) gravity flow or the need for pumping. Decision-making requires a fair amount of detailed information on the topography of the area and the hydrograph at the outlet, including levels.

Layout of the system
An early decision has to be made on the layout of the drainage system to be implemented: i.e. singular, composite, extended laterals etc. The layout will also affect the level of the subsurface drainage system. The decision also has to do with whether or not pumping will be required and at what level in the system. Other factors that play a role in this decision are soil type, micro topography, capacity of the installation equipment and available drainage materials. If manholes are needed then a decision needs to be made as to whether they need to be underground or aboveground. In Chapter 1.3 layout options for subsurface drainage systems are discussed.

Drainage materials to be used
The drainage materials needed for field and collector drain pipes, envelopes and structures need to be chosen. As far as *pipes* are concerned (collector and field drain) the choice is based on availability, quality and cost. In countries with no existing drainage industry it might be decided to start local production. This in itself is a project. For *envelopes* the available materials, both gravels and synthetic materials, should be matched with the characteristics of soils to be drained. If there is no experience with the suitability of the envelopes for the soils concerned, trials or pilot areas may be required. For *structures* such as manholes, sumps and connectors and to lesser degree pumps, local materials and designs are preferable. For more information on drainage materials, see Chapter I.4.

Installation Equipment
Selecting the type of installation equipment to be used (mainly trenchers or trenchless drainage machines) depends on the depth of the drainage system, the availability of the equipment, and of course the cost. Manual installation may be considered under a limited number of conditions, (mainly with small scale very shallow drainage systems in an area with a dry season so that installation can be carried out under dry conditions in stable soils). These conditions seldom prevail so in the majority of cases machine installation is technically the only feasible alternative. In countries with no existing drainage industry a decision to purchase the equipment will have to be made. This requires a scenario in which is specified how the equipment is financed, who will

purchase it from where and who will manage it. This in itself is also a project. For more information on drainage equipment, see Chapter I.5.

Implementation mode

Corresponding with rules, regulations and customs in the country, the implementation mode might such that the design and/or the construction is tendered on the private market. If no drainage industry or suitable contractors are available, the government entities might carry out part or all of the design and construction themselves. If international or donor financing is involved, the financiers could affix certain conditions to the financing agreement regarding the implementation mode. Implementation modes are discussed in detail in Chapter I.2.

Budget

A general budget for the implementation must be drawn up as a guideline for the implementation authority, confirming (or not) that the budget allocated by the government is adequate and specifying in broad terms items such as the budget for materials, for design and for installation. How to prepare a budget is discussed in detail in Chapter I.9.

I.1.3.4 Handing-over specifications

Once the planning and preparation has been completed, the next step is for the organisation in charge to request an implementation authority to implement the drainage systems. This request specifies the conditions that are in essence the outcome of the planning and preparation (Box 1.1)

Box 1.1	**Schematised output of planning and preparation**
Objectives	• Implement pipe drainage system in … area of approx …. ha • Create conditions (<*if applicable:* after reclamation>) that: • Groundwater level is maintained at levels of <…>m below field level • Soil salinity at root zone (<…>m) is controlled at a maximum of <…>dS/m
Area	• Total area is <…>ha, area to be drained approx. <…>ha. Location of area (on map) • Define excluded areas because of: too high, too low, built area etc.
Budget	• Total budget for the implementation is <…> <*monetary unit*>
Drainage Criteria	• Groundwater level <…>m below field level during <*month*> to <*month*> • Groundwater level <…>m below field level during <*month*> to <*month*> • Capacity of pipe drainage system <………>mm/day • Capacity of open drainage system to be <………>mm/day of the pipe drainage system plus <…>mm/day of surface runoff
Outlet	• Outlet of the system is located approx.<…………> • Outlet level at outlet location not lower than <……….>m +/- mean sea level • Discharge is (*either/or make choice*): • Fully by gravity • Pumped with approx. <*number*> pumping system(s) located <*near outlet at end of main open drain/ at the end of the secondary open drains/at the end of the piped systems*>
Drainage System	• The piped part of the drainage systems will be (*either/or*): • Singular system with field drains with lengths between approx <…>m and <…>m • Composite systems with field drains with lengths between approx <…>m and <…>m and collector drains with lengths between approx <…>m and <…>m

- Field drain spacing expected to vary between <…>m and <…>m but to be designed on the basis of the detailed field investigations. Standards spacings to be used are <…>m, <…>m, <…>m etc.
- Depth of field drains will vary between <…>m and <…>m below field level but be not deeper than <…>m
- Depth of collector drains varies between <…>m and <…>m below field level but be not deeper than <…>m
- Field drain pipes will be of *PVC/PE* of<…>mm, <….>mm, <…>mm Ø
- Collector drain pipes will be of *PVC/PE* of<…>mm, <….>mm, <…>mm Ø
- Collector drain pipes with Ø larger than <…> mm will be of concrete
- <*Aboveground/Underground*>, manholes <*pre fabricated/prepared in situ*> will be installed:
- At all junctions of field drains with collector drains
- In field drains so that the distance between manholes and/or end of the drain is no more than <*300m*> and or at change of diameter of the field drain
- Connections between field drain sections will be <… … …> the end of the field drain will be blocked by <………..>
- Connections between plastic collector drain sections will be <………>
- Connection between concrete collector sections will be <…>
- Field drains will covered all around by a <*granular envelope, designed for the soil texture*> or <*a pre-enveloped synthetic envelope of …(specifications)*>

Installation

- The piped field drains will be installed with <*trenchers/trenchless machines*> equipped with laser which can install pipes up to <…>mm Ø <*with/without*> envelope at a maximum depth of <….> m
- Piped collector drains will be installed with <*trenchers/trenchless machines*> equipped with laser which can install pipes up to <…>mm Ø at a maximum depth of <…> m
- Collector drains with a Ø of more than <….>mm will be installed <*by excavator/others*>

Field Investigations

- Field investigations will be carried out according to detailed terms of reference by <*make choice*>:
- <*Institute/department*>
- Nominated consultant <*name/to be selected by…*>
- Consultant selected through <*international/national/local/tendering*>

Design

- The design is to be implemented according to detailed terms of reference by <*choose: the same entity as the field investigations/a different entity as the field investigations*>
- <*make choice*>
- <*Institute/department*>
- Nominated consultant <*name/to be selected by…*>
- Consultant selected through <*international/national/local/tendering*>

Contents of design

- The design work shall <*include/not include*> the preparation of detailed specifications including the bill of quantities and <*include or exclude*> a full set of tender documents for <*national/international/local tendering or price comparison*> of the works under <*national/ international*> regulation

Construction

- The construction is to be carried out according to detailed specifications by <*choose*>
- <*Government unit … … …*>
- Nominated contractor <*name/to be selected by…*>
- Contractor selected through <*international/national/local/tendering*>

Supply of *drainage* materials

- The purchase of drainage materials based on detailed specifications shall be <*choose: part of the construction contract/purchased separately from the construction contract*>
- In case of separate purchase:
- The drainage materials shall be purchased through: <*choose*>
- Direct purchase from <*Government unit/supplier … … …*>
- Price comparison of at least <…> suppliers
- Tendering <*international/national/local*>

Supervision of *construction*

- The construction shall be supervised by<*choose*> <*The organisation/consultant that prepared the design*>, or:
- <*Government unit … … …*>
- Nominated consultant <*name/to be selected by…*>
- Consultant selected through <*international/national/local/tendering*>

I.1.4 Step 3: Actual implementation

I.1.4.1 Activities during actual implementation

Once all governmental decisions to proceed with the drainage project have been made and qualitative and quantitative details of the drainage systems have been worked out, the actual implementation process can start guided by the planning and preparation authority (as specified in Box 1.1). A government authority, hereafter called the implementation authority, is responsible for the implementation process. This authority can delegate or contract all the activities to specialised government units or consultants. Depending on the way the national government is organised it could well be that the planning and preparation authority is the same as the implementation authority. Note, that these are two distinct phases:

- Preparation phase, in which all the existing information is collected and analysed, results in principle decisions about the drainage systems and its mode of implementation and;
- Construction phase, in which the actual implementation takes place including the detailed preparation. The implementation process ends once the system is handed over to users or beneficiaries.

The actual implementation process can be divided into four clusters of activities (Figure 9):

- *Field Investigations and Design.* Field investigations and design is a specialised job best carried out by a specialised institute, department or consultancy firm who do this on a routine basis. The input for field investigations is a detailed Terms of Reference with the available basic information about the area. The output of the design is the information that will serve to construct the system, including a detailed bill of quantities for budgeting and tendering together with details for the preparation of specifications, or the specifications itself;
- *Planning and budgeting.* The physical implementation can be planned in detail and budgets can be made available based on the design. The planning and budgeting has to be carried out in close cooperation with the beneficiaries and/or land owners;
- *Tender preparation and tendering*. If construction and/or supervision are to be tendered, a specialised (governmental or private) organisation has to prepare the tender documents, which may involve a separate tender for construction, supervision and/or the procurement of drainage materials;
- *Construction.* The construction of the actual subsurface drainage system starts with handing-over the contractor the authority over the project area and ends with the handing-over of the installed subsurface drainage to the Implementation Authority. It is an activity in which three parties are involved: (i) the contractor(s) or governmental constructions unit; (ii) a supervision team either from the implementation unit or a contracted consultant (often the same consultant as the one responsible for the design and/or tendering procedures); and (iii) the drainage material suppliers.

All these four activities are required to be carried out by specialised unit(s), which may be government units, specialised (government or private) institutes or contracted consultants. These four clusters of activities are discussed in more detail in the following sections.

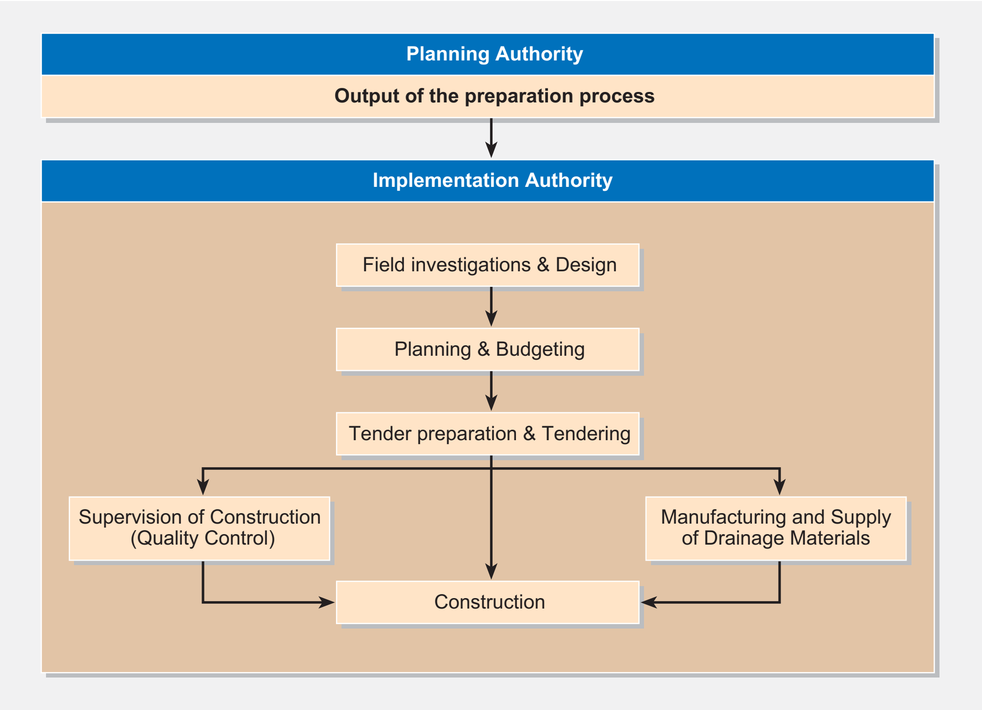


Figure 9 The actual implementation process can be divided into 4 main activities

I.1.4.2 Field investigations

The main purpose of the field investigations is to collect all the relevant information to enable a detailed design to be drawn up. Part of the collected data can also serve as baseline information for monitoring. Directions for field investigations are in the instructions or Terms of Reference stipulating:

- The objective of the drainage system, including the drainage criteria;
- Size and location of the area;
- Available soil, topographical, geological and (geo) hydrological information;
- Additional information to be collected, including the density and accuracy;
- Interpretation and presentation of the results: maps and scales of maps for topography, soil texture, salinity, hydraulic conductivity, drain spacing. Estimate of upward seepage and/or lateral inflow.

The output of the field investigations should include:

- Topographical maps with sufficient information about levels to assist the preparation of the detailed designs;
- Maps or tables with soil texture, soil salinity and hydraulic conductivity. If the information is provided in tables, it must be clear where the points referred to in the tables are located;

- Baseline information (detailed) on groundwater levels/salinity and soil salinity at different depths;
- Recommendations for making provisions for upward seepage and lateral inflow;
- Recommendation for drain spacing and the distribution over the area (presented on maps);
- Recommendations for the necessity and type of drain envelopes.

Detailed instructions or Terms of Reference for the design are derived from the output of the field investigations and the general instructions from the planning and preparation authority (Chapter I.1.3). More details about field investigations and design can be found in the publications discussed in the Bibliography.

I.1.4.3 Design

It is a common practice that the same entity that carries out the field investigations is also responsible for the design. The purpose of this phase is to design a drainage system that can be constructed and to obtain details of the budgetary requirements. The inputs required for the design are also compiled in the instructions/Terms of Reference and should stipulate:

- The general concept of the drainage system as described in the instructions of the planning and preparation authority (as discussed in Chapter I.1.3);
- All information collected and processed during the field investigations, including all detailed topographical maps;
- The drain spacing maps;
- A drainage rate (or a revised rate in case upward seepage/lateral inflow);
- A decision of the Implementation Authority about the type of envelope to use in specific areas;
- Design criteria stating at least the maximum and minimum slopes, length and depth of drainage pipes.

The output of the design should consist of:

- Maps indicating the layout of the drainage system, location of field and/or collector drains;
- Detailed list of each field and collector drain: location, starting-depth, end-depth, slope, diameter(s). These maps should have a scale of 1:5 000, for areas where important structures are to be built, e.g. around the drainage outlet or pumping station, maps at a scale of 1:2 500 may be required;
- Design of connections, manholes and drain outlets;
- Design of granular envelope (if applicable);
- Bill of quantities;
- Specifications.

A detailed cost estimate for the implementation can then be made as well as an estimate of the envisaged construction period and equipment required.

I.1.4.4 Planning and budgeting

After the design phase has been completed the final planning and budgeting can be prepared. Planning and budgeting are processes in which the implementation authority is required to play a key role.

Planning

Planning is based on an analysis of all the activities that must be carried out to implement a subsurface drainage project, whereby estimates are needed of: (i) the time required carrying out each activity; (ii) the interrelationship between the different activities; and (iii) the assignment of each activity to the different parties involved in the implementation process. The estimates can be based on experience obtained in previous projects. If there is no previous local experience, international norms can be applied. The result of planning is an optimal schedule clearly showing when the different activities need to be carried out and by whom.

Process control

Besides a clear allocation of tasks and periods during which these tasks have to be carried out, planning is also a tool for monitoring the progress of the project. The monitoring makes it possible to take corrective actions if the implementation or construction process is not carried out according to schedule (Figure 10).

In countries where drainage is not yet a matter of routine, a database of time requirements for each activity can be built up during the construction from the data collected during progress monitoring. Apart from managerial purposes, these results of progress monitoring can be used

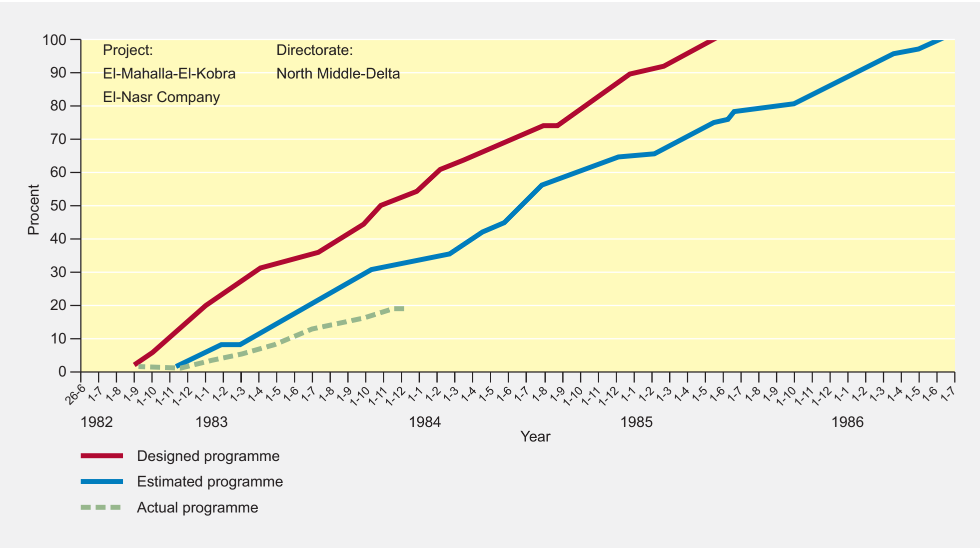


Figure 10 Progress of the actual implementation compared to the estimated and design programme (Example from the execution of a subsurface drainage project in the Nile Delta, Egypt)

to assess whether the original planning schedule was realistic or not. In this manner experience can gradually be built up with the time requirement for the different activities. The methodology for progress monitoring (operational monitoring) of the trencher installation given in Part II-A serves as an example.

Planning tools

A number of tools and techniques are available for the planning of the implementation of drainage systems. The most important ones are:

- Network planning;
- Bar charts.

Network planning

Network planning highlights the activities critical to the total progress of the project and the potential bottlenecks. Essential to network planning is the determining of the so-called "critical path". The critical path identifies the actions that are critical to be completed on time, which if not done will result in an increase of the total time required for completion of the implementation process or the need for additional equipment or staff.

Network planning requires an analytical approach of the whole implementation process in which the interrelationship of each activity is central. The interrelationship focuses on determining: which activity or activities must be completed before a next activity can start; which activity can start once an activity is completed; and which activities can be carried out simultaneously. The steps to be taken for the development of network planning are presented in Figure 11 and discussed in more detail in Part II-A.

In theory, network planning is an almost perfect planning tool. It provides a visualisation of the interrelationship of the various activities and the impact of each activity on the total progress. Network planning, however, is also a dynamic tool that is only functional for progress monitoring if it is rigorously maintained, necessitating the entering of the actual progress of each identified activity into the original planning at regular intervals. Consequently, after each interval a new critical path needs to be calculated resulting in a new expected end date. Based thereon the management can take the necessary corrective actions to assure that the activities of the (new) critical path get adequate attention. For instance, the management can reallocate staff or equipment to make up for lost time or assure that no more delays occur.

For scheduling and progress control, network planning has the following limitations:

- Preparing, maintaining and interpreting a network plan is a specialised job that requires continuous attention of qualified personnel during the progress of a project;
- Network planning is a dynamic tool, meaning that if no detailed progress monitoring is carried out the value of the network planning will be minimal;
- Network planning and progress monitoring with a network planning is labour intensive;
- Cost control is difficult to integrate into network planning.

Thus, generally speaking, network planning is only a suitable tool for very large and complicated projects, although some governments and development banks stipulate the need for network planning for all construction projects.

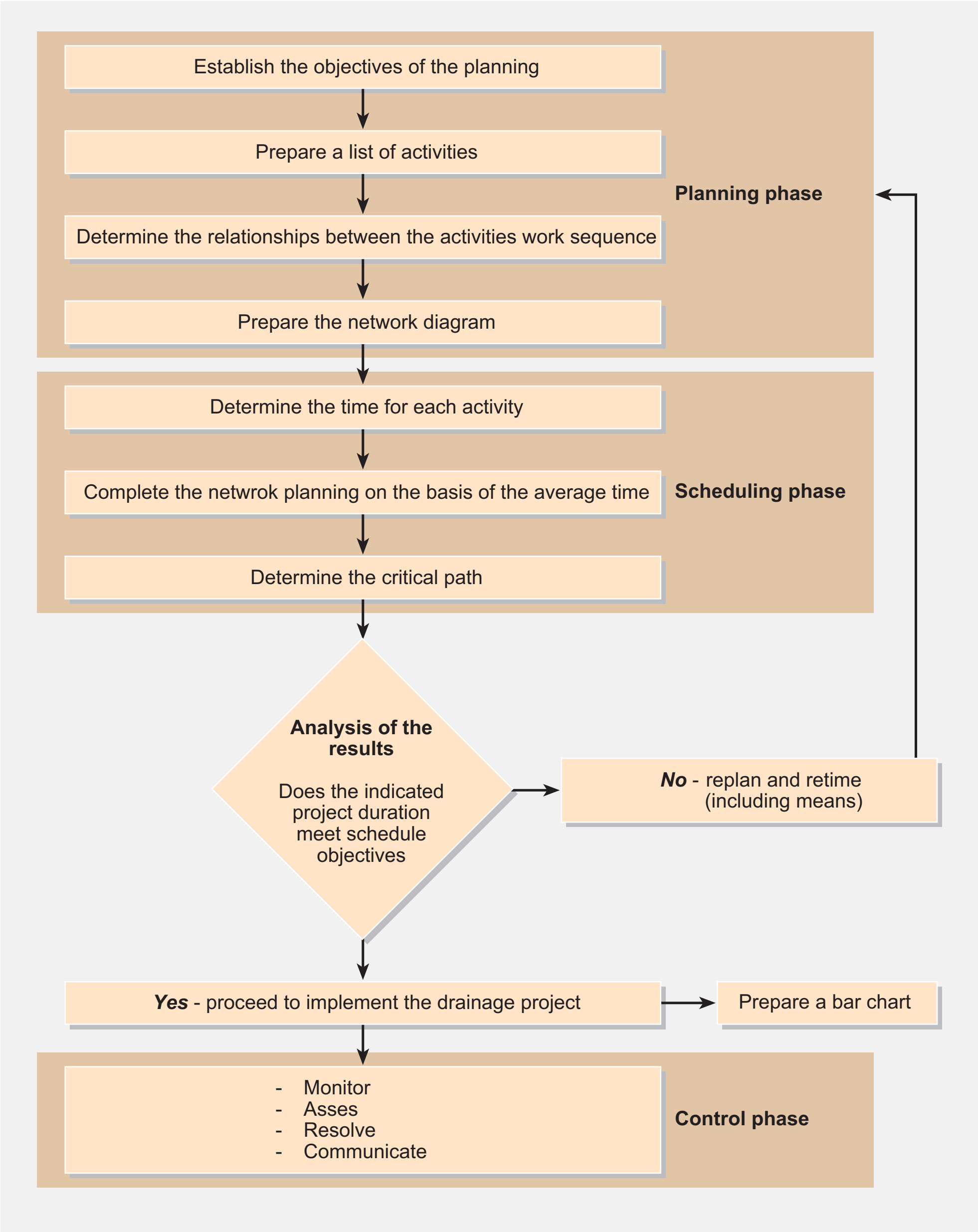


Figure 11 Steps in the planning and scheduling of a drainage project

Bar Chart

A bar chart is a simpler planning tool that visualises the timing and sequence of the various activities. The interrelationship and interdependency of these activities are less explicit compared to network planning. Bar charts are relatively easy to prepare and to update and are the most practical planning and progress control tool for smaller projects. Bar charts can be made by simple standard computer programs such as the bar chart tool of Microsoft projects or Timeline (see also Part II-A).

Planning and progress control are major tasks of project management whatever tool is used. The project's management has to review the progress on a regular basis and take the necessary measures to make corrections and reallocations of machinery or staff. In extreme cases it may need to call in extra staff or machinery either on a permanent or temporary basis. Just who bears the responsibility for which action and who bears the risks and the costs of the adjustments depends on the legal agreement between the different parties involved in the implementation process.

Budget planning

Each activity has its cost and must be paid for (cost calculations are discussed in Chapter I.9). The frequency of payment depends on the contract agreements or the customs of the country. Payments are normally made on a regular (monthly) basis and are either based on the volume of work done or on the completion of specified parts of the contract. If the construction is carried out by government entities, on a so-called *"forced account"* basis, payments are based on the input of the construction units. Determining the activities or percentage of the activities that must be completed at each payment interval is based on the planning. The payment to be made is based on the sum of the quantities of work carried during this period multiplied by the contracted or agreed unit prices. In this way budget planning is drawn up and to assure that the money is available in the right quantities at the right time. Realistic budget planning (disbursement schedule in case of loans) is essential for both governments that have to foot the bills or banks if credits are obtained for the project. Both governments and banks have to be sure that the necessary funds are available. More often than not delays in payments carry penalties, and if available money is not used (disbursed) there is almost always a loss of interest.

Budget control

Budget control has two main objectives:

- To check if the project is constructed within the limitations of the allocated total budget, and;
- To check if the previously planned payment schedule is adhered to. Obviously, budget control must go hand in hand with progress control.

If there are deviations from the planned payment schedule or budgeted amounts the management will need to take the necessary action. The paymasters must be informed that disbursements will take place at other moments to keep "idle" money to the bare minimum. If the payments requirements indicate that the total costs will exceed the budget, contingencies will have to be mobilised if available, or savings made for instance by limiting the scope of the project.

I.1.4.5 Tender preparation and tendering

To prepare tender documents for private (or state) contractors and supervisors, very clear instructions are necessary so that there is no doubt at all as to what is required and what the quality should be. These instructions are similar to the specifications required when government units carry out the construction and/or supervision tasks. Tender documents consist of: (i) the invitation; (ii) instructions for tendering; iii) the required (pre-) qualifications of the contractors; (iv) the contract and contract conditions; (v) the technical specifications; and (vi) the bills of quantities. If the tender procedure includes prequalification, the prequalification documents will also have to be prepared. Tendering involves the following activities: the advertising of the tender, the preparation of the tenders by the interested parties, the evaluation of the tenders and the tender award. A more detailed description of the tender procedure and tender preparation is given in the Chapter I.2.

I.1.4.6 Construction

The construction is a co-production under the overall responsibility of the Implementation Authority between the:

- *Contractor or construction unit.* The task of the contractor or construction unit is to construct the drainage system in accordance with the design and the specifications. Details of the construction are given in Part II of this handbook;
- *Manufacturers/suppliers of drainage materials.* The choice and specifications of drainage materials have already been made in an earlier stage (Chapter I.4);
- *Supervisors (quality control).* The supervisors have to ascertain that the construction (including the drainage materials) is in compliance with the design and specifications. They normally have the power (defined in the conditions of contract) in case of doubt, to stop the work or request corrections or replacement and/or to withhold payment. If there is severe doubt with considerable financial consequences, the supervisors will have to report back to the implementation authorities.

I.1.5 Step 4: Handing-over to beneficiaries and operation & maintenance

Once the construction is completed the system can be handed over to the users, beneficiaries or the organisation that will operate and maintain it. This handing over is mostly a task of the implementation authority. Subsurface drainage systems, of course, require operation and maintenance (Chapter I.8). The operation of subsurface drainage systems is mostly limited to the operation of pumps if pumping is done. In some cases, where controlled drainage is practiced, the operations can also involve opening and closing of gates. Maintenance of subsurface drainage systems consists mainly of removing sediment from the pipes and manholes, repairing and - if necessary - replacing these pipes, manholes and outlets.

I.2 Implementation Modes and Tender Procedures[4]

I.2.1 Implementation modes

I.2.1.1 Implementation process: activities and players

In Chapter I.1 the main activities and players in the implementation process were discussed. The various players such as government entities, consultants and contractors can implement one or more activities (Figure 12). The implementation mode defines which activities are carried out by whom and under what conditions. Basically two modes are possible to carry out activities, i.e.:

- By a (specialized) government entity;
- Contracted to a specialized company.

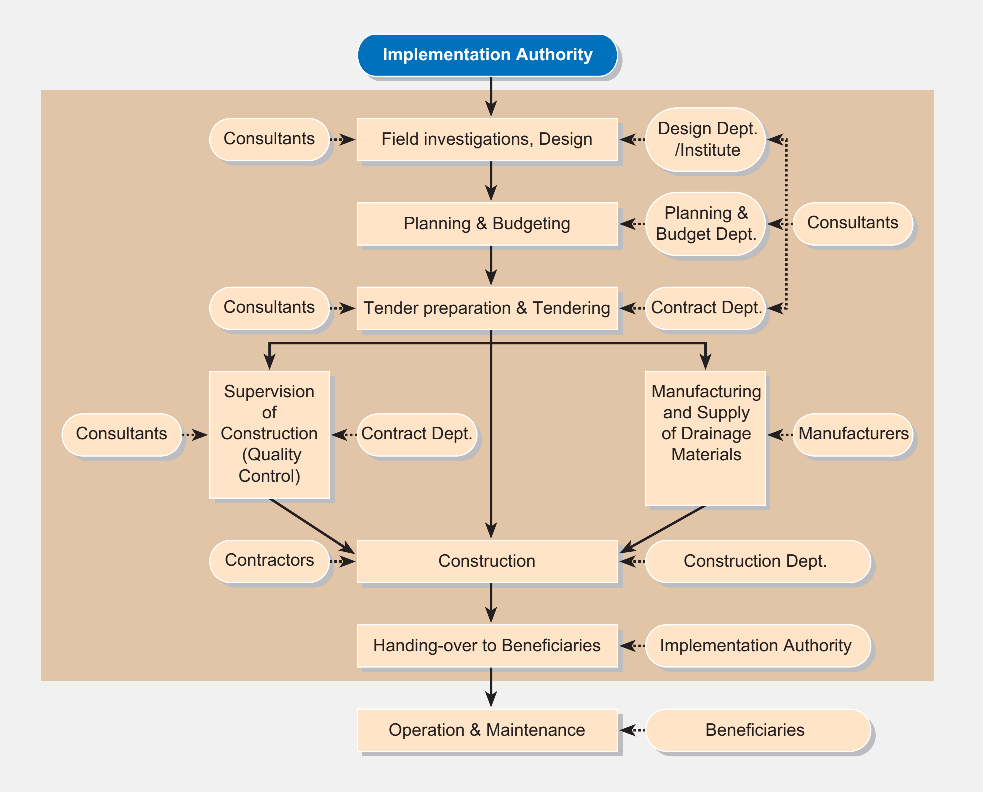


Figure 12 Implementation process: activities and players

[4] The review and upgrading of this chapter by Ir.J.P. Driessen, Senior Contract Engineer, is gratefully acknowledged.

The implementation authority has to decide the implementation mode for each activity of the implementation of the subsurface drainage system (Box 2.1). In many cases the mode is already routinely prescribed by the rules and regulations of the country and/or financers. In countries with a well-developed drainage tradition and drainage industry, contractors and/or consultants usually carry out most if not all of the implementation process. This is especially so in countries where privatisation is well established. If a country has no qualified consultants and/or contractors and/or suppliers of drainage materials, a decision must be made to either fully or partly privatise the development of the drainage technology (i.e. contractors/consultants/material supply) or request special government entities to build up the knowledge and skills and/or purchase the equipment. An alternative is to obtain all the services, equipment and materials on the international market.

Some activities like planning and budgeting and handing-over the completed system to the beneficiaries are purely governmental tasks. However, if a decision is made to contract out an activity, the implementation authority must supervise the contractor. If one or more activities are carried out by government entities, consultants may be engaged to support the entities.

In countries where contracting is common practice, the activities *"Field investigations and Design", "Tender Preparation & Tendering"* and *"Supervision of Construction"* are often grouped into one contract with one consultant. If the *"Construction"* is contracted out to a private contractor, the *"Supply of Drainage Materials"* can either be directly contracted by the implementation authority, or can be part of the *"Construction"* contract.

Box 2.1 Decisions that have to be taken at government level

At the start of the implementation process, the following decisions have to be taken at government level:
- Mode of implementation completely/partly by government entities or completely/partly through contracts;
- How the activities will be contracted and how will the contracted activities be grouped;
- How and in what way will the contracts be supervised;
- If no local drainage industry exists: will the development of drainage technology be privatised or will government entities develop all or part, and if so which part of the technology;
- If government entities require routinely or temporarily support of consultants.

I.2.1.2 Contracting procedures

Every country, ministry or department has their own rules for contracting services, supplies and construction. International financers also have their own procedures. They stipulate in the financing agreement, namely, the agreement between the financier and the Government, whether the national or the financier's procedures are to be used. One of the following contracting procedures can be used:

- International tendering (International Competitive Bidding: ICB). ICB is World Bank terminology. The World Bank uses the terms "bidding" and "bidders", whereas in UK English the terms are "tendering" and "tenderers". The latter is what this book will use;

- National tendering (national (or local) competitive bidding: LCB);
- Price Consultation (Prices have to be asked from a minimum number of contractors/ consultants/suppliers, this can be either locally, national or international);
- Restricted tenders;
- Direct Award.

The method to be used is often specified in the national rules or in the financing agreement, but is also dependent on the estimated value of the contract. Price consultation is often used for small supply contracts, while international or national tendering is the prescribed method for large contracts. Loans or grants from international development banks (World Bank, Inter American Development Bank, Asian Development Bank, African Development Bank) or international donors often stipulate that ICB is to be used for all larger contracts. Each procedure has its advantages and disadvantages (Box 2.2).

Box 2.2 Advantages and disadvantages of the various contracting procedures

- **International Competitive Bidding**: The advantage of ICB is that it may result in an international competitive price setting making available the knowledge and experience developed elsewhere. The disadvantage is that if the national tenderers (contractors/consultants/suppliers) are not very well versed or experienced with the complex tendering procedures, foreign or foreign related companies tend to win the contracts. In this way local knowledge and experience will not be developed. This can be partly overcome by favouring joint ventures between national and international tenderers. Furthermore, ICB tends to be complicated and often scares off smaller contractors who prefer not to/or cannot afford to go through the complicated and costly process with no guarantee of success. Development Banks try to counter the bias in favour of national tenderers by stipulating that in the final price comparison national tenderers are given the advantage of a certain percentage. In that case, the price of the national tenderer is reduced by a percentage before the price is compared with the other international tenderers. If the reduced national tenderer's price turns out to be the lowest the contract will be awarded to him at the real price of his tender. International contractors are seldom interested in smaller contracts since the costs of transport of personnel and equipment and the risks of working in a foreign country usually outweigh the profits.
- **National Tendering**: Similar to ICB with the exception that it avoids the complication and competition of foreign contractors. LCB also tends to scare off smaller contractors.
- **Price consultations**: This is the simplest form of tendering with the least complications. A minimum number (mostly three) of companies/contractors are requested to quote prices and the one who quotes the lowest price is awarded the contract. This system is mostly used for suppliers of materials of which the specifications are well known and generally accepted. The selection process of potential suppliers is inherently biased.
- **Restricted tender**: A restricted tender is a tender where a number of well qualified contractors/consultants /suppliers are requested to prepare a tender for a certain task. This system is biased since the term "well qualified" is not necessarily well defined. The problem can be overcome if a so-called "prequalification" round is carried out. This is a procedure in which interested contractors/consultants are requested to present their professional and financial credentials for rating. Of the contractors/consultants that fulfil the predefined norms, the best are selected (mostly between 5 and 10) and these prequalified tenderers are then requested to present a full tender. The advantages are: (i) that only a limited number of tenders are to be evaluated; (ii) the chance to win the tender increases for the limited number of tenders and; (iii) less money is spend on preparing tenders. Moreover there is an increased likelihood that professional and financially capable contractors/consultants will win the contract.
- **Direct award**: Direct award of contract is when one well-known contractor/consultant is invited to prepare an offer, on the basis of which the contract price is negotiated and the contract is awarded. This system is of course biased in favour of the chosen contracting partner.

I.2.1.3 Engaging Consultants

International or national consultants can be engaged following national procedures or international procedures. The development bank or international donors such as the World Bank (WB) and the European Union (EU) may insist that (International) consultants are engaged to perform the tasks of design, tendering civil engineering construction works and construction supervision. These institutions issue Guidelines for the Procurement of Consultants in which is stipulated that international consultants must fulfil certain prequalification criteria. When invited, the first step for consultants is to submit their pre-qualification papers presenting, among other things, an overview of their expertise and experience, as well as details of their financial strength. Their prequalification papers will be either evaluated by staff of the International Donors or by the Implementation Authority.

Following their qualification the qualified consultants will be invited to submit a Proposal. This Proposal is often based on the submission of two Envelopes.
- One containing the Technical Proposal;
- One containing the Financial Proposal.

In the "Technical Proposal" the consultants will, among other things, describe in detail how they intend to perform the task of implementing the relevant project. The general rule applied when evaluating the proposals is that the financial envelope is left unopened and that first of all the Consultants Technical approach and methodology is evaluated. This is done on the basis of a scoring table so that in the end the Consultants can be ranked in accordance with their capability. Only once this has been done will the financial envelopes of the top 2 or 3 Consultants be opened to select the consultant offering the most economically attractive proposal.

