PART III

CASE STUDIES
PART III - CASE STUDIES
Preamble

Part III presents salient features of the history, development and present practices of the implementation of subsurface drainage in China, Egypt, India, The Netherlands and Pakistan. Although subsurface drainage is practised in many more countries a selection of only these five countries has been made on the basis of availability of up to date information. Furthermore these five countries are considered to be representative for various climate regions and institutional settings. The most relevant experiences in the countries have already been used to compile Part I and Part II. These practices are not repeated in the case studies, the presented information is to highlight that each country has its specific physical and institutional conditions. For each and every country, technical and organisational arrangements have to be tailor-made to fit for the specific local conditions, straightaway copying practices and experiences from one country to another is no option. Thus the case studies are presented as a reference for the reader and are considered useful for those who want to start subsurface drainage on a local or national scale.

Countries were pipe drainage is or has been practised:

- Algeria
- Australia
- Belgium
- Chile
- China
- Colombia
- Denmark
- Egypt
- Ethiopia
- Finland
- France
- Germany
- Hungary
- India
- Iraq
- Iran
- Italy
- Jordan
- Korea (South)
- Mexico
- Morocco
- Poland
- Portugal
- Turkey
- The Netherlands
- Pakistan
- Peru
- Rumania
- Russia
- Senegal
- Slovakia
- Spain
- Syria
- Taiwan
- Czech Republic
- Tunisia
- United States of America
- Uzbekistan
- United Kingdom
- Yugoslavia (former)
Case Study - China
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1 Introduction

More than half of the cultivated land in China is affected by either waterlogging and/or salinity. Consequently waterlogging and salinity are important issues in China, even more so since the natural conditions of the country are such that only one third of the land is suitable for agriculture. Salinity problems occur in 13 to 14 million ha or 14% of the total cultivated land (around 97 million ha) and waterlogging in 24 million ha or 25% of the cultivated areas. In the northern parts of China, which has a rainfall deficit, about 50% of the cultivated lands are irrigated. Irrigation induced salinity occurs in more than 11 million ha or 23% of these irrigated lands.

Modern drainage techniques in combination with traditional methods can potentially solve most of the waterlogging and salinity problems at field level. Since the 1960’s major improvements have been realised by implementing large scale open drainage systems, (tube)well drainage systems and intensifying research and experiments with pipe drainage on pilot and practical scale.

2 Distribution of areas with drainage problems

The distribution over the country of the areas suffering from drainage problems can be summarised as follows (Figure 1 and 2):

- No obvious drainage problems occur in the western part of China: the mountainous areas of and around the Qinghai-Tibet plateau;
- The plateaus and plains and river valleys in the arid and semi arid north and northwest have considerable salinity problems often combined with alkalinity;
- The river plains in the North East that form a delta area (Three River or Sanjiang Plain) have high groundwater tables but no significant salinity;
- The North China Plain, located in the east (Huang-Huai-Hai Rivers Plain) is affected by a combination of high groundwater tables, saline groundwater and consequently soil salinity, in some areas combined with alkalinity. Large areas in the Yellow River Delta, an economically important part of the North China Plain, are either in direct or indirect contact with the sea and hence have saline groundwater and suffer from saline soils;

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1 This chapter has been written in close cooperation with Prof Fang Sheng of the Hebei Institute of Hydrotechnics, dr. Ding Kunlun of the IWHR, Engineer Lin Chi, retired from the CAERP, and Mr. Zhuang Huijiang of Municipal Government of Dongying Shandong. Use has been made of the Chinese publications of En. Yang Cheng Qu retired from the Xinjiang Agricultural Industrial and Trade Corporation (XAITC) and the experience of Mr. He Gang formerly of the (XAITC) and Mr. Zheng Cunhu of the Kingchuan Company Dong Ying Shandong.

The Yangtze Delta and the Pearl River Delta suffer from waterlogging and salinity problems. Salinity is more prevalent in the coastal areas, but because of the high rainfall it is less serious than in the North China Plain. Water logging is more prominent land inwards;

- The inland river plains of the huge Yangtze River basin have considerable, sometimes seasonal, waterlogging problems;
- The river plains of the Pearl River basin have the same considerable, sometimes seasonal, waterlogging problems. Since most of the areas in this basin are traditional rice growing areas, waterlogging does not always seriously impede crop growth.

Figure 1 Waterlogged areas in China

3 Historical developments

3.1 Drainage in ancient times

The Chinese population has been struggling with waterlogging and salinity control throughout its history. The earliest records of a search for solutions date from around 1000 years B.C. Over the years ingenious solutions have been found to control waterlogging and salinity, among which
of course is leaching through rice growing. Open drains have been built to convey the surplus water to rivers and seas. In inland areas drainage canals have been built and rivers have been deepened to allow disposal of drainage water and consequently lowering of water tables.

Salt management has been practiced by traditional methods, for example:

- Building up the soil level by so called “warping”. Warping is a technique consisting of filling manmade basins with silt-loaded irrigation water and then draining off the water once the silt has settled. In this way a new salt-alkali free soil layer is deposited on top of the salinised land, which allows temporarily cultivation in a relatively salt free environment;
- “Stone mulching” to reduce capillary rise and to prevent secondary salination to some extend;
- Land forming/levelling, a method to concentrate the capillary rise of saline groundwater in predetermined areas, so that crops can be planted in areas where no or limited secondary salinization occurs;
- Crop rotations, where rice crops are alternated with dry-foot crops, thereby allowing leaching of salts accumulated in the soil during the growing season of the dry-foot crops and percolation of water from the rice crops;
PART III - CASE STUDIES

- So-called winter irrigation. Winter irrigation is in fact a leaching of fields after harvest before the onset of frost at a moment when there is limited demand on the available irrigation water. The salts accumulated during the growing season are (partly) leached;
- Biological control, which involves planting trees on strategic places for the purpose of lowering groundwater levels and to limit secondary salinisation.

3.2 Drainage in China after the creation of the Peoples Republic

Construction of irrigation and drainage
After the Chinese revolution impressive efforts were made to bring large areas under irrigation. Within 20 years about 32 million ha, often located in remote areas, were provided with irrigation systems. The newly reclaimed and irrigated areas were equipped with open drainage systems. Well drainage systems, often in conjunction with groundwater exploitation, were installed in 17 provinces and municipalities in Northern China (2 980 000 wells!). Moreover some experiments were conducted with pipe drains.

In the 1960s and 1970s impressive successes with lowering groundwater tables and reducing salinity were obtained by improving the main drainage systems and the drain outlets towards the Bohai Sea in the North China Plain. These improvements increased the drainage capacity four to six fold making it possible to evacuate the salt out of the area with floods and the summer rains. This prevented the recirculation and accumulation of salts in soil and groundwater. It resulted in reducing the area affected with salinity/alkalinity problem in the North China plain with 50%.

The extensive well drainage in the North China Plain and where possible reusing the pumped water for irrigation has caused a serious overdraft of the shallow and deep aquifers that has resulted in regional lowering of the groundwater table, land subsidence and sea water intrusion into the aquifers.

Research
Considerable research efforts have been carried out since 1949 in the field of drainage and salinity control. On national level, the China Institute of Water Resources and Hydropower Research (IWHR) and the Chinese Academy of Agricultural Engineering Research and Planning (CAAERP) conducted and guided many local research activities both in basic research on soil plant water relationship and on applied research on drainage methods and materials. At field level pilot areas were equipped with pipe drainage and well drainage systems (for instance, pipe drainage in Tianjin, in the Yellow River Delta, and well drainage in the Yellow River Delta and in the Ningxia Autonomous Region).

Field research was also conducted in Hebei (Nanpi) to develop methods for comprehensive control of draught, waterlogging, salinity and groundwater salinity by making use of open drainage and well drainage/irrigation. In the Houying Pilot Area (Hebei Province) similar experiments were conducted by making use of open drainage system. Part of the experiments focussed on growing crops by irrigation consecutively with fresh and saline water.
Increased need for artificial drainage in China
The impressive intensification of agricultural, the expansion and consolidation of the irrigated areas and the progressive irrigation induced salinisation of part of the areas brought under irrigation in the last 50 years, as well as the reclamation of coastal areas for agricultural use will undoubtedly require some form of large-scale artificial drainage. And, there is the added complication of the scarcity of water for irrigation, which will reduce the automatic leaching and consequently worsen the salt balance.

4 Pipe drainage in China

4.1 Introduction

In theory all three drainage methods, i.e. open, pipe and tubewell drainage, can be used to fulfil the drainage needs in China’s agricultural lands. Well drainage will only be practical and feasible in limited areas where there is fresh groundwater that can be recycled for irrigation. The most common drainage method is open ditch drainage, a traditional and well-known technique in China. Open drainage has some disadvantages like considerable land loss and high maintenance costs.

The intensification of agriculture, coupled with the population pressure and the fast growing mechanisation results in an increasing interest in pipe drainage, because with pipe drainage there is almost zero land loss, there are less obstructions in the field and maintenance is expected to be limited. Added to this is the fact that the soil profiles in the arid north and northwest of China and in the North China plain show often unstable subsoils. Maintenance of the deep open drains that are required for the salinity control in these soils is either impossible or extremely cumbersome and thus expensive. Part of these problems can be avoided by limiting the length of (deep) open drains and replacing the up stream parts of the drainage systems with pipe drains.

4.2 Objectives of pipe drainage in China

In general terms pipe drainage in China is and can be used to realize the following objectives:
- Lowering groundwater levels for water logging control in coastal areas and inland river plains. The advantage over open drains is a limited or zero land loss and fewer obstructions for mechanised agriculture;
- Facilitating fast lowering of watertable in the more humid southern areas after the monsoon period. A fast lowering of the groundwater after a rice crop creates additional time in the crop calendar, time to grow of a third crop. Drainage systems have in that case to be "controlled drainage" systems so that they can be closed during the rice growing period;
- Lowering groundwater tables for salinity control, in some cases combined with waterlogging control. In the North China Plain and in North and North-West China this form of
drainage has mainly as objective to prevent secondary salinisation. In unstable soils, pipe drainage can control the watertable with limited land loss and minimal maintenance (Figure 3). In most cases pumping is required. In this way secondary salinisation can be reduced to harmless proportions;

- Timely lowering of watertables in North Eastern river plains. The cropping season in the cold and humid North East is extremely short. If summer rains are abundant or late, the heavy soils prevent a timely drainage of the water resulting in high watertables and ponding water. This hampers the timely (mechanised) harvesting of crops. Moreover a high ground-watertable at the moment the frost sets in, may result the following spring in ponding water above the frozen deeper soil layers. This can prevent timely soil cultivation in spring. Pipe drainage systems alone, or in combination with mole drainage and in some places soil ripping, can improve the drainage during and after the summer rain and thus create conditions for timely harvesting of the crops and creating soil water conditions that allow soil cultivation in the spring;

- Increase efficiency of the reclamation of salinised areas: A pipe drainage system can increase the efficiency of the initial leaching process considerably. This will save time and more important scarce water. The system can after reclamation be used to control the secondary salinisation.
5 Development of pipe drainage in China

Since ancient times, pipe drainage has been practised in China by using underground bamboo sticks with holes. Modern pipe drainage technology was introduced starting in the nineteen seventies in the following way:

- A tractor drawn Chinese trencher was designed and produced in the 1970’s. The trencher is still successfully used in southern China where shallow drainage for waterlogging control is practiced. Because of its light weight and manoeuvrability it is very well suited for the small plots in southern China;
- The first integrated self propelled trencher with hydraulic depth control and a horizontal chain was imported in 1979 in Tianjin. The objective was to determine if under coastal conditions in North China pipe drainage could be installed for waterlogging and eventually salinity control. The installation was carried out with tile drains. With this machine, large areas in the Tianjin municipality were drained;
- In the end of the 1970’s trials were conducted with hand installed subsurface drains in Shandong, (Dayuzhang irrigation district) with the objective to determine the technical viability of controlling water tables with piped drains;
- In 1985 a pilot area was set up in Shandong Yucheng County, for testing pipe drainage system as an effective method for salinity control. The installation was carried out with a 350 HP trencher with a vertical chain that was introduced as part of a Sino-Dutch cooperation project (Figure 4). This model was at that time the most advanced and is basically still the same as the models that are presently produced. In the pilot area the machine installation under North China plain conditions was tested out. A large variety of drain envelopes, gravel as well as pre-wrapped synthetic envelopes around locally produced corrugated PVC drain pipes were tested;
- In the early eighties a modern western corrugated plastic drain pipe drain production line (PVC) was started up in Shanghai. This line has produced large quantities of pipes for drainage and other purposes. Simultaneously a number of PE pipe producing plants were inaugurated in provincial capitals;
- Starting in the eighties in large parts of humid southern China singular pipe drainage system were installed by hand or by Chinese made trenchers at shallow depth. Many of the systems were installed in rice growing areas. The systems are blocked during the wet season when rice is grown and opened at the end of the season for fast drying out of the soil, to facilitate ripening and to allow the timely soil cultivation for sowing of a dry-foot crop;
- In 1987 in Southern Xinjiang, a pipe drainage project for salinity control was started on a state farm. The objective was to control secondary salinisation with relative deep pipe drains installed in the unstable sub soils, to replace the deep open field drains that were extremely maintenance intensive. A secondary objective was to reduce water use for leaching of the built up salinity. The systems were installed with two laser guided trenchers of 350 HP that could install both field drains and collector drains up to a maximum depth of 3 m. Because of the remoteness of the area a special PVC corrugated drain pipe producing plant was installed on the farm. The drain envelope consisted of a locally found and sieved gravel;
In the late nineteen eighties and the early nineteen nineties the installation of modern pipe drainage systems started in Ningxia Autonomous region. Initially several singular systems were installed by hand on an experimental scale and various pre-wrapped envelopes were tested. Towards the end of the nineties with assistance of a European Union sponsored project and somewhat later a Sino-Dutch cooperation project the large scale implementation of pipe drainage systems was started. The installation is done with three laser guided trenchers. Initially imported PVC corrugated plastic pipes were used, later locally made PE pipes. A Chinese produced thin typar is used as envelope and trials with other envelopes have been started. The planning is to install pipe drainage in 23 500 ha in five years;

In 1992 as an indirect follow up of the experiments in the eighties in Shandong, a detailed plan was prepared for applying large scale pipe drainage in the Yellow River delta. In 2000 a specialised private company was set up to design and install pipe drainage in the Yellow River Delta (Figure 4). The company is fully trained and is equipped with two trenchers and has the capacity to install 400-600 km of drains per year. Chinese made corrugated PVC drain pipes are used and gravel envelopes are applied. The majority of the gravel trailers are produced in China. The company has installed 6000 ha in the period 2000-2002.
6 Technical aspects of pipe drainage systems in China

6.1 Drainage systems

Drainage in China is can be divided into the drainage for waterlogging and into drainage for salinity control and/or waterlogging.

Drainage for waterlogging control
Drains for waterlogging control are mainly installed at relative shallow depth (0.5-1.0 m) in singular systems that discharge into open drains. Drain depth is determined by the water levels in the open drains and is often around 1 m. The length of the field drains is variable depending on the field lengths. Drain spacing is rather variable, spacing of 20 m have been noticed. Where controlled drainage is applied this is done by simply capping the outlets of the drains, or with more sophisticated structure. Installation is done by hand, or by tractor drawn Chinese trencher. Envelopes are not commonly used.

Drainage for salinity and waterlogging control
Drainage for salinity control and waterlogging in the North China plain and the North and North-West of the country is done by deep drainage (>2 m). Pumped composite drainage systems are therefore the most economic solution seen from a national or regional view point. Some of these systems have been installed in Xingjiang, Ningxia and Shandong (Figure 5). On local level
understandably the simpler gravity singular systems are preferred that discharge onto existing open drains. The actual water level in the existing open drains, dug into the unstable sub soils, is in most cases not more than 1-1.5 m below field level. The result is that the field drains cannot control the water level at the required depth of around 2 m for optimal salinity control. The result is consequently an only partial functioning system that solves in most cases the visible waterlogging problems, but does not fully limit the secondary salinisation during the critical spring and autumn periods.

Composite systems
The composite systems are mainly systems with extended field drains of up to 1000 m length. The field drains discharge into collector drains with maximum length around 1000 m. Slopes of field and collector drains are 0.7‰. This layout fit generally quite well into the existing field layouts. Because of the length of the laterals, in some cases every 300 m manholes for cleaning access are placed. Field drain spacing varies generally between 50 and 100 m in these areas. Since the systems are often installed in flat areas, the subsequent slopes of the field drains and collector drains result in outlet levels of 2.5-3 m below field level. These levels are much lower than the water levels in the existing open drains and consequently pumping is required. Therefore at the end of the system is sump is installed from where the water can be pumped by an electric underwater pump into the open drainage system.

Singular systems
The singular systems discharge directly in to open drains. Spacing of field drains vary between 50 and 100 m, slopes vary between 1‰ and 0.5‰. The drain depth at outlet is in theory above the water level in the open drainage system, in practise (temporary) submergence is allowed. The resulting average depth of the systems is often not more than 1 m in flat areas.

6.2 Installation
The installation in South China of shallow drainage systems is either done by hand or by Chinese built small tractor drawn trenchers. A considerable amount of these Chinese drawn trenchers are used mainly in southern China. The deeper installation in the often unstable subsoils in Shandong, Yellow River Delta and Xinjiang has been carried out with modern self propelled laser guided trenchers of about 300-350 HP with the capacity to install drains at depth of 2-3 m (Figure 6). There are (in 2003) half a dozen imported modern trenchers in the country. Trenchless drainage is not yet tested out in a systematic way although a sample machine is in the country. Where gravel envelopes are applied this is done with tractor drawn hydraulically driven gravel trailers. Gravel trailers have been imported into the country, but starting 2000 Chinese produced trailers have been introduced. The drain installation in areas with unstable subsoils, that are quite common in the North and Northwest China, is possible in most cases with modern trenchers but it requires special skills.
6.3 Drainage materials

Drain pipes
There are a fair number corrugated pipe producing factories in China both for PE and PVC pipes, quality is variable but this more a question of management than of the quality of the production equipment. The factories that can produce the larger diameter pipes for collector drains are relatively scarce. The maximum diameter is Ø 200 mm.

Envelopes
There is no universal functional pre-wrapped envelope available yet, although research is ongoing. Locally gravel is used as well as pre-wrapped envelopes made of Bidim, Typar and other geo-textiles. Extensive laboratory trials are done on pre-wrapped envelopes. Post installation observations and evaluations of the functionality of these envelopes at field level are rare. The
relative uniform particle distribution in the loess soils makes the selection of a suitable envelope rather complicated.

7 Challenges for the further development of pipe drainage in China

7.1 General

It is realised by many parties that pipe drainage is can contribute significantly to waterlogging and salinity control in North China and to waterlogging control in Southern and North East China. The waterlogging control in Southern China has reached proportions that it is undergoing most likely a self propelled development. Although the development of pipe drainage for salinity control has started in Northern China and North West China, it has not yet reached the status of a self sustained momentum. One of the reasons is that the investments in equipment and production of drainage materials are considerable and only justified if long term use is envisaged. The scattered initiatives for the implementation of pipe drainage at this moment do not lead yet to the required economy of scale. A regional approach for which specialised entities are created either private or governmental can in time overcome this problem. Besides this there are some additional temporary institutional complications. Large-scale drainage implementation requires a close cooperation between the government authorities and the private sector for implementation and for production of drainage materials. Privatisation is presently going steadily ahead in China, but is not fully completed and engrained. It will require some time before the situation is fully settled. The first positive developments into that direction are already visible in Shandong and Ningxia.

7.2 Technical aspects

There are some technical hurdles that have to be taken to facilitate the universal application and acceptance of pipe drainage in Northern China. These are:

Development of a pre-wrapped envelope
The only known envelope that can technically be relied on as universally applicable is the graded gravel envelope, designed on the basis of the local soil texture. Gravel envelopes are besides being cumbersome and logistically complicated, in many regions expensive because of long transport distances. Although laboratory test and some field test with pre-wrapped synthetic envelopes have started, no universally or regional functional pre-wrapped envelopes have been identified so far. This will require systematic research and multi local field tests. Once suitable envelopes are identified, the industrial production and the wrapping of the envelope in or near the pipe production plants has to be organised.

Development of small drainage pumping systems
The nature of the drainage problems on the valleys, plains and plateaus of North and North-West China is such that relative deep drainage is required. Such drainage system discharge at levels
of around 2.5 m below field level. The discharge can generally not be gravity discharge. Somewhere in the system pumping to lift the drainage water is required. Cost wise and technically this should not be a major problem. The costs are easily off set by the considerable savings in maintenance of deep open drains. Moreover China’s rural areas are relatively well electrified, so that electric pumps can be used and no cumbersome diesel engines and fuel supply are required. A solution with a small, automatically on and off switching under water pumps, for each collector system, looks in theory simple. In practise this solution is however considered rather complicated and not universally accepted. There is a preference for larger central pumping units that are manually operated for both security reasons and presumed saving of energy. The challenge is to develop simple small electrically driven pumping units (under water pumps) that are salt resistant and require a minimum of maintenance and are acceptable under the rural conditions.

**Development of smaller size self propelled trenchers**

The self propelled trenches of 300 HP and more than 20 tons are too heavy and too large for use in the smaller plots and the road/bridge infrastructure in large parts of the waterlogged southern part of China. A smaller size machine with proper depth control could very well increase installation speed and efficiency in these areas.
Case Study - Egypt
Case Study - Egypt

1 Background

Egypt’s Nile Valley and Delta, one of the oldest agricultural areas in the world, has been under continuous cultivation for at least 5000 years. Egypt has an arid climate, characterised by high evaporation rates (1500-2400 mm/year) and little rainfall (5-200 mm/year), thus agriculture depends almost entirely on irrigation from the river Nile (Figure 1). From ancient times onwards, irrigated agriculture in the Nile Valley and Delta depended on the annual floods of the River Nile. The receding floods also drained and leached the cultivated areas. The construction of the Aswan High Dam in 1964 ended the annual flooding but made irrigation water available throughout the year. Since then, two to three crops can be grown each year, resulting in a practical continuous growing season.