I.2.1.4 Engaging contractors

The procedures for engaging Contractors are different from those to engage Consultants. Contractors can be selected through direct tendering or through tendering amongst earlier prequalified contractors. With prequalification, the likelihood is avoided of engaging an inexperienced contractor that offers a price that in the end may appear to have been too low, resulting in protracted difficulties during the execution of the construction. Prequalification procedures will normally require more time than direct tendering. To avoid this, prequalification procedures can start whilst the design and the preparation of tender documents are taking place. The procedure for tendering construction works is a rather elaborate process and is dealt with in more detail in Chapter I.2.2.2.

I.2.1.5 Tender documents

As discussed earlier most countries have in the course of time developed their own tender documents and procedures. In case there is a need to develop new documents/procedures or if a financing agreement prescribe that international or donor related procedures are to be used, the following information can be useful.

There are basically two distinct sets of "Standard Tender Documents":

- The Standard FIDIC Conditions;
- The Standard Regulations and Conditions as issued by the European Union (EU).

The FIDIC (Federation International des Ingenieurs Conseils or International Federation of Consulting Engineers) is the first international body that has introduced the application of international standards in engaging Contractors way before the existence of the European Union. Consultants and Contractors therefore accept the relevant FIDIC Conditions worldwide, as they are fully conversant with its international application. Using these standard documents is preferable and more secure than developing an entire set of Standard Conditions from scratch. To allow for national regulations, the principles of the national requirements can be stipulated under "conditions of particular application".

The Regulations and Conditions as developed by the EU contain the specific requirements that all Member States of the EU should take into account. The relevant documents have been prepared by legal experts rather than by people experienced in the international construction industry (as is the case with FIDIC). The EU documents therefore differ notably from the FIDIC documents.

The application of either FIDIC or EU documents is as follows:

- The EU documents are applied solely for projects funded by the EU;
- All other International Donors such as: the World Bank, the Asian Development Bank, the African Development Bank, and the Abu Dhabi Fund use the FIDIC documents or documents based thereon.

I.2.1.6 Advantages and disadvantages of tendering

Generally speaking, tendering has the following advantages and disadvantages:

Advantages

- Provides a fair chance to all qualified contractors/consultants to win a contract;
- Theoretically the best price/quality relationship is obtained;
- Introduces competition that in most cases promotes efficient work and innovation;
- Fulfils the conditions of most governments for spending public money;
- Fulfils the conditions of most international donors/financers.

Disadvantages

- Mostly a long procedure;
- Costly both for the tendering organisation and the tenderers. The cost made by the tenderers will be recuperated in their contract price;
- Does not necessarily result in the best contractor getting the award, especially if price is the main selection criterion;
- In most cases biased against smaller and starting contractors;

- Can result, especially if rules are not well defined or strictly applied, in lengthy procedures before a contract is signed. However, experience in countries where the FIDIC contracts were introduced has shown that after an initial period of adjustments by all parties, the number of claims and the time required to settle claims were considerably reduced;
- Changes in the design can only be made to a limited extent.

I.2.2 Tender procedures

Tendering activities to consultants/contractors can be broken down into a number of steps (Figure 13). The tender procedure can be a direct tendering or a procedure with prequalification of consultants/contractors. The management of the tender procedures is directly or indirectly carried out under the responsibility of a (governmental) contracting department. They can carry out the task themselves or they can nominate either a consultant or a tender committee. This committee can include hired professionals (consultants) that mostly act as advisers or the consultants can be asked to carry out and take full responsibility for the task.

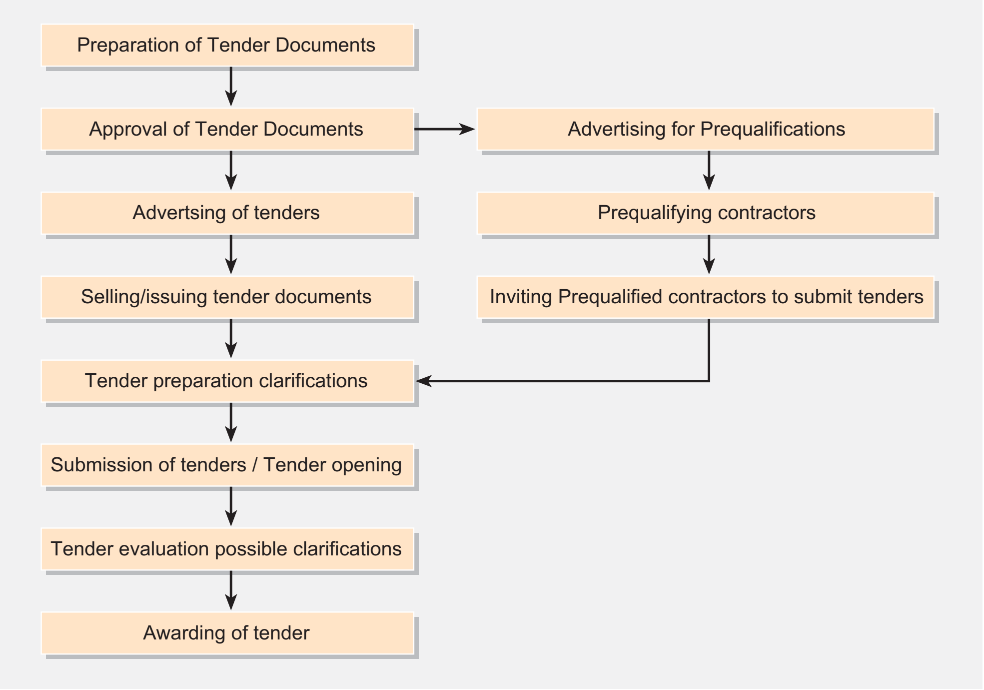


Figure 13 Activities of a tender procedure

To make the reader aware of the possibilities and complications of tender procedures, the steps are described in the following sections. Where relevant, references are given to publications that provide detailed information or can serve as models.

I.2.2.1 Preparation of tender documents

Preparation of tender documents is chiefly the task of the implementing authority. It is quite a complicated process especially for international tenders and mistakes can have costly consequences. Therefore, it is a professional job requiring specialists (quality surveyors) who are in regular employment or specially contracted. Model contracts can be used for the preparation. A widely accepted model is the standard Conditions of Contract for Works of Civil Engineering Construction (the so-called Red Book) prepared for international tendering by FIDIC. Although there are possible variations, an outline of the contents of tender documents is given in Box 2.3. Tender documents are meant to be clear and unambiguous and should provide all the requisite contractual and technical information necessary to prepare a "responsive" tender designed to carry out a quality job. Model tender documents such as the FIDIC documents are designed to be open and transparent to avoid conflicts, and to be fair towards all parties. Going into further details about contract preparation is beyond the scope of this handbook. FIDIC publications are very useful examples. Chapter I.2.2.6 contains some titles and addresses of organisations and development banks that publish model contract documents and instructions for the preparation of documents.

Box 2.3 Contents of FIDIC-based tender documents

- **Invitation to tender**. Description of who issues the tender, who finances the project, the nature and the volume of the activities/works is, time frame of the activities/works, general qualification of the tender, where, when and at what cost documents can be purchased, when and where the tender is due (the invitation gives in more detail the information provided in advertisements).
- **Instructions to tenderers**. This part contains an instruction to the tenderers and includes: who issues the tenders, the minimum qualifications of tenderers, how to prepare the tender documents including the qualifications of the tenderer, the rules and regulations of the tender procedures, the value of the tender bond, how, when and where the tender has to be submitted, the required validity of the tender, how the tender will be opened and how the tenders will be evaluated and awarded.
- **Forms of tender**. Letter to the implementation authority in which the tenderer commits himself in writing to perform the task according to the specifications for a certain amount. Tender bond (bid bond) in which the tenderer authorises his bank to pay the implementation authority a prescribed amount if he does not sign the contract in case the tender is awarded to him. In this way the companies submitting a tender guarantee that they will sign the contract if the contract is awarded to them. If they refuse or cannot sign they forfeit the tender bond and thus have to pay a penalty through this bond.
- **Qualification information of the tenderer (optional)**. Section in which the tenderer is asked for information about his company, its technical proficiency, its financial capacity his work record etc. This section is not necessary in the case of a direct tendering or prequalification.
- **Standard form of agreement**. Model of contract that has to be signed once the tender is awarded. Contract forms are rather standard, (general conditions) and have a section for "conditions of particular applications".
- **Conditions of particular application**. Section discussing the specific items valid for the contract for which the tender is issued. Most of the items have a direct reference to a section of the contract.
- **Bill of quantities**. For physical works: A detailed list of each item of the works to be carried out, the quantities, the unit costs and the total cost. The bill of quantities is used by the issuing organisation to estimate the cost of the works; the contractor uses this for preparing the cost of his offer. An example is given in Chapter I.9, Table 9.6.
- **Standard form of performance bond**. Model of performance bond that the bank of the tenderer will have to issue once the contract is awarded. The value of this bond (5-10% of the contract cost) is a guarantee that the tenderer will carry out the works as described within the time etc. In case of failure the implementation authority can request payment of the money by the bank.
- **Technical specifications**. Detailed specifications concerning all the part of the works to be carried out including the test to be performed to guarantee the quality. In case of studies, designs etc. the technical specifications are called the "Terms of Reference".

I.2.2.2 Direct tendering or prequalification?

If a decision is made to tender one or more of the task in the implementation process, a follow-up decision is to be made as to: whether the tender procedures will be direct or whether there is to be a prequalification.

Direct tendering
Direct tendering is usually a fast process. The tender is published in newspapers or magazines and interested tenderers can buy the tender documents. The charges for tender documents compensate for the production costs of the tender documents and are meant to attract only serious tenderers. If there is much interest in the tender the chances are that a large number of companies will prepare a tender. This can also be a disadvantage.
Part of the information requested in the tender documents will form a basis for determining whether the tenderer is qualified. This information focuses on the legal, professional and financial capabilities of the contractor based on which a tenderer can be qualified or disqualified. Contactors incur much expense and put a lot of effort into preparing a tender even though the chances are limited in view of the large number of tenderers. If a tenderer is disqualified all his efforts will be wasted. The cost of tender preparation will directly or indirectly always be incorporated into the final contract price. The tender evaluation in this case can also be a lengthy procedure.

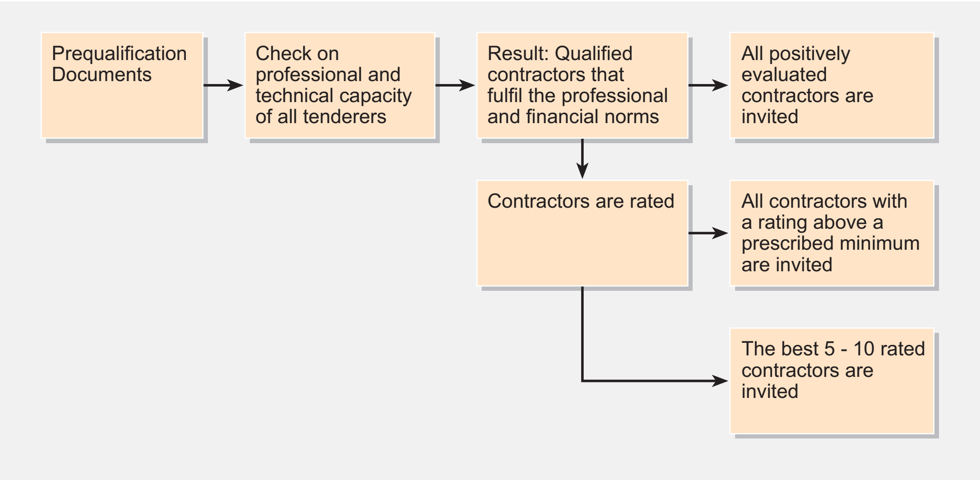


Figure 14 Schematic overview of the tender procedure with prequalification

Tendering with prequalification
The prequalification is published and interested tenderers provide the requisite information about their experience, financial and professional capacity. The prequalification applications are then evaluated to determine whether the tenderers are financially and professionally qualified to carry

out the tender (Figure 14). The selection of the contractors that are invited to prepare tenders can be done according to one of the following methods:

- Qualified contractors are invited to prepare a tender;
- The qualified contractors are rated from best to worst. (Mostly with a scoring system), and subsequently;
  - Contractors with more than a predefined number of points are then invited to prepare a tender;
  - Only the best contractors (mostly 5-10) are "short listed" and invited to prepare a tender. Both consultants and contractors prefer this system so that they do not have to go through the costly business of tender preparation with limited chances.

I.2.2.3 Advertising of tenders

Tenders are published in newspapers magazines or professional publications according to national or international rules and regulations. The text of the advertisement gives an indication of:

- The nature and the volume of the work to be carried out;
- Location of the work;
- Implementation authority (principle) and, if relevant, financer of the project;
- Timing of work;
- Summary of qualification of tenderers;
- Tender date, time and precise location of tender submission;
- Where and when to obtain tender documents and costs.

The advertisement for prequalification procedures should contain similar information. Many international financers prescribe the formulation of part of the advertising text.

I.2.2.4 Selling/issuing tender documents

A record of persons to whom documenters are sold is to be kept. Only the tenders of companies who are recorded as having bought the tender documents are accepted. For international tenders it is not unusual that tenders are sold at different locations (for instance at the office of the implementing authority and at the offices of the consultants or at major embassies).

I.2.2.5 Tender preparation by tenderers

Tender preparation is the task of the contractor. If there are aspects of the tender that are not clear, tenderers can ask for clarification in writing. The contracting department will answer the questions in writing, but to be fair to other tenderers, they will also copy the questions and answers to the other tenderers.

The preparation can include a visit to the site, either organised for all tenderers, including an explanation by the implementing authority, or individual visits by the tenderers to study the area. In case of an organised site visit, a report that records all the issues discussed and answers given is to be sent to all tenderers and will form part of the contract documents. In the case of individual visits, a register of the visits will normally be kept and/or certificates of the visits issued to the tenderers. If tenderers consider that there is not enough time for tender preparation, they may ask for an extension of the time limit. This can be granted or refused (normally if 3 or more tenderers ask for an extension, the extension is granted). The information about the extension of time is then sent to all tenderers.

I.2.2.6 Tender submission

The tenders are to be submitted at a pre indicated time (not later than…..) and a pre-indicated place. Directly after the time is passed the tenders are opened publicly. A list of the timely submitted tenders (name and address of company) and the main characteristics of the tenders (cost) is publicly read. The minutes of the public opening of tenders have a legal status and must be signed by the "tender committee" (and often those present at the tender opening) in order to maintain an official record of the tender opening proceedings. These minutes will serve as documentary evidence in case of legal challenges.

I.2.2.7 Tender evaluation

The "tender committee" may evaluate the tenders or engage consultants to do this. The objective of the evaluation is to select the most responsive tender, meaning the best quality at a reasonable price. During the evaluation the evaluators check whether the:

- Tenders are complete;
- Tenderers qualify (fulfil the norms);
- Tender is technically sound and fulfils the norms;
- Cost calculation is correct (the cost calculation can be corrected for arithmetic errors during the evaluation).

The rules and regulations for evaluation are all prescribed in the tender documents. In some cases the tender committee can ask the tenderer for clarification. These are to be securely documented because they are part of the potential contract. The tenderers are not allowed to make changes after opening their offer, or give clarifications on their own initiative. If they do so, they break the rules and this is reason for disqualification. The contract is eventually awarded to the tenderer who is qualified, has made a technically sound offer and has the lowest evaluated price. Generally, in public tendering procedures the price as given in the tender is the final contract price, which means that there will be no more price negotiations once the tenders have been submitted.

I.2.2.8 Background information

A considerable amount of literature, guidelines, handbooks and the like are available on tendering and tendering procedures. As mentioned before most countries have their own customs and regulations that may or may not conform to the generally applicable internationally accepted rules and regulations. International banks and donors have often their own rules, which in most cases are very similar to the internationally accepted rules. The fore-mentioned FIDIC systems of contracting and tendering are still the most widely used. The publication Construction Contract (1999) is the most important one. A prevision edition "Construction of Civil Works" can be informative. For smaller contracts, the publication "short form of contract" can be useful. A model Services Agreement is available for contracts for services (consultants). Provision of a detailed guideline for tendering and preparation of tender documents is not the objective of this handbook. For more detailed (practical) information and guidelines reference is made to the literature below. This selection should not be considered to be complete but provides a guide for further study.

FIDIC
(Federation International des Ingenieurs Conseils or International Federation of Consulting Engineers)
Address: P.O. Box 86, 1000 Lausanne 12 - Chailly, Switzerland. Website: http:/www/FIDIC.org, email: *fidic.pub@pobox.com*
Documents:
- Tendering Procedure. Procedure for obtaining and evaluating tenders for civil engineering contracts;
- Conditions of Contract for Works of Civil Engineering and Construction (the Red Book);
- Conditions of Contract for Electrical and Mechanical Works (the Yellow Book);
- Conditions of Contract for Design - Build and Turnkey (the Orange Book).

World Bank
Address: 1818 H Street N.W. Washington DC-20433 USA.
The World Bank has introduced its own set of Standard Documents. These are generally based on the FIDIC Standard Documents. The relevant WB documents are:
- Sample Bidding Documents. Procurement of Works;
- Sample Bidding Documents. Procurement of Small Works;
- Sample Bidding Documents. Procurement of Goods (also adopted by the Asian Development Bank and the Inter-American Development Bank);
- Standard Prequalification Documents. Procurement of Works. Major Equipment and Industrial Installations.

For ordering publications: P.O. Box 960, Herndon VA 20172-960 USA Fax: 001 7636611501 or by e-mail: *books@worldbank.org*

Asian Development Bank
Address: P.O. Box 789, 0980 Manila, Philippines, email: *adbhq@mail.asiandevbank.org*
Documents:
- Guide to Prequalification of Civil Works Contractors.

European Union
Address: Rue de la Loi 200, B-1049 Bruxelles, Belgium.
Documents:

- Information Note. How to participate in contracts financed by the European Economic Community in the Developing Countries;
- General Conditions for Works Contracts financed by the European Development Fund;
- General Conditions for Supply Contracts financed by the European Development Fund;
- General Conditions for Service Contracts financed by the European Development Fund;
- General Provisions. Contracts for the Supervision of Works.

I.3 Layout Options for Subsurface Drainage Systems

I.3.1 Layout considerations during the various steps of the implementation process

Although the detailed layout of the field drainage system will only be designed during step 3 of the implementation process (*Actual implementation - Field investigation and design* (Chapter I.1.4)), the selection of the general layout of the field drainage system must already be made during the planning (Step 2 Technical preparation), often as part of the feasibility study (Box 3.1).

Box 3.1 Choice of the layout of the field drainage system: decisions to be made during the planning phase of the implementation process

Considerations that play an important part in the decision-making process are:
- Configuration of existing infrastructure;
- Farming practices (mechanisation now or in the future);
- Slope of the area;
- Water levels at discharge point;
- Available drainage materials;
- Available installation equipment;
- If pumping is required: the place in the system where pumping will be done, i.e. at field level, at the discharge point or in between;
- Initial investments.

Early selection is necessary because the general layout affects the drainage materials needed, additional infrastructure, pumping and the initial investments, as well as the configuration and required water depth of the open drainage system to which the subsurface drainage systems will eventually discharge. The choice is likely to be automatic in countries with a well-developed drainage tradition and/or industry, however, if a country has no drainage tradition this could require considerable effort.
This chapter discusses the different layouts of subsurface drainage systems and the consequences of the selection of a particular layout. A general description of the alternative layouts was already presented in the preamble.

I.3.2 Elements of a drainage system

A drainage system consists of the following elements (Figure 15):
- *Field drains.* Field drains (in this handbook we only consider subsurface pipe drains) control the watertable and collect the excess water in the soil or from the groundwater and convey this drainage effluent towards the collector drain;
- *Collector drains.* Collector drains can be either open or piped. Open drains convey rain and groundwater towards the main drainage system and piped collectors only convey the drainage water from the field drains towards the main drainage system;
- *Sub main and main drains.* The main drainage system, which consist of several sub mains (if applicable) and a main drain, conveys the drainage water from the collectors towards

the discharge site. Main drains are normally open drains, although theoretically these main drains can be pipes, the required diameters are generally very large and therefore prohibitively expensive;

- *Discharge site.* The discharge site or outlet is the terminal point of the entire drainage system from where the discharging is done into a river, lake or sea. The outlet can be a gravity outlet structure or a pumping station. A gravity outlet structure is a drainage structure in an area with variable outer water levels where drainage can take place by gravity when outside water levels are low. In delta areas, drainage by gravity is often restricted to a few hours per day during low tide. In the upstream regions of a river, drainage by gravity can be restricted for several weeks during periods of high river discharges. A pumping station will be needed in areas where the required water levels in the drainage system are lower than the water level of the river, lake or sea.

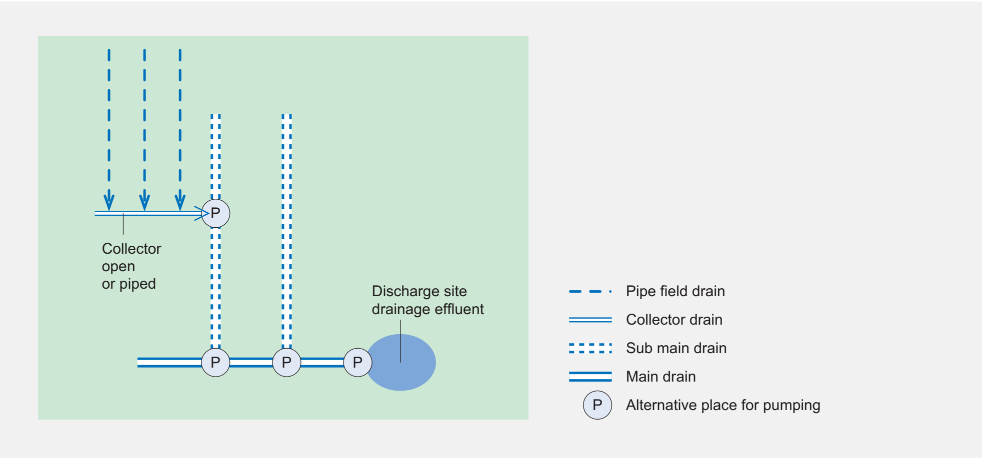


Figure 15 Elements of a drainage system

I.3.3 Considerations for the selection of a layout

Considerations for the selection of a layout are as follows:

- *Matching of layout of (subsurface drainage) with irrigation and road layout.* For new (reclamation) areas without existing agricultural development the layout of the drainage system has to match with the designed layout of irrigation, roads and possibly electrification. It is the most practical to design the irrigation, drainage and road systems at the same time, even if the drainage system is to be constructed at a later date;
- *The layout has to "fit" into the layout of the existing infrastructure.* In areas with an existing agricultural infrastructure, the configuration of the subsurface drainage system and accompanying open drainage system has to "fit" into the configuration of the existing fields in terms of lengths, direction of slope etc. (field drain length is approximately the same as field lengths). This will limit "damage" during the construction and thus additional costs to the existing infrastructure;

- *The level of the outlet of the subsurface drainage system* (determined by the drain depth, lengths and slopes) has to be at or above the highest water level in the main drain system. Depending on the natural slope of the area, the longer the subsurface system the greater the difference between the highest and the lowest point of the system and, normally, the lower the water level at the outlet needs to be. The minimum slope of piped drains is steeper than the minimum slope of open drains;
- *Pumping of the system.* In most cases (drainage is mainly necessary in relatively flat areas) pumping will be required somewhere in the system. If so, the location of the pump or the pumps will have a considerable influence on the layout, design and cost of the system. Alternative options are elaborated in the next section;
- *Available drainage materials.* In countries with a well-developed drainage industry, most of the drainage materials (field drain pipes in various diameters, collector pipes in various diameters, envelopes etc.) are readily available. The cost of the materials is chiefly related to well-balanced market prices. In countries where the drainage industry is not yet (fully) developed, available materials are either limited or the production of drainage materials has still to be set up. These limitations have to be taken into account and if the production has to be set up, each additional pipe diameter that will need to be produced will result in (considerable) additional investments;
- *Installation equipment.* The choice of layout is directly related to the depth of installation. The desired depth of the drains is determined by the drainage criteria, while the actual installation depth is determined by the drainage criteria and the slopes required in the system. The depth to which the installation equipment can install drains is limited so this must be taken into account when choosing the layout;
- *Subsoil conditions.* Unstable subsoils (in extreme cases quicksand) can limit the installation. Under these conditions installation is possible in most cases if plastic drain pipes are used. The installation, however, requires special techniques and skills, also for the installation of manholes and pipe connections. The installation of concrete collectors requires the use of special, expensive, techniques like vertical or horizontal well pointing systems.

I.3.4 Pumping

Most drainage systems require pumping somewhere in the system (Figure 15), especially in relatively flat areas. When pumping is required a crucial decision has to be made as to where in the system the pumping is to be done. This choice has its repercussions on the drainage layout, drainage materials, operation of the system and the total infrastructure of the area. The water level in an open drain or river determines the reference level for discharge; the bottom level of the drain is not relevant. Theoretically, one can pump at the end of each field drain and lift the drainage effluent above the water level of the open collector drain. At the other extreme one can pump at the outlet point of the total drainage system at the location where the system discharges the drain effluent into an evaporation pond, river, lake or sea. Locating the pumps farther away from the field drains and closer to the discharge site will result in a decreasing number of pumping points and an increase in the required capacity of the pumps.

Considerations in the choice of the location of the pumps are:

- *The relative cost of pumps and pumping stations.* Large pumping stations require elaborate civil engineering works and can therefore be a very costly. The cost of the pumps and engines is often a minor part of the cost of the whole pumping station. Small underwater pumps with automatic switch on/off functions are produced in series. These pumps are cheap and require very little and simple civil engineering works like sumps. The total cost of a great number of very small pumping stations is to be compared with the total cost of one or a few larger stations (including power supply, structures and operation & maintenance costs);
- *Power supply.* If electricity (of acceptable quality and continuity) is available, a cost comparison should be made between the possibilities to supply a large number of small pumps or a limited number of larger stations (or one) (including the cost of transformers!). If no electricity is available and diesel power is required, the stations become more complicated to build and operate. This often limits the choice to only a few (or one) larger pumping stations. The costs of road construction for supplying diesel to the stations must be included in the comparison;
- *Operational complications.* Small automatic pumping stations require very little attention, certainly no pump houses, guard houses etc. Larger stations and especially the diesel driven stations require virtually continuous attendance with all the added facilities. Small stations serve a limited area and can provide tailor-made water level control for that area. Large stations that serve a large area can only realise an average water level control for the whole area;
- *Water level in and depth of open drainage system.* Pump stations can discharge at any required level at practically the same cost. This means that if pumping is practiced, the water level in the open drainage system, or disposal area into which the system discharges, can be very close to field level. If there are a large number of small pumping stations the open drainage system can be shallow resulting in less construction and maintenance costs. Shallow open drains are especially advantageous in areas with unstable subsoils. If pumping is done at the downstream end of the system with one large pumping station, open drains will have to be constructed and maintained at considerable depths (especially in salinity control areas) of often up to 3-4 meters. These deep drains require an expensive complicated maintenance system (especially in areas with unstable subsoils).

I.3.5 Layout options of subsurface field drainage systems

I.3.5.1 Singular drainage system

Description of a singular drainage system

A singular system consists of field drains that discharge directly by gravity into an open collector drain. There are two variants of the singular systems (Figure 16):

- The one-sided singular system (in areas with a slope);
- The two-sided singular system (in flat areas).

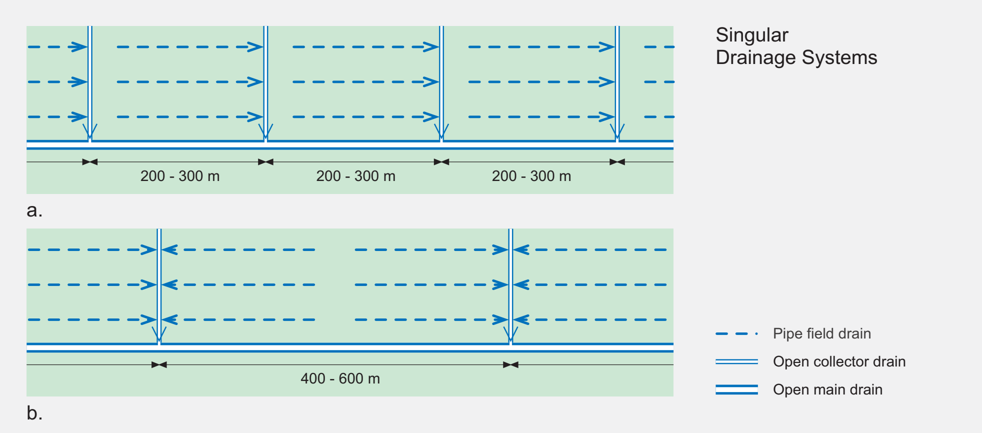


Figure 16 Singular drainage systems: one-sided (a) and two-sided (b) field drains

The length of the field drain is 300 m at the most, being the maximum length of cleaning devices. Field drains need to slope towards the open collector drain. The water level in the open collector drain has to be below the outlet level of the lowest drain. If pumping is required this can only be done from the open collector drain in the main drainage system. The difference in level between the desired drain depth (at the upstream end of the field drains) and the end of the subsurface system (the outlet) is between 0.15 and 0.20 m in flat areas with 300 m of drain pipes (Figure 17).

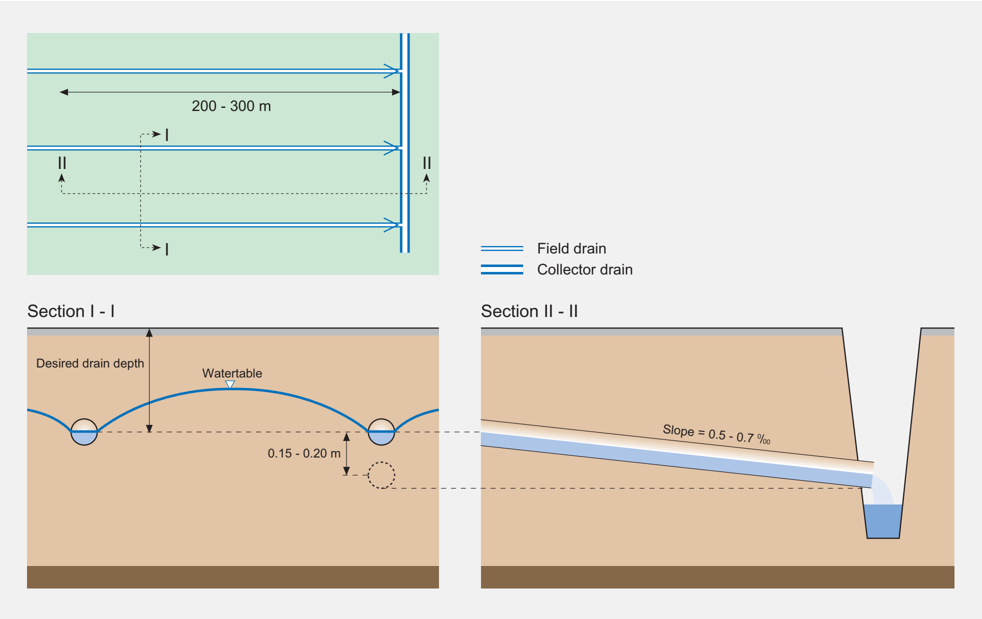


Figure 17 Relation between the desired minimum drain depth and the acceptable water level at the outlet of a field drain

Advantages of a singular drainage system

- Singular systems are simple to design and to install. The levels of the field drains do not have to be related to each other as long as the outlet of each field drain is above the highest water level in the open collector drain and the drains are within the prescribed depth range;
- Generally speaking, only one diameter of drain pipe is required;
- Once installed the functioning of singular systems is simple to check by visual observation at the outlet;
- Cleaning of the pipes is relatively easy and can be done directly from the outlet;
- Little level difference between the end of the field drain and the water level of the open system (only the slope requirement of the field drain).

Disadvantages of a singular drainage system

- Open collector drains spaced at every 300 or 600 m at the maximum require (expensive) crossings (culverts/bridges) and are an obstruction for mechanised farming even if there are crossings;
- Higher maintenance costs. Maintenance of open collector drains is often more expensive than maintenance of piped collector drains;
- Multitude of outlets, one per field drain. These outlets are susceptible to damage especially during maintenance of open drains.

I.3.5.2 Composite drainage system

Description of a composite drainage system

A composite system consists of field drains that discharge into a piped collector drain (Figure 18). Like the singular systems, there are two variants of the composite system:

- The one-sided composite system (in areas with a slope);
- The two-sided composite system (in flat areas).

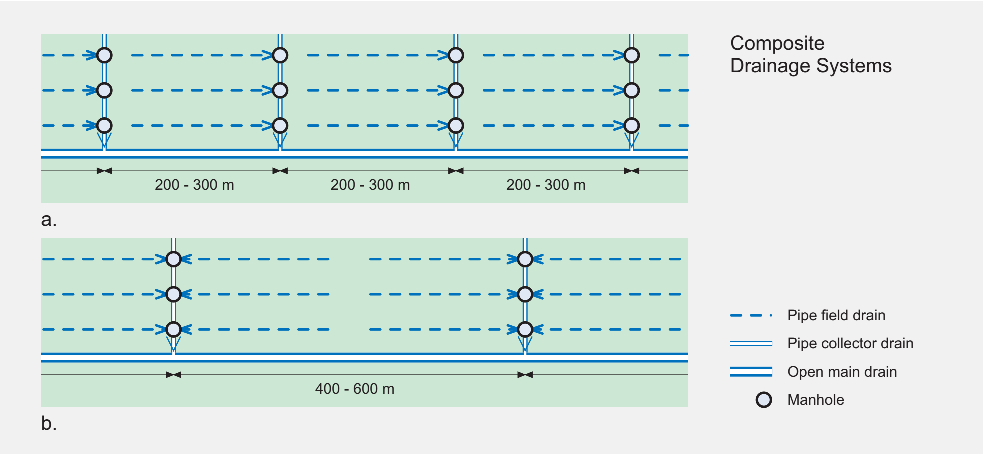


Figure 18 Composite drainage: (a) one-sided and (b) two-sided systems

A device is required at the junction of the field drain and the collector drain so that the field drains can be cleaned, this is normally a manhole. The length of the field drain is approximately 300 m at the most (the maximum length of cleaning devices). For hydraulic reasons a minimum slope is needed in both the field drains and the piped collector drain of 0.7-0.5 ‰. This result in considerable level differences, for example the level difference between the upstream end of the field drain and the outlet of the collector would vary between 0.90 and 0.65 m for field drains with a length of 300 m and a collector that is 1000 m long. To this must be added the desired drain depth to determine the acceptable highest water level in the open main drain at the discharge point (for flat areas). If the water level in the main drain is too high, a (small sump) pump can be placed at the end of the collector system. This pump can then discharge into a shallow open main drain system. Alternatively the open drain can be pumped to obtain an acceptable water level (Figure 15).

Advantages of a composite drainage system

- Composite systems require a lower density of open drains and consequently fewer crossings. The system forms only a limited or no obstruction to agricultural activities;
- Maintenance of a composite system is in most cases simpler and cheaper, because there is less length of open drain per area unit;
- If pumping is required this can be done cheaply and simply at the discharge point of the collector system;
- There is only one outlet per system.

Disadvantages of a composite drainage system

- During the design and construction phase the levels of field and collector drains have to match up well;
- Checking the functioning of composite systems is more complicated than checking singular systems;
- Maintenance (flushing) of the field drains requires special devices so that the flusher can enter into the field drain;
- The outlet of the system is deeper than the outlets of a singular system because of the slope requirement for the piped collector;
- Different pipe diameters are needed for both field drain pipes (mostly of one diameter) and collector pipes;
- Field and collector pipes cannot always be installed using the same installation equipment for all cases;
- Checking the functioning of each field drain is complicated.

I.3.5.3 Extended field drain system

Description of an extended field drain system

Extended field drain (lateral) systems are a variant of the singular and composite systems described above. The basic difference is that the field drains are much longer (up to some 1000 m) than the field drains of the systems described above that are approximately 300 m at the maximum. The following variants of extended field drain systems are possible (Figure 19):

- Extended field drain singular one-sided;
- Extended field drain singular two-sided (not shown);
- Extended field drain composite one-sided;
- Extended field drain composite two-sided (not shown).

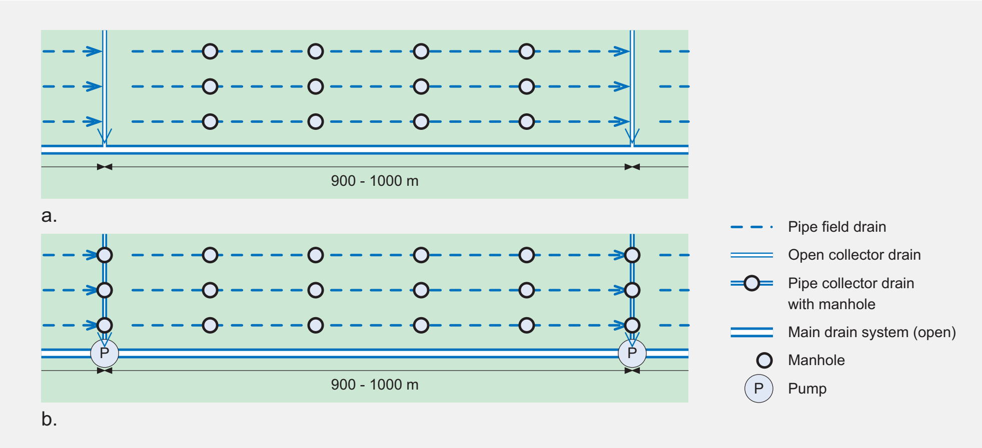


Figure 19 Extended field drain in a singular (a) and composite (b) drainage system

To clean these long field drains provisions (mostly manholes) have to be constructed every 300 m, in extreme cases up to a maximum of 350 m, provided that there are special flushers for the purpose. Because the long field drains serve larger areas than the regular ones, the capacity and thus the diameter of the pipes has to be greater. This raises the cost somewhat. Increasing the diameter of the field drain progressively in a downstream direction would be an economising measure. The changes in diameter can be made at a manhole. In the case of a singular system with a 1000 m long field drain, the head difference between the top end of the field drain and the downstream end would be between 0.5 and 0.7 m. In composite systems also with a collector of 1000 m in length, the head difference will be between 1.2 and 1.6 m. The downstream end of the extended drainage systems is therefore at a greater depth than for singular and com-posite systems.

Advantages of an extended field drain system

- Extended lateral systems require far fewer open drains and consequently fewer crossings than the other systems and consequently form much less obstructions to agricultural activities;
- Maintenance of a composite system is in most cases simpler and cheaper, because there is less length of open drain per unit area;
- If pumping is required this can be done relatively cheaply and simply at the end of the collector pipe (only for the composite variants). Fewer pumping points per ha will be needed than for the regular composite collector systems;

- The system has fewer outlets per unit compared with the regular singular and composite systems.

Disadvantages of an extended field drain system

- In the composite system, the design of the levels of the field and collector drains has to match up well;
- The downstream end of the system (thus field drains for the singular systems and collector drain for composite systems) is deeper than in the regular systems because of the slope requirement and the length of the field drains. Consequently, the whole system (including collector pipes) is deeper so this can make installation somewhat more complicated;
- The entrance for cleaning device (manholes if above ground) can form obstructions for agricultural operations;
- For economic reasons the diameters of field drains are sometimes required to be larger. Thus, the diameters of the collector drain (for composite variants) are also required to be larger than the regular composite system;
- The functioning of each drain in the system is difficult to check.

I.3.6 Quantitative comparison of different layout systems

An example of the calculation of the required infrastructure for different layouts of drainage systems is presented in Table 3.1. Note, Table 3.1 is an example only and has no universal applicability. The calculations refer to an area of 1000 m x 1000 m = 100 ha (one sided) or 2000 m x 1000 m = 200 ha (two sides). Drain spacing is taken as 50 m (thus 200 m field drain/ha) and the length of field drains for singular and composite drainage systems are 250 m. The extended field drains are 1000 m in length. A similar table can be made to suit any and every situation. Such a table can also help in the preparation of a cost comparison of the system if local unit prices are known.

For this example it can be concluded that:

- The length of field drains per ha is the same for all layout options;
- Field drains tend to have a larger diameter in the extended systems and more diameters tend to be used;
- In the case of composite systems, the length of collector pipe is considerably less in the extended systems than in the regular systems;
- The length of open drain is considerably less in the composite systems than in the singular systems. Of all the systems, the extended systems require the least density of open drains. Fewer open drains generally results in less maintenance cost (and problems);
- As can be seen the number of outlets is vastly reduced in the case of composite systems and is the smallest in the extended composite system;
- Extended systems normally have more manholes, which has a cost repercussion. The composite one-sided system has the most manholes;

- Extended systems have the least the number of crossings. In this example the norm of one crossing per 500 m of open drain has been arbitrarily taken, which is likely to be insufficient for small fields;
- The extended systems end at lower levels than the regular systems, which may make installation more complicated;
- In the composite systems pumping can be done at the end/outlet of the subsurface systems. Considerably fewer pumps are needed for the extended composite systems than the regular systems. If pumping is done the open collector drains and (sub)main drains can be shallow;
- The main drains have to be deep in the singular systems; the water level has to be lower than the level of the outlets. This may pose complications for the maintenance of these open drains. If no pumping is done the same is true for the composite systems.

Table 3.1 Example of calculation of required infrastructure for different layouts of drainage systems for areas of 1000 m x 1000 m (100 ha) and 1000 m x 2000 m for two sided systems. Based on spacing of field drains of 50 m, length of field drains in singular and composite systems of 250 m, extended systems 1000 m. Minimum slopes of pipes (collector and field drain) 0.5-0.7 ‰, and collector pipe Ø =200 mm.

Type of system	Pipe Drains				Open Drains			Structures			Head	In case of Pumping	
	Field Drains		Collector Drains		Collector drain [a]		Main drain	Outlets	Manholes	Crossings	top to	Pumping	Number
	Length	Ø	Length	Ø	Length	(S)hallow	(S)hallow				outlet	Possible	pumps
	(m/ha)	(No.)	(m/ha)	(No.)	(m/ha)	or (D)eep	or (D)eep	(No./ha)	(No./ha)	(No./ha)	(m)	(Yes or No)	(No./ha)
Regular systems													
Singular one sided	200	1	0	0	40	D	D	0.8	0	0.08	0.12-0.15	No	0.8
Singular two sided	200	1	0	0	20	D	D	0.8	0	0.04	0.12-0.15	No	0.8
Composite one sided	200	1	40	<1	10 (5 [b])	S/D	S/D	0.04	0.8	0.04	0.72-1.05	Yes	0.04
Composite two sided	200	1	20	<1	7.5 (3.7 [b])	S/D	S/D	0.02	0.4	0.02	0.72-1.05	Yes	0.02
Extended field drains													
Singular one sided	200	>1	0	<1	10	D	D	0.2	0.4	0.02	0.5-0.7	No	0.2
Singular two sided	200	>1	0	<1	5	D	D	0.2	0.4	0.01	0.5-0.7	No	0.2
Composite one sided	200	>1	10	<1	<1	S/D	S/D	0.01	0.6	0	1.2-1.6	Yes	0.01
Composite two sided	200	>1	5	<1	<1	S/D	S/D	0.005	0.5	0	1.2-1.6	Yes	0.005

[a] or sub main drain in case of composite systems

[b] in case of two sided use of the sub main drain

I.4 Materials for Subsurface Drainage Systems

I.4.1 Considerations on material selection during the various steps of the implementation process

Selection of the drainage materials to be used has to be done at an early stage of the implementation process, because the choice of specific drainage materials can have far-reaching, long-term consequences that may require additional investments (Box 4.1).

Box 4.1 Drainage materials: Major decisions to be taken during the planning phase

- What type of pipe should be selected for the field and collector drains?
  If the preferred type is not readily available:
  - Will the pipes be imported or produced locally?

  If the pipes are going to be produced locally:
  - In which way will the production process be started (by private parties or by the government)?
  - How will the production facilities be financed?
  - Who will be responsible for the establishment and running of the local production facilities?

- What type of drain envelope should be selected?
  If there is no experience with envelopes in the soils to be drained:
  - How will a suitable type of envelope be selected?

  If field trials have to be done:
  - Who will carry out and who will finance the field trials?

  If the selected envelope is not available in the country:
  - From where will the envelope be purchased (imported or local manufacturing)?

  If the envelope is going to be produced locally:
  - How will the production process be started (by private parties or by the government)?
  - How will the production facilities be financed?

Some of the materials used for drainage are also used for other civil engineering constructions. Materials specific to subsurface pipe drainage systems are:

- Field drain pipes and fittings;
- Collector drain pipes and fittings;
- Drain envelopes;
- Drainage structures.

This chapter provides an overview of these specific drainage materials from which, during the design and planning stage of the implementation process, a final choice has to be made. The materials are described insofar as their nature and characteristics have an impact on the choice. For more detailed and background information please refer to the FAO Irrigation and Drainage Paper no. 60 and ILRI Publication 16 (see Bibliography).

I.4.2 Pipes for field drains

I.4.2.1 Function of a field drain

The function of a field drain is to collect excess groundwater and to convey it to a collector or open drain. The pipes have to be permeable (perforated) or require openings at the joints of pipe sections so that water can enter them. The perforations or openings of the pipes should be (Figure 20):

- As large as possible to limit the entry resistance of the water;
- As small as possible to prevent the soil particles surrounding the pipes entering the pipe as a result of mobilisation by the water flow. If soil particles enter the pipe they will sediment in the pipe and obstruct the flow.

These are contradictory and incompatible requirements. In most soils, especially in soils with little cohesion (sandy or loamy soils and even some clay soils), the perforations or openings cannot be made so small that the soil particles cannot enter the pipes. This is why in most soils an envelope has to be placed around the pipe.

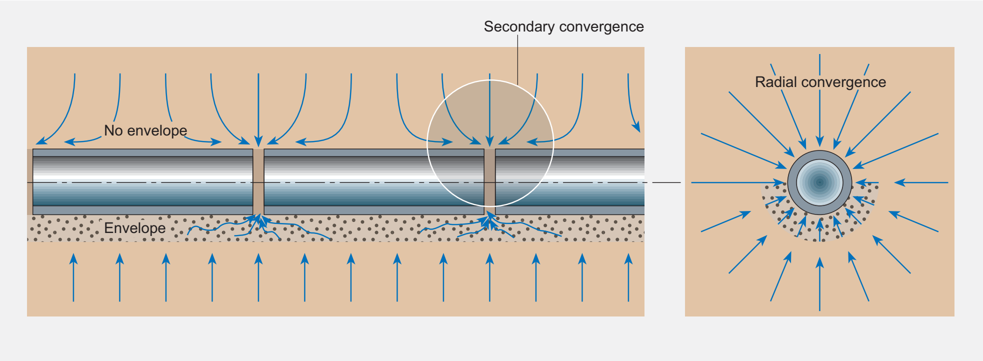


Figure 20 The perforations in a drain pipe should be large enough to let the water in and small enough to prevent soil particles to pass

I.4.2.2 Types of pipes for field drain

Pipes for field drain can be made of:

- Perforated plastic (PVC or HDPE);
- Concrete;
- Clay (tile)[5].

[5] The terminology used for clay pipes varies. With clay pipes is meant ceramic pipes made of clay that is fired at high temperatures. English literature often refers to tiles (tile drainage).

Plastic drain pipes (either PVC or HDPE) are currently the most common and the easiest and most secure types of pipes for machine installation. The plastic material is inert and is not affected by soil chemicals. The production of plastic pipes is a specialised process requiring high cost equipment.

Concrete pipes can be used if plastic pipes are unavailable or if only small quantities of pipes are required. They can be made relatively simply, onsite. The installation of drains with concrete pipes is more cumbersome and much more susceptible to misalignment than the installation of plastic pipes. Under unstable soil conditions it is almost impossible to properly install concrete pipes. Some soil chemicals attack concrete pipes. When making cost comparisons the risks of breakage and possible high transport costs have to be taken into account.

The quality of clay pipes or tiles is comparable to concrete pipes. They are somewhat lighter than concrete pipe and are chemically resistant to soil chemicals (see below). The production of clay pipes is a specialised process requiring expensive equipment. The use of clay pipes/tiles used to be standard in Europe in the first half of the 20th Century. However, since the 1960s clay pipes have been completely replaced by corrugated plastic pipes.

I.4.2.3 Plastic field drains

General

Corrugated (perforated) plastic drain pipes are standard at present, especially for field drains. Most of the installation equipment is geared to the installation of these flexible corrugated plastic pipes.

Base materials

Plastic pipes can be made of polyvinyl chloride (PVC[6]), high density polyethylene (HDPE), and to a minor extent, polypropylene (PP). The choice from these three materials largely depends on the availability and price of the parent material. All plastic pipes are resistant to all chemicals that may be found in agricultural soils. The major differences between the base materials are:

- All plastic materials are sensitive to ultra violet (UV) radiation and should not be exposed to direct sunlight therefore. UV filters can be included in the base material that can give some, but not complete, protection;
- HDPE is sensitive to deformation at high temperatures;
- PVC becomes brittle at low temperatures (near freezing point), HDPE also becomes brittle, but at somewhat lower temperatures and may thus be installed at lower temperatures. Once installed neither PVC nor HDPE are affected by low temperatures;
- HDPE requires approximately 20% more base material in weight per meter than PVC to attain the same strength.

[6] Sometimes more specifically called *Unplastified* PVC or U PVC.

Types of plastic pipes
Plastic pipes can be:
- Rigid smooth pipes;
- Corrugated pipes;
- Double walled pipes (corrugated outer pipe and smooth inner pipe).

Rigid pipes are less easy to install and are considerably more expensive than corrugated pipes. To achieve the same strength and resistance to outside pressure a rigid pipe requires 3 x the amount of base material and, consequently, is about 3 times more expensive. The slightly rougher wall of the smaller diameter corrugated plastic pipes will require marginally larger diameters. The extra costs thereof are negligible compared to the extra cost of either rigid or double walled pipes. The double-walled pipes were originally developed specifically for irrigation and can withstand higher than necessary internal pressures. They have the same disadvantages as the rigid pipes but are slightly lighter. The use of these expensive pipes is only justified for larger diameters required for special conditions.

Available pipe diameters
Corrugated plastic pipes are available in diameters ranging from 40 to 600 mm. The smaller diameter pipes can be produced in coils in lengths of up to 300 m weighing between 30 and 50 kg. The larger the diameter, the smaller the length that can be coiled, e.g., 200 mm PVC pipes can be coiled up to a length of 50 m and the largest diameter pipes are seldom delivered on coils but as straight lengths of 6 or 9 m.
- *PVC drain pipe sizes* are standardised and refer to the *outside* diameter (in mm). Standard outside diameters are 40, 50, 65, 80, 100, 125, 160 and 200 mm, but larger diameters are also available;
- *HDPE drain pipe sizes* are standardised to the *inside* diameter in inches. Standard diameters are 2, 3, 4, 5, 6, 8, 10, 12, 15, 18, and 24 inches.

Production of corrugated plastic pipes
The production of corrugated plastic pipes is a specialised job. It requires expensive production lines consisting of: extruders, corrugators, perforators and coilers (Figure 21). During the production process a constant quality control is required. The production capacity of a modern line is about 500 kg/per hour, for an Ø 100 mm pipe it amounts to approximately 1000 m/hour. The extruder can also be used for the production of rigid pipes. The corrugator and the perforator are parts of the production line that are specifically made the production of corrugated drain pipes.

The corrugator gives the pipe its form; the form of the corrugation determines the strength of the pipe. Sophisticated corrugation forms can give the pipe the required strength at minimal wall thickness. The smaller the required wall thickness, the less the base material needed and thus the cheaper the pipe.

The perforator has to provide perfect holes in the pipe for water entry at the indicated place (in the valley of the corrugation) so that the perforation does not influence the strength of the pipe. The perforator should make holes and not slits or cuts. This means that the cut-out material has to be removed from the pipe. Slits and cuts tend to bend back and close the perforation over time.

There are production lines for roughly Ø 40 - 100 mm and for Ø 100 - 200 mm. For each diameter to be produced on a production line, special tooling is required on the extruder, corrugator and perforator. These special tools are expensive. So, if a drainage industry is to be developed, there is an interest to limit the number of pipe diameters to be used and thus produced.

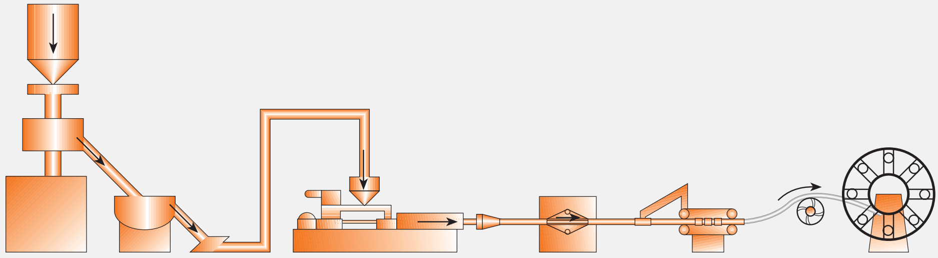


Figure 21 A production line for plastic pipes consists of a blender, extruder, corrugator, perforator and coiler

Transport of plastic pipes

Transport of corrugated pipes over long distances is rather expensive, because of the high volume/weight ratio (it boils down to the expensive transport of air). To counteract these pipes ought to be produced as close as possible to the site of installation. Mobile factories have even been produced in the past, but these proved to be expensive and complicated because of necessary power supply and cooling. They are hardly used any more: transferring the production line from one factory hall to another is far simpler to do. Comparative studies indicate that transporting the production facilities to a location close to the construction site is economical if the distances are more than 300 - 500 km. The importing of large quantities of plastic drain pipes is therefore not considered to be a rational option.

Quality Control

The quality of corrugated plastic pipes is documented in national and international norms and standards. Quality control of the production is a specialised job, which is beyond the scope of work of drainage engineers and should be left to specialised institutes. The staff in charge of installation should ascertain that pipes are produced according to a national or international standard as indicated in the specifications. Some examples of the most commonly used international norms and standards are given in Table 1.

Visual checks that can be done before installation are to assess: form, resistance, size regularity and quantity of perforations and brittleness. Although experienced drainage engineers may do these checks they cannot match up with specialised quality checks. If a proper factory test has been carried out on the pipes, the quality control during the installation process can be confined by checking whether the pipes:

- Have been produced, transported and stored according to norms and/or contract specifications;
- Have not been produced longer than 3 months before delivery;
- Have been stored in the shade;
- Have not been damaged during transport;
- Are stored on the site outside the direct influence of sun shine;
- Have not been damaged during the installation process.

Table 1 Standards for corrugated plastic drain pipes [a,b]

Country	Standard No.	Type of pipe	Source
Europe	CEN/TC155/WG18 (1995)	Plastic piping system for agri. land drainage U-PVC	CEN Draft
Germany	DIN 1187	U PVC pipes	RAL
ISO	1985 Draft	Pipes and fittings of UPVC for sub soil drainage	ISO
USA	ASTM F-405, F-449	Corrugated PE Ø75-150 mm and fittings	American Society for Testing and Materials
	F-667, F-800, F-892	Corrugated PE Ø200-300 mm and fittings	

[a] Only one of these standards should be applied, combining parts of different standards does not necessarily result in well-balanced effective standards.

[b] The draft European standards are given in the Annex to the FAO Irr. & Dr. Paper No. 60. Thus far, these standards are (2003) the most complete ones available.

I.4.2.4 Concrete field drains

Types of concrete pipes for field drains

Concrete pipes for field drains generally come in a cylindrical form in lengths of about 0.30 m. The ends are either straight or in some rare cases have a spigot and groove (Figure 22). Water entry is through the joints between pipe sections. Pipe diameters are as desired; 60-100 mm is common for the (internal) diameters of concrete pipes for field drains. Like clay pipes, however, they virtually became obsolete when plastic pipes were introduced.


a.


b.

Figure 22 Concrete (a) and clay (b) drain pipes generally come in a cylindrical form in lengths of about 0.30 m

Base material
Concrete pipes are produced from cement and sand. If concrete pipes are used in acid or sulphuric soils, sulphate resistant cement must be used, in which case the density of the concrete has to be high so that it absorbs little or no water.

Production
Concrete pipes can be produced either in a factory or on site. The pipe production in a factory usually has a better and more homogeneous quality. It is up to the manufacturer to prove that the quality standards (often national standards) are met and that they are checked by an independent entity. If the pipes are produced in a factory, the pipes have to be transported to the site. During transport some breakage normally occurs.

Moulds, preferably vibration tables, weighing units, hoppers and curing basins are required for on site production of pipes. Quality production requires considerable supervision and quality control needs constant attention. The advantage is that no transport to the site is required and part of the breakage risk is eliminated.

Transport
Transport of concrete drain pipes over long distances is hardly economical as the weight of a Ø 100 mm is about 18 kg/m and, in addition, there is the breakage (5%) to consider. One of the redeeming features of concrete pipes is that they can be produced near the installation site. Importing of concrete pipes is not considered to be a feasible option.

Quality control
The required quality of concrete pipes is documented in national and international norms and standards. Quality control during the production is a rather specialised job that is the responsibility of the manufacturer. Quality control concentrates on: form, dosage of cement, concrete and water, quality of the cement, quality of the water (no saline or muddy water), cleanliness of the sand, compaction, curing period and regular wetting during curing. The staff in charge of installation should ascertain that pipes are produced according to a national or

international standard as prescribed in the specifications (Table 2). These standards focus on (see also FAO Irr. & Dr. Paper no. 60):

- Roundness and curvature;
- Verticality at end of pipes;
- Resistance to weathering and deterioration in the soil;
- Resistance to freezing and thawing cycles;
- Density;
- Water adsorption;
- Crushing strength;
- Sulphate resistance (if required);
- Acid resistance (if required).

Visual quality control in the field before installation focuses on checking that the pipes:

- Have been produced according to the prescribed norms and/or contract specifications;
- Are regular in roundness and thickness;
- Are not damaged;
- Have straight ends (are vertical at end planes;
- Are not chipped.

Table 2 Standards for concrete drain pipes

Country	Standard No.	Type of pipe	Source
USA	ASTM C412M-99	Concrete drain tile	American Society for Testing and Materials (ASTM)
	ASTM C44-95	Concrete pipe Perforated	ASTM
	ASTM C118M-00	Concrete pipe for Irrigation and Drainage	ASTM

I.4.2.4 Clay field drains

General

In the past, clay pipes were standard usage in most European and some (South) American countries. They have gradually been phased out since corrugated plastic drain pipes became available. They are rarely used nowadays. High quality clay pipes are resistant to weathering and aggressive chemicals in the soils.

Types of clay pipes

Clay pipes are cylindrical in form and about 0.30 m in length. Ends are either straight or sometimes have *"collars"* (effective but expensive) (Figure 23). Water entry is through the joints between pipes. The most common pipe diameters are 50, 65, 75, 80 and 100 mm. Diameters of 130 and 160 have been known to be used at times. The wall thickness varies between 12 and 24 mm.

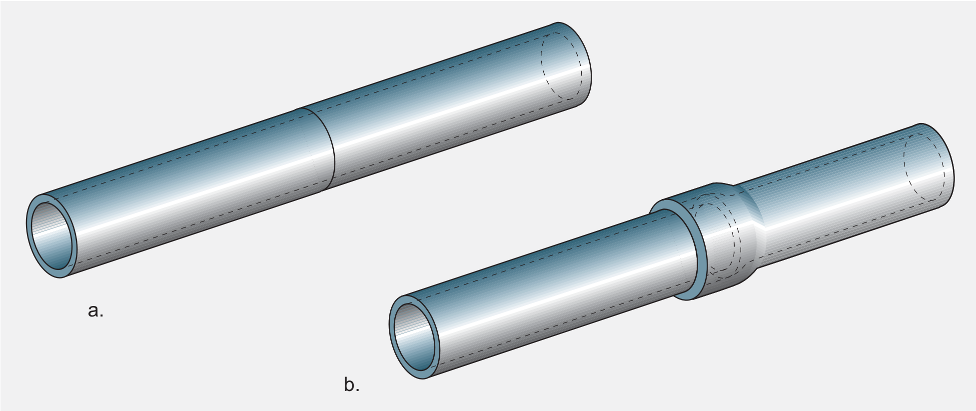


Figure 23 Clay pipes have either straight joints (a) or collar (b)

Base material

Clay pipes are produced from clay through vitrification in an oven at a high temperature (>900 °C). For the production of high quality pipes the clay should have no or limited content of montmorrilonite.

Production

Clay pipes have to be produced in a specialised plant. The mixing and wetting of the clay, the pressing through the mould, the cutting, the storing and the baking in the oven are all specialised jobs requiring specialised equipment. The baking process is highly sensitive, since the vitrification of the clay minerals only takes places at specific high temperatures that are to be maintained during a number of days. It also demands a considerable amount of energy. The pipes have eventually to be transported to the site carrying a risk of breakage.

Transport

Transport of clay pipes over long distances is not considered to be economical. The weight of a Ø 100 mm pipe is about 12 kg/m and there is also the added breakage risk of 5% to consider. Importing of clay pipes is not feasible.

Quality control

The required quality of clay pipes is documented in national and international norms and standards. Quality control during the production process is a rather specialised job and is the responsibility of the manufacturer. The staff in charge of drain installation should ascertain that pipes are produced according to a national or international standard as prescribed in the specifications (Table 3). These standards focus on the same aspects as concrete pipes (see previous section). The quality control in the field before installation focuses also on the same aspects as concrete pipes.

Table 3 Standards for clay drain pipes

Country	Standard No.	Type of pipe	Source
Germany	DIN 1180	Clay pipes	RAL
USA	ASTM C4-99	Clay drain tiles and perforated drain tile	American Society for Testing and Materials ASTM
	ASTM C498-95	Clay drain tile, perforated	ASTM
	ASTM C700-99	Clay drain tile, vitrified perforated	ASTM

I.4.2.5 Pipe fittings

Couplers

For concrete pipes plastic rings with grooves were used to restrict inflow of sediments in case of damaged pipe ends (Figure 24a). For plastic pipes, so-called couplers (connectors) are used to connect two sections of drain pipes (Figure 24b). Sophisticated click couplers are the most practical in use. If couplers are not available, connections can be made by hand using iron wire, knives and small parts of drain pipe (See Part II). The larger the diameter of the drain pipes the more difficult it will be to make coupling by hand.

End caps

End caps are used at the upstream end of a plastic field drain to prevent soil and water flow into the drain. End caps that click onto the pipe are also produced in a special production facility. If these are not available the pipe ends can be closed of by first heating the end of the pipe (on the exhaust of the drainage machine) and then by closing it by folding over.

T-joints

T-joints are used to connect plastic field drains to a collector drain (Figure 24b) and also require a special production process. They can be manufactured by welding two parts of rigid PVC pipe or by blow moulding. The T-joint can be extended to allow for easy access for the flushing of the field drains.

Y-joints

Y-joints are similar to T-joints.

Couplers for concrete pipes

In rare instances plastic couplers are used for concrete pipes (Figure 24c). They provide a secure joint of the pipe sections and avoid dislocation and inflow of sediment material.

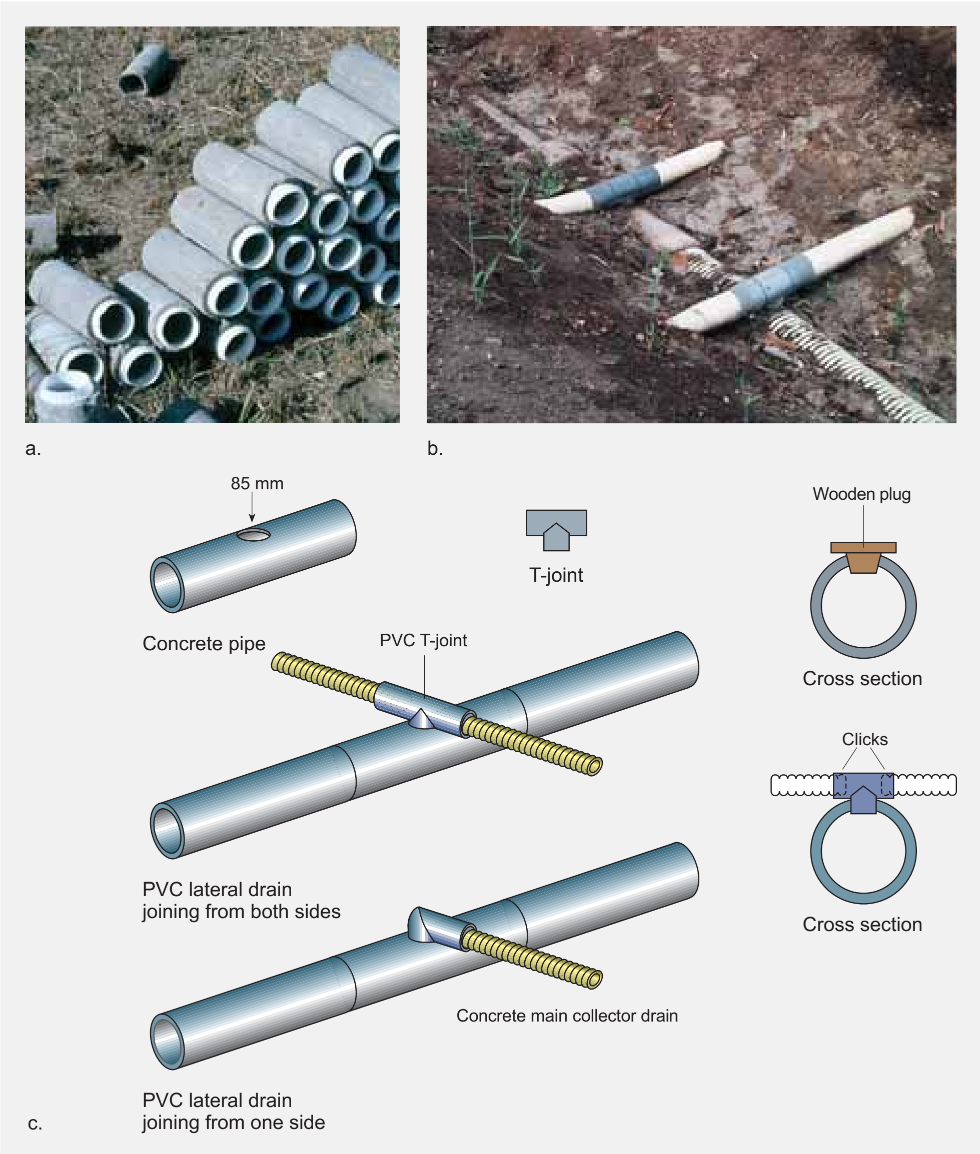


Figure 24 Pipe connectors between (a) field drains and (b) field and collector drains

Outlet pipes

Outlet pipes for singular drainage system are mostly rigid PVC pipes that can be coupled to the drain pipe.

Transport

Since the quantity of fittings is rather limited and neither the weight nor volume considerable, transporting over long distances and/or importing can be considered.

Standards
The standards for fittings are often included in the standards for the drain pipes (Table 1) Additional standards are:
- ISO norm 2507, 2507-1 and 2507-2 for thermo plastic pipes and fittings;
- ISO norm 4493 for PVC-U pipes and fittings;
- CEN/TC 155 WI 127 for joint strength.

I.4.3 Pipes for collector drains

I.4.3.1 Function of collector drains

Collector drain pipes are usually only for the purposes of conveying the excess water to an outlet. These pipes are closed, the joints are sealed and there are no perforations, thus the groundwater only enters through the junctions with the field drains. Under specific conditions it may be useful for collector drains to also have a draining function, in which case the pipes will need to be perforated.

Cost comparisons of installed subsurface drainage systems reveal that total costs (both material and installation costs) for plastic collectors with diameters of 300 mm or less are considerably cheaper than for concrete collectors. Concrete collectors are cheaper for diameters over 300 mm. This price balance may vary with the cost of base materials. Furthermore, concrete collectors are more cumbersome to install than plastic ones and there is a higher risk of displacement occurring especially in unstable subsoils resulting in leakage and damage. Therefore, if there is a choice, plastic collectors are preferable.

I.4.3.2 Types of pipes for collector drains

Collector pipes are generally similar to field drain pipes, only the diameters tend to be larger. Collector pipes are normally made of plastic (PVC or HDPE) or concrete. The production of clay collector pipes of larger diameters is complicated and expensive. Therefore clay pipes are seldom used for collector drains.

I.4.3.3 Plastic collector drains

The characteristics of plastic collectors are similar to field drain pipes, with the exception that they are usually not perforated. Plastic collectors can be produced in pipes on coils, but especially for the larger diameter, they are often produced in lengths of 6 or 9 m. The norms and standards for the production of plastic collector pipes are the same as those for field drain pipes (Table 1).

I.4.3.4 Concrete collector drains

For many years, the use of concrete for collector drains was standard practice. Over the past twenty years plastic pipes have gradually been replacing the smaller diameter concrete collector drains. Concrete pipes are still in use for larger diameter collector drains, but may very well be slowly phased out. There is practically no limit to the diameter of concrete pipes, although the concrete must be reinforced for large diameters (> 400 mm). Wall thickness varies between 25 and 50 mm. Pipe ends are straight or have a collar, or a spigot and groove.

The length of the individual pipe sections varies between 0.75 and 1.0 m, depending on local custom and diameter. A limitation is the weight per section. The sections have to be installed and transported. The quality production and quality control for collector concrete collector pipes is similar to those of concrete field drain pipes.

I.4.4 Envelopes

I.4.4.1 Function of envelopes

A drain envelope is a porous material placed around a perforated drain pipe to perform the following functions:

- Filter function: to prevent or restrict soil particles from entering the drain pipe where they may settle and eventually clog the pipe;
- Hydraulic function: to provide a porous medium of relatively high permeability around the pipe to reduce entrance resistance.

I.4.4.2 Envelope Materials

Drain envelopes (or filters) can be made of granular (or mineral), organic and synthetic materials (Figure 25).

Figure 25 Envelopes can be made of wrapped polypropylene fibres (a, f & g), polystyrene granules (b) and coconut fibres (c), non-woven nylon (d) and woven typar (e)

Granular envelopes

Granular envelopes are made of sand, gravel (both natural and crushed), slag (often industrial waste products) or fired clay granules. They have been tried world wide and have been proven to be functional in almost all soil types, provided the grading of the envelope is designed in relation to the soil texture, although granular envelopes cannot be used with trenchless drainage.

The application of granular envelopes requires a logistically perfect organisation and special equipment (gravel trailers and front loaders). Imperfections in the supply line tend to hold up the whole installation process. Generally, the use of granular envelopes is considered to be cumbersome. Large volumes of heavy, well-graded envelope material (for example 4 m^3/100 m of field drain Ø 80 mm weighing some 8 tons) have to be transported to the site and in the field towards the drain. Because of its weight alone, transport and application costs can be high, especially when the base material has to come from far away.

Correct placing of the granular envelope around the pipe can be done using modern drainage trenchers that can be equipped with hoppers and gravel gates. In the case of liquid subsoils, special hydraulic provisions can be attached to the drainage trencher to place the gravel around the pipes.

Although well-designed and applied granular envelopes have proven to be technically functional, they are less desirable for practical reasons. In new areas without drainage experience where no field tests on synthetic envelopes have been conducted, a granular envelope is still the first most secure choice.

Organic envelopes

In North and West Europe peat, coconut fibres, (flax) straw, chaff, heather, wood chips and sawdust have been used, but have been phased out. They tend to decompose over time; decomposition materials of some organic envelopes tend to block the water entry to the pipes. The coconut fibre envelopes used in Western Europe, have been totally replaced by PP fibre envelopes (see below). Furthermore, in warmer climates the decomposition process is speeded up and the organic materials tend to last less than one or two seasons. Generally speaking, organic materials are not a feasible proposition for drain envelopes.

Synthetic envelopes

Synthetic envelopes that are normally used in combination with corrugated plastic pipes are made of:

- Loose voluminous synthetic envelopes of polymeric fibres (polyamide (PA), polyethylene (PE), polyester (PETP = polyethylene terephtalate) and polypropylene (PP). Polystyrene (PS) granules in netting around the pipe also belong to this category;
- Geo-textiles are woven, knitted or non-woven (thin) sheets. The fibres used for the production of the geo-textiles are the same as those used for the voluminous synthetic envelopes.

Voluminous envelopes combine the filter and hydraulic functions of an envelope. The geo-textiles mainly serve as envelope and tend to clog earlier. Synthetic materials are inert and are not affected by soil chemicals.