These developments had as a secondary effect that the natural annual drainage and leaching ceased to exist. The absence of this natural drainage and leaching, in combination with the intensification of agriculture, made it necessary to provide the Nile Valley and Delta with an artificial drainage system to control water logging and salinity. Although the quality of the water from the River Nile is good (EC = 0.3 dS/m), salinity control is needed; otherwise over the years salt will be accumulated in the root zone. Therefore, in the 1960’s, the Egyptian Government started an ambitious programme to drain all of Egypt’s agricultural land (approximately 2.5 million ha). This programme is expected to be completed around 2012. Since the 1960, organisational reforms, the local production of drainage materials, mechanisation of the installation together with the necessary basic and operational research has resulted in a drainage organisation and drainage industry that has an annual implementation capacity of about 75 000 ha.

The drainage systems in Egypt consist of a network of piped field drainage systems and open main drains (Figure 2). The field drainage system consists of subsurface field (lateral) and collector pipes that runs by gravity. The pipe collectors discharge into open main drains from where the drainage water is pumped into large open gravity drains which eventually discharge into the River Nile or the sea. Pumping is necessary almost everywhere in the Delta and the Valley, except in some areas in Upper Egypt, where there is enough gradient to dispose of the effluent freely by gravity.

The implementation of drainage systems involves the following steps:
- Construction of open main drains or the remodelling of the existing main drains;
- Construction of drainage pumping stations to keep the water level in the open main drainage system at 2.5 m below field level so that the pipe systems can discharge by gravity in these main drains;
- Construction of pipe field drainage systems consisting of field drains (named laterals in Egypt) and pipe collector drains.
2 Organisation

2.1 Role of the Government

The Egyptian Government has been closely involved in the development of land drainage in Egypt right from the start. This is reflected in the early creation of a specialised authority for the implementation of the national drainage programmes. Moreover the prevailing fragmented land use and land ownership practically precluded the construction of private pipe drainage systems.
In the 1930's, well before the construction of the Aswan High Dam, the Irrigation Department started to construct open drainage system and the pumping stations, while the installation of the field drainage system was left to the initiative of the individual farmer. This practice was modified in 1949, when Law No. 35 was issued, decreeing that the State should undertake the implementation of subsurface drainage projects on all agricultural land and that farmers would be accountable for the costs thereof. The total area provided with pipe drainage systems in the years 1942/43 up to 1952/53 was about 20,000 ha.

In 1958, a new drainage policy stipulated that the construction of new pumping stations on newly reclaimed lands, the rehabilitation of deteriorated drainage systems in the "old" land and the renewal of existing pumping stations to meet the required water level in the main drainage system, i.e. 2.5 m below field level.

In 1978, the drainage policy was revised again to include long-term planning up to the year 2000 and to guarantee sufficient flexibility of its implementation. The basis for the new policy was:

- To provide, in the long run, all cultivated lands with pipe drainage networks at a depth suitable to the prevailing crops grown in the area. The construction of open field drains and soil amelioration works were recommended in areas north of latitude 31 in the Nile Delta where dark alkali clay soils and summer rice prevail. However, these plans required assessment to permit the future conversion to pipe drainage. The farmers had to repay the costs of the field drains in 20-year interest-free annual instalments;
- To accommodate the widespread use of drainage machinery and plastic pipes for the implementation of the pipe drainage systems. This to assure higher implementation rates and the proper functioning of the drains;
- To enable the use of appropriate envelope material dictated by the texture of the soil;

![Schematic representation of the drainage system used in Egypt](image-url)
In 1969, the Nile Delta Authority for Tile Drainage projects (NDDA) was established with executive responsibility for the construction of drainage projects in the Nile Delta. Then, in 1971, the newly established Egyptian General Authority for Drainage (EGAD) became responsible for the drainage projects in Upper Egypt. In 1973, NDDA and EGAD were merged in the Egyptian Public Authority for Drainage Projects (EPADP) under the authority of MWRI, by Presidential Decree No. 158.

In 1975, the Egyptian-Dutch Advisory Panel on Land Drainage (APP) was established to assist the Egyptian Government in its efforts to accelerate the implementation of drainage projects. The main objective of the Panel was to assist the Ministry of Water Resources and Irrigation in carrying out its responsibilities towards managing the quality and quantity of Egypt’s freshwater resources more efficiently and effectively.

The General Authority for Reclamation Projects and Agricultural Development (GARPAD) and the Egyptian Authority for Land Improvement Projects (EALIP), both under the Ministry of Agriculture, are in charge of the newly reclaimed areas. Land reclamation companies are responsible for the construction of land reclamation projects, designed and prepared by GARPAD. The sole concern of activities related to drainage at field level is the construction of shallow drains and the addition of gypsum to reclaim alkali soils.
2.2 The Egyptian Public Authority for Drainage Projects

The Egyptian Public Authority for Drainage Projects (EPADP) has been implementing subsurface drainage systems ever since it was established in 1973. EPADP still has comprehensive responsibility for the field drainage works, including the planning of projects, data collection, preparation of designs, contracting and supervising the installation of subsurface drains, monitoring of the impact of drainage, budgeting, and operating project accounts (Figure 4). In addition, EPADP is charged with any remodelling of open drains receiving drainage water from subsurface pipe drains, and also new pumping stations that may be required for the open drains. In 1992, EPADP was also given the responsibility for the maintenance of all open drains.

Much emphasis was placed on the execution of the drainage projects from 1973 until the mid-1980s. After their construction and formal acceptance by the contractors, the project works were handed over to Department of the MWRI, who then became responsible for all operations and maintenance. The first Department of Drainage Maintenance was established within EPADP in 1978. An additional important task since the late 1980s has been the rehabilitation of subsurface drainage systems that had been previously installed whose function was impaired or maintenance had become excessively costly. A new organisational set-up was needed to cope with the increasing responsibilities in terms of rehabilitation and maintenance (Figure 5). The main change concerned a division of the organisation into five geographically based regions (Figure 6). EPADP is a semi-autonomous authority, headed by a Chairman with the rank of First Under-Secretary directly responsible to the Minister of Water Resources and Irrigation. EPADP has one Vice-Chairman supported by five regional Departments, each headed by an Under-Secretary. At present EPADP employs about 4000 permanent staff at its headquarters and directorates and about 3000 casual labourers who mainly work in the maintenance of drainage systems.
Figure 5  Organisational Structure of EPADP
Figure 6  Location of EPADP’s Headquarters and Drainage Sectors
2.3 Research and consulting institutions

The Drainage Research Institute (DRI) was established in 1976 as part of the National Water Research Centre (NWRC) of MWRI to conduct applied research, monitoring, testing, and evaluation of drainage methodologies and techniques. Its activities are intended to support EPADP’s implementation programme and to solve their technical problems. DRI employs about 72 professional staff and 150 supporting and administrative staff.

The Research Institute for Ground Water (RIGW), another research institute of the NWRC, carries out groundwater surveys and groundwater development studies. This institute also provides the drainage implementation programme with significant research input. It has investigated the seepage from the new land schemes located at higher elevations, which has caused waterlogging and salinisation problems in the old lands. RIGW has implemented studies on the technical and economic feasibility of vertical drainage in these zones, known as the fringe zones of the Nile Valley.

The Soils, Water, and Environment Research Institute (SWERI) is one of the Agricultural Research Centre Institutes of the Ministry of Agriculture and Land Reclamation (MALR). Its main function is to carry out soil surveys on irrigated land. SWERI has conducted extensive research on the drainage of heavy clay soils in the northern part of the Middle Delta. SWERI has also undertaken research on concurrent applications of gypsum and subsoiling and its effect on drainage enhancement.

2.4 Egyptian-Dutch Advisory Panel on Water Management

Following the establishment of EPADP in 1973, the Egyptian Government and the Dutch Government agreed on the establishment of a joint (Egyptian-Dutch) Panel. Initially, the Panel’s objective was to assist the Egyptian Government in its effort to control waterlogging and salinity through accelerating the implementation of drainage projects. This was done under the following initial set-up:

- Twice-yearly Panel Meetings (once in Egypt, once in the Netherlands);
- Appointment of a Resident Drainage Engineer, stationed at the Drainage Research Institute (DRI);
- Appointment of various Associate Experts guided by the Resident Engineer;
- Allocation of a budget for: (i) Applied Research on drainage design and implementation; (ii) Consultants (national and international), and (iii) Training, both local and international, through participation in ILRI’s International Course on Land Drainage.

A few of the “early drainage issues” dealt with by the Panel are:

- Development of new drainage technology;
- Selection of pilot areas for the investigation of various land drainage problems;
- Study of water management in drained and non-drained rice areas;
- Economic evaluation of land drainage;
• Reuse of drainage water for irrigation;
• Maintenance of drainage systems;
• Drainage design in rice fields;
• Economic evaluation of drainage.

The Advisory Panel Project developed over time. During the first stage (1976-1982), the Panel was a separate and independent project whose activities were solely directed towards different technical aspects of drainage. After 1982, when the technical activities of the Panel increased, the decision was made to separate the activities into different project identities with the Panel as umbrella. It was during this stage (1983-1990) that the Panel started to guide the activities of the Dutch “water” projects and to advise on some “water policy” issues. An evaluation of the Panel’s performance preceded the third stage (1992-2004) during which the Panel’s role became primarily one of advising on policy issues and coordinating the ongoing Dutch projects.

The Panel is chaired by the Egyptian Minister of WRI and is co-chaired by a Dutch Panel member. The other members of the panel are: six Egyptian and six Dutch members with scientific and administrative experience in drainage, land reclamation, and water resources development and management and include representatives from both the Egyptian and Netherlands Governments. The Panel secretariat services are rendered by MWRI and Alterra-ILRI. A World Bank representative, provider of the necessary funds for the unprecedented drainage implementation, also attended the first Panel meetings. The technical assistance required for this World Bank programme is supplied through the Egyptian-Netherlands bilateral cooperation.

Some selected achievements:
• Solutions were found to many technical problems;
• Policy was formulated or assistance was given to policy formulation;
• The capability of the staff involved (both Egyptian and Netherlands) was greatly enhanced;
• The work has greatly contributed to the introduction of integrated water resources management, by dealing with issues such as water quantity, water quality, environment, socio-economic conditions and gender;
• Cooperation of the Netherlands has paved the way for other donors to deal with the MWRI in an effective and efficient way.

3 Planning

EPADP’s Planning Department is responsible for setting up the five-year and annual execution plans, along with the financing of projects. Negotiations with financiers of EPADP projects are done through this Department. A key element in the planning is the policy to carry out projects in clusters or land blocks, which at present are around 3 500 to 8 500 ha in size.
3.1 Investigation and design

Designing begins by obtaining surveying maps of the project area from the Egyptian Survey Authority (ESA), with updated information on villages, towns and built-up structures. Following the preparation of project maps, the field investigation programme is prepared for site sampling locations (generally forming a grid of 500 x 500 m). Groundwater levels, soil permeability and salinity are measured in the field and soils samples are collected and sent to DRI for analysis. Based on the soil permeability and groundwater levels, the layout of the subsurface drainage system is prepared and then longitudinal profiles of the collectors are made.

3.2 Tendering and contracting

Once the design album and the lists of quantities have been prepared, the project is tendered among pre-qualified drainage contractors. Local public and private sector contractors do the earthwork for remodelling open drains and installing subsurface drains. Structures to be rebuilt in open drains are awarded to local contractors in the private and public sectors, following local procedures for tendering.

The Irrigation Department was responsible for the installation of subsurface drainage systems that were constructed on a limited scale - mostly manually - until the end of the 1960s. Then, in the 1970s, Public Excavation Companies (PEC) were established for the mechanical excavation and construction of both canals and drains. These companies that belonged to the MWRI until recently are now fully owned by the Minister of Business Development, as a step towards privatisation, and are part of a separate holding company: Public Holding Company for Public Works. The introduction of mechanised installation involved several public sector companies capable of handling this technology. Gradually, more contractors from both public and private sectors joined in. The private sector companies started work as sub-contractors (for labour) to public main contractors, and later executed complete projects on their own. To facilitate this, EPADP supplies the contractors where necessary, together with the drainage machinery to get the job done. Contractors have to pay for the machinery from the instalments due for their work in the projects. When mechanised installation of subsurface drainage systems began 90% of the contractors were public contractors. Nowadays, the balance has shifted in favour of private contractors.

4 Drainage materials

Since the inception of pipe drainage projects in the 1930s, important developments have taken place in the use of drainage materials. The development of new materials and the development of new installation techniques are interdependent. This section contains a summary of the developments in drainage materials.
4.1 Pipes

At first there were clay pipes that were 100 mm in diameter and 0.30 m in length which were installed manually. Then in the 1950s came cement pipes of the same diameter but 0.50 m in length. With the introduction of mechanical laying\(^1\) in the early 1960s, shorter cement pipes of length 0.30 m were found to be more convenient both for handling and for providing additional water entry surface. When in 1979 the production of corrugated plastic PVC pipes started it significantly helped to boost the progress of Egypt's large-scale drainage projects. The PVC pipes used nowadays for the field drains have an outside diameter of 80 mm and an inside diameter of 72 mm and are produced in government owned and managed factories.

**Plastic pipes**

The production of plastic pipes is a rather complex process whereby the parent material (i.e., PVC powder or PE pebbles) is heated and melted to form the correct shape and dimensions (Figure 7). This requires an industrial set-up in a factory, although for smaller diameters mobile production plants have been developed. The PVC (or PE) resin, normally delivered in bags, is mixed with other additives, like fillers, heat stabilisers, lubricants, UV stabiliser and colour, in a blender at a temperature of about 100 °C. To avoid contamination of the resin with foreign matter like paper shreds from the bags and stones and so forth, it is advisable to sieve the resin before it is poured into the blender. The blended compound is fed into the barrel of the extruder via a feed screw coupled with a dosage meter. The blended compound is then plasticized at a temperature of about 200 °C and extruded through a die by means of two screw conveyors. This die delivers the pipe in a plain round shape and a corrugator attached to the end of the extruder shapes the corrugations. The pipe is cooled by heat exchange using chilled water and cold air. Finally the pipe is perforated, cut into appropriate lengths and coiled for storage and transport.

\(^{1}\) The FAO/UNDP Pilot Drainage Project.
In 1988, a corrugated plastic production line was installed at the pipe factory in Aga² capable of producing HDPE pipes with diameters varying between 100 and 600 mm. In 1998, the Egyptian Public Authority of Drainage Projects decided that for all new projects collector drains pipes should be made of PVC or HDPE, 200 to 400 mm in diameter and 6 m long. Reinforced concrete pipes are still used, but only at the outlet, the flushing inlet and at places where the collector drains cross roads and irrigation canals.

Concrete pipes
The field drains until 1980 consisted of concrete pipes with a diameter of 100 mm and lengths of 0.3 m and 0.5 m. Concrete pipes of 0.3 m were used for mechanical laying and lengths of 0.5 m for manual laying. Collector pipes are also made of concrete with diameters ranging between 150 and 600 mm and in lengths of between 0.75 and 1.00 m. The larger diameter pipes (> 400 mm) are reinforced.

A factory with an industrial set-up is needed to manufacture concrete pipes (Figure 8a), but they can also be made in a comparatively simple (mobile) production unit that can be easily erected in the project area (Figure 8b). The wall thickness of concrete pipes varies between 25 mm for the smaller diameter pipes and 40 mm for the larger diameter pipes. Typically, concrete pipes are made up of 500 kg cement to one m³ of sand; the water added to this mix is about one-third of the weight of the cement. Care should be taken to use clean sand and water, certainly no brackish, saline or muddy water. The sand and cement should be properly mixed and when the water has been added it should be processed within 15 minutes.

Figure 8   Concrete pipe factory in Tanta in the Nile Delta (a) and a mobile production unit in a field workshop, were concrete pipes are stored in a shaded area (b)

² The Integrated Soil and Water Improvement Project (ISAWIP) in Daquahliya, North East of the Nile Delta.
The drainage contractors usually manufacture their own pipes. The equipment the contractors use is simple and easily dismantled. Contractors set up temporary field factories close to the drainage works.

Concrete pipes are manufactured in a mould that rotates and moves up and down at the same time as the cement mix is poured in so that compaction takes place (Figure 9). To ensure that good quality pipes are produced, it is necessary to regularly check that:

- The mould is circular. After being used for a long time the mould becomes oval and the connections suffer from wear and tear resulting in pipes with an irregular wall thickness over the cross section of the pipe;
- The clearance between the mould and the rotating shaft does not exceed 2 mm. A wider clearance results in an irregular wall thickness over the axis (lengthwise) of the pipe, which after installation may cause sediment to collect at the joints or obstruction of the movement of the head of a flushing machine;
- The rotating shaft is correctly set, because worn bearings will also result in irregular wall thickness;
- The correct mixture of cement, sand and water is used, otherwise the result will be an irregular surface of the inner pipe wall or even collapse of the pipe after the mould has been removed.

After the pipes are manufactured they should be stored in a roofed area in such a way that they can be thoroughly wetted daily (Figure 8b). Pipes should not be transported to the field within 28 days to allow sufficient curing.
4.2 Envelopes

Traditionally, a graded gravel envelope surrounded the joints of manually installed clay and cement pipes. Even after the introduction of mechanical installation of pipes, gravel envelopes continued to be installed manually along the sides and on top of the pipes as soon as they left the trench box of the machine. In the late 1970s machines were developed with funnels to evenly spread the gravel envelope, but still only along the sides and on top of the pipe. Research revealed that the cohesive clay soils of the Nile Valley and Delta do not require an envelope because they have a good structural stability. Nowadays, natural gravel is used for the envelope only if the soil is light textured with a clay content of less than 30%. Furthermore, as gravel envelopes were costly and difficult to apply, pre-wrapped synthetic envelopes were introduced in 1994. Currently, sheets of voluminous polypropylene fibres are wrapped around field drains in the factory (Figure 10).

Figure 10 PVC pipes are pre-wrapped with a voluminous envelope in the factory in Tanta
4.3 Structures

Initially, glazed crosspieces were used to connect the field drains with the smaller-diameter collector pipes and buried manholes for the larger-diameter pipes. The installation of these connections required considerable excavation and dry working conditions. Then in the 1980s, an improved connection using a plastic T-joint was introduced (Figure 11). However, though flushing inlets connected with these T-joints were tested on a pilot scale for flushing the field drains, they never achieved project status. To facilitate maintenance, concrete manholes (Ø 0.75-1.00 m) are still installed in the collector drains at every third or fourth field drain (distances varying between 150 and 200 m) and at places where there is a change in pipe diameter. The length of the hose of a flushing machine determines this distance. The last manhole is connected to an irrigation canal at the upstream end of the collector line. This so-called flushing structure can be used to flush the collector drain with irrigation water and to check whether the collector drain is functioning properly (Figure 12). At the downstream end, an outlet, normally a pitching with stones and mortar provides a safe outlet to an open main drain (Figure 13).
5 Installation

5.1 Organisation

The Egyptian Public Authority for Drainage Projects (EPADP) prepares the design of the field drainage system after thorough field investigation including in-situ measurements of the hydraulic conductivity, watertable depth and collection of soil and water samples for physical and chemical analysis. The preliminary alignment of the drains is checked for physical obstructions, intersections and farm boundaries. The unit design area is the catchment of a main drain or group of drains which form one interconnected hydrologic unit, averaging about 2 100 ha in size. The

Figure 12  Flushing structure at the upstream end of a collector drain to flush the collector drain with irrigation water

Figure 13  Outlet Structure of a collector drain
final designs are tendered for bidding among drainage contractors. The contractor is responsible for checking the designs against the field conditions and requesting approval for modifications if deemed necessary. The contractor provides the materials, machinery and workmanship necessary for implementing the project within the specified time.

The drainage contractors prepare the site and logistics such as field offices, stores and workshops for stocking materials and producing concrete pipes. They transport the plastic pipes from EPADP’s factories to the project site. For good timing of implementation the intensive cropping system in Egypt calls for close coordination with the farmers. The rate of construction slows down during the summer when the cotton crop is near maturation and during the rice season. Farmers are compensated for crop damage during construction based on actual surveys of the damaged area and the market price of the harvested crops. This compensation, which represents social support to the farmer during the construction phase, is recovered as part of the cost recovery system adopted in Egypt. The cost of the field drainage system is recovered in full over a period of 20 years without interest commencing five years after construction of the drains, which allow farmers to gain full benefits.

5.2 Field Conditions

The field conditions in Egypt, namely, type of soil and agro-hydrologic conditions are uniform. The soil consists of relatively deep alluvial soils with a high clay and silt content. However, at the fringes of the Nile Valley and Nile Delta soils tend to contain more sand and lose their structural stability. When the watertable is high these soils become problematic particularly under high hydraulic gradient creating quicksand phenomena (Sherashra and Haress). In the Western Nile Delta, some areas are characterised by calcareous hard rocks in the subsoil (Nubariya). The low areas in the northern part of the Nile Delta are subject to artesian pressure: significant upward seepage occurs where the resistance of the overlaying low permeable soil decreases.