As yet there are no common standards and norms for the functionality of synthetic envelopes in keeping with the soil characteristics in which they are placed. Positive results of synthetic envelopes in laboratory tests do not necessarily translate into positive results in the soil. In areas where there is no experience with synthetic envelopes, field tests are the only known method to determine whether a certain envelope is functional. In some countries some envelopes (often geo-textiles) have given positive results when used as filters for wells. The hydraulic conditions (pressures) around wells are different than around drain pipes. These experiences cannot be extrapolated simply. The production of envelopes of synthetic materials requires a specialised industry, both for the production of the fibres and for the wrapping around the pipe. For further information see the bibliography.

Conclusion
Pre-wrapped synthetic envelopes are the most practical for the installation of subsurface drainage systems. If suitable, well-tested and proven synthetic envelopes are available, the use thereof being most desirable. If this is not the case, the most logical approach would be to start with the technically secure graded gravel with a view to replacing it as soon as possible with a well- tested and proven synthetic envelope.

I.4.4.3 Granular envelopes

Production
The required particle size distribution of granular (gravel) envelopes is dependent on the particle size distribution of the soil in which the drain will be installed. In other words, the envelopes have to be designed and later mixed or sieved on the basis of the prevailing soil texture at drain depth in the project area. If there are important variations in soil texture in the project area, the "average" granular envelope must be checked to see if it is functional under all conditions. If this is not the case, the necessary adjustments need to be made to suit the specific area.

Preparation of these types of envelopes is done by sieving out particles of an undesirable size from natural or crushed base material, or by mixing particles of specific size ranges. Vibration during transport can cause a de-mixing of the particles, if this occurs the gravel has to be mixed again at the site.

Standards
The first criterion for granular envelopes is that the particles are stable (stone or sand) and will not deteriorate over time, e.g. by soil chemicals, or dissolve in water. Selection of the required particle size analyses has to be done during the design phase of the project. The results must be documented in the specifications. Detailed information is presented in FAO Irr. & Dr. Paper 60 (see Bibliography).

I.4.4.4 Synthetic envelopes

Synthetic envelopes are commonly pre-wrapped, meaning that the envelope is wrapped around the pipe before delivery to the site. Consequently, they can only be used in combination with corrugated plastic pipes.

Production

Production of the synthetic material is a very specialised job mostly carried out by the chemical or artificial fibre industry. Since the volume and the weight of the synthetic material are limited, transport over longer distances and import is not prohibitively expensive.

a.

b.

Figure 26 Pre-wrapping drain pipes can be done manually (a) or mechanically (b)

Pre-wrapping

Geo-textiles can be manually wrapped around the pipes, although it requires a considerable amount of labour and a large (long) workplace (Figure 26a). Pre-wrapping of the loose voluminous materials can only be done with wrapping machines. Wrapping machines require conscientious management and high-quality machinery to assure that an even layer (even in thickness and even in density) is wrapped around the pipe (26b). Very strong nylon thread is required to fix the envelope around the pipe. The exact type depends on the wrapping machine.

Since the envelope has to be wrapped around the pipe, carrying out the process of pipe production and wrapping in one location would be preferable and save on transport costs. If this is not possible it would be logical to do the wrapping as close as possible to either the pipe factory or the installation site.

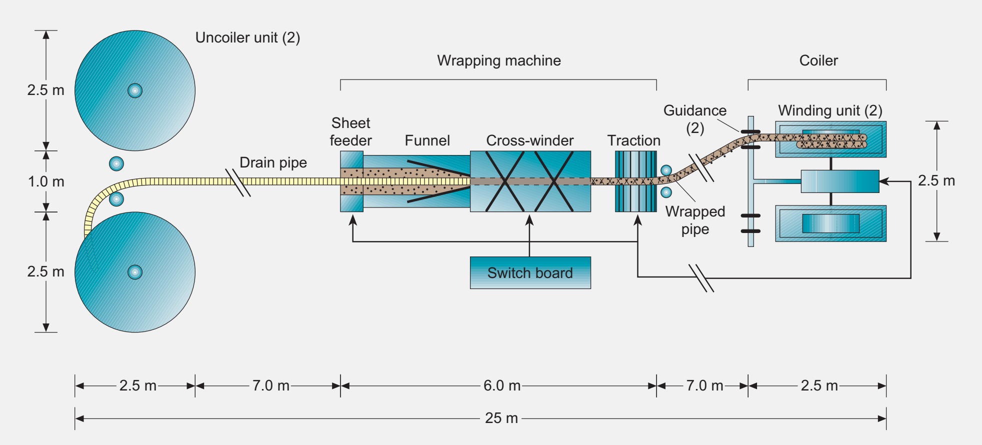


Figure 27 An envelope wrapping-unit consist of an uncoiler unit (2), sheet feeder & funnel, cross-winder and winding unit (2)

Depending on the type of envelope (loose fibres or sheets) two basic technologies are used to wrap drain pipes:

- Sheet-wrapping machines. This type of machine can handle both voluminous envelope materials like PP450 or PP700 or thin geo-textiles. The production process is rather simple: needle-punched envelope sheet purchased from specialised factories are wrapped around the pipe and fixed with strong nylon thread;
- Loose fibre-wrapping machines. This type of machine is used to wrap envelopes made from loose fibres, either organic or synthetic. The loose fibres are loosened (they are often compacted during transport), mixed, fed into the wrapping machine and fixed. The necessary technology here is more complex than in the sheet-wrapping machines as the quality of the envelope material depends on the production process (mix, feed and wrapping strength all influence the final quality of the envelope).

A wrapping unit consists of four components (Figure 27). It covers a net area of approximately 25 x 6 m and should be placed on a level and preferably a concrete floor. The equipment can be moved from one place to another relatively simply.

Standards
Pre-wrapped synthetic envelopes are a recent development in drainage technique. No common standards and norms have been developed for determining which envelope is to be used in which soils. There are a multitude of synthetic envelopes that are used or are still under experimentation. Quality standards for pre-enveloped synthetic material as such (thus not the relationship envelope/soil) focus on: material tensile strength, fibre length and density, or unit weight per unit length and pore size opening. European norms (EN) and ISO norms for testing several aspects of the synthetic envelopes have been prepared (see Bibliography).

Quality control
Quality control must be carried out by specialists before the pre-wrapped pipes are transported to the site. The best procedure is for the factory to deliver a quality certificate with the pre-wrapped pipes issued by an independent organisation.

I.4.5 Structures and pumps

I.4.5.1 Considerations on the selection of structures and pumps during the various steps of the implementation process

Many structures used for subsurface drainage systems are made of concrete or brick and, in most circumstances, can be produced in a conventional way. A number of decisions have to be made before the design phase by either the planning or implementation authority (Box 4.2). If pumping is necessary the decisions "where to pump in the system" and "what pumps to use" can be crucial for management and maintenance of the system.

Box 4.2 Structures and pumps: decisions to be made

- Are the structures, where possible, going to be prefabricated or "cast in place"?
- If they are prefabricated: will this be done by a specialised industry or prefabricated onsite?
- If manholes are used: are they to be aboveground or underground?
- If pumping is required: what energy source is to be used, what type of pump and what automation?

The decisions depend very much on the local situation, customs and existing building practices:

- Casting of concrete structures onsite or building them from bricks (manholes sumps etc.) can be troublesome in situations with a high groundwater level and/or unstable soils;
- The quality of prefabricated structures in specialised industries is often higher and more uniform than "prefabrication onsite". Quality control is also less complicated;

- Aboveground manholes are easier to open; cleaning and inspection of subsurface drainage systems is easier. Aboveground manholes, however, are obstacles to agricultural activities that can be easily damaged and vandalised or used as an outlet for excess irrigation water;
- Underground manholes do not have the disadvantage of being an obstruction, but are cumbersome to dig up and difficult to locate once installed. The techniques to locate them with metal detectors are not always successful in practice;
- Pumps can be either driven by electric motors or diesel engines. Electric motors are by far the most economical, convenient and reliable. They can be automated relatively simply. They require, however, a connection to the electric grid;
- A choice has to be made between underwater pumps (pumps where the electric motor and the pump are combined, suction pumps (electrically or diesel driven) or long axel pumps (also electrically or diesel driven).

I.4.5.2 Manholes

Manholes can be used for connecting field drains to collector drains, for creating access to (long) field drains. The manhole can be either aboveground or underground (buried) (Figure 28) and can be made of pre-cast segments, cast in place concrete or masonry.

I.4.5.3 Sumps

The term sump is used for the last manhole in a composite drainage system. Here all the water is collected and discharged either by gravity or by pumping into the discharge area (open drain). Sumps are in effect similar to manholes, and have either a concrete pipe as gravity outlet or serve as reservoir from where the water is pumped. The dimensions should tally with the pumps. Sumps have the functions to:

- Provide storage capacity in the subsurface drainage system, so that pumps do not have to operate continuously;
- Act as pump house;
- Act as silt trap.

Sumps can be made of pre-cast concrete rings or brickwork (Figure 29). The diameter depends on the required storage capacity. Calculation of the required storage capacity is dependent on the capacity of the pump, the design drainage rate, the over-dimensioning of the drainage system for safety, the maximum number of switching per hour and the storage capacity in the collector drainage system. Furthermore, the diameter depends on the type of pumps, e.g. under water pumps, suction pumps and to a lesser extend the required storage capacity. In practice the collector system itself provides the major part of this storage, the sump itself contributes hardly to it. Installation of sumps is often problematical because of the required depth (needed to create silt trap capacity below the invert level of the collector drains) combined with the frequently high groundwater levels, especially in areas with unstable subsoil.

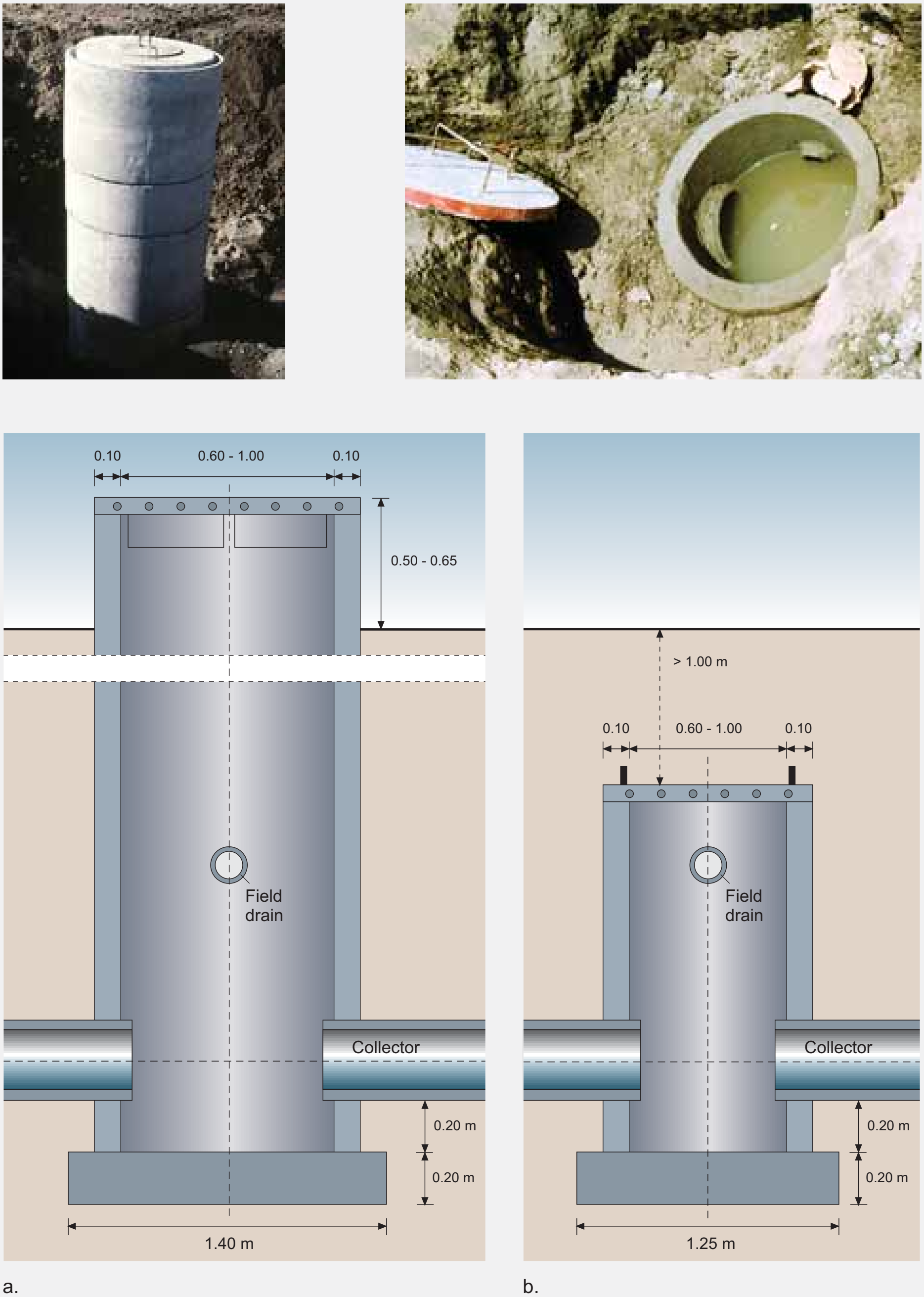


Figure 28   Manholes with a cover above (a) and below (b) the soil surface

a. b.

Figure 29 Sumps are made of brickwork (a) or pre-cast concrete rings (b), examples from Drainage Pilot Areas in Rajasthan, India

I.4.5.4 Outlets

A singular drainage system has a large number of field drain outlets, so they should not be too expensive. Furthermore, because all outlets of a singular system can easily get damaged, regular inspection and repair is necessary. The outlets are mostly drain pipes of plastic or concrete that protrude from the slope of the open collector drain (Figure 30a) or minor structures built in the slope with the necessary protection devices against erosion.

The outlets of a composite drainage system are similar to the outlets of singular system, their construction is more permanent and robust since there are fewer outlets and the area served is larger than that of a singular system (Figure 30b).

a. b. c.

Figure 30 Outlet of a field drain (a), collector drain (b) and sump (c) in an open main drain

I.4.5.5 Pumps

Diesel driven pumps

If there are no electrical connections available or if a connection to the electric grid is considered too expensive, diesel driven pumps can be selected for the drainage system. For diesel powered pumping one larger station serving a large area usually be a more logical choice than a number of smaller pumping stations. This is because of the logistics of fuel supply and the need for the stations to be almost continuously attended. Automation (automatic switch on and of) is possible but rather complicated. Larger stations pump from open watercourses, consequently the diesel pumps are best placed at the end of an open drainage system into which the subsurface drainage systems discharge.

Electrically driven pumps

Electrically driven pumps are mostly smaller and can be combined with the motor. They are relatively simple to automate (switch on and off in relation with water levels). These pumps are available for a large range of capacities sizes and can efficiently pump water directly from subsurface system without any special housing. Electrically driven underwater pumps require hardly any specialised housing and can easily be installed in sumps (Figure 31). The only infrastructure required is a connection to the electric grid (240-380V). With electrically driven underwater pumps, a number of small pumps can be installed at the end of the subsurface systems, instead of pumping the water from the main drainage system by installing larger pumping stations at the outlet. Once properly installed the maintenance of electrical pumps is minimal.

If pumps are used in a saline environment, the pump, pipes, etc should be made of salt resistant components.

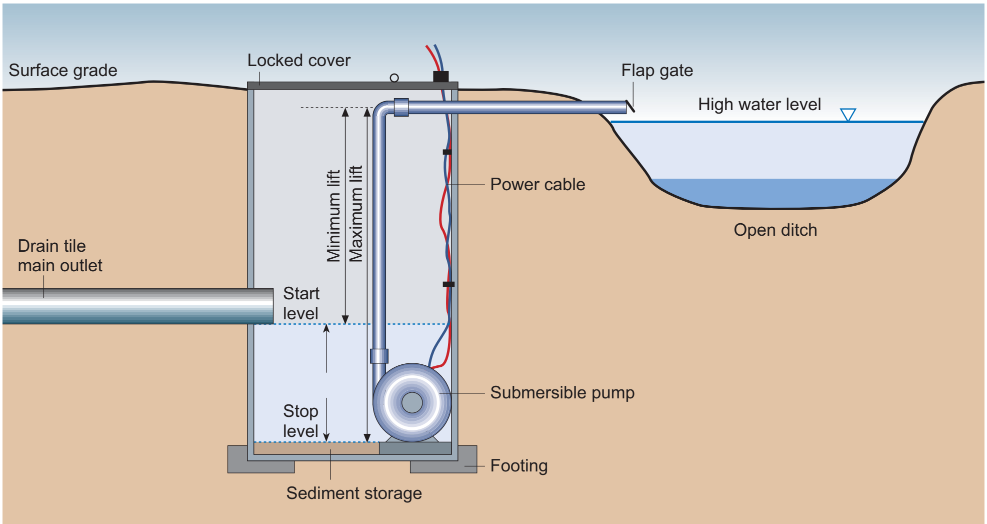


Figure 31 Sump with electrically driven underwater pump

I.5 Installation Equipment for Subsurface Drainage Systems

I.5.1 Introduction

I.5.1.1 Installation equipment: decisions to be made during the planning phase

The selection of installation equipment has far-reaching consequences for the implementation process as it affects the degree of freedom of choosing the depth and the layout of drainage system and the pertinent drainage materials. If there is an existing drainage industry and tradition, the characteristics of the available installation equipment will be well known, and consequently are a readily available input for the planning and design process. In countries where drainage is just starting, suitable and cost effective drainage installation equipment will need to be selected. The characteristics of the equipment will be a basis for estimating the required investments in case the equipment has to be purchased, and they are an essential input for the planners of the implementation authority. Information about installation equipment can also be found in ILRI Publication 16 or publications of the manufacturers. This chapter will be confined to the information required to making a cost effective choice of installation equipment under the prevailing conditions.

Box 5.1 Installation equipment: major decisions during the planning phase

1) What would be the most cost effective type of installation equipment under the given conditions?
2) How much equipment will be required to carry out the installation within the foreseen time frame?
3) Is the equipment available in the country?
   If not:
   a) Does the quantity of the work warrant the purchase of equipment or should leasing, renting, temporary import or other installation methods be considered?
   b) Will the desired equipment have to be rented or purchased and by whom?
   c) Is the government involved in the specification and/or purchase or is this left to contractors?
   d) Is there enough work for the equipment to make the purchase commercially viable?
   e) Can the equipment be properly maintained in the country, if not how and by whom is this going to be organised?

I.5.1.2 Equipment requirements resulting from the chosen drainage method

The equipment requirement follows from the selected installation methods of which there are three to choose from:

- Full manual installation;
- Combined mechanical and manual installation;
- Mechanical Installation.

The conditions and preferred and appropriate type of drainage installation method is discussed in Chapter I.6. Generally speaking, for large areas mechanical installation is the most appropriate methodology. Manual installation and/or a combination of mechanical and manual installation is used only for draining small areas and/or if machines have no access to the site. Each of these methods requires specific equipment:

- Special hand tools have been developed for manual installation consisting of specially designed spades and hooks for placing the clay pipes in position (see Figure 49 and Part II);
- Hydraulic excavators are mostly used for digging the trenches in the combined mechanical & manual installation method. Hydraulic excavators are well-known machines that are available in most countries;
- Mechanical installation necessitates the use of specialised drainage machines, often in combination with excavators, bulldozers and tractors.

This Chapter focuses on mechanical installation while the methodology for manual and combined installation will be described in Part II.

I.5.2 General considerations on the selection of installation equipment

I.5.2.1 Installation equipment

A complete set of equipment is necessary for the installation of drainage systems. The constitution of the set largely depends on the characteristics of the drainage systems and drainage material to be used. A list of the required equipment for an installation unit can be found in Chapter I.6 and I.9 and in Part II. Most of the equipment is support equipment that can also be used for other purposes (tractors, trailers, hydraulic excavators, front loaders etc.) and is not specific to drainage. Since this is equipment that is mostly well known and available in most countries no further comments are needed. Equipment specific to subsurface drainage installation is confined to: drainage machines and to a lesser extent the gravel trailers and backfill equipment. This chapter focuses on the drainage machines.

I.5.2.2 Required characteristics of drainage machines

A drainage machine must be capable of installing a drain pipe at the desired depth with the desired grade with minimal deviations under the prevailing soil conditions. Allowable deviations are plus or minus 25% of the drain diameter. In practice the drainage machines have to install the pipe at the required depth and grade either:
- In a trench (trencher) that is later backfilled, or;
- At the desired location by pulling the pipe in a gallery formed by a knife like device (trenchless machine).

Both methods require near perfect grade control.

Although drainage trenchers and pipe layers or cable laying machines (used for Public Utilities like electricity, drinking water pipes and gas pipes) are very similar at first glance, there are some essential differences. Pipe and cable laying machines dig a trench in which a cable or later a pipe is placed directly. Since within relatively large ranges only depth below field level is important for pipes and cables, these machines are not constructed for precise grade and depth control. For subsurface drainage, however, it is essential to have the capacity to install pipes at the desired depth at a near perfect grade. In general, pipe & cable laying machines do not have the capacity to install agricultural drainage pipes in flat areas with the required precision of grades and depth. In hilly or sloping areas where drains are installed with the slopes, grade control is less of a sensitive issue. On the other hand, drainage trenchers are perfectly suitable for making trenches for pipes or cables.

I.5.2.3 Maintenance requirements for drainage machines

Drainage machines need maintenance, spare and wear parts. Since a considerable amount of hydraulic drives and hydraulic commands is integrated into modern drainage machines, it is essential for maintenance facilities for hydraulic systems to be either available or created. The wear parts consumption, such as the digging knives and chains belonging to drainage trenchers machines is relatively high. These parts are made of highly specialised steel. To permit a continuous and smooth operation it is vital that the supply of these spare parts (including financing and import facilities) is available or organised.

I.5.2.4 Depth and grade control with laser

In order to facilitate the essential depth and grade control and to limit operator errors the facilities for automatic depth/grade control with laser have become standard on all agricultural drainage machines. Laser can directly command the hydraulic valves of the depth regulation (see Part II). Depth and grade control have since the introduction of laser vastly improved. The cost of laser equipment in comparison with the cost of drainage machines is limited (<10%). (The visual depth control as used up to the seventies of last century, although theoretically still possible, is in practices completely superseded by laser depth and grade control. (see ILRI Publication 16, Chapter 21.4.1).

I.5.3 Hydraulic excavator/backhoe

As discussed in Chapter 5.1.2, drain installation with a hydraulic excavator that digs trenches in which drain pipes are placed by hand is an option if:

- No specialised drain installation equipment is available, and/or;
- Only small (trial) areas are to be installed with subsurface drains, and/or;
- It concerns areas where the access of drainage machines is problematical.

The excavation of a uniform graded trench bottom on which the pipe can be laid with the proper grade is difficult and often results in a slow working speed (Figure 32). The depth and grade control under these conditions has to be done with the aid of levelling instruments; the precision is very dependent on the skill of the operator. A laser system can also be used, but this will not automatically regulate the digging depth of the excavator. Proper installation can only be done if there is no water in the trench and the soils are stable. Under unstable soil conditions, installation using an excavator can prove to be an impossible task and/or dangerous for the labourers. Since the hydraulic excavator is a multiple purpose piece of equipment it is often readily available. The cost effectiveness, however, is dependent on the speed of installation and consequently the cost per meter of installed drain.

Figure 32
Hydraulic excavator digging a drain trench

The advantages and limitations of installation of drain pipes by hand in trenches dug by excavators are:

Advantages:

- Excavators are well known and normally readily available;
- Excavators can be used for other jobs if there is no drain installation.

Limitations:

- Proper installation is only possible in stable soils (no caving in of trench) and during periods that there is no water in the trench;
- No automatic depth/grade control is possible and the skill of operators is essential;
- Progress is slow;
- Depth limited because of danger to labourers of trench collapse.

I.5.4 Trencher drainage machines

I.5.4.1 General

The vast majority of drainage machines used worldwide are so-called drainage trenchers or short "trenchers" (Figure 33). Trenchers dig a trench with its bottom at the required depth and the required grade and place the drain pipe on the bottom of the trench. After the pipe has been placed, the trench has to be backfilled either by hand or with motorised equipment (Chapter I.6.8.8). Trenchers are produced in various sizes in a wide range of capacities and depending on the type, can:

- Install pipes to a depth about 3 m (deeper installation is possible but requires specialised equipment);
- Make trenches up to 0.50 - 0.60 m in width;
- Install drain pipes in hard or stony soil with special components (knives, chains) for the trencher (see Chapter I.5.7);
- Work in soils with hard layers using machines that are specially designed for the purpose (see Chapter I.5.7);
- Install drains in unstable subsoils and/or under the groundwater level (in extreme cases special attachments have to be used).

Figure 33 Trencher drainage machine

I.5.4.2 Composition of drainage trenchers

A trencher is basically composed of the following elements (Figure 34):

- Machine frame with the engine;
- Crawler tracks;
- Intermediate frame from where the depth/grade regulation takes place;
- Digging mechanism, consisting of a digging boom and continuous digging chain with digging knives;
- Trench box.

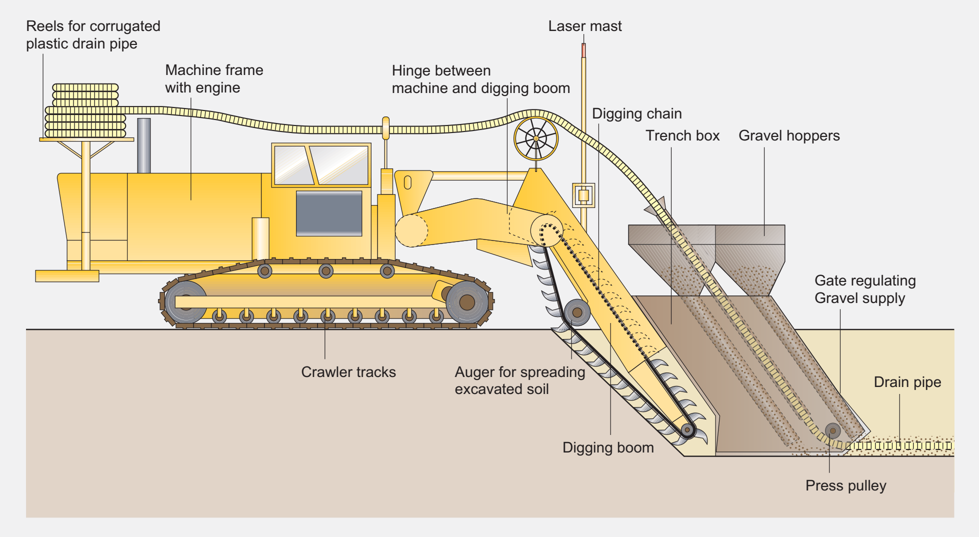


Figure 34 Schematic layout of a trencher showing the main elements

The following attachments/variations are available (Figure 35):

- Two gravel hoppers can be mounted on the trench box (Figure 35a). Chutes from the hoppers guide the granular envelope downwards and subsequently place it under (hopper 1) and above (hopper 2) the drain pipe. These hoppers and guides are only required if a granular envelope is used;
- If a granular envelope is used at the end of the trench box a valve can be installed to regulate the thickness of the granular envelope;
- The trench box dimensions can vary according to the desired depth of the drain installation and the width of the trench. The required width of the trench can be determined as: the diameter of the largest pipe to be installed+ the thickness of the envelope + the thickness of the trench box sides (2 x 25 mm). The thickness of a granular envelope is often taken as 2 x 75 mm. The trench width should not be not too large since most of the energy for the installation is used up in the digging exercise and the more soil volume is dug out the more energy is required. If the trenchers are used for installation at a variable depth, a change of trench box and length of digging boom can be advantageous, for instance, when collector trenchers are used for field drain installation;
- The knives on the digging chain and the distance between the knives can vary in accordance with the soil conditions;
- Part of the digging mechanism is an auger to transport the excavated soil to both sides of the trench. In the case of deeper and wider trenches, the amount of soil may be too much to handle by an auger and so a conveyor belt is used (Figure 35b);
- The commands of the hydraulic valves of the intermediate frame can be connected to the electronics of the laser equipment for automatic manipulation by the laser (this is practically standard);

a.

b.

c.

d.

e.

f.

g.

Figure 35 Attachments to trenchers: (a) gravel hoppers; (b) conveyor belt; (c) water tank; (d) water sprayer alongside the trench box; (e) blinding device; (f) reel for corrugated plastic pipe, and (g) platform for pipes

- A water tank can be installed on top of the engine to feed a water spraying installation that lets water flow along the outside of the trench box (Figure 35c&d). This prevents the clay from sticking to the trench box in heavy clay soils;
- For corrugated plastic drain pipes delivered on rolls, reels can be mounted on the trencher with hydraulically operated hinges (Figure 35f). The rolls can be loaded on these reels and guiding devices guide the drain pipes towards the trench box. The pipe feeding and guiding devices have to be designed to accommodate the largest diameter drain pipe;
- In the rare instances when clay or concrete pipes are used, a platform can be built on the machine to store pallets of drain pipes (Figure 35g). A crane can also be built on the trencher to lift the pipe pallets onto the platform;
- A so-called blinding device can be attached to the trench box for scraping some of the topsoil off the trench behind the trencher (Figure 35e). This soil covers and stabilises the just installed drain pipe. This device can only be used on stable homogeneous soils. In other soils it can disturb the depth regulation of the trencher;
- If, for the installation, a trencher has to work in liquid soils with a granular envelope, a gravel extruder can be mounted to extrude under the pressure the granular envelope surrounding the pipe;
- Trenchers can be equipped with retractable crawlers. The width of the crawler can be increased for more stability. The crawlers can be retracted for transport;
- The cabin and the control panel of the trencher can be either mounted on the chassis or on the digging boom. If the trencher is not equipped with laser the cabin needs to be positioned on the digging boom to make visual grade control possible. In case of grade control by laser the cabin can be positioned in either place. Mounting of the cabin on the chassis is generally more comfortable and gives less disturbance of the installation depth caused by staff moving in and out of the cabin.

I.5.4.3 Sizes of trenchers

The engine power of the most commonly used trenchers ranges between 100 and 400 HP (70 -300 KW). Lighter types have an engine power of up to 200 HP (150 KW) and weigh about 8-10 tons. This type is mostly used for shallow drainage (routine < 1 m maximum 1.5 m), often in parks, for sporting facilities or in horticulture. The medium-sized drainage trenchers have an engine power of around 300 HP (225 KW) and can install pipe drains up to a maximum depth of 2- 2.5 m and trench width of around 0.30 m. They weigh around 20 tons and are mostly used for field drain installation. The heavy drainage trenchers have an engine power of around 400 HP (300 KW) and can install pipe drains up to a maximum depth of 3 m with a trench width of around 0.40 - 0.50 m. They weigh around 23-25 tons and in extreme cases up to 40 tons and can be used for larger diameter collectors. Larger drainage trenchers with more power are used for special conditions like in rocky soil.

I.5.4.4 Types of trenchers

Among the several principles and models have been tried out and used over the years, the major developments were as follows:

- The initial trenchers were fitted with a bucket wheel type digging mechanism (Figure 36a). Although they are still used in some parts of the world they are outmoded and cannot deliver the required exactness of depth and grade control;
- Trenchers mounted on and behind wheel tractors (36b). These are sometimes used on sloping areas for shallow drains. For flat areas they lack adequate depth and grade control;
- Trenchers with a so-called "flat digging chain" have been used in the past in softer soils for shallow drain installation. Machines with flat digging chains have no intermediate frame and the digging mechanism is attached to the frame of the machine. The variation of depth is obtained by varying the vertical angle of the digging boom;
- Trenchers consisting of a separate digging mechanism and trench box that is pulled by a crawler tractor and activated by the power take off (PTO) are used for shallow drain installation in some parts of the world. The depth/grade control is not adequate;
- Trenchers mounted on tracked machinery with trench boxes and a so-called vertical digging boom that are attached to intermediate frames (parallelogram construction) are currently the most common and universally applied (Figure 33).

a. b.

Figure 36 Bucket-wheel type trencher on tracks (a) and mounted behind a wheel tractor (b)

I.5.4.5 Advantages and limitations of installation of drain pipes with a trencher

Advantages

- High speed of installation: 2000 m/hr at the maximum with an overall installation output of 1.5-2.5 km per day, depending on the logistics supporting the machine. The installation speed per hour is of limited significance, since it does not take into account the preparation time, time required for starting the drain at the correct level, the time to drive

back to the next drain after completion etc. Thus, the actual installation speed per day that takes these factors in to account is of more practical value during the planning phase;
- Next to perfect depth and grade control is possible;
- All currently known envelopes can be applied;
- Trenchers are available/adjustable for a wide range of depths and trench width and soil conditions;
- Trenchers can be easily coupled to depth/grade control devices based on laser technology;
- The backfilled trench generally has a limited flow resistance and can improve drainability of the soil.

Limitations
- Practically speaking, trenchers can only be used for drain installation;
- Digging knives/chains wear out continuously and must be replaced with parts made from specially hardened steel;
- Well-trained handling and maintenance is needed;
- The full potential and depth control of trenchers can only be used for installing either corrugated (flexible pipes) or small clay or concrete pipes with a maximum length of 1 m. The trencher can prepare the trench for installing rigid pipes of greater lengths. The pipe has to be deposited in the trench later after the machine has completed the trench.

I.5.5 Trenchless drainage machines

I.5.5.1 General

The technique of trenchless drain pipe installation has been developing since the late 1960s/early 1970s. 'Ploughing-in' of drains became possible with the introduction of the flexible corrugated plastic drain pipes delivered on coils. These pipes can make the rather sharp curves at the spot where the pipe leaves the machine. With the trenchless installation technique a blade is pulled through the ground to break and lift up the soil to make room for the pipe, which is guided into position through the hollow part of the blade, or through a pipe guide trailed behind the blade.

Trenchless drainage machines can work faster than trenchers and suffer less wear and tear. However, they require more power for the same installation depth than the trenchers. A daily installation output of 4 km/day is not uncommon in a logistically well-organised environment.

These machines can install only corrugated plastic pipes of limited dimensions (Ø 100 - 25 mm). If envelopes are required only pre-wrapped envelopes can be used; no granular envelope can be installed. The maximum depth of installation is 1.8 m, however an average depth range of 1.4 m - 1.5 m is a more realistic figure.

Trenchless drain installation is quite common at present in Western Europe and North America. The main reason is that under the economic conditions in these countries with high labour costs and relatively shallow drain installation, trenchless installation is faster and cheaper. The application of trenchless drainage in irrigated areas in arid and semi-arid zones is rather limited because the limitation in depth. Up to now very limited experience has been obtained in these areas, the only well documented experiences are: the use of a plough-type trenchless drainage machine in the Mardan SCARP project in Pakistan and the RAJAD project in India (both projects are discussed in Part III) and the testing of a V-plough in Egypt (see Bibliography).

I.5.5.2 Composition of trenchless machine

A trenchless machine consists of a machine frame with the engine mounted on crawler tracks and an installation blade hinged to the machine frame. The hinges can be operated hydraulically to regulate the depth of the installation (Figure 37).

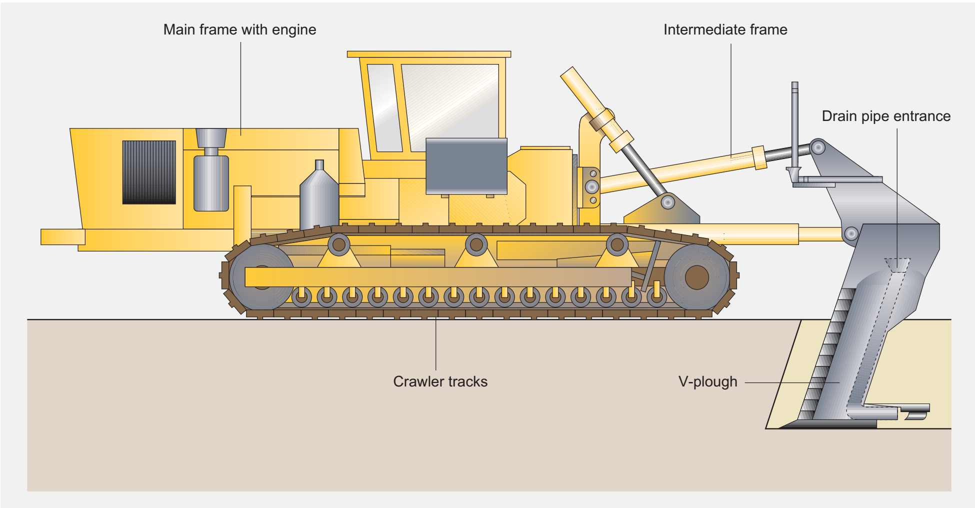


Figure 37 The hinges of a trenchless drainage machine can be operated hydraulically to regulate the depth of the installation

Tracks

A trenchless drainage machine has a much higher traction requirement than a trencher. The engine power is almost completely transferred to the tracks, whereas with a trencher the power is mostly transferred to the digging chain. The tracks used for trenchless drainage machines are therefore different than the tracks for trenchers. Trenchers are equipped with "Triple Grouser" plates. These tracks function well under dry conditions but do tend to slip, especially on wet soils. If the field conditions are too wet vertical plates or so-called cleats can be mounted on the Triple Grouser plate for extra traction (Figure 38a). The mounting process is a time-consuming job. Moreover, cleats cause more vibration and wear and tear on the machines. A second best alternative is to use "APEX" plates with delta shaped enlargements (Figure 38b). Tracks with these types of plates can also be used on dry fields with minimal vibrations and give sufficient traction on wet fields.