*Sherashra: quick sand*

Implementation of the drainage system of the Sherashra catchment area, southwest of Alexandria, was planned to take place in 1974. Auger holes drilled during the field investigation showed a distinct change in the soil profile with unstable light soils below a depth of 1.0 - 1.5 m. As soon as the auger hit the unstable soils groundwater rose under pressure to a shallow depth below the soil surface and the auger holes caved in when digging exceeded the depth of the stable surface soil. Further investigations of the hydro-geologic conditions revealed the prevalence in the area of a piezometric head of around 1.0 m. A first pilot area implemented at Sherashra produced disastrous results. The concrete pipes used for field drains were soon completely filled with sand. The manually installed collector pipes were dislocated from their positions under the effect of quicksand conditions. Only after the introduction of plastic pipes and mechanical installation of collectors in 1983 did the construction of pipe drainage become a possibility in this area. However, the results were not entirely satisfactory due to problems with the installation of the gravel envelope.
Haress: upward pressure
The Haress area, located to the northeast of Sherishra, has a lot of marine deposits in its top profile. The layers of shells found in the subsoil significantly increase the permeability of the soil at the drain depth. A pilot area was constructed in 1993-1994: pre-wrapped PVC corrugated plastic pipes were used for the field drains and corrugated perforated HDPE pipes for the collectors. The field drains were installed successfully and their performance was adequate. This was not the case, however, with collectors installed at a greater depth (2.0-2.5 m). Groundwater rising under pressure in the trench behind the trencher machine made the imperforated pipe (filled with air) float above the water. The problems were even greater when an attempt was made to lay the bigger pipes in a trench that was excavated with backhoe. To overcome these problems the solution was to use perforated pipes for the collectors as well: during installation these perforated pipes quickly filled with water and consequently stayed in place. A cheap type of envelope (thin sheet) was used to prevent the silt from entering the pipe. Clogging of the envelope was not a problem since the collector is not designed to have a dewatering function. The conditions in the Haress area were the motive behind the use of trenchless machines under these conditions, which proved to be successful later in 1996.

Nubariya: hard rock
The Nubaria area is part of the Nile Delta’s western fringes reclaimed during the 1960s-1970s. The alluvial silty clay topsoil of the Delta diminishes towards the west and calcareous soil dominates the profile with hard rocks frequently intersecting the soil profile. Under the reclamation programme of that time a high water table developed so that a drainage system was necessary. The normal type of trenchers operating in the Delta failed to operate under the Nubaria conditions. A partnership and cooperation between the contractor and the machine supplier yielded a special type of trencher with a more powerful engine and a different design and material for the digging mechanism (Figure 14).

Figure 14  A rock trencher installing a concrete collector drain operating in the Nubaria area
5.3 Installation Methods

Pipe drains were installed manually until the beginning of the 1960s. They were laid in ditches excavated manually with spades. Then in the early 1960s, continuous chain tile laying machines (flat trencher) were introduced for the first time in a number of pilot areas marking the beginning of Egypt's modern drainage. The objective was to test new technologies and develop design criteria for use in the large-scale post High Aswan Dam drainage projects. With the start of the World Bank funded projects in 1970, mechanical installation of pipe field drains was introduced on a large scale. By the mid-1980s there were heavy trenchers to install concrete collector drain pipes with diameters of up to 250 mm. Larger diameter pipes were still installed in trenches dug by excavators. A trenchless drainage machine was successfully tested on a pilot scale in 1995-1996. Hydraulic excavators and draglines are used for digging main open drains.

The use of imported machinery in Egypt went through a process of adjustment and modification to suite local conditions. Among these was a water tank to spray water on the cutting blades of the trencher chain and along the sides of the trench box to reduce the resistance of the cohesion forces of the sticky clays. Another modification had to do with the width of the crawlers to produce adequate pressure for the bearing capacity of the Egyptian soils. Similar adjustments were made to the length of the trench box, the arrangement and design of blades on the revolving machines and so forth. Successive development of technical specifications followed to specify the appropriate type and characteristics of machines suitable for the local conditions.

The required depth and grade of the manually installed pipe drain systems were adjusted and verified using a surveying level. Visual controls (sighting targets) were used to adjust the depth and grade of the drain pipes laid by machines. After installation the depth and grade were checked again using a surveying level for quality control. Laser equipment was introduced in the late 1980s. In the 1990s the use of laser equipment became a compulsory condition of the construction contract. In the beginning of the 21st Century it was decided that large size diameter corrugated PVC or PE pipes would be used for the installation of collector drains (Figure 15).

While tractors and trailers transport the materials in the field, manual labour is still used to move the materials (pipes & envelopes) around and to feed the machines during operations. The use of manual labour significantly lessened with the introduction of pre-wrapped corrugated plastic pipes. The excavation for structures is either done manually or with backhoes depending on the contractor. Backfilling the trenches is mostly a manual operation although some contractors use tractors provided with a dozer blade.

The contractors own and provide the drainage machinery. However, the Government of Egypt has been helping the contractors from the beginning to purchase drainage machinery through a special arrangement under the World Bank projects. The machinery is imported by the government imported the machinery, handed over to the contractors and the cost collected in installments while the project is being implemented. This has helped the civil contractors to build up their capacity to implement large-scale projects. Economic change and the transfer of con-
TRACTORS mostly to the private sector has resulted in most contractors now being able to buy their machines directly from the market, although the original arrangement is still a viable option.

Figure 15  Installation of large size corrugated PVC pipe

6 Operational Research

Accurate data on capacities, efficiencies, availability of machines, equipment and contractors are needed for the planning and contracting of the drainage projects. To collect such data, an Operational Research Unit/ORU was established in 1993 within the Planning and Follow-up Department/PFD of EPADP, to carry out the following:

- Determine the work and time standards for the planning and follow-up of the drainage projects, including financial budgets;
- Analyse and support the purchase procedure of machinery and equipment for the Mechanical Department;
- Analyse and improve working methods of the various activities of EPADP.

The results of the Operational Research Unit are used to:

- Monitor the performance of individual projects;
- Assess the performance of contractors and subsequently award new contracts;

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3 This section is based on the Chapter Capacity and Efficiency of Drainage Machines in Egypt published in the book Drainage along the River Nile, edited by H.J. Nijland. Authors are Eng. Resk Menshawy, J. Penninkhof, Eng Omayma S. Saheen, and Ir. H.J.P. Visser.
• Determine the number of machines needed to implement EPADP’s annual plans;
• Advise the Mechanical Department on the purchase of new machinery and equipment.

Some results of the operational research activities are presented in the following sections.

6.1 Capacity and Efficiency of Drainage machines in Egypt

An installation rate of about 75,000 ha per year implies the installation of approximately 1850 km of collector drains and 18,500 km of field drains. One of the main factors affecting the implementation rate of subsurface drainage is the number, productivity, and quality of the drainage machines. Inventories of data were made on the efficiencies and capacities of the various types of drainage machines operational in Egypt collected by the Operational Research Unit from which the efficiencies and capacities of these machines were assessed. The results are used for the planning of future projects.

Inventory

In 1994, an inventory was made of all drainage machines working all over Egypt. Three categories of data were collected:

- **Machine specifications**: chassis number, engine number, machine type, manufacturer, year of manufacture and date of purchase;
- **Project-related data**: sector, directorate, contractor;
- **Performance data**: general condition of the machine, condition of the main engine, hydraulic system, cutting system, drive shaft, traction and chassis.

A total of 144 field and 58 collector drainage machines were assessed. A specially developed ‘Drainage Machine Inventory Program’ processed the data. The overall condition of a machine was specified as ‘good’, ‘moderate’, ‘bad’ or ‘beyond repair’ (Figure 16). Drainage machines classified as ‘good’, ‘moderate’, or ‘bad’ were considered operational machines. Most machines were not fully operational the whole year around. On a yearly basis it was estimated that about 85% of the ‘moderate’ and 60% of the drainage machines in a ‘bad’ condition could be

![Pie charts showing the condition of collector and lateral machines in 1994](image)

*Figure 16* Result of the inventory conducted in 1994: Condition of drainage machines
considered operational. Of the machines classified as “beyond repair”, none would be able to work. The conclusion was that of all drainage machines in Egypt 59% of the field drainage machines and 76% of the collector drainage machines were operational.

Both field and collector drain machines were in a “good” condition up to the age of approximately 7 years, changing to a “moderate” condition between the age of 8 and 15 years. After approximately 16 years, the condition between field and collector drainage machines started to deviate. Of the field drainage machines older than 16 years nearly 75% were “beyond repair” and 14% were in a “bad” condition. Figures for collector drainage machines were 13% and 43%, respectively. Thus, collector machines have a longer lifespan than field drainage machines. But, as efficiency increases over the years the operational lifetime will drop to 10 to 12 years in the future.

Efficiencies of drainage machines
Efficiency studies were conducted by field engineers of the EPADP Directorates with the support of the ORU. Different types of field and collector drainage machines were selected in various projects. Efficiency sheets were filled in on a daily basis, indicating how many hours the machine was working and, if applicable, the reasons why it was not working. A special computer program processed the data from which it could be determined how many days per year and how many hours per day the machines were working, and the reasons for not working (Table 1). In Egypt, the average number of working days per year is 198. The non-working days are Fridays, holidays (including unofficial “days off” taken by contractors), and the “crop stoppage period” when rice or cotton are grown. Although Ministerial Law enforces the “crop stoppage period” it varies from project to project, and most drainage machines stand idle in this period even though the projects have not stopped completely. The length of a working day was 9 hours on average with an average effective time of 2.9 hours/day for collector drainage machines and 4 hours/day for field drainage machines (Table 2). There is a clear difference in time losses between the two types of machines: for collector machines, the field condition and the organisation of the work are more important, which can be explained by the higher ground pressure of the collector machines and the more demanding work organisation because of the concrete pipes. For field drainage machines, the technical breakdowns and the maintenance are more important since field drainage machines suffer more wear and tear and subsequent mechanical problems.

Table 2 represents the average situation of the machines. The efficiency, however, has a close relationship with the age of the machines: the older the machine the lower the efficiency (Table 3). The efficiency decreases from more than 4 hours per day for new machines to less than 2 hours per day after 15 years. The technical condition of the machines is the most important cause of this decrease in effective time.
Table 1  Example of a time and motion study of a field (lateral) drainage machine

<table>
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<tr>
<th>Elements</th>
<th>Total time [cmin]</th>
<th>Drain length [metres]</th>
<th>Frequency</th>
<th>Time/100 m [cmin]</th>
<th>Time/freq [cmin]</th>
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<tbody>
<tr>
<td><strong>Direct effective time</strong></td>
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<tr>
<td>Main element:</td>
<td></td>
<td></td>
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<tr>
<td>- Laying pipes</td>
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<td><strong>Indirect effective time</strong></td>
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<tr>
<td>Support elements:</td>
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<td></td>
</tr>
<tr>
<td>- Driving back</td>
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<td>23,057</td>
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<td>- Lifting shoe</td>
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<td>Short organisational:</td>
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Table 2  Daily availability times of collector and drainage machines

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<th>Field drains %</th>
<th>Collectors (hours)</th>
<th>Field drains (hours)</th>
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<td><strong>Non-available time:</strong></td>
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<tr>
<td>* Field condition</td>
<td>16</td>
<td>9</td>
<td>1.4</td>
<td>0.8</td>
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<tr>
<td>* Technical breakdown</td>
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<td>17</td>
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<td>2.4</td>
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<tr>
<td><strong>Available time:</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>* Non-effective</td>
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<tr>
<td>- Maintenance</td>
<td>7</td>
<td>12</td>
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<td>- Meal time</td>
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<td>- Organisation</td>
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<td>* Effective time</td>
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<td>100</td>
<td>9.0</td>
<td>9.0</td>
</tr>
</tbody>
</table>
PART III - CASE STUDIES

Table 3  Effective time of field and collector drainage machines related to different ages

<table>
<thead>
<tr>
<th>Age of machines [year]</th>
<th>Field drain machines [%]</th>
<th>Field drain machines [hrs/day]</th>
<th>Collector drain machines [%]</th>
<th>Collector drain machines [hrs/day]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-5</td>
<td>53</td>
<td>4.8</td>
<td>46</td>
<td>4.1</td>
</tr>
<tr>
<td>6-10</td>
<td>42</td>
<td>3.9</td>
<td>33</td>
<td>3.0</td>
</tr>
<tr>
<td>11-15</td>
<td>27</td>
<td>2.4</td>
<td>23</td>
<td>2.1</td>
</tr>
<tr>
<td>&gt;15</td>
<td>18</td>
<td>1.6</td>
<td>18</td>
<td>1.6</td>
</tr>
</tbody>
</table>

Capacities of drainage machines

Up to 1996, a total of 300 time and motion studies had been conducted. In each time and motion study, the work process of the drainage machine had been measured in a clearly defined part or activity, a so-called element (Table 4). Most elements, such as lifting and lowering the shoe, adjusting the laser and stop for gravel, were not influenced by the type of machine and the circumstances in the field. Only the element "laying pipes" (digging activity) was highly dependent on the type of machine, the condition of the soil, the type of pipes used (corrugated plastic pipes or concrete pipes), the applied envelope material (gravel or pre-wrapped synthetic envelopes), drain depth, and so forth. Assessment of the time for elements not influenced by the type of machine and the field circumstances was done by taking the average of all observations for field and collector drainage machines, respectively. The element "laying pipes" needed to be determined for each type of machine and each circumstance separately.

A specially designed "Norm Calculation Program" processed the field data. This computer program calculated the work standards for each type of drainage machine producing work and time standards, expressed in m/hour and h/km (Table 5). These standards were based on the effective time determined by the efficiency studies (Table 2). The work standards were based on the "standard" subsurface drainage system with field drain lengths of 200 m and collector lengths of 1500 m. Note, the efficiency of the machines is related to the age of the machines as well as the capacity of the machines. The results apply to field drainage machines installing corrugated PVC pipes without gravel, and collector machines installing concrete pipes.

The following conclusions were drawn based on these efficiency studies:

- Depending on the age of the machines, the capacity of field drainage machines varied between 190 and 380 m per hour, and that of collector machines between 55 and 100 m per hour;
- The capacity of the older machines was significantly lower than that of the newer machines, partly due to decreasing quality and partly due to innovations on the newer machines.
Table 4  An example of the calculation of a Work and Time Standard for laying pipe drains without envelope

| Method: Laying plastic pipes of 80 mm in diameter from both sides of the collector drain |
|--------|---------------------------------|
| Average length of the drain 200 m |
| Depth of trench 1.20 to 1.50 m |

<table>
<thead>
<tr>
<th>Machine:</th>
<th>All field drainage machines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Envelope:</td>
<td>none</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Elements of work process</th>
<th>Work standard per km field drain</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minutes/element</td>
</tr>
<tr>
<td>--------------------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>1. Laying pipes</td>
<td>112.0</td>
</tr>
<tr>
<td>2. Turning and driving back</td>
<td>24.7</td>
</tr>
<tr>
<td>Lifting shoe</td>
<td>1.8</td>
</tr>
<tr>
<td>Lowering shoe</td>
<td>1.8</td>
</tr>
<tr>
<td>Digging connection</td>
<td>8.7</td>
</tr>
<tr>
<td>Inlet outlet connection</td>
<td>6.4</td>
</tr>
<tr>
<td>Filling water tank</td>
<td>0.9</td>
</tr>
<tr>
<td>Subtotal</td>
<td>44.3</td>
</tr>
<tr>
<td>3. Short technical breakdowns</td>
<td>1.6</td>
</tr>
<tr>
<td>Subtotal</td>
<td>1.6</td>
</tr>
<tr>
<td>4. Short organisational breakdowns</td>
<td>25.4</td>
</tr>
<tr>
<td>- Stop for pipes</td>
<td>18.0</td>
</tr>
<tr>
<td>- Stop for fuel</td>
<td>3.7</td>
</tr>
<tr>
<td>- Adjustment laser</td>
<td>1.8</td>
</tr>
<tr>
<td>- Field obstructions</td>
<td>1.9</td>
</tr>
<tr>
<td>Subtotal</td>
<td>25.4</td>
</tr>
<tr>
<td>- Stop for gravel</td>
<td></td>
</tr>
<tr>
<td>5. Transportation in the field</td>
<td>0.7</td>
</tr>
<tr>
<td>Subtotal</td>
<td>0.7</td>
</tr>
<tr>
<td>Total minutes per km field drain</td>
<td>184.00</td>
</tr>
</tbody>
</table>

Work Standard: metres/hour $= (1000$: total minutes) $\times 60$

Time Standard: hours/kilometre $= \frac{\text{Total minutes}}{60}$

Table 5  Capacity of field and collector drainage machines based on effective time

<table>
<thead>
<tr>
<th>Age of machine (years)</th>
<th>Field drainage machine (m/hour)</th>
<th>Collector drainage machine (m/hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 5</td>
<td>380</td>
<td>100</td>
</tr>
<tr>
<td>6 - 10</td>
<td>320</td>
<td>95</td>
</tr>
<tr>
<td>11 - 15</td>
<td>250</td>
<td>85</td>
</tr>
<tr>
<td>&gt; 15</td>
<td>190</td>
<td>55</td>
</tr>
</tbody>
</table>
6.2 Application of the research results

The operational research proves to be an important tool in upgrading the quality and quantity of drainage projects implemented by EPADP. It provides indicators that can be used for management support, for instance, to assess the performance of the available machinery as a planning tool or for the purchase of new machines.

Performance Assessment
The overall results of the inventory and time and motion studies revealed that in January 1997:
- A total of 57 collector and 126 field drainage machines were operational;
- For the implementation of subsurface drainage, about 198 working days were available per year;
- The effective time for collector and field drainage machines was 3 and 4 hours per day, respectively;
- The capacity of collector drainage machines decreased from 100 m/h for new machines to 55 m/h for machines that were older than 15 years. The figures for field drainage machines were 380 and 190 m/h, respectively.

Planning Tool
Results of the time and motion studies are used for planning new drainage projects. The capacity of the field drainage machines is a decisive factor for the implementation rate of drainage projects. With the available research data on field drainage machines, it was possible to calculate the total capacity of all drainage machines operational in Egypt, but also the capacities of individual contractors, and suchlike. The data can be used as a follow-up tool for individual projects. For example, say the following machines are available for a project: 3 field drainage machines, each 8 years old and 1 collector drainage machine 15 years old. Therefore, for this project the yearly capacity will be:
- Laying of collector drains: 198 days x 1.62 hours/day x 55 m/hour = 17.6 km collector drain;
- Laying of field drains: 198 days x 3.78 hours/day x 320 m/hour x 3 machines = 718.5 km field drain.

The research data can also be used to determine the number of new machines needed to implement EPADP’s annual plan. For example, in the annual plan for 1995-96, the target was providing 108 000 ha with subsurface drainage. The available capacity, calculated by the Operational Research Unit was good for 94 000 ha, thus new machines had to be purchased for 14 000 ha. With an average capacity for new machines of 400 m/h, 198 available working days, and 4 effective hours per day, it was determined that about 10 new field drainage machines would be needed to implement the drainage in the additional 14 000 ha. So in 1995, EPADP purchased 10 new field drainage machines and 5 new collector drainage machines (3060 km of field drains requires 198 x 4.77 x 0.380 = 8.5 field drainage machines and 340 km collector drain requires 198 x 4.14 x 0.1 = 4.2 collector machines).
Purchase of Drainage Machines
Selection of suppliers can be done according to the performance of machines bought in the past. An example is presented in Table 6, in which the capacity of two types of machines has calculated from time and motion studies conducted in 1990-1991. The capacity of machine X is slightly higher than the capacity of machine Y, but the differences are small indicating that the capacity does not play an important role in the selection criterion for new machines.

Table 6  Capacity of two types of field drainage machines calculated from time and motion studies conducted in 1990-1991

<table>
<thead>
<tr>
<th>Type of drainage machine</th>
<th>Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>metres/hour</td>
</tr>
<tr>
<td>Machine X</td>
<td>380</td>
</tr>
<tr>
<td>Machine Y</td>
<td>362</td>
</tr>
</tbody>
</table>

A breakdown of the total time (Table 7) indicated that there is no significant difference between the two machines. Although there are differences in non-available and available time as machine Y has fewer technical breakdowns, but the substantially higher time for maintenance counter-balances this advantage. The overall conclusion is that the performance and quality of both machines are good. The choice of one or other of the machines must thus be based on other selection criteria (such as price or after sales service).

Table 7  Comparison efficiencies of two different types of field drainage machine

<table>
<thead>
<tr>
<th>Time specification</th>
<th>Machine X</th>
<th>Machine Y</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(%)</td>
<td>(hours)</td>
</tr>
<tr>
<td>Non-available time:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>* Field condition</td>
<td>10</td>
<td>0.9</td>
</tr>
<tr>
<td>* Technical breakdown</td>
<td>19</td>
<td>1.7</td>
</tr>
<tr>
<td>Subtotal non-available time</td>
<td>29</td>
<td>2.6</td>
</tr>
<tr>
<td>Available time:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>* Non-effective</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Maintenance</td>
<td>13</td>
<td>1.2</td>
</tr>
<tr>
<td>- Meal time</td>
<td>10</td>
<td>0.9</td>
</tr>
<tr>
<td>- Organisation</td>
<td>12</td>
<td>1.1</td>
</tr>
<tr>
<td>Subtotal non-effective time</td>
<td>35</td>
<td>3.2</td>
</tr>
<tr>
<td>* Effective time</td>
<td>36</td>
<td>3.2</td>
</tr>
<tr>
<td>Total time</td>
<td>100</td>
<td>9.0</td>
</tr>
</tbody>
</table>
6.3 Quality Control: Video inspection

EPADP in cooperation with DRI is continuously looking for ways to improve existing practices, not only pertaining to design and implementation but also research. For example, to assess the performance of the drains, the Drainage Research Institute tested a video inspection unit in the Abu Matamir area in the Western Nile Delta region (Table 8). To interpret these results we recommend the classification system below:

- **No maintenance required**: Sediment on the bottom of the pipe is stirred up by the camera;
- **Need for regular maintenance (flushing)**: Sediment is pushed in front of the camera occasionally, but camera can still pass. Estimated height of sediment > ¼ of pipe diameter;
- **Need for major maintenance/rehabilitation**: Camera cannot pass, amount of sediment is (i) pipe is ¼ full, (ii) pipe is ½ full, or (iii) pipe is completely blocked.