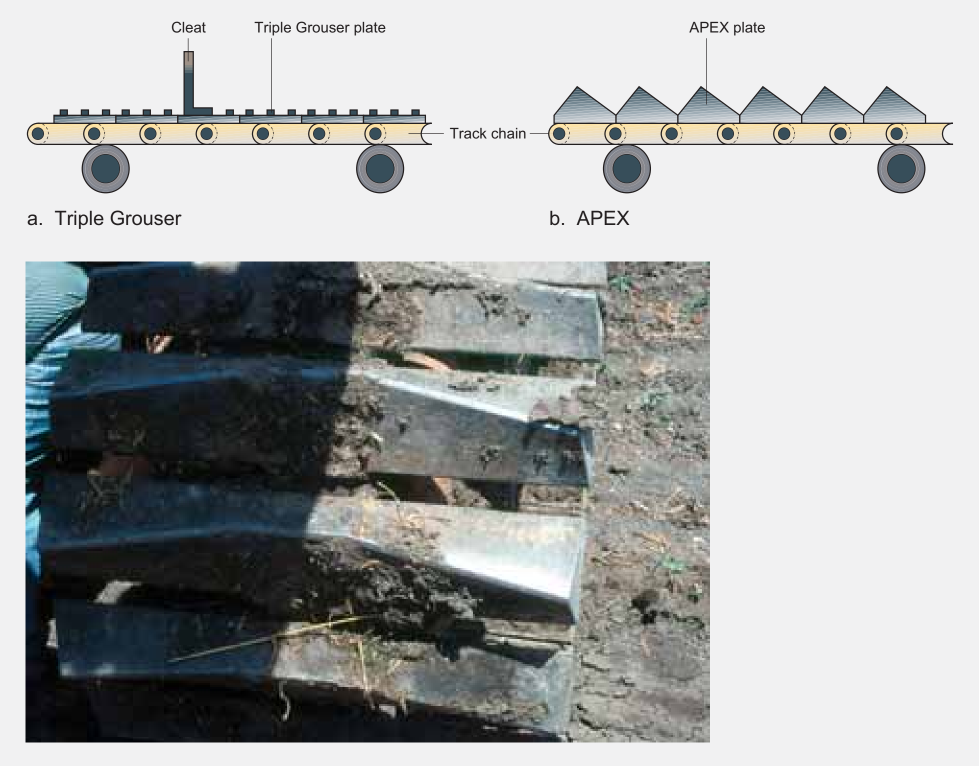


Figure 38 Tracks used for trenchless drainage machines: a) Triple Grouser plate and; b) "APEX" plates

Engine and engine power

Trenchless machines require higher engine power than trenchers, because these machines are heavier and because ploughing the soils at high speed requires more energy than digging. The power is almost exclusively used for traction. The power requirement increases with the square of the installation depth.

Generally speaking for installation to 1.8 m (maximum) the power requirement is in the range of 400 HP (300 KW) and weights of the trenchless machines are around 30 tons.

Installation blades

Two main types of trenchless drainage machines are presently used:

- *Subsoiler type blade*. The vertical plough acts as a subsoiler (Figure 39). In some soil types and under specific moisture conditions, the soil is lifted up to a limited depth and large fissures and cracks are formed. If these extend down to the drain depth, the increased

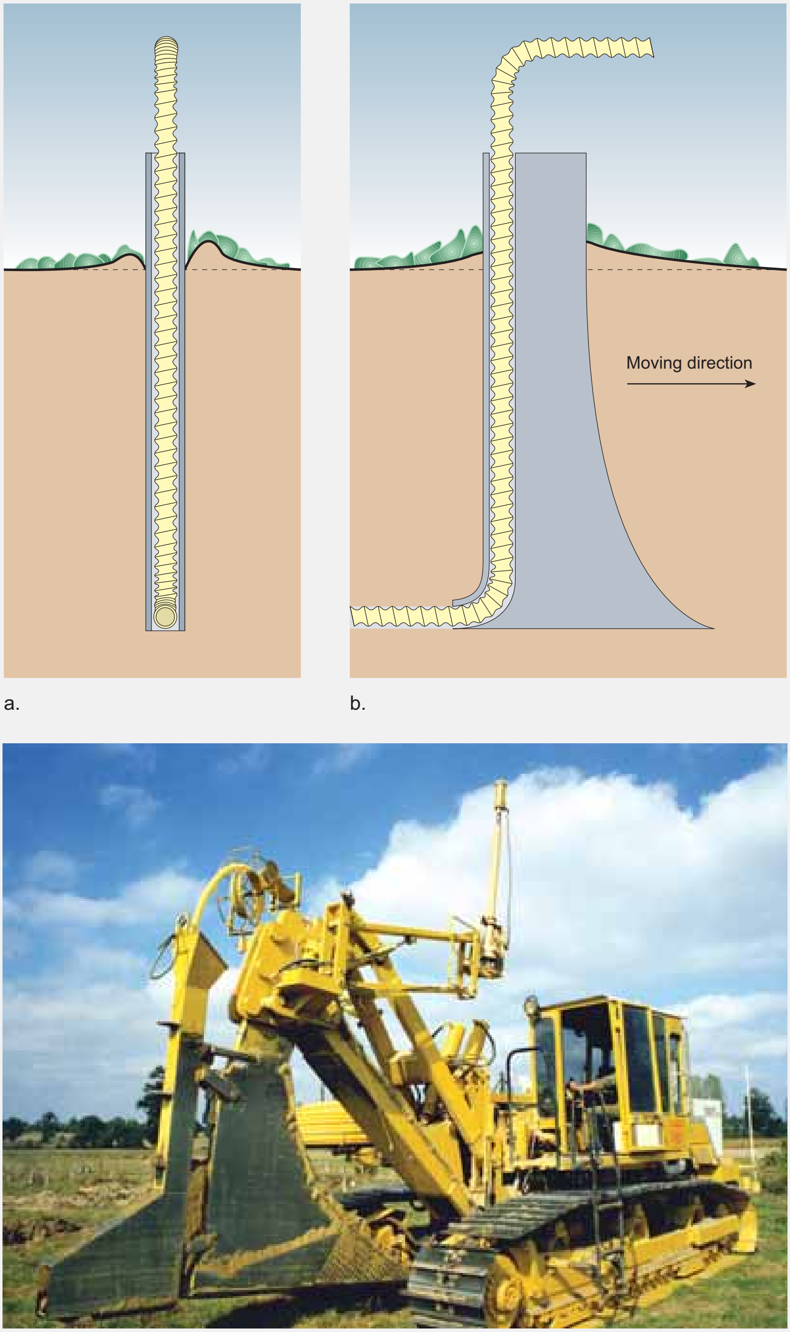


Figure 39 Trenchless drainage machine: subsoiler type

permeability leads to a low entrance resistance and an enhanced inflow of water into the pipe. Beyond a certain critical depth, however, the soil is pushed aside by the plough blade instead of being lifted and fissured. This results in smearing, compaction, and destruction of macro pores, reducing the permeability and increasing the entrance resistance. The critical depth depends mainly on the soil texture and water content during pipe installation. Soil resistance is higher in fine-textured soils than in coarse-textured ones;

- *V-plough type blade*. The V-plough lifts a triangular "beam" of soil while the drain is being installed (Figure 40). The corrugated drain pipe is conveyed through one "leg" of the V-plough. With this type of blade the problem of soil compaction does not arise and the required traction is also somewhat less than with the subsoiler type. The V-plough in Figure 40 can be equipped with a roller that runs over the uplifted soil when the machine drives back to the next drain to install to compact it. A drain can only be installed from the outlet in an upstream direction.

I.5.5.3 Advantages and limitations of installing drain pipes with a trenchless drainage machine

Advantages

- High installation speed (net installation speed up to 4 km/hr, daily installation of 4-5 km);
- Less wear of the pipe laying implement as there are no revolving part;
- Lower drain installation costs in western countries;
- Less damage to soil surface and crops;
- No need to backfill trenches.

Disadvantages/limitations

- Only suitable for flexible corrugated plastic pipes delivered on coils;
- Limited to smaller diameter pipes;
- Only suitable for pre-wrapped envelopes;
- Maximum attainable depth approximately 1.8 m;
- Trenchless machines are heavy and require large tracks;
- High traction required which can cause smearing of topsoil;
- Difficult to install under wet conditions. The grip of the tracks on the land surface is more critical;
- Installation cost increases with depth more than in case a trencher is used (Chapter I.5.6.1);
- Depth and grade control: only possible by laser. Manual depth regulation not possible;
- No possibility of visual inspection of correct positioning of drain pipe or correction;
- Possible compaction of soil around the pipe;
- Cannot be used in unripe soils in reclamation areas, as the drains only begin to function when soil has ripened around the drain and this may take many years.

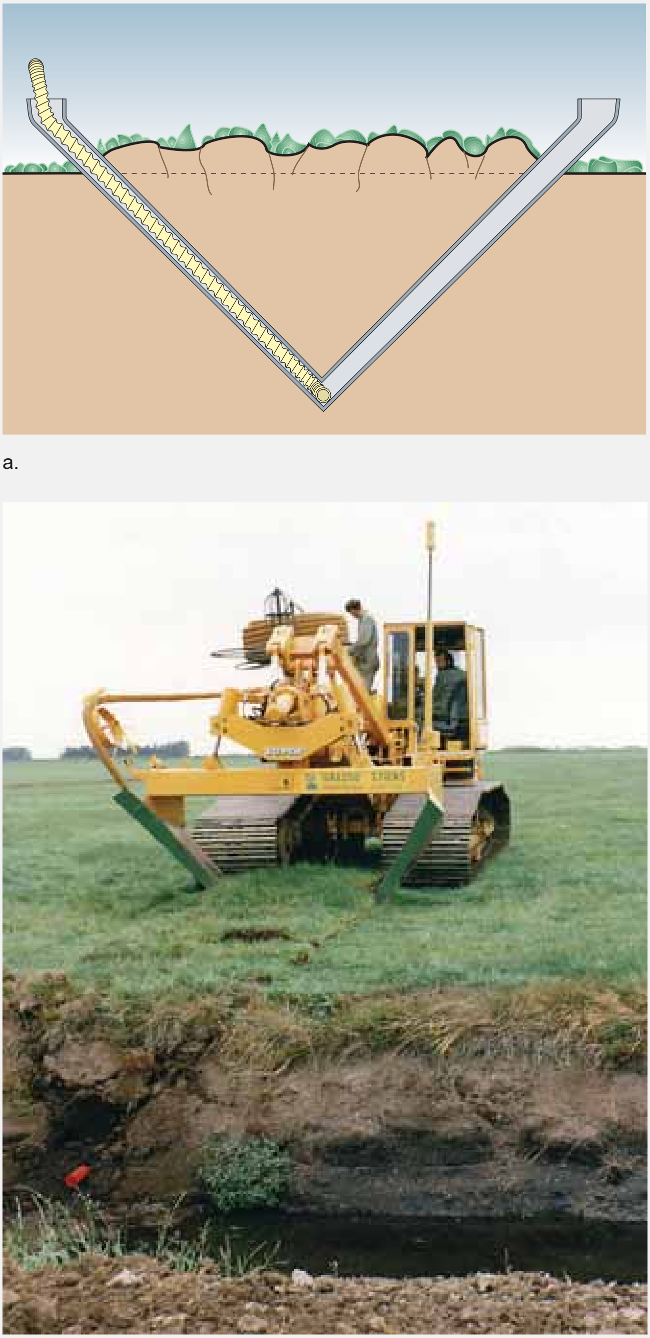


Figure 40   Trenchless drainage machine: V-plough type

I.5.6 Comparison of capacities and cost of drainage installation machinery

I.5.6.1 Cost comparison of trenchers and trenchless installation

The cost of trencher installation and trenchless installation is dependent on many local factors. A study in the Netherlands in 1990 revealed that at shallower depths trenchless installation is cheaper than trenching (Figure 41). The cost of trenchless drain installation, however, increases disproportionately with depth compared to the higher cost of trenchers.

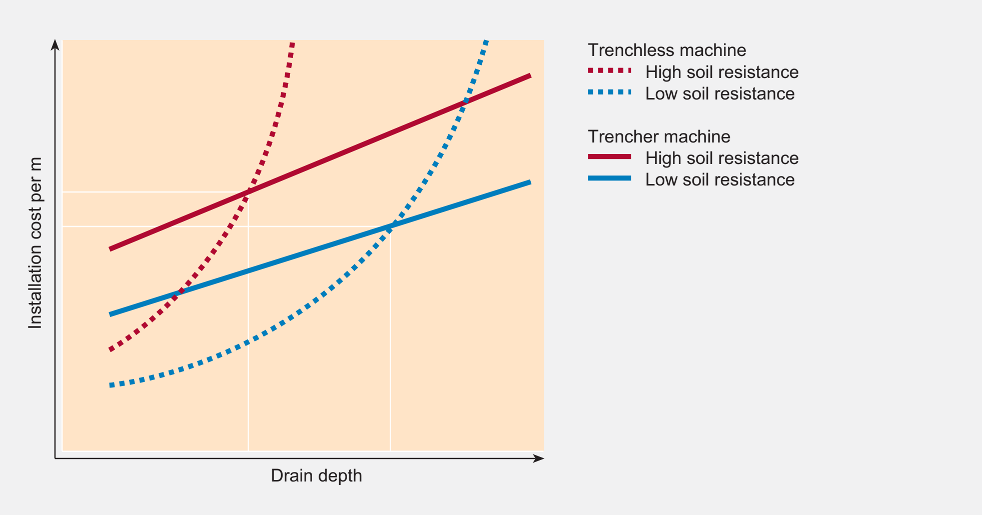


Figure 41 Cost comparison of trenchless and trencher drain installation

I.5.6.2 Capacity of drainage machinery and supporting equipment

The technical capacity of drainage machinery can be obtained from the manufacturer. An indication the average capacity of the main types of machines is presented in Table 5.1.

The actual implementation capacity depends on the organisation of the logistics, maintenance, skills of operators, etc., and consequently largely on the local conditions. The capacities of the drainage machines and the supporting equipment are decisive factors for the implementation of drainage projects. Time estimates with respect to the drain pipe laying activities (collector drain/ lateral drain) can only be made if these data are available. The actual production of a drainage machine is influenced by a number of factors, such as:

- Operator capability;
- Age of the drainage machine;
- Type of drainage machine;
- Weather conditions;

- Soil conditions;
- Drain depth;
- Net operating time (effective time);
- Type drain pipe (PVC/PE or concrete pipes);
- Application of granular or pre-wrapped envelope.

Table 5.1 Drainage machines and their technical capabilities

Machine type	**Excavator**	**Trencher**			**Trenchless**	
		Light	**Medium**	**Heavy**	**Subsoiler**	**V-plough**
Power (HP)	100-200	200	250-350	350-450	325-525	325-525
Power (KW)	75-150	150	185-260	260-340	245-400	245-400
Weight (tons)	15-25	8-10	18-20	20-30	30-35	30-35
Average installation speed [a] (m/hr)	150	800	800	450	2500	2500
Installation depth (m)	2.0 m	1.5	2.0 m	3.9m	< 2.0m	< 2.0m
Trench width (m)	0.60 and up	0.20-0.30	0.20-0.45	0.20-0.65	No trench	No trench
Drain pipes (type)	All types (including rigid pipes)	Clay, concrete, corrugated plastic			Only corrugated plastic pipes	
Drain diameter (mm)	Not specified	< 200	<200	<400-500	Up to 200	Up to 125
Envelope material	All types	All types	All types	All types	Pre-wrapped	Pre-wrapped
Depth control	Manual	Manual + laser	Manual + laser	Manual + laser	Only Laser	Only Laser
Stony soil	+	-	-	-	+	+/-
Damage to crop and soil surface	Yes	Yes	Yes	Yes	Little	Very little
Visual quality control	Yes	Yes	Yes	Yes	No	No
Unstable soil	No	Yes	Yes	Yes	No	No
Wear parts	Less significant		Significant		Less significant	
Comparative Investment cost (general indication only)	80%		100%		140%	

[a] Installation speed of a trencher depends on soil type, digging depth, trench width and machine power. Under normal soil conditions, the installation speed can be calculated by using the formula: I = HP/E, where I = installation speed (m/hr), HP = horse power of the trencher and E = m^3 of soil excavated per m' drain (= drain depth x trench width). For hard rock conditions I = HP/3E.

Taking all these factors into consideration, it is seldom that more than 50% of the theoretical capacity is actually realised. Part II (A.2) discusses how standards and norms for the capacity of drainage machines and support equipment can be obtained through operational research or monitoring during implementation. Based on operational research the capacity and efficiency of lateral and collector laying drainage machines (trenchers) can be calculated. An example for Egypt is presented in Part III.

Operational research data can be used to determine the number of new machines required to implement the annual plan of a drainage organisation or department. Not only can the duration of the pipe laying activities be estimated, it is also possible to calculate the total capacity of all drainage machines operational in a certain country or region, or the capacities of individual contractors, and so forth. The data can also be used for awarding drainage contracts. Contractor estimates can be checked more easily when installation figures are sufficiently known. Furthermore, the figures can be used for monitoring individual projects. If there is a fixed period during which the drainage project has to be implemented the number of machines required can be calculated.

Data can also be used by mechanical sections in organisations for decision-making on the procurement of new equipment. The capacity and efficiency and performance of different kinds of drainage machines can be compared as well as the assessment of the performance of different machine under various field conditions.

Capacity of supporting equipment

The capacity of supporting machinery, like bulldozers, excavators, etc., is generally well known by local construction units or contractors. Work norms for the *bulldozers* to clear the surface of the drain line or to backfill the drain trench have to be assessed so that the duration of these activities can be estimated. The duration of transport of materials to the site by *trailers* and tractors or *trucks*, and the amount transported to the site are also important data for planning.

I.5.7 Specialised drain installation machinery

Besides the drain installation machinery described above, the machinery designed for special conditions includes:

- Hard rock trenchers;
- Trenchers for orchards;
- Dewatering equipment.

I.5.7.1 Rock trenchers

Installation of drains in soils with hard layers requires a great power source and special cutting knives or bits at the digging chain of the trencher. There are machines that have been specially designed for very hard soils that have been used in desert reclamations areas (Figure 42).

a. b. c.

Figure 42 Rock trencher (a) with special knives at the digging chain (b,c)

I.5.7.2 Drain installation machines for orchards

Proper drainage is also vitally important for orchards to obtain good quality fruits and high production. Drains have to be installed in between the row of the fruit trees. Because the space between the rows is rather narrow the design of the drainage machine is such that it enables the drains to be installed without damaging the trees. As can be seen in Figure 43: the reel accommodating the coils of the drain pipe are placed high above the operator and can be lowered in front of the machine to put a new coil of drain pipes on the reel. Another feature is that the machines have narrow tracks.

Figure 43
Drainage machine operating in orchards

I.5.7.3 Dewatering equipment

Horizontal well pointing machines
The dewatering equipment has been developed to install concrete collector drains in unstable/liquid subsoils. Essentially, it consists of installing a drain at a great depth (4-5 m). This drain is connected to a pump. By pumping the watertable is lowered, so that the collector drain can be installed in a stable environment. After installation, the pumping is stopped and ground

water rises again (Figure 44). The pipe is installed by a machine that resembles a trencher (Figure 5.14), but with a vertical digging chain and no trench box. The trench usually collapses immediately behind the machine. Depths of more than 6 m are feasible with a horizontal dewatering machine.

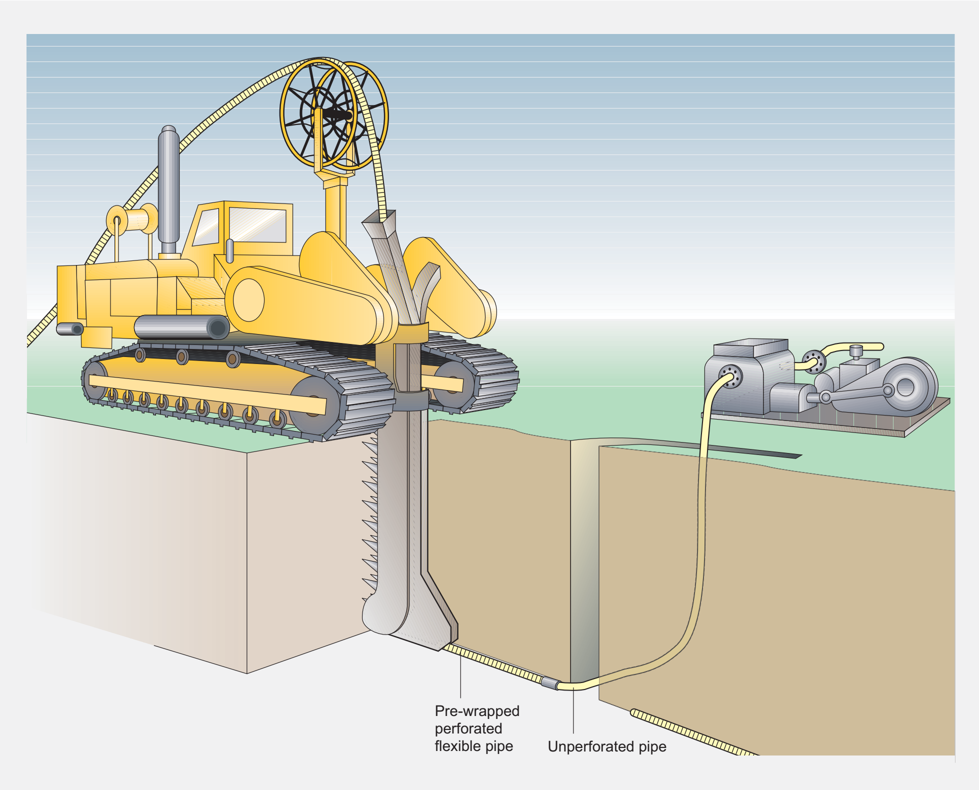


Figure 44 Installation of horizontal dewatering pipe

Figure 45
Horizontal dewatering machine

I.5.8 Specialised drain installation support equipment

The specialised support equipment can be confined to:

- Gravel trailers;
- Backfilling equipment;
- Transport equipment.

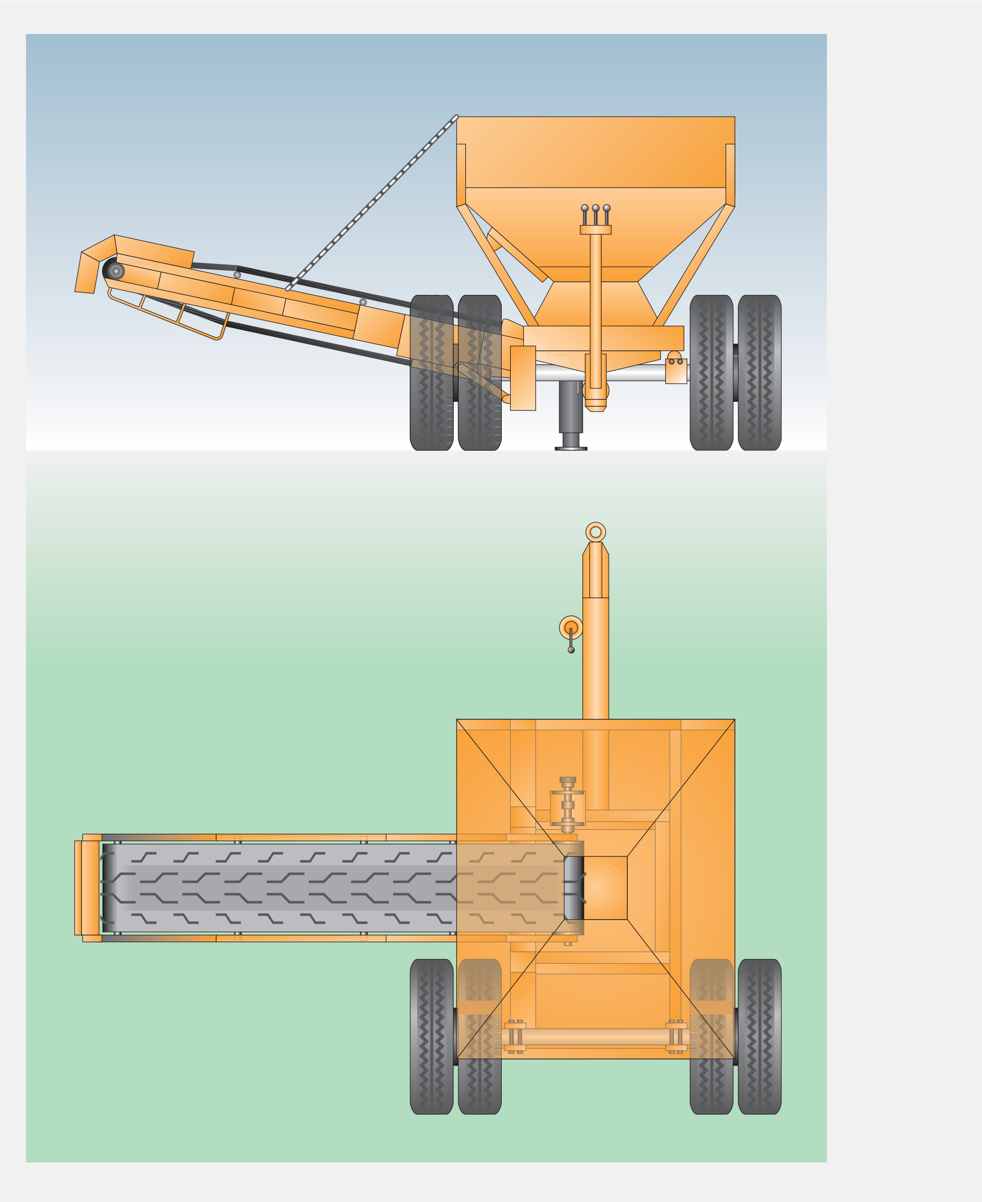


Figure 46 Schematic layout of a gravel trailer

Gravel trailers

A gravel trailer consists of a wheel-mounted hopper with a conveyor belt (Figure 46) and is pulled by a tractor. The tractor is driven parallel with the trencher, while the conveyor belt unloads the granular envelope into the gravel hoppers on the trencher. The conveyor belt is either mechanically activated by PTO (power take off) of the tractor or hydraulically by the hydraulic pump of the tractor. A gravel trailer has a load capacity of some 4 m^3 (approximately 8 tons!), which is adequate for some 100 m of field drain of Ø 80 mm. Efficient uninterrupted operation of each trencher requires three gravel trailers (one unloading, one loading, one travelling). The construction of a gravel trailer must be sturdy enough to bear the weight of the gravel trailer.

a.

b.

Figure 47 Backfill equipment: tractor with dozer blade (a) and V-shaped disc-blade mounted at the rear end of a subsoiler type trenchless drainage machine (b)

Backfilling equipment
Numerous motorised solutions are used for backfilling including (Figure 47):
- Bulldozer driven perpendicular to the trench;
- Angle dozer driven parallel with the trench;
- V-shaped disc-blade mounted on bulldozer or tractor;
- Grader;
- Levelling blade on tractor.

The most appropriate system depends on the available machinery and soil type. The dryness of the soil to be backfilled can be a determinant for the choice of the equipment.

Transport equipment
Transport over longer distances of drain installation machines that are track mounted has to be done with low loaders (Figure 48) as track mounted equipment is not designed for road transport and will damage the roads and the tracks.

Figure 48 Transport of drainage machine using a deep loader

I.6 Installation of Subsurface Drainage Systems

I.6.1 Introduction

The implementation authority has to be instructed on how to install the pipe drainage systems. The installation method has far-reaching consequences for the speed of installation, the required equipment, the total cost and total investments to be made. The following installation methods can be considered:

- Manual installation;
- Combined mechanical and manual installation, (installation of pipes by hand in trenches dug by excavators);
- Mechanical installation.

Mechanical installation is the most common method for large-scale installation, using trenchers, excavators, bulldozers tractors, gravel trailers, laser equipment and pumps. It is the best cost and quality effective method. Special circumstances calling for other installation methods include:

- Non-availability of specialised drain installation equipment;
- Only small (trial) areas require to be installed with subsurface drains;
- Areas where the access of drainage machines is problematical.

This Chapter places the emphasis on the mechanical installation of subsurface drains. Manual and the combination of mechanical and manual installation will only briefly be touched on in Part I, but guidelines for manual installation are included in Part II for the sake of completeness.

Box 6.1 Installation methods: major decisions during the planning phase

During the planning phase, the authorities concerned have to decide on:

- The most cost effective and functional installation method to use under the given conditions;
- The equipment, personnel, organisational set up and investments needed for the chosen installation method.

I.6.2 Installation methods

I.6.2.1 Manual installation

Digging trenches by hand and placing the pipes in the trenches by hand was common practice in the past and is still practiced sporadically. Special tools have even been developed for manual installation (Figure 49). Manual installation is a possible alternative:

(i) If the groundwater is not high (placing a pipe at a desired grade under water is practically impossible);

(ii) If the depth is limited (<1 m, greater depth is only feasible under certain conditions with stable soils and seasonal watertables below drain depth).

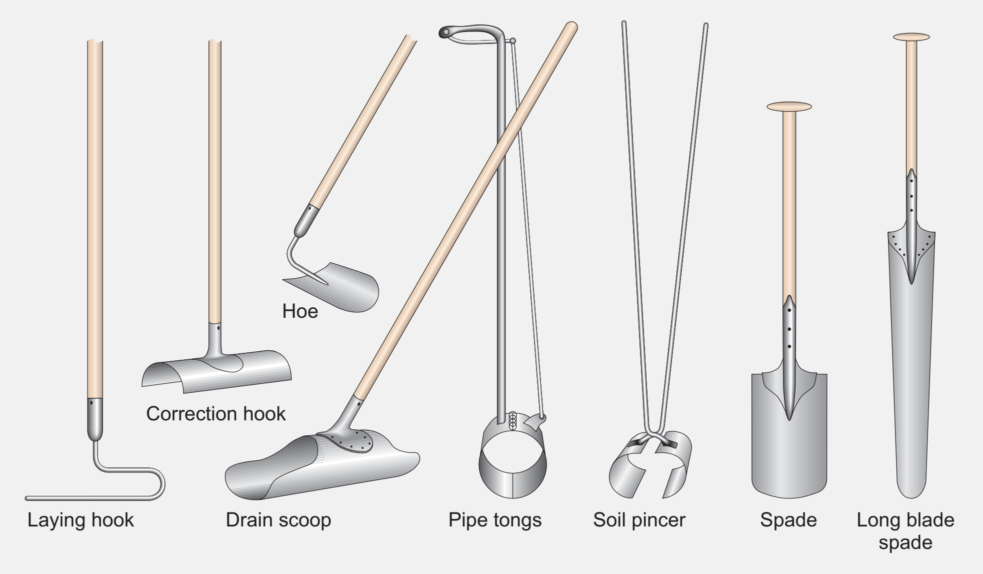


Figure 49 Special tools have been developed to install drains by hand

The process of manual installation is slow and very labour intensive. For example, in the relatively light soils in the Netherlands the standard was around 25 m'/person/day at a depth of 0.8 m and 13 m'/person/day at a depth of 1.5 m (Case The Netherlands in Part III). Grade control also requires particular skill and care of the installation crew. Manual installation in unstable soils with high watertables and installation at greater depths is perhaps theoretically possible, but is not recommended. The economics of manual installation depends entirely on the cost and availability of labour. In general, manual installation is more expensive than machine installation. For example, in 1986 and 1987, the contractor rate for the manual installation of pipe drains in India was about € 1.10 per meter compare to € 0.35 per meter of machine installation in The Netherlands (Bibliography: Ochs and Bishay 1992). See for installation instructions Part II, Chapter C.32.

I.6.2.2 Combined mechanical and manual installation

The combination of mechanical and manual installation consists of digging trenches with hydraulic excavators and placing the drain pipes into the trench by hand (Figure 50). The excavation of a uniform graded trench bottom on which the pipe can be laid with the proper grade is difficult and the progress of the work is often slow. The depth and grade control under those conditions has to be done with the aid of levelling instruments; consequently the precision is very much dependent in the skill of the operator. A laser system can also be used, but this will not automatically regulate the digging depth of the excavator. Proper installation can only be done if there is no water in the trench and the soils are stable. Under unstable soil conditions installation with an excavator is practically impossible and/or can be dangerous for the labourers.

Figure 50 The combination of mechanical and manual installation consists of digging the drain trench with a hydraulic excavator and placing the drain pipes into the trench by hand (Example Segwa Drainage Pilot Area, Navsari, Gujarat, India, for more details see Part III)

Since a hydraulic excavator is a "multipurpose" piece of equipment it is often readily available. The cost effectiveness, however, depends on the speed of installation and consequently the cost per m of installed drain. See for installation instructions Part II, Chapter C.33 and the example in India in Part III.

It can be concluded that manual installation of drains in trenches dug by excavators has the following advantages and limitations:

Advantages

- Excavators are widely known and normally readily available;
- Excavators can be used for other jobs if there is no drain installation.

Limitations

- Proper installation is only possible in stable soils (no caving in of trench) and when there is no water in the trench;
- No automatic depth/grade control is possible and the skill of operators is essential;
- Progress is slow;
- Depth is limited because of risk to labourers of trench collapse.

I.6.2.3 Mechanical Installation

Mechanical installation consists of installing the drains either with a trencher or a trenchless drainage machine. With this method drains can be installed in most conditions with an automatic depth and grade control, either above or under the water level. The organisational requirements for the full mechanical installation methods, which are to be taken into account during the planning phase, are discussed below.

Drainage machines are expensive pieces of equipment that cost a few hundred thousand euros. The technical lifespan of these machines is at least 10,000 hours or some 10 years. The purchase of a drainage machine may not be economically justified if only small areas are to be drained and no extensive areas are to be equipped with subsurface drainage systems in the near future. Besides renting, temporary import, and so forth, other installation methods can also be considered, although these are not always optimal.

I.6.3 Machinery and equipment requirements for mechanical installation

The machinery and equipment required for installing drains depends on the selected:

- Drainage method;
- Layout of drainage system;
- Drainage materials.

Table 6.1 presents a list of suggested machinery and equipment for the mechanical installation of composite and singular drainage systems with either granular envelopes or with pre-wrapped envelopes. The list is based on the assumption that two trenchers are set to work in the same installation unit. Not included is the equipment required for the transport of the gravel and drain pipes to the field, nor the requirements for making electrical connections for the sump pumps, if applicable. It is assumed that these tasks will be carried out under contract by the relevant organisations. Included are the general and infield transport facilities for personnel, which of course will be locally determined. Efficient installation, including prevention of waiting times, requires adequate transport both to and in the field. The rapid development of the use of mobile phones (cell phones) and walky-talkies as infield communication between the different units has proven to improve efficiency by reducing waiting times. The extent to which this can be realised depends on local conditions. Investment costs of the machinery and equip-ment are discussed in Chapter I.9.

Table 6.1 Suggested list of machinery and equipment require for pipe drain installation for a composite and singular system with and without granular envelope, respectively (requirements for granular envelopes given in italics)

Item	Quantity		Remarks
	Composite	Singular	
Field drain installation machine with laser	1	2	If gravel is used trencher to be equipped with gravel hoppers
Collector installation machine with laser	1		Machine to be adjustable for field drain installation, equipped with gravel hoppers if gravel is used
Laser transmitter	2	2	Matching laser receivers on installation machines
Battery charger for laser	1	1	Not required for modern laser
Hydraulic Excavator	2	1	For making start holes and manhole/sump installation. Not required for singular system in case of start from open ditch.
Gravel trailer	*6*	*6*	
Tractors for gravel trailers	*6*	*6*	*> 75 HP*
Bulldozer	1 - 2	1 - 2	Field preparation/trench closing/support
Front loader	*1*	*1*	*For loading of gravel into gravel trailers*
Agri. tractor & trailer	2	2	Infield transport op pipes etc.
Dewatering pump	1 - 2		Facilitation manhole placement
Fuel tanker & tractor	1	1	Infield fuel supply possibly contracted to fuel supplier
Servicing/maintenance truck (or pickup)	1	1	
Topographic equipment	2	2	Mainly levelling instruments
Cars	1 - 2	1 - 2	For fast transport to field
Motor cycles	1 - 2	1 - 2	Mainly in field transport
Bus for personnel transport	1	1	If necessary
Communication equipment			Depends on local conditions

I.6.4 Organisation and staff requirements for mechanical installation

I.6.4.1 Organisational set-up for mechanical installation

Mechanical installation requires a well-defined organisational set-up. There are no hard and fast rules for the organisation, but it must be geared to the available equipment, the drainage system, the drainage materials to be used and the local customs. The set-up presented in Figure 51 has proved to be effective for the implementation of various drainage projects.