Table 8  Some results of the video inspection of field drain with/without envelope at Abu Matamir, Western Nile Delta, Egypt

<table>
<thead>
<tr>
<th>Field drain (no.)</th>
<th>Manhole (no.)</th>
<th>Collector (no.)</th>
<th>Length (m)</th>
<th>Envelope</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>2</td>
<td>2</td>
<td>86</td>
<td>With</td>
<td>No problem</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>2</td>
<td>100</td>
<td>Without</td>
<td>Camera stuck at 50 m</td>
</tr>
<tr>
<td>13</td>
<td>4</td>
<td>4</td>
<td>100</td>
<td>Without</td>
<td>Pipe broken at 2.5 m</td>
</tr>
<tr>
<td>14</td>
<td>4</td>
<td>4</td>
<td>166</td>
<td>With</td>
<td>Camera stuck at 128 m</td>
</tr>
<tr>
<td>17</td>
<td>5</td>
<td>4</td>
<td>121</td>
<td>With</td>
<td>Camera could not move, pipe dry</td>
</tr>
<tr>
<td>7</td>
<td>3</td>
<td>6</td>
<td>100</td>
<td>Without</td>
<td>Outlet broken</td>
</tr>
<tr>
<td>9</td>
<td>4</td>
<td>6</td>
<td>100</td>
<td>Without</td>
<td>Traces of sediment</td>
</tr>
<tr>
<td>10</td>
<td>4</td>
<td>6</td>
<td>175</td>
<td>With</td>
<td>Roots at 17 m</td>
</tr>
<tr>
<td>9</td>
<td>3</td>
<td>8</td>
<td>100</td>
<td>Without</td>
<td>Lot of sediment</td>
</tr>
<tr>
<td>10</td>
<td>3</td>
<td>8</td>
<td>215</td>
<td>With</td>
<td>Camera stuck at 133 m</td>
</tr>
</tbody>
</table>

6.4 Performance Assessment

In Egypt, performance assessment is used to establish the need for rehabilitation of a drainage system (Figure 17). The performance assessment involves three sequential steps (Figure 18). Each step is only undertaken when the previous step has confirmed its necessity and, therefore, the performance assessment process may end after a particular step. Therefore, it may not be necessary to complete all three steps or to do them in the indicated order. For example the preliminary investigation may be stopped when the complaint assessment indicates that the complaints do not require further action (and it would be resumed when the complaints persist or when other new information becomes available).
**Figure 17** Performance Assessment of drainage implementation activities done by EPADP

**Figure 18** Standard Performance Assessment procedure used by EPADP
PART III - CASE STUDIES

Step 1  Preliminary investigation based on existing information
This first step is a preliminary investigation, mainly based on analysis of the existing information and includes the following activities:

- Complaint management: review and assessment of the complaints received from the users (farmers);
- File/database search: this includes the age of the project together with the applied technology (materials and construction methods); the applied quality control; the contract documents;
- Agricultural data search: crop productivity and cropping pattern;
- Rapid appraisal: a short field survey to assess the drainage conditions.

The need for the second step is assessed based on this preliminary investigation.

Step 2  Preliminary investigation based on new data
This step requires considerable field work and expenditure and should only be undertaken when step 1 has confirmed that there are sound indications that there are indeed waterlogging and/or salinity problems in the area or in a considerable part of the area, and that these problems are most probably due to a malfunctioning of the existing drainage system. In this step, this assumption is confirmed or rejected by collecting data on watertables, soils salinity and crop yield and comparing these with the accepted standards of good performance. This step can be divided in two sub-steps:

- Data collection and processing: monitoring the selected indicator parameters followed by some form of processing to facilitate the use of the collected data;
- Data evaluation: comparing the collected indicator data with the accepted standards on the basis of which judgements can be made on the performance of the pipe drainage systems.

It is of course possible that this step reveals that there are no real waterlogging and salinity problems in the area or that the prevailing conditions are not due to malfunctioning of the pipe drainage systems. If this is the case, the performance assessment is terminated.

Step 3  Cause analysis
If step 2 has confirmed that the performance of the installed pipe drainage systems does not meet the expected standards, the cause(s) of the under-performance of the system(s) have to be identified. The outcome of this step can be either an improved maintenance programme or the rehabilitation of (part) of the system.

7  Capacity Building

7.1  Drainage Executive Management Project

In the 1970s, EPADP and the contractors faced the problems of mechanised installation of drain pipes, personnel with little experience with this drainage technology and the large scale of the
projects. The enormous amount of modernised drainage machinery demanded experienced civil engineers, supervisors, operators, skilled technicians and foremen, as well as proper planning and organisation of the implementation of the projects.

Initiatives were taken to tackle these problems under the umbrella of the Egyptian-Dutch Panel on Land Drainage. The Drainage Executive Management Project (DEMP) was established aimed at strengthening the EPADP organisation and upgrading the qualifications of the staff of EPADP and the personnel of drainage contractors, improving the standards of design, implementation, operation and maintenance of drainage. Through the DEPMP project long-lasting cooperation between EPADP and Rijkswaterstaat in the Netherlands developed.

It was considered necessary to set up a training programme at various levels to acquaint EPADP engineers with the different aspects of handling and dealing with new materials and techniques, made necessary through the advancement of mechanisation. Specialised and/or additional training had to be organised for a considerable number of personnel. Only in this way could EPADP and its contractors sustain a high standard of durable construction work.

7.2 Tanta Training Centre

When the DEMP project commenced there was no training centre for trainees to go to. Moreover, it was mutually agreed that on-the-spot training would be the most practical and effective approach in the short run. The conclusion was that the trainers should go to the field, and in this way the on-the-job training for EPADP and contract field staff began. This training programme was known as "in-service training"; and became a regular event (Figure 19).
First, Dutch instructors together with their Egyptian counterparts visited and trained the staff of EPADP and the staff of the contractor in the directorates all over Egypt. Gradually, the Egyptian instructors took over the training ("train the trainers"). The "in-service training" proved to be an instrument not only to train staff successfully in mechanised drainage implementation, but also to introduce new techniques, such as using laser equipment and rodding equipment for quality control. Training of EPADP staff in the Netherlands was also part of the DEMP project. However, after a few years it was felt that the range of training was still too limited. The need for more specific training courses became evident during the "in-service training" visits and ultimately the visits of EPADP staff to vocational training centres in the Netherlands convinced the EPADP management of the need for a permanent training centre. This led to the establishment of the Drainage Training Centre in Tanta.

The Drainage Training Centre in Tanta was established in 1991 to secure specific training and/or refresher courses for different levels of responsibility in land drainage projects. The DTC is currently a fully operational vocational training centre and an integrated part of the EPADP organisation. The DTC contributes to strengthening and upgrading the entire organisation. The training activities at the DTC focus on personnel of the EPADP organisation and contractors, in order to:

- Increase their skills for the job;
- Obtain essential knowledge to perform their job;
- Improve the quality and the quantity of their performance.

The DTC has all the facilities to conduct practical training courses (Figure 20). Besides the theoretical lessons much attention is paid to practical training of the trainees. All the instructors at the DTC are engineers with many years of experience in drainage practice in Egypt. The Annual training programme includes: field engineer execution courses, maintenance engineer courses, laser courses, surveying courses, operating drainage machines courses, channel maintenance with mowing buckets and so forth. The "in-service training" has become an integrated part of DTC's course programme.

Figure 20  Training activity at the Drainage Training Centre
Case Study - India
Case Study - India

1 Background

Subsurface drainage practices were introduced to India only recently. Thus far, only about 18 000 ha waterlogged saline land in canal irrigation commands have been provided with subsurface drainage systems, the majority of which is less than 10 years old. The bulk of the coverage is in Rajasthan (15 000 ha), Haryana (1 500 ha) and Karnataka (2 000 ha). Therefore, much of the drainage experiences in the country are related to these three areas (Figure 1).

Figure 1 Subsurface drainage projects in India
India experiences a wide range of climatic and physiographic conditions and a correspondingly wide range of waterlogging and soil salinity problems. These problems are broadly classified into the following three groups:

- **Rainfed induced waterlogging** is found naturally in imperfectly drained land in much of the country during the monsoon season, with the exception of the arid parts of Gujarat and Rajasthan;
- **Natural salinity** occurs in various locations in the semi-arid parts of the north-western and western part of the Gangetic plain under the prevailing hydrologic and geochemical conditions of the land. Natural salinity is also found in the plains and deltaic areas along the coast;
- **Irrigation-induced waterlogging and salinity** is a relatively recent feature that developed in the late 19th century when large-scale canal irrigation was introduced. These problems are found in different command areas throughout the country, either in the form of waterlogging only, or a combination of waterlogging and soil salinity.

It is estimated that some 8.4 million ha is affected by soil salinity and alkalinity, of which about 5.5 million ha is also waterlogged, mainly in the irrigation canal commands and 2.5 million ha in the coastal areas. Even though some surface drainage improvements have been undertaken in rainfed and irrigation-induced waterlogged areas, the drainage requirements of much of the farmland are yet to receive any attention. Control of waterlogging and soil salinity through subsurface drainage has been gaining ground in recent years. Large expansions in this field may come up in the coming decades to safeguard the sustainability of agro-economy in the canal-irrigated areas that are seriously threatened by waterlogging and soil salinity. Research for the control of waterlogging and soil salinity received a big boost under the Canada aided Rajasthan Agricultural Drainage Research (RAJAD) project and the Netherlands aided Haryana Operational Pilot Project (HOPP) and Indo-Dutch Network Project (INDP). The necessary research developments for large-scale expansion of subsurface drainage have emerged from these projects.

2 Organisation

The improvement of drainage in India is largely planned and implemented as a flood control measure. As a result most of the attention has been on the construction of flood protection embankments along the rivers and major surface drains. Nevertheless, on-farm drainage has started to receive some attention in irrigation command areas. The development of water resources and their use is a state issue. The Central Government through the Ministry of Water Resources provides the policy, directions and expertise for planning, development and use of water resources within the states as well as among the states. International projects on Water Resources are also dealt with by the Central Government. The Command Area Development Wing, headed by a Commissioner, looks after the water and land management issues in irrigation commands. Under the Command Area Development Programme, the construction of irrigation systems up to tertiary levels, land development, drainage improvement and construction of road networks are taken up in an integrated manner. The Agriculture Departments of the State
Governments, supported by the Agriculture Department of the Central Government, are responsible for the appropriate agriculture practices to the farming community as well as land reclamation and soil and water conservation activities.

Water management and drainage research is conducted at both central and state level under the Indian Council of Agricultural Research (ICAR) through its own specialised research institutes and the various state agricultural universities. The research mainly pertains to crop drainage requirements and land reclamation practices. The construction aspects of drainage have received very little attention.

In some states like Haryana subsurface drainage is considered to be a measure for land reclamation and, therefore, executed by the Agriculture Department. The surface drainage network and the canal water supply, distribution and management are, however, under the purview of Irrigation Department. Thus the improvement of on-farm (subsurface) drainage is not integrated with the improvement of the main irrigation and drainage systems and improvements in management.