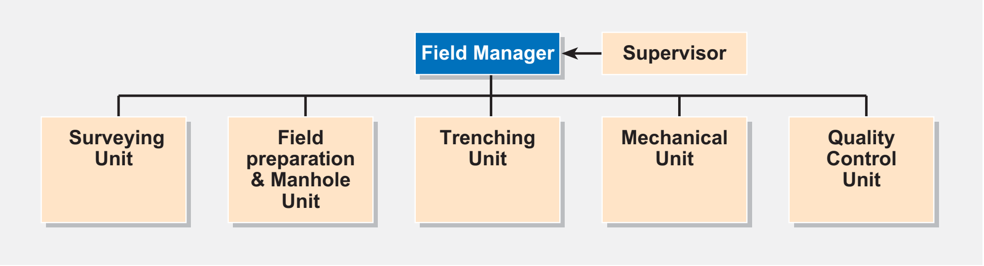


Figure 51 Example of an organisational setup of a drain pipe installation unit

I.6.4.2 Task requirements for mechanical installation

The Staff needed for the construction of subsurface drainage systems vary from project to project. The Staff requirements, including their tasks, for a typical project are presented below. Depending on the situation, the allocation of tasks can vary. The Field Staff of the contractor is normally checked by supervisors representing the implementation authority and/or the beneficiaries.

Field manager
The task of the field manager is the overall management of the installation process. Furthermore, he can be responsible for the coordination of the supply of drainage materials (pipes, gravel, manholes, sumps) and the transport thereof to the site. Whether or not the job can be combined with the supervision of other aspects of the implementation of drainage systems depends on the volume of work.

Surveying Unit
The surveying unit is responsible for:
- Setting out the drainage system (with pegs in the field indicating where the drainage system will come, where the manholes are to come etc.);
- Giving reference levels for the installation of the drainage system (for adjustment of the laser);
- Managing the laser: transporting, charging and setting up the emitter and adjusting the slope;
- Giving levels for installation of manholes and checking the levels during installation.

The survey group may be linked to the quality control group.

Field preparation and manhole unit
The field preparation and manhole group will be responsible for:
- Physically preparing the field, including clearing and smoothing the alignment of the field and collector drains (closing ditchers, removing banks, trees etc., restoring the drains and irrigation canals after installation);
- Making start holes for the trenchers with an excavator, if required;

- Installing manholes and sumps (if relevant);
- Providing all required construction assistance (for instance making of drain bridges);
- Closing drain trenches after installation.

Trenching unit
The trenching unit will have the task of:
- Preparing the pipes for installation (check on the quality) and, if required, laying them out in the field;
- Installing the pipes;
- Managing and applying the granular envelope;
- Carrying out daily maintenance on the machinery (in cooperation with the Mechanical O&M group).

Mechanical O&M unit
The mechanical O&M unit will:
- Carry out with the operators the daily maintenance on all equipment, including oil changes minor repairs, routine inspections etc.;
- Organise the fuel supply fuel to the machinery in the field;
- Advise the field manager on stoppage of the machines if required for technical reasons;
- Prepare major maintenance.

Quality control unit
The tasks of the quality control unit are:
- Checking the quality of the installation (mainly levels of drains installed) (This task can be combined with the surveying group).

Supervisor
The supervisor or supervising unit, as representatives of the implementing authority, has to check and verify if the works are carried out according to the standards and specifications. Supervision can be done in a passive or active way. In the latter case, the supervisor has taken over the tasks of the Quality Control unit. The detailed tasks, rights and duties of the supervisor are described in the conditions of the contract and its specifications. Some more details are discussed in Chapter I.7.

I.6.4.3 Staffing requirements for mechanical installation

The staff requirement for mechanical installation will depend on the selected layout of the subsurface drainage system and the materials that will be used. Local customs and practices can also play an important role. In Table 6.2, "model" staffing requirements are given for installation units working with two drainage machines to install a composite drainage system and a singular system both with and without granular envelope. The total number of staff required to install 3 to 5 km of drains per day varies from between 23 and 25 persons for a singular drainage system without granular envelope and between 36 and 48 persons for a composite drainage systems with granular envelope. The cost of the staffing is discussed in Chapter I.9.

Table 6.2 Staffing requirement for installation unit working with two drainage machines for installing a composite and singular drainage systems with and without granular envelop, respectively (requirements for granular envelopes given in italics)

Unit	**Staff**	**Requirements (Qty)**	
		Composite system	**Singular system**
Field management	Field manager	1	1
	Driver	1	1
	Bus driver	0 - 1	0 - 1
	Tractor driver [a]	1	1
Subtotal Field Management Unit		3 - 4	3 - 4
Surveying Unit	Surveyors [b]	2	2
	Assistant surveyors [b]	4	4
Subtotal Surveying Unit		6	6
Field preparation Unit	Manager	0 - 1	0 - 1
	Excavator operator	2	1
	Bulldozer operators	1 - 2	1 - 2
	Assistants	3 - 4	1 - 2
	Masons etc.	2	
Subtotal Field Preparation Unit		8 - 11	3 - 6
Trenching Unit	Trencher operators	2 - 4	2 - 4
	Tractor drivers (gravel trailers)	6	6
	Loader drivers	1	1
	Gravel manager	1	1
	Operator assistants	2-4	2 - 4
Subtotal Trenching Unit		4 - 8 *(12 - 16)*	4 - 8 *(12 - 16)*
Mechanical Unit	Mechanics	1	1
	Fuel tractor driver	1	1
	Assistants	2	2
	Driver	1	1
	Subtotal Mechanical Unit	5	5
Quality Control Unit	Surveyors [b]	2	2
	Surveyor assistant [b]	2	2
	Labourers	2	2
Subtotal Quality Control Unit		2 - 6	2 - 6
Grand Total		**28 - 40 *(36 - 48)***	**23 - 25 *(31 - 43)***

[a] For infield transport, if required.

[b] Combination with quality control and survey group possible.

I.6.5 Planning and Preparatory Aspects for Subsurface Drainage Installation

I.6.5.1 General

The installation process of pipe drainage systems should fulfil a number of conditions to assure that the installation is cost effective and results in systems that are functional. Besides the actual installation techniques and methodologies, as treated in Part II of this handbook, a number of aspects are of relevance during the planning and preparation stage. A summary of these aspects is given in the following sections.

I.6.5.2 Installation season

Drains should be installed under favourable working conditions, meaning dry soil conditions and a relatively deep watertable. Under most climates, drains cannot be installed all year round. Determining the dates and the length of the installation season is an essential input for the planning. There are, so-called, favourable seasons for installation and unfavourable seasons during which installation should preferably be avoided. For optimal results drains should be installed under working conditions that are as favourable as possible. Less favourable or unfavourable periods are:

- Wet seasons when both ground water levels tend to be high and field surfaces wet;
- Wet soils during the rainy season or just after irrigation, when the heavy machinery could easily slip and damage the soil structure;
- Winter season during frost (hard frozen soils are difficult to dig, moreover, plastic drain pipes become brittle);
- Cropping periods: Although installation can technically continue if a crop is in the field, the crops on top of the drain line have to be removed before installation or they will be destroyed by the machinery (a line of minimal 5 m wide when no gravel is applied and minimal 12 m wide when gravel is applied). Such crop damage is usually not acceptable. (In Egypt in the past, installation continued when crops were in the fields and farmers were financially compensated for the crop loss).

I.6.5.3 Logistics

The drainage machines are the highest single cost factor in the installation process (this will be elaborated in Chapter I.9). To reduce costs of the total process the drainage machines have to be used continuously and as effectively and efficiently as possible. Thus waiting times, for whatever reason, have to be avoided. Experience has taught that the bottleneck for the speed of pipe installation is usually not the capacity of the drainage machine, but the organisation and logistics connected with keeping the machine going. This is why it is of utmost importance to organise the logistics around the machine in an optimal way. This is also true for the field preparation, so that the machines can start working immediately and uninterrupted when they arrive at the site. It also applies to the organisation of fuel supply and maintenance of the machines to minimise breakdowns and waiting times and ensure the timely supply of drainage materials (pipes, envelope, gravel etc.). Generally speaking, money spent on logistics and preparation is soon earned back in more efficient operation.

I.6.6 Steps in pipe drain installation

The process of drain installation starts with the handing over of the area to the contractor or installation unit and ends with the final reception of the works by the implementing authority or the beneficiaries. For planning and preparation it has to be kept in mind that drainage systems have to be installed starting from the downstream side towards the upstream side. There are two reasons for this: (1) for the purposes of level control, and (2) because drainage systems often start to discharge directly after or even during installation. If there is no opportunity for downstream discharge of water, undesirable muddy and wet working conditions will be created. Thus:

- The open main drainage system has to be ready and functional before the installation of pipe drains can start;
- The outlet of a composite system, with or without pumps, has to be ready and functional before the collectors are installed. If the pumps are not available or ready, temporary pumps can be used like dewatering pumps, for instance;
- Collector pipes have to be installed before the field drains are installed (starting downstream!);
- Connecting manholes (if any) have to be installed before the field drains are installed;
- The field drains are installed (from downstream to upstream) as the last element of the system;
- After the installation of each drain pipe, the trench box is lifted out of the soil and the drainage machine drives (without installation) to the downstream staring point of the next drain.

The construction of the subsurface drainage system consists of the following steps:

1. Outlet construction;
2. Setting out alignments and levels;
3. Grade Control;
4. Excavating the trenches;
5. Placing the drain pipes;
6. Placing the envelopes;
7. Installation of the junctions/manholes;
8. Backfill of the trenches.

In case of mechanised installation the steps 3 to 6 are a one-time operation. The steps are briefly discussed in the following section. Detailed descriptions of the process are presented in Part II of this handbook (Chapter II.C.19-C.38).

I.6.6.1 Outlet construction

Gravity outlets

If gravity outlets are used, the side slopes of the open drains must be protected from erosion by the out flowing drainage water. Samples of possible protections are presented in Figure 52 and details are given in Part II C.27.

a. b.

c.

Figure 52 Construction of the outlet of a field drain (a) collector drain (b) and sump (c)

Pumped outlets (sumps)
In flat or gently sloping areas, the land gradients are generally not sufficient for free fall and gravity disposal of drainage water into surface drains. Pumped outlets are established by constructing a sump at the point of disposal of the drainage system and by installing a pumping system to pump water and maintain gravity flow within the system. The size of the sump depends on the area drained by the collector unit and the operating time of the pump (pumping capacity). Small-size sumps can be installed in the same way as manholes (see Part II C.28).

In case larger brick-built sumps are constructed under high watertable conditions or in unstable subsoils it may be necessary to use *vertical well-pointing* techniques to lower the watertable during the construction. This requires special skills and equipment. The *vertical well-pointing* technique consists of forcing well points, i.e. pipes with a perforated bottom part and a filter, into the soil around the building pit. The well points are connected to a suction pump. By pumping, the watertable around the building pit is temporarily lowered and construction can be carried out under dry conditions. Details on *well-pointing* techniques can be found in literature of the building industry and are not discussed in this handbook.

In case large brick or large pre-cast concrete rings are used, *well-sinking* techniques may be used. For this technique also special skills and equipment are required. The *well-sinking* technique consists of placing a concrete ring on the soil surface and by removing the soil from within the ring (in wet conditions the soil can be bailed out) the ring is lowered in the soil. After the ring has been lowered a new ring is place on top and the excavation is continued, till the sump has reached its design depth. The same technique can be used for lowering a brick structure. Details on *well-sinking* techniques can be found in literature on well construction and are not discussed in this handbook.

I.6.6.2 Setting out alignments and levels

The location and alignment of the drain lines must be set out before the actual digging can begin, (Figure 53). First, the downstream location of the drain is marked off by placing a row of pegs along the collector drain at the design drain spacing. Next, the centre line of each drain is set out by placing another row of pegs at the upstream end. Stakes are placed in the soil at both ends of the drain line with the top of the stakes at a fixed height above the future trench bed using a levelling instrument. This very clearly indicates the drain line. The direction of the field drains is assessed standing at the starting point at the collector line, thereafter marking off the location of the field drains with pegs.

I.6.6.3 Grade control

Grade control during the installation of the drain pipes can be done by:
- Automatic grade control by laser on drainage machines, both trenchers and trenchless machines (Figure 54);

- Grade control for manual installation;
- Driver controlled depth regulation on trenchers.

A laser must be used for grade control for mechanical installation of subsurface drains because it contributes to a better quality of drain installation.

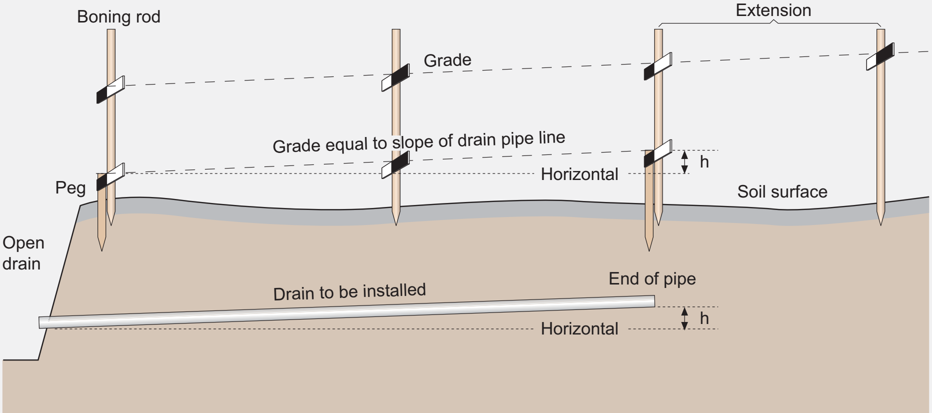


Figure 53 Setting out alignments and levels

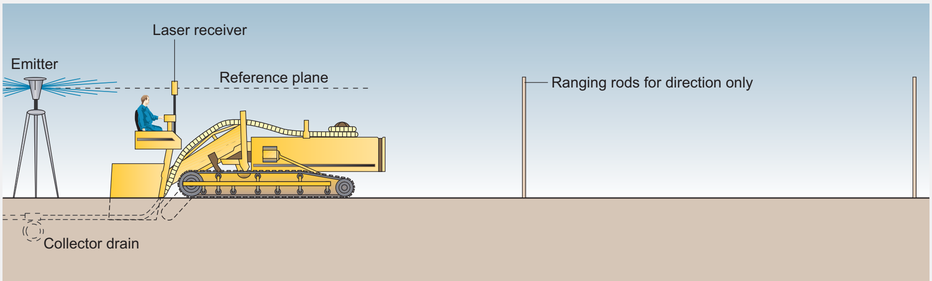


Figure 54 Grade control by laser

I.6.6.4 Excavating the trenches

As discussed in Chapter 5, there are three methods of mechanical installation (Figure 55):

- *Excavator.* All steps in the implementation process are separate steps, implemented one after the other. The trench is dug by the excavator to about 5 cm above the required drain depth and up to the last few centimetres, when the levelling and placing the drain pipes is done by manual labour;
- *Trencher.* Digging the trench, placing the drain pipes and (if applicable) the envelope, is done in a one-time operation. The pit from where the laying of the pipe will start is either dug by the trencher itself or an excavator;
- *Trenchless.* Just like the trencher method, it is a one-time operation, but instead of digging a trench the pipe is directly ploughed into the soil.

Figure 55 Excavating the trench

I.6.6.5 Placing the pipes

Several methods can be used to place the drain pipes, depending on the type of pipe (Figure 56):

- *Concrete/clay drain pipe.* The drain pipes are loaded to a platform on the machine and then put along the chute in the trench box to the bottom of the trench. This requires one labour on the platform to put the pipe in the chute and one labour in the trench box to put cloth or other sealing around the joints;

a.

b.

c.

Figure 56 Placing the pipes: (a) concrete/clay pipes (b) flexible corrugated pipes and (c) large diameter plastic pipes

- *Flexible corrugated drain pipe*. The field drain pipes are delivered in coils and the coils are put on reels attached to the machine. The drain pipe is guided over rollers into the trench box. A press pulley puts the pipe at the bottom of the trench;
- *Plastic collector pipes are larger in diameter and cannot be coiled*. The pipes are delivered in sections of 6-12 m. These larger diameter pipes are usually laid out on the field beforehand. The pipe sections need to be connected in the field over the full length of the collector drain before the pipe laying starts and then guided through the machine.

I.6.6.6 Placing envelope

Synthetic and organic envelope

Synthetic and organic envelope material can be pre-wrapped around the pipe, this is usually done in the pipe factory. Envelopes are either applied in voluminous layers (> 10 mm) completely surrounding the drain pipe in bulk or as a pre-wrapped mat, or as thin sheets. Special (band) wrapping machines are available for pre-wrapping of pipes in factories. In case the wrapping has to be done in the field, special labour and provisions have to be made available. The installation of pre-wrapped drain pipes can de done by hand (e.g. in pilot areas) or by a trencher or trenchless drainage machine.

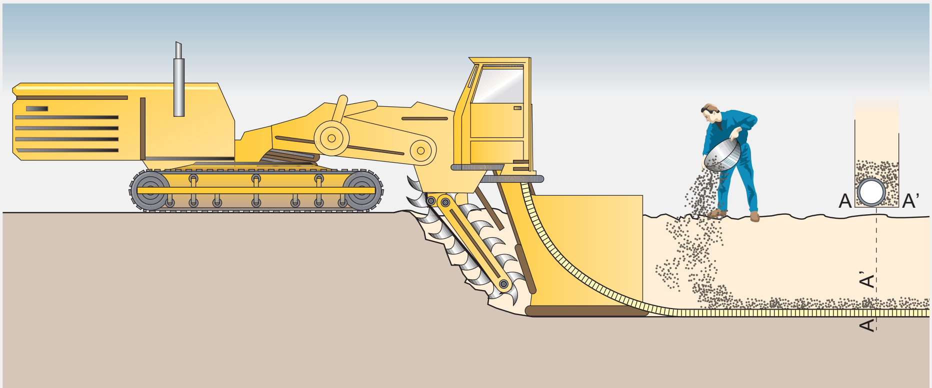
Installation of granular envelope

A granular envelope requires a considerable fleet of extra equipment to ensure a continuous supply to the machine. How to organise the gravel supply to the site is discussed in Part II. Installation by hand is not recommended as the drain pipe can easily get dislocated (Figure 57a), the only proper solution is to use the gravel box, as shown, which results in the correct positioning of the granular envelope (Figure 57b). Installation of granular envelopes with trenchless drainage machines is a cumbersome procedure. The gravel easily gets stuck in the narrow funnel through which the gravel has to be transported, resulting in part of the drain pipe not being covered with gravel and is therefore not recommended.

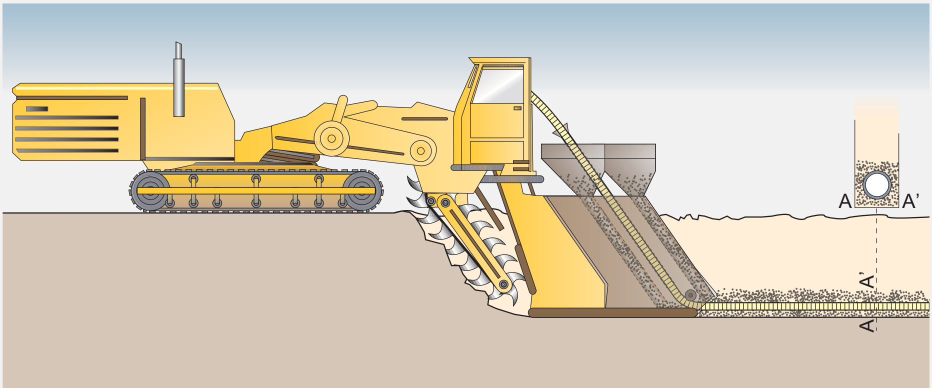
I.6.6.7 Installation of junctions or manholes

Field drain - collector connection

The field drains are connected to the collectors by means of standard drain pipe fittings (cross-pieces, T-joints, Y-joints) or through junction boxes or manholes (Figure 58). If no manholes or junction boxes have been installed, an access pipe for cleaning of the field drains needs to be installed at the junction. Installation of the manhole or field-collector pipe connection is done at the start of the installation of the field drain pipes, after the collector has been installed. This should be done preferably under dry conditions, thus a pump should be at hand to pump dry the excavated pit at the field-collector junction.



a.



b.

Figure 57 *When the gravel is placed manually, the drain pipe easily gets dislocated (a), when gravel is applied through a gravel box mounted on the trench box of the trencher the drain is not dislocated (b)*

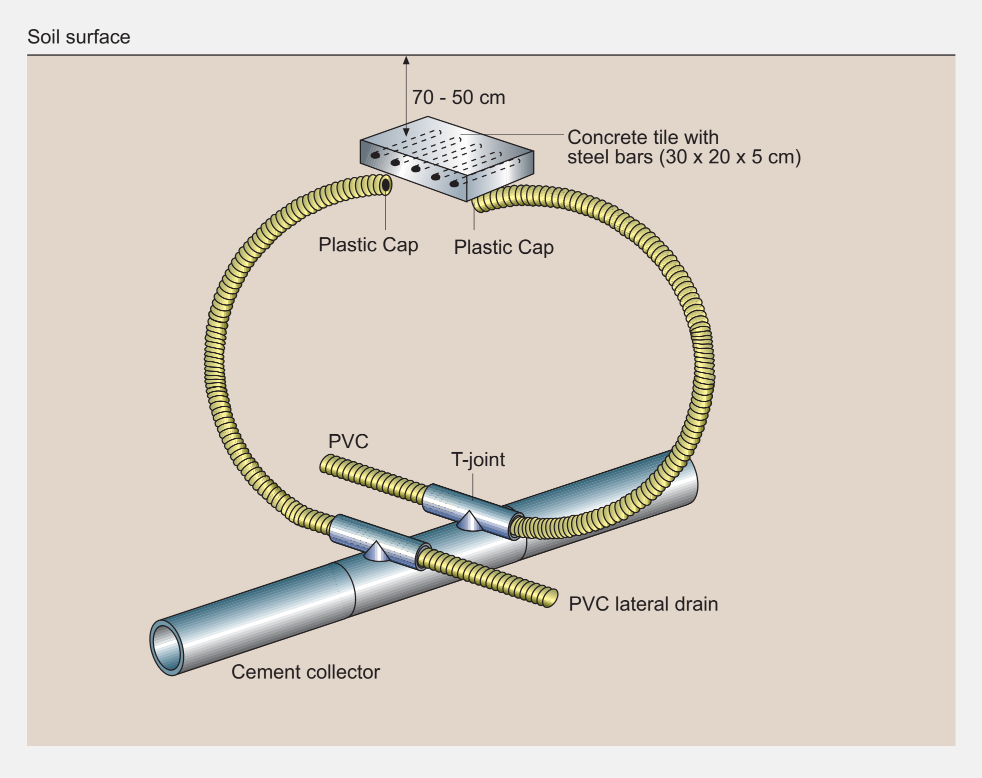


Figure 58 Example of field drain - collector connection and flushing joints

Flushing provisions
In a composite drainage system the field drains have no outlets into an open drain. In this case provisions should be installed at the junction of the field and collector drain for easy access of maintenance equipment. The T-joint should be extended with an access pipe. The end of the access pipe should be closed by a plastic cap and covered by a reinforced concrete tile 0.5 - 0.7 m below the soil surface. The access tube can be traced using a metal detector and a pit dug so that flushing of the drains can be done whenever required.

I.6.6.8 Backfilling of trenches

Backfill of the drain trench is a three-step operation (Figure 59):

- *Blinding*. Careful placing of an initial backfill of 0.15 to 0.30 m of soil around and over the drain is referred to as blinding. This is done to ensure that the drain will remain in line when the remaining excavated material is placed in the trench. Blinding the drain may be done by shaving off the topsoil at the top of the trench with a spade or with an attachment (scraping knife) to the trench box. Care should be taken that the alignment of the drain is not changed;

- *Backfill*. The fill should be firm but not compacted too much so that it prevents the passage of water to the pipe. All trenches should be filled to a sufficient level above the surface of the ground to allow for settlement. Trenches are preferably backfilled the same day they are dug to avoid a possible destabilisation of soil under wet conditions, such as irrigation, rain or high watertable. Only in unripe soil is it advisable to leave the trenches open for some time to initiate ripening;
- *Compaction*. Compacting is required to avoid serious problems arising in irrigated areas when water moves rapidly through the unconsolidated trench fill causing severe erosion (piping).

Trench backfilling is done by the following methods:
- Hand with shovels;
- Bulldozer;
- Grader;
- Tractor equipped with a dozer blade;
- Screw augers mounted on the trenching machine.

Figure 59 Backfilling of the drain trench: using a dozer and grader

I.6.7 Site clean-up

Surplus soil that is not injurious in nature should be spread over the surrounding field. Material such as large stones and roots that are likely to damage implements or livestock, or of a size and character abnormal to material found on the surface of the field, should be removed. The contractor should arrange to remove surplus pipe material, bands and ties, wood, glass, metal cans, and containers and other rubbish from the work area. Finally, all temporary passages, breaches in canals etc. should be repaired and fencing and other farm property should be repaired or replaced.

I.7 Quality Control in Drainage Construction

I.7.1 Quality control process

After installation, the subsurface drainage system would seem to have almost completely "disappeared" beneath the soil. Should malfunctioning occur, pinpointing its origin would be difficult and repairs often an elaborate, laborious and expensive procedure. Thus, the functioning of a subsurface drainage system depends almost entirely on the quality of the drainage materials used and the quality of installation. Small defects can have enormous consequences and can result in malfunctioning of the system. A properly integrated and functioning quality control system requires that the quality of each step in the construction process is checked and that possible imperfections are corrected before the next step is carried out, a so-called total quality system (Box 7.1). This means that quality control is not a stand-alone activity to be carried out at specific points in the construction process, but a process that is fully integrated into the construction process and concerns all parties involved. The implementation authority will have the final responsibility for the quality of the system, but normally nominates supervisor(s) to take responsibility for the actual quality control. The implementation authority has to decide how the quality control will be carried out during the planning stage (Box 7.2).

Box 7.1 Total Quality System

A Total Quality System is a modern system of quality control into which the contractor/manufacturer is fully integrated. Every person in the implementation process, from the planning up to the operation and maintenance, is responsible for the quality of their own work and for carrying out a quality control on the output of the previous persons. Basically, if one step is not carried out properly, the persons responsible for the next step should refuse to continue with the process until the previous step has been rectified (Figure 60).

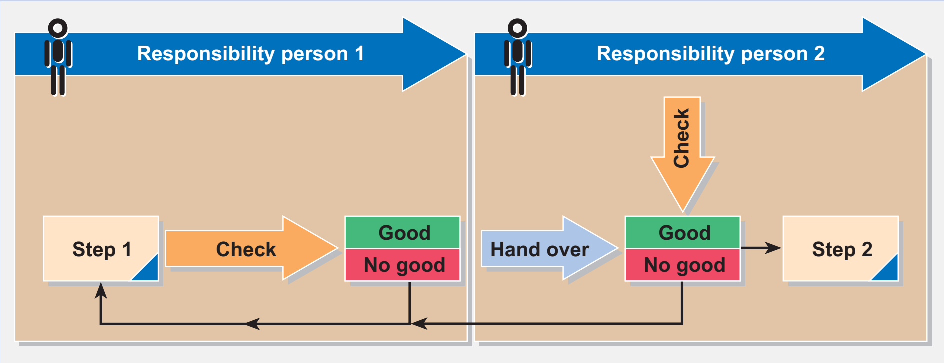


Figure 60 Principles of the total quality control system

Box 7.2 Quality Control: Major decisions during the planning phase

- Who is responsible for the day-to-day quality control and what is his mandate?
- Is the active or passive system of quality control method to be used?
- To what degree is the national/international standard quality control systems integrated?

Quality control can only be correctly carried out if:

- The quality of the work and the individual components is clearly and unambiguously formulated in the specifications and, where applicable, in the conditions of contract (see Chapter I.1);
- Quality control methods and procedures are clear and transparent and fully described in the conditions of contract and/or specifications;
- The persons responsible (supervisors) are equipped with the means and authority to carry out quality control and can impose the requirements of good quality work (in effect this means that there should be sanctions for not delivering according to the quality standards);
- All persons involved in the construction process have an understanding of the quality requirements;
- All parties involved are fully aware of the quality control system to be used and its consequences.

Quality control can be active or passive:

- *Active:* the supervisors or inspectors carry out very regular quality checks at all points of the installation process;
- *Passive:* The contractor/installation unit/manufacturer carries out the quality checks according to prescribed procedures and/or on order of the supervisor. If discrepancies are noted, these should be corrected immediately and verified with a follow-up check. The results of the checks are recorded and handed over to the supervisors who can carry out spot checks for verification or request double checks in his presence.

The passive system is the least complicated, provided that contractors have the adequate motivation and capacity to carry this out. If the construction works are contracted, it is very helpful if it is obvious from the contract that there is an interest for the contractor to deliver quality work. This can be reflected in the payment conditions, such as bonuses for good or above standard quality work and/or penalties for below standard quality work. This creates quality awareness by the construction team and avoids a mentality of "*let us cover it up before it is checked*". In the passive quality control approach, the implementation authority has to make sure that:

- Specifications and conditions in the contract are transparent and unambiguous;
- Stipulations in the specifications are clear, such as: (i) what needs to be checked; (ii) when must it be done; (iii) how should it be done; (iv) in the presence of the supervisor or not; (iv) how it has to be recorded; and (v) what to do in case of discrepancies;
- Supervisors who are capable and active and can carry out frequent spot checks and/or are present at the moment of control;

- There is a written statement from the contractor agreeing with the design;
- There is a written statement from the supervisor (preferably the design organisation) agreeing with the design modifications in the field, otherwise flaws in the design may result in malfunctioning of the systems for which the contractor may be held responsible.

The quality control in the implementation process includes the following aspects:
- Quality control of drainage materials: before and during installation;
- Quality control of installation: during and directly after installation is completed;
- Control of functioning of the system after installation: control of both the design and construction processes.

The following sections give an outline of what, when and how the quality control can be carried out. In Part II-D the details of quality control at field level are worked out.

I.7.2 Quality control of drainage materials

The drainage materials that have to be checked are (i) drain and collector pipes, (ii) envelopes, and (iii) structures. If these materials are supplied by independent suppliers or specialised units it is important that the quality is well defined in the supply contracts.

The quality of drainage materials can best be checked in three to four steps:

1^st^ Quality Check

The materials produced by the manufacturers are expected to comply with the specifications and/or national or international norms. All materials should be satisfactory for the intended use and should meet the requirements as stated in the contract. The standards for testing are normally stipulated in the contract or standards (Chapter I.2) for which methods are used: certification and control. By certification, the manufacturer has to present a certificate that the products indeed fulfil the requirements of these norms (Box 7.3). In many countries there are nationally recognised independent authorities that verify that the products leaving the factory comply with these norms. Control means that the supervisor or the contractor (if the contract stipulates that the contractor provides the drainage materials) checks the quality and the quantity before it leaves the factory/before transport (Figure 61). This is to prevent products that are below standard from being transported. Ideally, the quality check should be confined to checking the quality certificates and the completeness of the order.

Box 7.3 Certification

Certification implies that the quality control is the responsibility of the manufacturer who must guarantee that his products meet the required certification standards. The certification is issued and checked by an independent organisation. Control is normally done by random checking during the production process. Part III of this handbook presents an example of how certification works in the Netherlands.

Figure 61
Testing the strength of a plastic drain pipe at a factory in Egypt: elongation test

2 nd Quality Check
A second quality check can best be carried out on the site upon arrival of the drainage materials to verify if the materials rejected in the factory are excluded from the shipment and to assure that the supply of the materials is according to the ordered list of supplies and that no transport damages have occurred. Any surplus or rejected materials must be removed immediately by the supplier/contractor from the site to prevent confusion.

3 rd, 4 th Quality Check
A third and in some cases a fourth quality check takes place just before or at the moment of installation and after installation.

I.7.3 Quality control of installation

The quality checks are carried out at different moments of the installation process as described below. Which checks have to be carried out depend on the system to be installed and the materials used. The checks are:

1 st Quality Check: before installation starts on drainage materials
The first quality check is the same as the last check of the quality of the materials, namely, a check in the field depots to see if the quality (and quantity) of the materials tallies with the standards.

2 nd Quality Check: before installation starts on alignments and levels

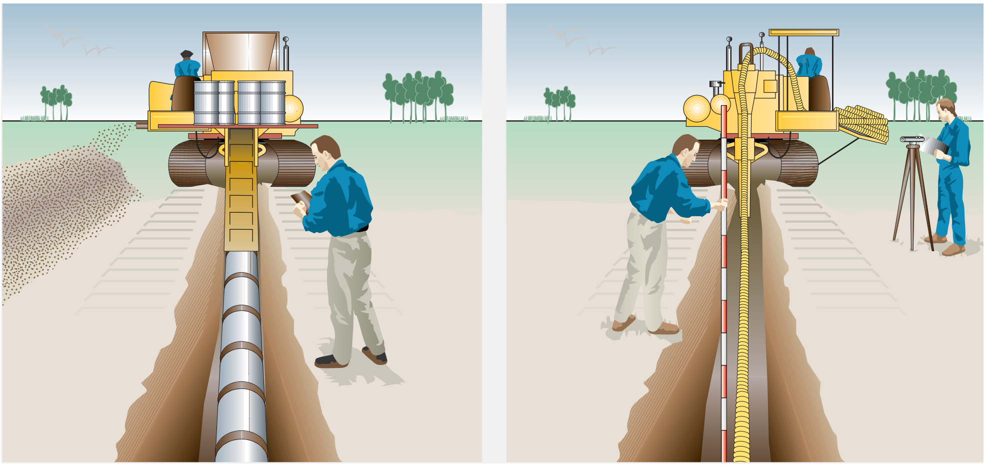
A second quality check is done after the contractor/construction unit has staked out the field and determined/verified the levels according to the design. The alignment and levels have to be checked. At this stage, discrepancies between the field conditions and the design can be detected that are mostly caused by imprecise topographical information. These discrepancies have to be solved immediately and preferably in cooperation with the designers.

3 rd Quality Check: before installation starts on equipment

The third quality check just before installation is to determine whether all the equipment to be used complies with the specifications and can be expected to install the system correctly.

4 th Quality Check: during installation

The fourth quality check is done during installation and focuses on: grades of the pipes, horizontal straightness, levels, joints of pipes, connection pipes and manholes and covering of pipes with granular envelope (if applicable) or the damage to pre-wrapped envelope. The quality standards are extensively described in the specifications (Figure 62).



a. b.

Figure 62 Traditionally used quality control: visual inspection (a) and checking the drain level (b)

5 th Quality Check: after installation

The fifth quality check is right after installation before the trenches are closed. It focuses on visual inspection of the pipes, envelops, connections, joints and structures as well as floating of pipes and other distortions. It serves as a double check and, in case of doubt, the levels can be (re)checked and corrections made by the contractor can be verified.

6 th Quality Check: after backfill

The sixth quality check is after the trenches have been backfilled. It focuses on the backfill of the trenches, the compaction, covering of manholes and sumps, and the installation of end pipes.

I.7.4 Checking of the functioning of the drainage system

The performance of the system has to be checked once the construction has been completed and before handing over the drainage system to the beneficiaries or organisation that will take over the responsibility. Rules and procedures for acceptance are normally specified in the contract. This check should be done immediately after a drainage system has been installed. The check focuses on verifying that all elements of the system are functioning properly, such as field drains, collector drains, manholes, sumps, outlets and, if applicable, pumps. For example, checks are done as to whether the field drains are discharges after rain or irrigation and whether there is water is flowing in the manholes and collector drains. Note, if the groundwatertable is below drain level there will usually be no flow. This can be verified from the ground water observations. If this is the case, the check should be done during the following irrigation or rain event.

I.7.5 Post installation quality checks

The post-installation quality checks mentioned above are used to check the actual hydraulic performance of the drains to find out whether the drains discharge after irrigation or rainfall, or if water is flowing in the manholes, collectors and so forth. Of course it is a whole different story to check whether the drainage system functions according to the design objectives (Chapter I.1.3.4), namely, whether the groundwater level is maintained at the specified level or whether the soil salinity in the root zone is controlled at the specified level, and the like. This type of quality check has to be done by specialised research organisations and is beyond the scope of this handbook. For more information see the bibliography. Only if there are discrepancies and the system or part of the system is not functioning properly, or if there are doubts about the proper installation, a post-installation quality check should be carried out. Post installation checks are also rather complicated because the trenches are already backfilled and, thus, no visual inspection and use of surveyor staffs is possible anymore. The checking method focuses on determining which parts of the system are not functioning properly. The check starts with a visual inspection at the outlet and in the manholes, for instance, and subsequently more sophisticated methods are used to examine the suspected pipe sections. These checking methods require sophisticated equipment that often requires specialised personnel. Furthermore, the checks are rather complicated and time-consuming and are more suited for research and pilot projects than for routine operations. The following methods are available:

Rodding
Rodding is a technique to check whether there are abrupt disturbances in the drain line, like broken pipes, loose couplings and sharp changes in the slope. In this method, a glass fibre rod is pushed manually through the pipe outlet into the drain pipe over its entire length. In this method a solid steel rod with a torpedo-shaped go-gauge and possibly a transmitter is mounted on a glass fibre rod (Figure 63a). If the drain has been correctly installed, the rod can pass unhindered. The required pushing force increases slightly with the length of the drain. However, if the drain spirals, the required pushing force increases with the length of the drain. The required

force should not exceed a pre-set limit. If the rod cannot pass a particular point in the drain, there is a fault in the installation and the drain has to be excavated at this point. Drains up to a length of 400 m can be checked by rodding. In principle, every single drain can be tested but this will prove to be rather expensive (see Part III, Case Study in the Netherlands). It is therefore recommended to randomly test only a limited number of drains, for instance, 10% of the drains. Testing can be increased if more than a prescribed percentage of drains fail the test. The number of drains to be tested, the method and whether or not the contractor has to replace malfunctioning drains must be specified in the contract. Rodding is also a useful means of making sure that the drain will be accessible for flushing. Although rodding is a useful tool to check whether there are disturbances in the drain line, the method cannot be used to check the slope of the drain line. To do this continuous depth recording is required.

Continuous depth recording

Vertical alignment and grade can be checked using the Collins apparatus, a method based on the ancient water-level gauge, which was developed by Collins at the Leichtweiss Institute of the University of Brunswick, Germany. One end of a hose is connected to a special open container, the water surface of which serves as a reference level. A pressure transducer, fitted to the other end of the hose, slides into the drain (Figure 63b). This transducer transforms the hydrostatic pressure into an electric signal, which is proportional to the hydrostatic pressure over the reference level. The transducer can be inserted into the drain to a maximum length of 200 m. Measuring takes place while the hose is being withdrawn from the pipe. The hydrostatic pressure can be measured with an accuracy of less than 2 mm. The data can be recorded in digital form and plotted graphically. This method is quite costly: in the Netherlands the cost per metre amounts to about half the total costs of pipe drainage. Thus, a routine check of all installed drains is too expensive, so a system of random checking and certification has to be adopted.

The methods above are described in more detail in Part II, Chapter D.5.

Video inspection

Visual inspection of the drain pipe itself is also possible by using a video camera, whereby damage to pipes, siltation in pipes and the exact location can be determined. The camera is pushed through the inside of the pipe manually. As the camera has its own lighting, the inspector can directly check the interior of the pipe on the video display and can freeze the camera and make a print if he observes disturbances like sedimentation, ochre, roots, collapsed pipe section or loose couplings (Figure 63c). He can enter his remarks on the computer. Thus, apart from the video record a printed report can be made of the irregularities in a drain line. Inspection of a 150 m long drain line takes around ¾ hour. If the pipe is damaged to such an extent that excavation is required, the location can be deducted from the distance the camera has been pushed in to the drain or with a tracking device coupled to the camera. The disadvantage is that it is not possible to record the exact slope and the method is rather costly. An example is presented in Part III Case Egypt.

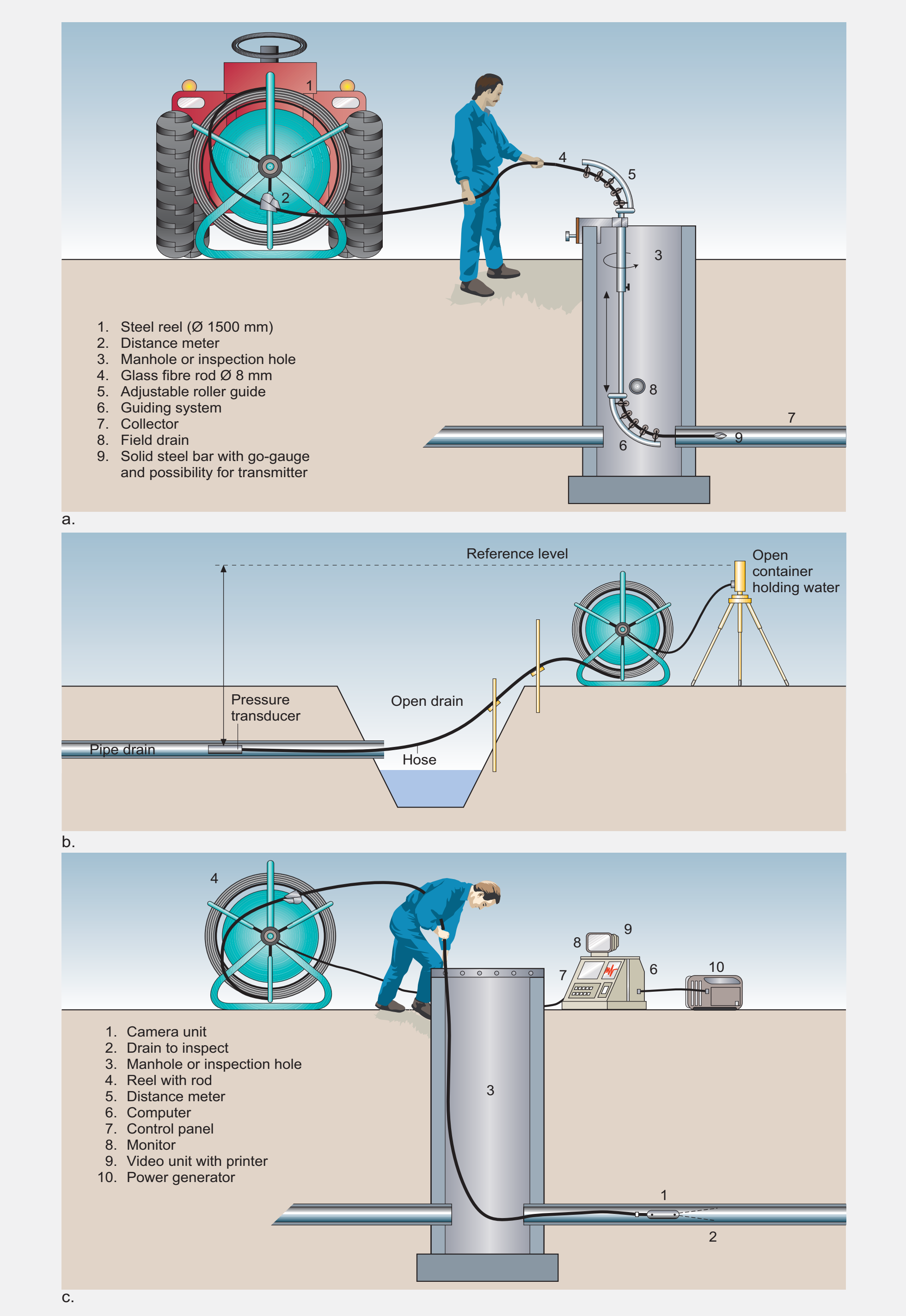


Figure 63 Methods for post-installation quality checks: (a) rodding, (b) continuous depth recording and (c) video inspection

Tracking

The exact location of an obstruction of any kind can be determined by using a small transmitter fixed to the jet head of the flusher. The location of the jet head can be determined with a corresponding receiver and if the jet head gets stuck the exact location of the obstruction is known.

I.7.6 Post construction performance assessment

Once the drainage system has been operational for a number of years the performance of the system can be assessed to determine if the system is still functional and if not which measures have to be taken to correct the situation. The performance assessment can be done periodically (monitoring) or ad hoc if there are indications that the system is not functional.

The following periodic assessments are often carried out:

- *A periodic assessment of the functionality of the system* can be carried out to determine whether the system is functioning in accordance with the design. The assessment can give indications on the need of maintenance or rehabilitation and over time a knowledge base for the frequency and nature of maintenance can be built up. The methodology for checking the functionality of the system is given in Part II-D;
- *A periodic assessment of the effect of the system.* The rational behind this assessment is to determine if the system functions according to the design criteria, i.e. if the design groundwatertables and discharges are realized with the installed system, i.e. are the drain spacing, drain depth, drain envelope and dimensions of the drainage system correct. This assessment basically consists of the periodic, and according to pre-determined protocols, measuring of groundwater levels in between the drains and where relevant soil salinity levels;
- *A periodic assessment of the impact of the drainage system.* This assessment is to check if the expected benefits of the drainage system are realized. This assessment will focus on increases of yields, farmer income and possibly effects on the environment.

Next to these periodic assessments, the following ad hoc assessments are often made:

- *Complaint based ad hoc assessment.* These assessments can be carried out if there are substantial complaints made by the beneficiaries of the system about the functionality of the system. These assessments will focus on those parts of the system that are subject of the complaints;
- *Assessment to determine the need for rehabilitation.* During this assessment the main indicators studied are the frequency and cost of maintenance and repairs and the impact of the malfunctioning of the system on yields and income. It may be rational if these costs and loss of incomes surpass a certain threshold to replace the system.

A performance assessment is based on a comprehensive list of indicators. An indicator is defined as a value derived from two or more parameters that describe conditions and changes in time and space. These changes cannot usually be explained by a single indicator but only in relationship with other indicators. Ideally, the monitoring programme should contain a minimum of activities at the lowest possible cost, but resulting in a maximum insight in the performance of the system. Depending on the objectives of the monitoring programme, one or more of the following performance indicators should be measured:

- Crop yield;
- Water ponding in the fields after heavy rainfall or irrigation;
- Depth of the groundwater midway between the drains;
- Discharge at the outlet;
- Discharges in some selected manholes;
- Water levels in manholes;
- Sedimentation in manholes.

A periodic assessment program or monitoring can be contracted to a specialized agency or research organization. Once the program has been set up the actual monitoring activities are straightforward and can if so required be done by the organization in charge of the management of the system or for the impact assessments by the agricultural authorities.

I.8 Operation and Maintenance of Drainage Systems

I.8.1 Introduction

Like everything else in a country's infrastructure, subsurface drainage systems require operation and maintenance. The operation of subsurface drainage systems is mostly limited to the operation of pumps if pumping is done. In some cases, where controlled drainage is practiced, the operations can also involve opening and closing of gates. Maintenance of subsurface drainage systems consists mainly of removing sediment from the pipes and manholes, repairing and - if necessary - replacing these pipes, manholes and outlets. Maintenance of the open (main) drains is chiefly confined to removing sediment and weeds. Maintenance of the pipe (subsurface) drainage system is not entirely separate from maintenance of the downstream open (main) drains and/or outlets. If the downstream open drainage system is not properly maintained, it will influence the functioning and maintenance of the pipe drainage systems. Generally speaking, the objective of the maintenance of an open drainage system is to keep the water level below the outlet level of the pipe drainage system(s) at all times. Maintenance of open drainage systems is not discussed in this handbook and only the maintenance of pipe drainage systems will be further elaborated. When and how much maintenance is needed depends on the functioning of the subsurface drainage system, the monitoring of which has been discussed in Chapter I.7. This chapter discusses the general principles of operation and maintenance, while detailed guidelines for operation and maintenance activities are given Part II-D and E.

I.8.2 Decisions during the planning stage of the implementation process

During the planning stage of a subsurface drainage project, a number of decisions will have to be made on the future operation and maintenance of the system as well as on the allocation of responsibilities, institutional set-up and the techniques that will be used (Box 8.1). This is to ensure that:

- Designs can be harmonised with the proposed operation and maintenance methodologies;
- Support activities for operation and maintenance can be developed;
- Skills and institutions for the specialised operation and maintenance techniques can be assessed and developed;
- The maximum length of drains can be determined based on the available cleaning equipment;
- The capacity of local farmers for carrying out part or all of the maintenance can be assessed;
- Maintenance norms, supervision methods and institutions and so forth can be developed;
- A realistic division of tasks and cost allocation for the future maintenance can be decided upon;
- A fair cost estimate required for budgetary provisions can be made;
- Farmers can be informed in an early stage about the maintenance requirements and costs.

Box 8.1 Operation & Maintenance: Major decisions during the planning phase

During the planning stage clear ideas must be developed and decisions need to be made on:

- The maintenance activities for the proposed drainage system required;
- Whether the required maintenance activities can be carried out by the farmers and/or the existing organisations or support industry and if not what the missing elements are;
- Which maintenance activities can realistically be carried out by the farmers and which have to be carried out by specialised entities;
- If special facilities have to be created, how this can be done and what the costs are;
- If farmers have to be trained and/or equipped how can this be done and what the costs are;
- What investments costs will be required for creating the missing elements and how these will be financed;
- What the expected intensity (frequency) of the maintenance will be;
- What the annual operation and maintenance costs could amount to, based on the required maintenance activities and frequency;
- The part of the annual maintenance that will be financed and how (by farmers, local government or national government etc.);
- Whether timely availability of the annual maintenance budgets can be made at all levels;
- The entity that will have the overall responsibility for the maintenance and how and by whom the control/supervision methods are going to be implemented.

I.8.3 Operation of subsurface drainage systems

The operation of drainage systems is primarily confined to the operating of the pumps or pumping stations if the systems require pumping. The total operational cost of pumping is a sum of the cost of energy (electricity or diesel fuel), oil, grease and staff costs. The energy requirement can be estimated from the annual amount of drain water to be pumped, the required lift of the water and the characteristics of the pumps. For diesel pumps, the cost of oil and grease can be calculated as percentage of the fuel consumption. For electrically driven pumps, grease and oil expenses are marginal expenses that can be included in the contingencies. Modern small electric pumps are often equipped with automatic switches that switch on and off automatically at predetermined water levels. This reduces staff costs and human error. Diesel powered pumps require more supervision and thus more man-hours need to be taken into account. They can also be equipped with automatic switches if desired to reduce these higher staff costs. Depending on the organisational set up, the repairs, overhauls, annual technical service, replacement etc. of the pumps can be listed as operational cost or as a part of the maintenance cost of the drainage system. If it is considered to be an operational cost, the total annual cost of pumping can be calculated from the models given in Chapter I.9. Personnel costs for the operations are based on the number of man-days or man-hours required per year.

I.8.4 Maintenance of subsurface drainage systems

I.8.4.1 Objectives of maintenance

The objective of maintenance is to keep the drainage system functioning at its design capacity. Malfunctioning of a drainage system can be directly or indirectly noticed, for instance:

- If there is little or water no flowing out of the pipes/outlets directly indicating that the system is not functioning as required, whereas there should be a drainage flow (mainly some time after an irrigation or rainstorm);
- If the groundwater level has not dropped or remains above the desired depth, which is an indirect indication of malfunctioning.

The impact of a non-functioning system is water logging and/or that soil salinity is not decreasing or even increasing. Unfortunately these phenomena can only be noticed after some time usually when most of the damage has already been done. The ultimate result of a non-functioning drainage system is that crop growth is hampered.

I.8.4.2 Maintenance process

The maintenance process consists of the following activities:

- Regular checking of the functioning of the different elements of the system;
- Regular routine minor cleaning/maintenance;
- Periodic integral check of the functionality of the system;
- Periodic general cleaning (flushing) of the system;
- Repairing broken or obstructed parts of the system, when needed;
- Carrying out preventive maintenance and repairs of pumps (if relevant).

Maintenance should be based on accurate as-built drawings of the drainage system that have been checked and approved by both the implementing authority and the beneficiaries. Records of the construction process also need to be handed over to the maintenance units. This will facilitate the maintenance activities, especially when obstructions in the drains have to be located.

I.8.4.3 Frequency of maintenance

The cost of maintenance of pipe drainage systems is proportional to the frequency/intensity of this maintenance. There are examples of well-installed drainage systems that did not require any maintenance for 25 years. In other systems the sedimentation was so high that annual maintenance was required. It is not uncommon for fairly frequent maintenance to be necessary at first, gradually reducing over the years as conditions stabilise. The frequency/intensity of maintenance depends on:

- *Site-specific conditions:*
  - If soils consist of unstable aggregates, the systems tend to sediment relatively quickly and will thus require fairly frequent cleaning. The sedimentation will be substantially less in areas with stable soil aggregates;
  - In climates and/or under irrigation regimes where there is year-round flow in the drains, sedimentation is less likely to occur than under conditions with only seasonal drain flows.

- *Drainage materials used:*
  - If clay or concrete field drains are used, there will be three joints per metre length. The likelihood that the pipes might not be perfectly aligned and that sediment can enter at least through several of the joints are considerably higher than if a plastic corrugated pipe is used. Hence, a greater frequency of maintenance can be expected for systems made of concrete/clay pipes;
  - If a completely functional envelope is installed there will be little or no sediment flow into the system, thus little maintenance will be required.
- *Quality of installation:*
  - Little or no sedimentation will collect in drain pipes that are correctly installed (even grade and horizontally straight). If pipes are less perfectly installed more sedimentation will occur (because of minor flow obstructions in the pipes);
  - If during installation the joints are not tightly installed or the pipes become dislodged (especially in case of use of clay or concrete pipes) sediment can enter through the joints requiring frequent maintenance.

Consequently, as such a large number of parameters determine the required frequency of maintenance, no general rule can be given. An important conclusion, however, is that a well planned and next to perfect subsurface pipe drainage system installation will require considerably less maintenance than a system installed with less care and less suitable materials. The extra cost of high quality installation will be recuperated in the form of less maintenance costs and better functionality of the drainage system.

I.8.4.4 Estimating the frequency of maintenance

An estimate of the required frequencies of the maintenance activities is required for planning and budgeting. This can be done by:

- Extrapolation of any local experience gained with maintenance of pipe drainage systems;
- If there is no local experience, a not uncommon maintenance frequency of cleaning the systems once every three to five years. Whether or not budget estimates have to be based on a frequency of once every 3, 4 or 5 years will depend on the site-specific conditions and installation conditions as given above;
- Monitoring the actual maintenance intensities to eventually provide a firm basis for budgeting once the system is fully established.

I.8.4.5 Routine checking of the functioning of the system and minor maintenance

The functioning of the drainage system needs to be checked on a regular basis, almost daily. The checking consists of verifying whether the drains flow normally, that there is no built-up of water levels in the manholes (Figure 64), no leakage from the system and no accumulation of sediment in parts of the system (manholes!). During the checking process minor routine maintenance activities, like removing sediment from manholes and replacing covers on manholes, can be carried out. For practical reasons, these activities can best be done by the farmers who, for various other reasons are often in the field anyway. Moreover, by involving the farmers no additional costs will be involved. If irregularities are noticed that cannot be corrected during the routine checks, the farmers should notify the organisation responsible for the overall maintenance.

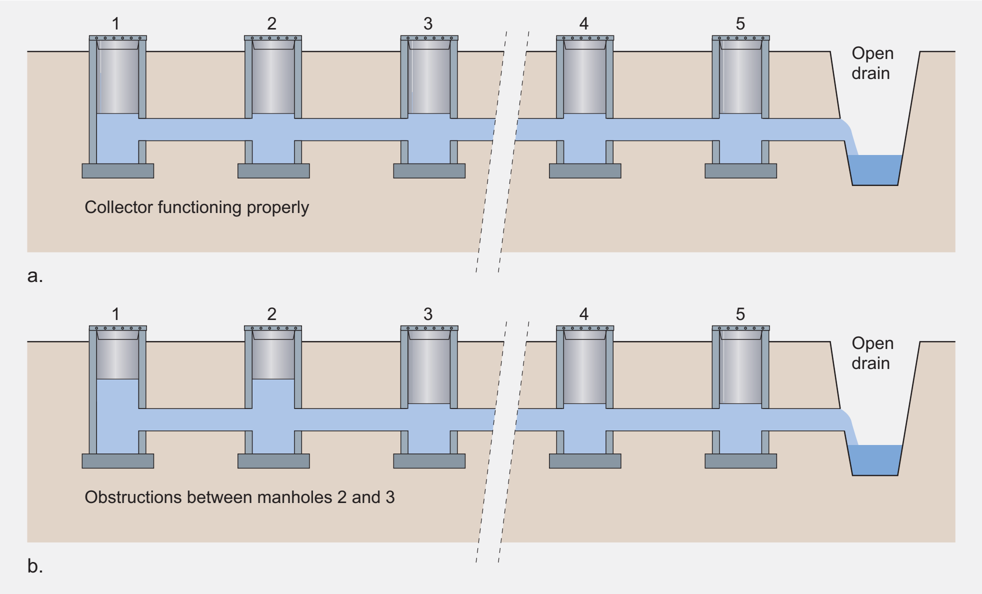


Figure 64 Visual inspection of the water level in the manholes to check the hydraulic performance of a collector line: (a) collector is functioning according to the design (= no overpressure); (b) overpressure in manholes 1 and 2 indicates an obstruction in the collector between manhole 2 and 3

I.8.4.6 Periodic integral check of the functioning of the system

It is advisable to do an integral check of the system periodically, namely, once or twice a year. The faults found during the checks can then be remedied at an early stage. The checking method is described in Part II-E. There will of course be some staff costs involved because time has to be spent on it (man-hours).

I.8.4.7 Periodic cleaning of the system

Since there will always be some sedimentation in the pipes it is advisable to remove this sediment periodically to prevent any excessive build-up. Sediment can be removed from a pipe drainage system by flushing (Figure 65). Theoretically, the sediment ought to be removed when it covers more than 25% of the cross section of the pipes (Figure 66). For practical reasons, especially in areas where the drain flow is seasonal, it may be better to remove the sediment earlier. Note, flushing can damage the envelope so less frequent flushing is better. Exactly how long it will take for this build-up to occur is not known and will have to be determined by monitoring sediment built up in the pipes. The cleaning of a subsurface drainage system by flushing is a specialised job that requires trained personnel and special equipment, and is normally done by a contractor or a specialised unit. The job is even more complex for composite drainage systems than for singular systems. Details of the flushing operation are described in Part II-E. Flushing by gravity with irrigation water from the upstream or top end of the system is practiced in some countries. This method is not recommended because it is likely to carry sediments further into the system accumulating in the downstream part where it can cause obstructions.

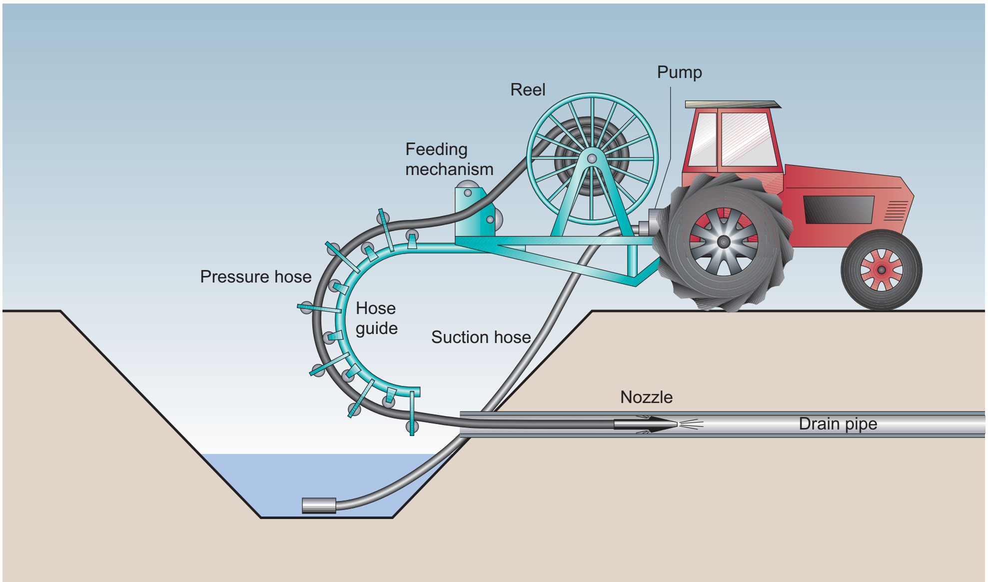


Figure 65 Tractor-mounted medium-pressure flushing unit

Figure 66
Plastic corrugated collector pipe half full with sediment (example from Pakistan)

The costs of flushing are machinery and staff costs. As a rule of thumb a fully equipped flushing unit can flush some 3 - 4 km of pipes per day. Calculation of the costs should take into account that flushing can only be carried out when there is a drainage flow. In the case of composite systems, crop growth may limit the period when flushing can be carried out.

I.8.4.8 Carrying out repairs on the different parts of the system if and when needed

The need for repairs is indicated by the farmers or during the yearly or half-yearly inspections of the maintenance entity. Repairs may consist of:

- Repair of manholes (breakage, leakage, covers etc.);
- Flushing one or more pipe lines that are obstructed;
- Repairing one or more drain pipes at place of obstruction, breakage etc.;
- Repair of pumps (if relevant);
- Repair of outlets (in case of composite systems);
- Repair of end pipes (in case of a singular system).

The costs are difficult to estimate, nevertheless, if no wilful damage is done to the system, the regular checking and arranging minor problems is well done and the system is properly installed, the costs will be minimal.

I.8.4.9 Preventive maintenance and repair of pumps

The manufacturers of the pumps prescribe regular maintenance. These instructions have to be followed and should be given adequate attention the maintenance planning. In areas with a serious frost hazard, it may be necessary to carry out frost protection of the pumps.

I.8.5 Cost of operation and maintenance

As can be concluded from the paragraphs above, the actual cost of operation and maintenance of subsurface drainage systems are site-specific and influenced by a number of unforeseeable parameters. If no operation and maintenance experience is available, the best is in the planning phase to obtain a pessimistic estimate of the cost so that budgets can be made available. If the activities and cost of operation and maintenance are carefully recorded in the course of the first years, a more realistic estimate can be made for subsequent years on the basis of these records. The costs can be calculated making use of the cost calculation methods as indicated in Chapter I.9.

I.9 Cost of Subsurface Drainage Systems

I.9.1 General

The construction costs of subsurface drainage systems are substantial (Box 9.1), therefore, it is of utmost importance that accurate cost estimates are made. The costs to be considered include:

- Preparation costs, including the cost of feasibility studies, field investigations and design, tender preparation and tendering (investment costs);
- Construction costs (investment costs);
- Operation and maintenance costs (recurrent costs);
- Cost of accompanying measures, both investment cost and recurrent costs;
- Financing costs.

And where no drainage tradition or industry exists in the country:

- Training costs of staff;
- Investment costs to set up a drainage industry and/or equip the various government units.

Costs, of course, result in benefits. Estimating the direct and indirect benefits of drainage systems requires special studies that are not the subject of this handbook, but a few general observations are presented in Section 9.1.2.

Box 9.1 Construction costs of subsurface drainage systems

Construction costs of subsurface drainage vary from country to country and from situation to situation. Costs also depend on whether or not an open main drainage system, complicated outlets or pumping stations are required. A cost survey done in several countries with large-scale installation infrastructures and a more or less mature drainage industry resulted in a cost price that varied between € 750 and € 1500 per hectare (prices in 2002) for the construction of subsurface drainage systems, excluding the open main drainage systems.

These cost estimates play a role in each step of the implementation process, namely, (Figure 67):

- During decision-making by national or regional government;
- During the detailed planning process;
- As part of the design process (Engineers estimate);
- For budget planning;
- For cost control during construction.

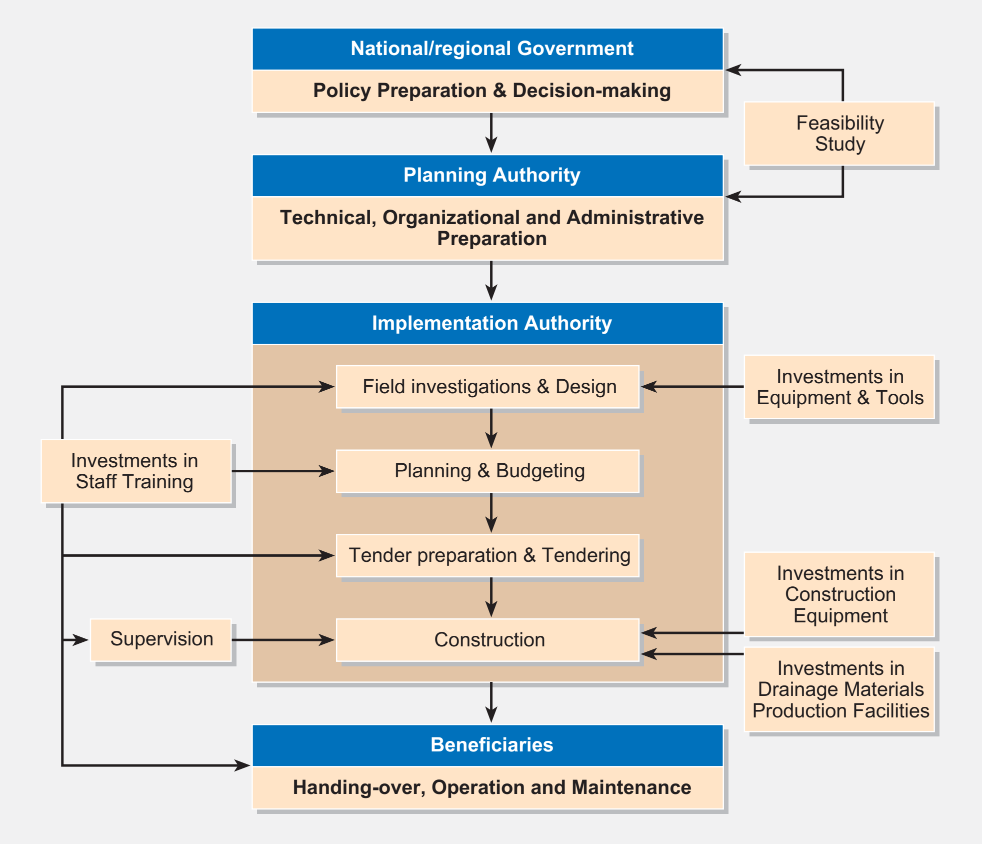


Figure 67 Cost elements of the implementation process of subsurface drainage systems

In the following paragraphs the outlines of cost calculations are presented. In Part II-B detailed instructions for cost calculations are worked out.

I.9.2 Considerations for determining cost, benefits and financing of drainage projects

I.9.2.1 Cost estimates during the implementation process

Cost estimates during decision-making by national or regional government
During the decision-making process at government level, the following questions concerning costs have to be answered:
- Is the implementation of drainage systems financially and economically feasible? (Determining the cost benefit relationship is the main objective of a feasibility study).
- What are the benefits of the systems to be installed compared with other possible investments of (scarce) government resources?

- Can the required one-time investment costs such as preparation and construction costs be made available from government sources, international financers or private sources?
- Can budgets be made available for the recurrent costs and from what source?

If a drainage industry needs to be set up in the country in question, answers to the following questions will also have to be obtained:
- Can the required investment cost of setting up a drainage industry be made available and, if so, from which sources and in which form?
- Is there enough scope for future use of the plant and equipment to justify the investments therein?

Financing from private sources is a (theoretical) possibility, but in most cases the government or a government agency will in someway be involved in the financing and thus the decision-making. The involvement can be as a direct financer, regulator, subsidiser, organisation responsible for accompanying measures, or the entity responsible for the future management and maintenance. All these (partial) involvements have consequences for the government budget.

The accuracy of the cost estimates at this stage of the implementation process is the so-called "feasibility" level precision, which can vary by 10% either way. The cost estimates in a feasibility study include the estimated costs, overhead costs and if applicable general costs, risks and profits and contingencies (often around 10%). The information about the costs can be obtained from the following sources:
- Previous projects in countries with experience with drainage;
- Feasibility studies, because cost estimates are a vital part of feasibility studies, certainly if international financing is involved, in countries or regions with little or no experience with large-scale drainage implementation;
- International prices as a first estimate, if there is no local experience and no market prices are available.

Cost estimates during the detailed planning process

The planning authority has to prepare a detailed cost calculation, preferably divided into:
- Preparation costs;
- Construction costs;
- Possible investment costs in setting up a drainage industry;
- Cost of accompanying measures (if any) and operation and maintenance costs.

If a feasibility study has been done during the decision-making phase, then most of the cost calculations required for this phase will already have been made. In this phase, the cost calculations are also used to compare alternative technical solutions and to select the least costly ones. The investment costs for setting up a drainage industry are long-term investments that have to be written off over many years thus over many drainage systems. Although it is seldom done, during this phase an estimate should also be made of the financing cost of each cost element. The financing costs refer to the unavoidable banking costs and interest payments if capital has to be made available from commercial sources or development banks. If part or all of the implementation activities are carried out by private entities the costs that these entities incur and/or will invoice covering risks, overheads and profits must be included.

Cost estimates as part of the design process
Detailed cost calculations are made during the design process when all details are known. These estimates, based on well-established unit prices, are reported on in a *Bill of Quantities* (Chapter I.9.4.9). This total cost or "*Engineers Estimate*" is input for the detailed budget preparation and tender procedures. When design engineers are asked to prepare adequate designs that are cost effective, they are often also asked to determine the most cost effective and technically acceptable alternatives.

Budget planning
Budget planning is done to determine which payments have to be made during the construction process and when. Budget planning can only be made at the end of the design process after a detailed construction schedule has been prepared. In the case of tendering, the resulting payment schedule will be included in the conditions of payment of the contract and has consequences for the possible financing costs. Contractors interested in the tender will also prepare their own detailed cost estimates for their tender price, including coverage for risks, overheads and profits. These costs should be part of the engineer's estimate, albeit possibly at another rate.

Cost control during construction
Supervisors and contractors will both carry out their own individual cost control during construction to suit their own purposes.

I.9.2.2 Benefits of drainage systems

Quantification of the benefits is a complicated thing to do because it is difficult to separate the diverse direct and indirect effects of drainage from other variables that can also influence the yields, production costs and so forth. Data on the actual effects and benefits of drainage systems based on field verification are scarce, and a so-called post-construction verification and quantification study is complicated because the implementation period of drainage systems stretches over a number of years. Moreover, the full effects may only emerge several years after the implementation has been completed. During this period many parameters influencing the benefits will have altered and the process of identifying the direct benefits from the drainage from other factors will be a complicated business. This type of study is not a component of the implementation process and should preferably be carried out by specialised research organisations. Estimating the benefits of drainage systems along the lines as described below is one of the major components of a feasibility study.

Benefits of agricultural drainage can be divided into direct, associated and secondary benefits, i.e. one or more of the following:

Direct benefits:
- Increase in yield due to absence of water logging;
- Increase in yield due to reduced soil salinity.

Associated benefits:
- Better access to fields for mechanised operations resulting in lower production costs and reduced risk that activities cannot be carried out on time;
- Opportunity to grow other, higher value, crops;
- Opportunity to grow an extra crop each year.

Secondary benefits:
- Controlling a salinisation process will also stop environmental deterioration;
- Deeper groundwater levels will facilitate sanitation in an area and thus improve public health;
- Removal of standing water will reduce or eliminate water-borne diseases and thus improve public health.

These secondary benefits are particularly difficult to quantify.

The "without drainage" case

Drainage is primarily a measure to reduce water logging and to control salinity. Salinisation is a dynamic process that causes a slow but sure decline in the productivity of the land. Thus, an important invisible "benefit" that is considered in most feasibility studies is stopping the progressive reduction of the productivity that would just simply continue if the drainage systems were not implemented. This can be quantified by comparing the expected development of the pro-

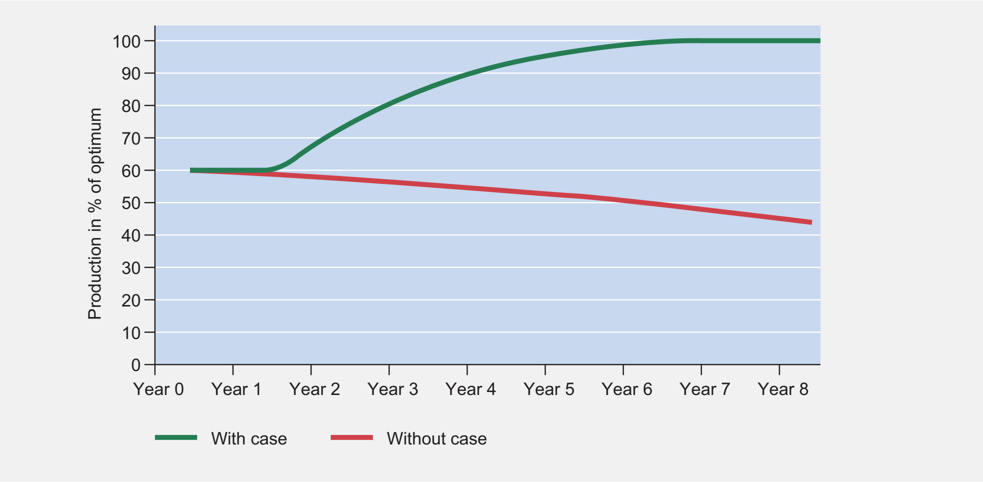


Figure 68 Expected development of the productivity of the area after the implementation of the drainage system ("with drainage" case) compared to the expected decline of the productivity of the area if no drainage systems were implemented ("without drainage" case)

ductivity of the area after the implementation of the drainage system in the "*with drainage*" case, with the expected decline of the productivity of the area if no drainage systems were implemented, the "*without drainage*" case (Figure 68). The production decline in the "*without drainage*" case can be estimated by extrapolating the production decline of the last years (decades). As can be seen in the figure the production in the "*with drainage*" case rises from 60% to 100% of the potential in 5 years. The first year is the construction year during which a decline in yield may occur. The direct benefit of the drainage system for each year is the difference of the value of the production between the "with" and the "without" project situation. The benefit of the project as a whole is the integration of the discounted annual benefits.

I.9.2.3 Influence of the existence of a national drainage industry on budgetary requirements

The budgetary requirements for implementing drainage systems depend very much on the existence of a drainage industry in the country. In general, subsurface drainage is only economically/financially justified if it is carried out on large scale. To make economical sense, the investments required for setting up a drainage industry including pipe and envelope production facilities, installation machines and equipment, and training of staff (Box 9.2) all of which easily amounting to several millions of euros, has to be written off over long periods and covers large areas. Apart from the cost of the preparation and construction, a budget has to be made available for the creation of such an industry. If the industry is going to be privatised, the private sector has to provide either all the investments or part of it with government support. The private sector will only be ready to do this if there are guarantees that there will be adequate work during the lifetime of the investments so that the investments can be written off over a reasonable period. If there is a drainage industry in existence then there will be no need for the additional investment. The proportional depreciation of the investment costs already incurred are partly reflected in the unit costs for drainage materials, drain installation and overheads. A similar situation can be created if the construction of the drainage system is tendered internationally. As international contractors will include a fee for risks and will try to write off as much machinery and plant costs as possible for their "one time" project, the costs will tend to be higher than if a national drainage industry exists.

Box 9.2 Investment costs needed for the implementation of subsurface drainage systems

A drainage machine costing between € 200,000 and € 250,000 (Table 9.2) can easily install 2000-3000 km of drains over its economic lifetime of 10,000 hours (or 10 years). Assuming an average drain spacing is 50 m, this will cover 10,000-15,000 ha.

A pipe production line for three diameters of pipes costs between € 1.2 and € 1.5 million and can produce 2500 km of Ø 100 mm pipe (550 tons) per year in 1 shift. Assuming again a drain spacing of 50 m, this covers 12,500 ha per year or 125,000 ha over a 10-year period (its life time).

I.9.2.4 Financing of drainage projects

As stated earlier, drainage projects can either be partly or wholly financed by a government from public funds as part of a public task to improve the production potential and/or to arrest further deterioration of the production potential and environment. The national benefits are expected to be an increase in local and, hence, national income. This can be translated into an improved tax base, better living conditions and perhaps reduced health costs. If the government does not have the budget to finance the drainage systems, it can try to obtain loans from the capital market or from development banks. Private initiatives for construction and financing of large-scale drainages systems are rare. In western countries, however, the construction or improvement of field drainage systems by owners of privately owned areas is quite common.

Organising the financing and recovery of the cost is largely dependent on the national customs and policies. It can range from being completely financed by government funds with the expectation that costs will be recovered through taxes, to being completely financed by the direct beneficiaries, either directly or through loans. All intermediate solutions are also possible. An approach often used is as follows:

- The main infrastructure, i.e., the main drainage system including the outlets and/or pumping stations, is considered a public good and is entirely financed by the government with public funds either directly or though loans. Repayment is eventually expected to come from an increased tax base;
- The on-farm works, i.e., the field drainage systems, are considered to be the direct benefit of the land owner/user. Therefore, the landowners have to finance these works, either fully or partly. Partly, because in some cases governments subsidise these works. Again the government expects repayment of their subsidies through additional tax revenues in the future;
- Landowners finance their part with a loan with a commercial loan or a subsidised loan. The repayment conditions of the loans (grace period, repayment period etc.) can be made on the basis of projected yield improvements.

I.9.3 Estimating the cost of drainage projects

I.9.3.1 Principles of estimating costs

A total cost estimate can be made by breaking down the implementation process into its components and subsequently breaking down these components into the constituent elements (Figure 67). The total implementation cost is the sum of the costs of all the components. The constituent elements are some or all of the following:

- *(Base) material costs* including transport and insurance to site and the normal breakage and or other losses;
- *Staff costs* including direct salaries, social charges, cost of schooling, cost of downtime, general overheads, specific overheads like tools, instruments and consumables;

- *Equipment costs* including running cost (consumables), repairs, spare parts, depreciation, storage costs, insurance, financing costs and cost of downtime;
- *Management costs* including time of managers, administration costs and contracting costs;
- *Financing costs,* namely, cost of bank credits or loss of interest;
- *Overhead costs.* The term "overhead cost" is a "catch all" phrase for all costs that are not accounted for elsewhere. They are often the costs that can be called "general running costs" of an entity or establishment and can include the cost of renting offices, secretarial assistance, professional insurance and services to personnel. Most of these costs cannot be attributed to only one project and are therefore accounted proportionally to the turnover of a project or contract;
- *Taxes and duties;*
- *Insurance, risks and profits.*

If some or all activities are contracted out to private entities the provision for risks and profits should be estimated for the contracted parts. In the case of an entirely government designed and implemented drainage system, the overhead costs are often part of the government's general budget and the state takes all the risks of cost or time overruns. These costs are then still real but less visible.

I.9.3.2 Methodologies for estimating costs

The easiest and most realistic way of calculating the cost of the components of a drainage system is to base the unit costs on market prices, if available. For instance, if there is a regular production of drainage pipes in the country with listed market prices, these prices can be included in the cost estimate. As a precaution, because some prices could fluctuate with world market prices, it may be wise to make appropriate allowances in the budget for them. If there are no market prices available in the country costs will have to be estimated. The methodology for calculating the "cost types" is given in Part II-B and includes: cost of staff, cost of machinery and equipment, cost of transport and cost of base material.

I.9.3.3 Cost estimates in this handbook

The discussion of cost estimates for subsurface drainage systems in this handbook will be confined to the costs related to the implementation of subsurface drainage systems, excluding the open drainage systems, associated works and associated measures. The cost of open drainage system is basically the cost of soil movement and civil engineering works (bridges, culverts, bypasses etc,) that are generally well known. The associated works are specific for every area thus no general suggestions can be made. The cost of operation and maintenance will be discussed in a non-quantitative way for the sake of completeness.

In the following sections some guidelines will be given for calculating the investments costs in case there is no drainage industry in the country and for construction costs.

I.9.4 Investments for the creation of a drainage industry

I.9.4.1 General

If no drainage industry exists and it is decided that such a drainage industry is to be established, long-term investments have to be made in staff training, machinery and the plants specific to subsurface drainage. The investments cost of machinery and plants must include all costs, including taxes and duties, transport, erection and test runs. The investments should be depreciated (amortised) over their lifetime, which can be calculated as an economic lifetime and/or as technical lifetime. Even if equipment has been received as a gift it is advisable to depreciate it, in this way a capital can be built up for replacements once the equipment has exceeded its lifetime. The investment costs are proportionally written off and are accounted for in the cost of drainage materials and the costs for drainage construction.

I.9.4.2 Investments in staff training

Specialised knowledge is required for the design and implementation of subsurface drainage systems (Table 9.1). Depending on the national customs and systems this can apply to the government or private staff. Since training needs vary with the basic education of the selected staff, the organisational set-up and local customs, no basis for cost calculation can be suggested. The possible training required for producing drainage materials and maintaining equipment is not included. The intensity and level of training that will be required has to be determined on a case-by-case basis. In most countries the basic knowledge will be available. For the calculation of training costs the following items can be taken into account:

- Training fees;
- Travelling and boarding costs of trainees;
- Training materials;
- Salaries and other cost of trainees.

Table 9.1 Training subjects

Preparation & tendering	Installation	Management & supervision
• Collection of field data	• Operation trenchers	• Contracting
• Topographic surveys	• Managing laser	• Progress control
• Soil surveys	• Operation tractors	• Quality Control
• Soil chemical and physical testing	• Operation excavators	• Budget control
• Defining drainage criteria	• Operation loaders	• Handing over procedures
• Defining design criteria	• Application of gravel envelopes	• National regulations
• Design of subsurface drainage systems	• Topographic survey	• Relations with stakeholders
• Calculation of unit prices	• Mechanical servicing and repair of equipment	
• Preparing Bills of quantities	• Setting out of field	
• Least cost analyses	• Quality control of installation	
• Preparing installation instructions	• Quality control drainage materials	
• Contracting	• Economic installation	
• Preparing tender documents	• Managing installation process	
• Tender procedures		

I.9.4.3 Investment in drainage equipment

The equipment used for drain installation consists of (Chapter I.5):

- *Specific drainage machinery* that can only be used for subsurface drainage installation including: trenchers or trenchless machines equipped with lasers, and if necessary gravel trailers as support equipment;
- *General construction equipment,* meaning equipment required for drainage though commonly also used for other purposes, which includes: excavators, bulldozers, tractors, trailers, front loaders and topographic equipment.

The equipment that will be required and how much of each item is very dependent on the system to be installed and the methods used. For the installation of subsurface drainage systems in large areas, working in units of 2-3 trenchers has proven to be economical for organisational purposes and for effective use of the support equipment and support staff.
The economic life of mechanical equipment in western countries is considered to be 10,000 hours or some 10 years. Under normal conditions drains of up to 2500 km can be installed with a drainage machine over this lifetime (Box 9.2). Beyond a period of 10 years, the cost of maintenance and repairs together with the time losses due to mechanical failures are thought to be greater than the costs of new equipment. In some countries, especially where import duties are high and/or exchange control problems exists, it may be logical to keep the equipment functional for a longer period.

The cost estimate of equipment for subsurface drainage installation depends on what equipment is required for the implementation of a specific design. It also depends on what is available in the country and what has to be purchased at the international market. Transport cost, import duties, insurance cost and exchange rates also play an important role in the final price. A general estimate for two basic units for drainage installation, namely, one with granular envelopes and one without granular envelopes is given in Table 9.2. Both units consist of one drainage machine for the field drain installation and one for the collector installation. The collector machine can also install field drains. The minor support machines like agricultural tractors, trailers etc. are not valued, since these are normally available in a country and prices can differ very much from world market prices.

Table 9.2 Cost estimate of drainage installation unit (both field and collector drains) with granular and pre-wrapped envelopes around the field drains (costs based on international market F.O.B. prices of tenders in year 2002)

Item	Unit	Quantity	Unit price (€)	Total price (€)
Drainage system with granular envelope				
Field drain installation machine equipped with laser	unit	1	200,000	200,000
Gravel trailer	unit	6	20,000	120,000
Collector installation machine with laser	unit	1	250,000	250,000
Excavator	unit	2		
Tractors for gravel trailers >75 HP	unit	3		Local market price
Bulldozer	unit	1		Local market price
Front loader (gravel)	unit	1		Local market price
Agric. tractor + trailer	unit	2		Local market price
Servicing/maintenance truck	unit	1		
Topographic equipment	set	2		Local market price
Quality control	set	1		Local market price
Spare parts imported equipment 20%				134,000
Total Drainage system with granular envelope				
Drainage system with pre-wrapped envelope				
Field drain installation machine equipped with laser	unit	1	200,000	200,000
Collector installation machine with laser	unit	1	250,000	250,000
Excavator	unit	2		
Bulldozer	unit	1		
Agric. tractor + trailer	unit	2		Local market price
Servicing/maintenance truck	unit	1		
Topographic equipment	set	2		Local market price
Quality control	set	1		Local market price
Spare parts imported equipment 20%				90,000
Total Drainage system with pre-wrapped envelope				

I.9.4.4 Investment in a plastic drain pipe production plant

The following considerations play a role if investment is required in drain pipe manufacturing plants (Chapter I.4.2.3):

- A pipe manufacturing plant consists of the following components: extruders, corrugators, perforators and coilers. The most expensive parts are the corrugators and perforators;
- A drain pipe production line can manufacture a range of diameters roughly measuring Ø 60-125 mm and Ø 100-200 m. The extruder requires a specific die head for each diameter and the corrugators and perforators require specialised components. Thus the investment increases considerably for each additional diameter needing to be produced. Limiting the number of diameters of drain pipes during the design can be economical;
- A pipe manufacturing line requires a constant supply of electricity and cooling water. Depending on the conditions in de area this supply may require additional investments;
- A pipe manufacturing line requires a production hall with adequate storage room (plastic drain pipes have to be stored outside the direct sunlight);
- The cost of a corrugated drain pipe is directly related to its weight per m'. The weight per m' is a function of the diameter and the pipe thickness;
- The form of the corrugations is related to the required pipe thickness to obtain the norm strength of the pipe. The most optimal form of the corrugation is thus the form that gives the pipe its required strength with the minimum pipe thickness and thus the lowest weight per m. An indicator of quality of the production line is the required weight per m' pipe to obtain the norm strength. Although production lines that produce the same pipe strength with less weight per m' tend to be more expensive, the saving on base material normally offsets the extra cost of the line within a short period of time;
- Transport of pipes is costly since the pipes are voluminous. Thus, the location of the factory in regard to the installation site can have an important influence on the cost price of pipes "delivered onsite";
- If transport distances are excessive relocation of the production line to a location closer to the site may be considered. Mobile pipe production lines were manufactured in de 1970s and 1980s, however, the cost and limitations of mobile production lines proved to be higher than moving the components of a fixed production line to other premises;
- Importing pipes is normally not a feasible option. The cost of transport very quickly exceeds the value of the pipes;
- Importing base material for the production of pipes can be a reasonable solution;
- PE production lines tend to be somewhat cheaper than PVC production lines. However, PE requires about 20% extra base material and on the world market PE tends to be more expensive per kg than PVC;
- The capacity of production lines tends to be very high compared to the installation capacity of trenchers, namely, a production line can produce in 24 hours a quantity of pipes that 8 -10 trenchers can install per day. Buying a line with a reduced capacity, however, will hardly save any costs since the extruder determines the capacity and is only a minor part of the total cost.

The production capacity of a production line is usually expressed in kg base material per hour. Outputs per line vary from 500-800 kg/hour. For Ø 100 mm pipes this can be translated into 1150-1800 m/hour. If required the drain pipe production line can work 20-24 hours per day all year round. The technical lifetime of a production line is approximately 80 000 hours (10 years of 8000 hours per year), the tooling has to be replaced after approximately 25 000 hours.

Conclusions

The investment costs of a pipe manufacturing line is dependent on: (i) the diameters and the number of diameters that are to be produced; (ii) whether PVC or PE pipes need to be made; (iii) the available facilities in the country (electricity and cooling water); and (iv) the cost of the civil works, and the like. The following are the indications of the investment costs: a good quality production line itself without generators including extra cooling facilities etc., costs vary between € 1.2 and 1.8 million for a line with three diameters. For each additional diameter an investment of approximately € 150 000 is needed.

I.9.4.5 Investments in drain envelope production

Drain envelopes can be either made of granular or a pre-wrapped synthetic material (Chapter I.4.4).

Granular envelopes

Granular envelope production is a question of transport and sieving with or without the crushing of natural gravel. If a gravel production is to be set up the investment will consist of sieves, possibly crushing plants and transport equipment. These costs are largely locally dependent and mostly well known.

Synthetic envelope

The production of most synthetic envelopes requires complicated industrial processes, which have no economic justification if they are only used to produce drain envelopes. If the appropriate envelope material cannot be made locally, it has to be imported. The volumes and the weight are relatively limited so transport costs are not excessive. Wrapping the envelope around the pipes is most logical done at or close to the place where the pipes are produced. The equipment required therefore depends very much on the enveloping material and the preparations that have to be made before it can be wrapped around the pipes. Cost can vary from € 5000 - € 250 000 in prices of the year 2002.

I.9.5 Cost calculation of the pre-construction activities

I.9.5.1 Preparation of a feasibility study

Feasibility studies can be useful for the decision-making process at government level, especially when foreign financing is required and in countries with no drainage tradition and thus no experience of costs and benefits. The costs of preparing a feasibility study with the precision and contents acceptable to international development banks can be important. No general estimates can be given since it very much depends on the extent of the study, the readily available basic information, the possible complications of lowering groundwatertables for surrounding areas, the drain water disposal, the possible environmental impact and problems in estimating the benefits. Preparation costs of a multidisciplinary feasibility study is mainly based on an estimate of the time and unit costs of the required specialists.

I.9.5.2 Field investigations

Field investigations consist mainly of (Chapter I.1.4.2):
- Topographic surveys;
- Pre-drainage soil surveys.

If there is little or no information of the geo-hydrology and geology of an area, surveys such as these may also be required although their outcome will have a much wider application than purely for drainage. The cost of these additional surveys should also be taken into account.

Topographic surveys
Detailed topographic information is required for the design of a drainage system that can seldom be extracted with enough precision from existing topographic maps, and consequently, additional surveys are needed. Calculation of the costs of these topographic surveys is mostly done per hectare, and only if long alignments need to be levelled outside the direct area to be drained, the alignments may be calculated per km.

Pre-drainage soil surveys
The requisite soil information for determining drainage requirements is seldom found in existing soil maps. For drainage purposes hydraulic conductivity has to be determined, and information about soil salinity and groundwater levels and salinity is required as well as soil texture and the occurrence of impermeable layers. Since the required information is quite well defined (see ILRI publication 16) as well as the density, a costing on a per hectare basis can be estimated (Box 9.3).

Box 9.3 Cost estimate pre-drainage soil survey

If the required survey density is about one observation point per 5 - 10 ha a survey team can survey at least 4 locations per day depending on local conditions such as transport. Thus pre-drainage soil survey can have a daily output of some 20 to 40 ha (excluding laboratory work).

I.9.5.3 Design

A detailed design of drainage systems is based on reliable field information and a set of clear design criteria (Chapter I.1.4.3). The latter are prescribed by the implementation authority (Chapter I.1) and specify the groundwater levels that have to be maintained and the capacity required of the system, including practical information on available materials, installation equipment, desired layouts and so forth (Chapter I.3). The design process itself can quickly become a routine in which computers play an important role. The cost of the design of the subsurface system itself is mainly a question of the cost of the designer's time and can be accounted for on a per hectare basis. Special features like road crossings, pumping stations or complicated outlet structures are normally less routine-like in nature and should be considered separately.

I.9.5.4 Tender preparation and tendering

The tender preparation, the tendering, the supervision of the construction and the design are often combined in the one contract. It is quite common for the cost of these services are expressed as a percentage of the contracting construction costs. The amount of work depends on the existence of tender routines in the country with standard procedures, standard contract forms and specifications etc. If all of these have to be developed the work and the costs can be considerable. But, if properly drawn up in line with the national policies they can serve as a model for a following contract and thus have an application beyond the drainage system(s) for which they have been prepared (Chapter I.2). The cost can be calculated as: (i) a lump sum; (ii) a percentage of the contract sum; or (iii) on the basis of estimated expert time required.

I.9.5.5 Summary pre-construction costs

Table 9.3 presents the cost calculation of the preparation of the construction of a drainage system. In this table the cost of the governmental interventions are not taken into account.

Table 9.3 Sample of bill of quantities for budgeting of preparation costs

Item	Unit	Unit cost	Quantity	Total cost	Sub total
Feasibility study:					
• Time input	Person days				
• Associated cost	Lump sum				
Subtotal Feasibility study					
Field investigations:					
Topographic survey:					
• Area topography	ha				
• Alignments	km				
Pre-drainage soil survey:					
• Area soil survey	ha				
• Laboratory analysis	No. samples				
Subtotal Surveys					
Design:					
• Design of subsurface network	ha				
• Design of associated work	unit				
Subtotal Design					
Tender preparation and tendering:					
• On percentage basis	% of constr.				
• On time basis	days				
• Lump sum					
Subtotal Tendering					
Total Pre-construction Costs					

I.9.6 Construction costs

Methodologies for cost calculation of the major activities required for the construction of subsurface drainage networks are discussed in the following sections. The basic cost elements of the construction process are: staff costs, equipment cost, transport cost and material costs.

I.9.6.1 Field preparation

Field preparation consists of a number of activities (Chapter I.6.6) that have to be priced separately:

- Setting out alignments and levels: this includes staking out of the locations where the drains and manholes have to be installed with indications of levels. The cost can be calculated in staff time, some materials (stakes, bench marks, etc.) and equipment time;
- Accessibility of fields for drainage equipment: This includes the making of temporary passes of canals or drains and removing obstructions. It can be estimated in machine hours and staff time. Sometimes temporary bridges or culverts have to be installed

requiring the necessary materials for the purpose. The costing should include the removal after the construction is completed;
- Levelling alignment of drains: this involves the preparation of an alignment so that the drain machine can drive unobstructed. Normally, it is a matter of levelling a path with a bulldozer or grader. In case gravel is used with gravel trailers the path must be wide enough to accommodate the gravel trailers. The cost is calculated on the basis of machine (bulldozer, grader) hours;
- Preparation of a gravel storage place (if required): this involves the smoothing of a strategic location with good accessibility for both delivery trucks and gravel trailers with tractors. The cost can be calculated on the basis of machine hours;
- Preparing field storage place for drain pipes, manholes and the like: in the case of plastic drain pipes this often involves a shaded place. The cost is calculated in machine hours, staff time and materials;
- Camp preparation: for large projects sometimes contractor camps are made for lodging of the personnel, equipment maintenance facilities, etc. Costs depend very much on local conditions;
- The equipment has to be transported to the site, the cost depending on where the equipment comes from and on local transport costs and available transport equipment.

I.9.6.2 Drainage materials

The type and quantity of drainage materials to be used is determined according to the selected construction method (Chapter I.6). Cost estimates can be obtained as indicated below.

Plastic drain pipes
The price of plastic pipes varies considerably worldwide, partly caused by supply and demand, and partly by the volume that is produced. A factory that has a full workload can produce more cheaply than a factory that only works occasionally. The cost of plastic drain pipes can be calculated from the following:
- Commercial market prices plus transport costs, if there is an industry in the country;
- Base material costs (world market prices fluctuate!), production equipment costs plus transport costs, if there is no industry in the country and the industry is going to be set up;
- World market prices plus import duties plus transport costs, if imported pipes are going to be used.

Tips:
- Include in the cost 5-10% extra pipes for losses, damage and waste;
- A first approach for a price can be: 2 x the cost of base (raw) materials + transport cost.

Accessories for plastic drain pipes
The cost of accessories like connectors, reducers, end stops and pipe ends should be based on market prices or production costs similar to the plastic pipes above.

Rigid plastic pipes
Rigid plastic pipes are often required as end pipes, outlets, drain bridges and the like. The prices can mostly be derived from local manufacturers.

Concrete drain pipes
The cost of concrete drain pipes can best be based on the local cost of such pipes that are used for other purposes. If these costs are not available an estimate can be based on the national cost of m^3 of high quality concrete. Transport to the site must be added.

Granular envelopes
The cost of granular envelopes is a sum of the costs of all or some of the following items:
- Quarry rights (locally variable mostly a cost per m^3);
- Crushing (labour costs, cost of crusher equipment) if required;
- Sieving (labour costs plus minor costs of sieves and internal transport);
- Loading (labour + conveyor belts);
- Transport.

Synthetic envelopes
If there are no commercial listed prices for synthetic pre-wrapped envelopes, the price can be estimated from the cost of:
- The base material including transport costs to the factory;
- Thread to tie the material around the pipe;
- Wrapping machinery including, if necessary, the preparation of envelope material;
- Transporting the pipes from pipe factory to wrapping plant.

Note: if pipes with a pre-wrapped envelope are used, the price is based on the pipe with envelope.

Structures
Structures, in particular manholes, sumps, drain bridges, end structures and outlets, are mostly made of concrete the cost of which can be based on the volume of (different classes of) concrete in accordance with the design and unit cost of concrete per m^3.

I.9.6.3 Drain installation

Depending on the design, drain installation consists of some or all the following activities (Chapter I.6.6):
- Installation of field drains;
- Installation of end pipes;
- Installation of joints with collectors;
- Installation of manholes;
- Installation of crossings (drain bridges);

- Closing of field drain trenches;
- Installation of collector drain;
- Installation of joints field drains/collector drains;
- Installation of manholes and sumps;
- Installation of outlets;
- Closing of trenches of collectors.

The cost of installation is a total of the machine costs and labour costs. Since both costs are daily or hourly based, it is crucial to know the productivity per day or the length of drains that can routinely be installed per day. The required machinery, equipment and personnel for installation is dependent on the local situation, the design and the used materials, such as singular or composite system, concrete or plastic pipes and granular or pre-wrapped envelopes, for instance.

To calculate the cost of the installation, the composition of an efficient working installation unit in terms of machinery, equipment and personnel needs to be determined first. Costs per day of such a unit can then be calculated from the unit cost of each component. The cost of the drain installation can then be calculated by dividing the daily cost by the expected daily productivity of the installation unit.

Table 9.4 and 9.5 presents examples of installation cost calculations for field drains and collector drains, respectively. These are fictitious examples both as far as the unit cost is concerned and the equipment and personnel required. These two tables together provide the model for the cost calculation of composite systems with granular envelope. The installation units for the installation of singular systems or systems with pre-wrapped envelopes will be smaller than the units given in the example. In Part II-B details of cost calculations are further elaborated.

Comments

The cost of the installation very much depends on how the installation is organised. Often the cost of the installation machines is the single most expensive item. Consequently, the use of these machines should be optimised, meaning that everything must be done to keep them working continuously. Because the quantity of collectors is generally less than 20% of the quantity of field drains, the collector installation machines are idle for part of the time if they work in tandem with the field drain machines. This can be prevented by either having a number of field drain installation machines working together with one collector machine or by using the collector drain installation machine also for the installation of field drains by attaching another trench box.

Table 9.4 Example (fictitious) of the methodology for cost calculation for field drain installation. It is assumed that the collector installation machine can install both collectors and field drains. The cost per m' installed is the cost of an average m' of field and collector drains

Item	Quantity	Unit cost per day (€)	Total Cost per day (€)
Machinery and equipment:			
Field drain installation machine + laser	1	570	570
Gravel trailer	3	25	75
Tractors for gravel trailers	3	50	150
Excavator	1	450	450
Bulldozer	1	250	250
Front loader (gravel)	1	50	50
Agric. tractor + trailer	2	25	50
Servicing/maintenance truck	1	75	75
Topographic equipment	2	10	20
Car for field manager	0.5	40	20
Field transport for topographic and control personnel	1	30	30
Subtotal machinery and equipment			**1740**
Staff:			
Field manager	1		
Gravel manager	1		
Mechanics	1		
Topographers group	1		
Laser management	1		
Labourers	5		
Quality control	2		
Subtotal personnel			
Total daily cost Field Drain Installation			
Length of drain installed per day in m' drain [a]			
Cost per m' drain			

[a] The number of m' of field drains installed by a field drain installation machine depends on logistics, management, local conditions, capacity of the machine etc. For plastic flied drains, installation rates between 1500 m and 2500 m per day can easily be reached.

Table 9.5 Example of the methodology for cost calculation for collector drain installation (In this fictitious example, the cost of a composite system with granular envelope is taken into account, the assumption being that the collector installation does not require an envelope)

Item	Quantity	Unit cost per day (€)	Total Cost per day (€)
Machinery and equipment:			
• Collector/field drain installation machine + laser	1	650	650
• Excavator [a]	1	450	450
• Bulldozer [a]	1	250	250
• Agric. tractor + trailer [a]	1	25	25
• Servicing/maintenance truck [a]	0.33	75	25
• Topographic equipment [a]	2	10	20
• Car for field manager [a]	0.25	40	10
• Field transport for topographic and control personnel [a]	0.33	30	10
Subtotal machinery and equipment			**1440**
Staff [a]:			
• Field manager	1		
• Gravel manager	1		
• Mechanics	1		
• Topographers group	1		
• Laser management	1		
• Labourers	5		
• Quality control	2		
Subtotal personnel			
Total daily cost Collector Drain Installation			
Length of collector installed per day; in m' drain [b]			
Cost per m' drain			

[a] The quantities of these machines are to be taken up in proportion of the time spend for field and collector drain installation and can thus be a fraction. So if one collector machine works with two field drain installation machines 1/3 of the cost must be attributed to the collector installation.

[b] The number of m' installed per day by a collector machine depends on logistics, management, local conditions, capacity of the machine etc. For plastic collector pipes a installation rate of 1000 - 1500 m per day can easily be reached. The installation rate for concrete collector pipes is considerably lower (700 m/day).

I.9.6.4 Installation of manholes, sumps and joints

The cost of the installation of manholes/sumps, crossings, joints, outlet pipes and the like is an integral part of the drain installation. The cost also represents a combination of the cost of the staff and machinery. Most practical would be to foresee in the composition of the installation unit adequate staff and machinery for this installation and calculate the cost as an integral part of the drain installation. The cost of the supply of pipes if contracted out is sometimes separated from the cost of the pipe installation as such. If this is the case the costs are based on the machine hours and staff costs.

I.9.6.5 Backfilling of trenches

When drain pipes are installed using trenchers, the trenches have to be filled back, preferably with some overfill to compensate for subsidence. This can be done manually or mechanically (bulldozer, grader tractor with grader or bulldozer blade). The cost thereof is thus the cost of the machinery and/or the staff.

I.9.6.6 Construction and Installation of pumps/pumping stations

Construction of pumping stations is a civil engineering task the details of which are outside the scope of this book. Installation of pumps includes the supply of pumps and the connection to electric lines. The cost of the pumps can be obtained from manufacturers or suppliers based on the specifications. The cost of electric lines, transformers and so forth can be obtained from local electricity companies.

I.9.6.7 Cost of quality control and supervision

The cost of quality control and supervision can be divided into the cost of:

- Quality control of the materials: this is a cost that is part of the production cost of these materials, with a final check on the site, which is part of the "regular" supervision task. No extra costs have to be included;
- Quality control of the installation during the installation process: this is basically checking of the vertical and horizontal alignment of the drain pipes and levels of the manholes, sumps and outlets.

I.9.6.8 General Costs

Besides the direct construction costs, there are the so-called general costs such as:

- *Clearing of the site:* After the construction has been completed the site must be cleared of all leftover materials, refused materials and temporary constructions. The costs amount to mainly machinery and staff costs;
- *Quality control:* A final quality check has to be one to determine whether the system is functional as part of the handing over procedure of the site to the future users. This is mainly a staff cost;
- *As-built drawings:* Precise maps need to be made of where the drainage systems are located at the end of the installation, so that they can be traced for maintenance purposes. In most cases the exact location of the drains does not always coincide with the designed location;
- *Organisation overheads:* These costs include the time of the general management, accounting and administration, which is often carried out in parallel with similar tasks for

other projects. These costs are normally taken as a percentage of the construction costs. The overhead cost of the individual staff members is included in their unit cost;

- *Profit and risk:* If the installation is carried out by a private entity they have to make allowance for profits and for risks. After all they may be held responsible if something goes wrong, for any miscalculations or for human error. If government entities carry out the work they also run risks, but usually the government will pay for the extra cost. The amounts charged for overheads, profits and risks might vary considerably. They depend on the experience in the country, the trust in supervisors, the quality of the design, the general business risks in the country, and so forth. Figures varying between 20 and 50% have been known to occur;
- *Contingencies:* Most cost calculations reserve an amount for contingencies, namely, 10 - 20%. This is a reservation for extra work, unforeseen problems, price rises and such like. The conditions of contract determine how and when contingencies payments are to be made.

I.9.6.9 Total cost of construction

The total cost of construction is often summarised as a bill of quantities. Here the aggregated unit prices are given for the main items (Table 9.6).

Table 9.6 Bill of Quantities for the construction of a composite drainage system (items marked are not relevant for all projects)*

No.	Item	Units	Unit cost	Quantity	Total Cost
1	**Field Preparation:**				
1.1	Setting out of field	ha			
1.2	Accessibility of field	unit			
1.3	Levelling drain alignments	m'			
1.4	Preparing gravel storage*)	unit			
1.5	Preparing pipe storage	unit			
1.6	Preparing camp*)	unit			
1.7	Transport equipment to site	unit			
	Subtotal Field Preparation				
2.	**Field drain Installation:**				
2.1	(Pre-wrapped) drain pipes on site Ø 80 mm	m'			
2.2	(Pre-wrapped) drain pipes on site Ø 100 mm	m'			
2.3	Connections*)				
2.4	End-caps and couplers on site	no			
2.5	Rigid end pipes/bridges	m'			
2.6	Granular envelope (if relevant)	m^3			
2.7	Installation drain pipes plus envelope	m'			

Table 9.6 Continued

No.	Item	Units	Unit cost	Quantity	Total Cost
2.8	Installing joints to collectors*)	no.			
2.9	Installing manholes*)	no.			
2.10	Installing end pipes*)	no.			
2.11	Installing crossings*)	no.			
2.12	Trench backfilling	m'			
2.13	Quality control	m'			
	Subtotal Field Drain Installation				
3	**Collector Drain Installation:**				
3.1	Collector pipes on site Ø …. mm	m'			
3.2	Collector pipes on site Ø …. mm	m'			
3.3	End-caps and couplers on site	no.			
3.4	Rigid end pipes/bridges	m'			
3.5	Installation collectors	m'			
3.6	Installing manholes*)	no.			
3.7	Installing sumps*)	no.			
3.8	Installing outlets*)	no.			
3.9	Installing crossings*)	no.			
3.10	Trench backfilling	m'			
3.11	Quality control	m'			
	Subtotal Collector Drain Installation				
4	**Additional works:**				
4.1	Construction pumping stations	no.			
4.2	Supply of pumps	no.			
4.3	Installation of pumps	no.			
4.4	Electrical connections	no.			
4.5	Transformers type …	no.			
4.5	Electricity supply lines	km.			
	Subtotal Additional Works				
5	**General Cost:**				
5.1	Clearing of site	unit			
5.2	Final Quality Control	unit			
5.3	Management and accounting	unit			
5.4	As-built drawings	unit			
	Subtotal General Costs				
	Total Net Cost				
	Overhead profit and risk	% of total net cost			
	Contingencies	% of total net cost			
	Total Cost of Construction				

I.9.7 Cost of operation and maintenance of subsurface systems

The cost of operation and maintenance depends on many factors and can very considerably, namely:

- *Operation cost* (Chapter I. 8.3): The operation is generally confined to the pumping cost (if there is pumping). This involves energy costs (diesel or electricity) and some times staff costs. Operation costs can also be mentioned in the regular inspections, the staff cost for supervision and complaints management;
- *Maintenance* (Chapter I.8.4): Maintenance is mainly the cleaning and repairing of the subsurface drains (field drains and collector drains) and the associated structures (outlets, manholes, crossings, pumping stations etc.). Some maintenance work can be carried out by the landowners as part of their general field maintenance, and will thus have no direct cost consequence. This for instance applies to the checking of the drains, cleaning of the manholes, the checking and clearing of the outlets. The flushing of the drain pipes with flushers is a professional job. The cost is mainly determined by the required frequency of flushing, so no general rules can be applied. The required frequency depends on the soil types, envelopes, quality of installation, intensity of use and climate, among other things. For budgetary purposes a frequency of flushing one every 3-5 years is a good estimate. The length of drain that can be flushed per day depends very much on local situations and equipment. Until experience is available one can consider a potential production of 2 km per day for budgetary purposes. The cost of flushing is the cost of staff and equipment. Other maintenance costs pertain to the maintenance of the pumps and repairs of drains (mainly outlets and manholes). These costs are mainly staff costs, some equipment and spare parts.