Drainage improvements within an irrigation command are entrusted to the Command Area Development Authority (CADA) in some states like Rajasthan. CADA is headed by Area Development Commissioner (ADC) under whom come the wings of irrigation, agricultural extension, agricultural research, land development and revenue, all under the overall responsibility of the Department of Command Area Development and Water Use. The major drainage and irrigation networks are operated and maintained, scheme-by-scheme, by the Irrigation Wing and the on-farm drainage improvements by the Land Development Wing. Outside the command areas, the improvement of drainage is the responsibility of the Irrigation Department. Thus there is no integrated and centralised organisation for improving drainage and the policy and practices also suffer as they vary with each department.

3 Planning

As there are no centralised organisation in India to diagnose, monitor and implement drainage measures there is also no systematic planning to address the drainage problems. The drainage improvements are limited to waterlogged areas in the form of open drainage and subsurface drainage for waterlogged saline areas. The monitoring activities, identification and implementation are spread over several departments.
4 Drainage materials

Pipes
The principal materials that have been used for subsurface drainage systems are clay pipes in South India and PVC pipes in the North India.

Clay pipes
Bell-mouthed clay pipes with a row of eight perforations on the underside, 60 cm in length and 100 mm diameter for field drains and 150 mm diameter for collectors, were used in South India in the 1970s and 1980s because plastic pipes were not available. The material cost was three times the cost of installation. Furthermore, the performance of drainage systems was severely affected by the displacement of the pipes and choking of drain lines. At present there are a few pilot projects in progress with corrugated PVC drain pipes that may gradually replace clay pipes.

Concrete pipes
Concrete pipes have been used only for collector and field drains on a pilot scale. For example in the Sampla and Mundlana pilot areas in Haryana (Figure 2).

Figure 2  Concrete pipes (Ø 100 mm) used in Sampla Pilot Area, Haryana

PVC pipes
The production of corrugated PVC drain pipe only commenced in the early 1990s and then only up to 100 mm in diameter conforming to DIN specifications. These corrugated PVC pipes were used for field drains and reinforced cement, concrete or PVC rigid pipes for collector drains. Then, in the mid-1990s under the RAJAD project, corrugated PVC drain pipes of seven sizes became available, ranging in diameter from 80 mm to 450 mm (Table 1).

Envelopes
In the large drainage installation projects both granular and synthetic envelope materials have been used. In areas where clay pipes were used sand blinding, namely, backfill with sand around the pipe was practised (Figure 3). A considerable amount of testing of envelope materials has
been done in sandy loam soils under the HOPP and IDNP projects and in clay soils under the RAJAD Project. Field investigations under RAJAD and laboratory investigations at the Central Soil Salinity Research Institute (see Box 1) showed the soil texture (clay percentage) and sodium absorption ratio (SAR) to be the significant determinants of the need for an envelope. The criteria for deciding on the need for envelope were as follows:

- Clay > 40% Envelope not required
- Clay 30 - 40% & SAR > 16 Envelope required
- Clay < 30% Envelope required

The specifications for the envelope adopted by respectively the HOPP and RAJAD project material were as follows.

- **Sandy Soils**: For sandy loam soils, non-woven polypropylene material of a minimum thickness of 3 mm weighing 300 gm/m² or more with a pore size of 0.90 and between 350 and 550 microns is recommended. The envelope should be strong enough for manual or machine wrapping and for transport and installation by hand or machine;
- **Clay Soils**: For clay soils, non-woven polypropylene material of a minimum thickness of 0.9 mm when compressed and a weight of at least of 240 gm/m² is recommended. The permeability of the envelope should be at least 20 m/day and 95% of the openings of the fabric should be smaller than 150 microns but not smaller than 100 microns. The tensile strength of the envelope should be at least 360 N.

### Table 1  Technical specifications of corrugated PVC drain pipes

<table>
<thead>
<tr>
<th>Nominal diameter in mm</th>
<th>80</th>
<th>100</th>
<th>160</th>
<th>200</th>
<th>294</th>
<th>355</th>
<th>455</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inside diameter in mm</td>
<td>72</td>
<td>88</td>
<td>144</td>
<td>178</td>
<td>258</td>
<td>315</td>
<td>401</td>
</tr>
<tr>
<td>Depth of corrugation in mm</td>
<td>4.2</td>
<td>6.0</td>
<td>7.6</td>
<td>10.3</td>
<td>17.1</td>
<td>19.0</td>
<td>24.6</td>
</tr>
<tr>
<td>Pipe coil length in metres</td>
<td>100</td>
<td>75</td>
<td>30</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>No. of perforations per metres</td>
<td>120</td>
<td>140</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>No. of perforations in cross section</td>
<td>3</td>
<td>4</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Width of perforation in mm</td>
<td>1.8</td>
<td>1.8</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Length of perforation in mm</td>
<td>Min</td>
<td>8.5</td>
<td>8.5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td>15.0</td>
<td>15.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Water inlet area in cm²/m</td>
<td>Min</td>
<td>18.4</td>
<td>21.4</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td>32.4</td>
<td>37.8</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Bending radius at 0 °C in mm approximately</td>
<td>240</td>
<td>300</td>
<td>480</td>
<td>600</td>
<td>882</td>
<td>1065</td>
<td>1365</td>
</tr>
</tbody>
</table>
Figure 3  Installation of a sand envelope in the ACRIP Appikalta Pilot Area, Andhra Pradesh: 
a) sealing the joint; b) sand filter around a concrete drain and c & d) around a plastic drain
5 Installation equipment

Large-scale subsurface drainage installation is relatively new in India. International contractors imported the drainage machinery and undertook the bulk of the installation under RAJAD project. For HOPP, the Netherlands Government provided a trencher, with which about 1000 ha area has been covered so far.

6 Examples of large-scale drainage projects

6.1 Rajasthan Agricultural Drainage Research Project

The Rajasthan Agricultural Drainage Research Project (RAJAD) was the first major project to install subsurface drainage systems at a large-scale in India. The project was a joint undertaking funded by the Government of Canada, Government of India and the State Government of Rajasthan. The project was a large-scale, applied research project on the use of horizontal subsurface drainage and associated water management techniques to control soil salinity and waterlogging problems in irrigated agricultural lands. The project was located in the Chambal Command area in Rajasthan. The total Chambal Command area is 385 000 ha, of which 229 000 ha is under irrigation. Waterlogging and salinity problems followed the introduction of irrigation in the area in the 1960’s. The project aimed at:

- Capacity building of the state government and farmers to address the problems of waterlogging and soil salinity;
- Development of design criteria for subsurface drainage through pilot area research;
- Establishment of facilities for drain pipe supply;
- Demonstration and implementation of large-scale mechanised subsurface drainage installation;
- Construction of subsurface drainage using local machines and persons;
- Pilot testing of Integrated Water and Agriculture Management.

The project started in 1991 and by the end of 1998 an area of about 15 000 ha was provided with subsurface drainage at an overall costs of € 41.3 million (2000 prices). The overall crop yield increased about 25%.

Project organization

The Government of Canada designated the Canadian International Development Agency (CIDA) as the agency responsible for the implementation of the project and CIDA appointed a Canadian Project Executing Agency. The Commissioner of the Chambal Command Area Authority appointed the Project Manager (Figure 4). A Project Steering Committee (PSC) was responsible for the programme review, policy, budget approval, external institutions coordination and report review. A Technical Coordination Committee (TCC) coordinated the Pilot Research and design criteria recommendations.
Planning

RAJAD was an integrated project in which both research through pilot studies and implementation of subsurface drainage in large areas took place. The following schedule was followed:

| Item                                | SSD(ha) | '91 | '92 | '93 | '94 | '95 | '96 | '97 | '98 | '99 | '00 |
|-------------------------------------|---------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Human resource development          |         |     |     |     |     |     |     |     |     |     |     |     |
| Small test sites                    |         |     |     |     |     |     |     |     |     |     |     | 410 |
| Investigations & design             |         |     |     |     |     |     |     |     |     |     |     | 1010|
| Large test sites                    |         |     |     |     |     |     |     |     |     |     |     |     |
| Monitoring & evaluation             |         |     |     |     |     |     |     |     |     |     |     |     |
| Pre-contract 1                       |         |     |     |     |     |     |     |     |     |     |     | 700 |
| Contract 1                          |         |     |     |     |     |     |     |     |     |     |     | 10,671|
| Areas with patchy salinity          |         |     |     |     |     |     |     |     |     |     |     | 2134|
| Operation and maintenance           |         |     |     |     |     |     |     |     |     |     |     |     |

Delineation of saline areas was done by EM38-survey on a 77 ha grid. In the affected areas, soil samples were collected on an 8.5 ha grid and analysed on mechanical and chemical properties. For classification of salt affected soils the following criteria were used:
PART III - CASE STUDIES

Class | $EC_e$ (dS/m) | ESP | PH
--- | --- | --- | ---
Saline soil | $>4$ | $<15$ | $<8.5$
Saline-alkali soil | $>4$ | $>15$ | $>8.5$
Alkali soil | $<4$ | $>15$ | $>8.5$

Layout
A composite subsurface drainage system was installed with field drains at an average depth of 1.2 m and 60 m spacing connected to collector drains that discharge by gravity in open main drains.

Drainage materials
Corrugated PVC drain pipes of seven sizes were used. The pipes were locally produced by a private company and were subject to stringent quality testing prior to use.

Envelopes
Synthetic fabric envelope materials were used in case the criteria for use of envelope mentioned in Chapter 4 required to do so.

Installation equipment
Four trenchless machines and one trencher were used. Initially only field drains were installed by the trenchless ploughs and collectors were installed using excavators. The first machine to be used was a trenchless plough equipped with a 400 HP diesel engine and an operating weight of 40 Mt. Its overall length when operating was 10.5 m with a width of 3.30 m and a height of 7.0 m (3.0 m laser light receiver mast in the upright position). The second machine was a bulldozer with a drainage plough added on the rear. In the international contract, in which subsurface drainage system has been installed in about 10,600 ha, two trenchless machines (one vertical plough and a V-plough) and a trencher were used. The V-plough was used to install drains of Ø 80 and 100 mm. The vertical plough was used to install the field and collector drains of Ø 160, 200 and 294 mm. Local equipment included: backhoe for excavating at joints, junctions, outlets and the like; bulldozers for removal of abrupt grade changes and restoration work; tractors, trucks etc. for transportation of material and hydraulic vibrators for compaction.

Construction practices
Prior to installation, a laser transmitter was set up, calibrated to the nearest benchmarks and checked to ascertain that the existing topography and proposed depth of the field and collector drains was indeed correct. First the collector drain was installed. An excavator/backhoe then excavated down to the collector and a T-joint was connected to the collector pipe. The field drain pipe was fed through the plough boot, the connection elevation confirmed, connected to the T-joint, plough boot elevation set to design grade and finally installed by the plough. After completing the drain line, the machine returned over the same line to compact the soil and then moved on to the next line. A bulldozer followed the machine to compact the soil once more. Finally, the farmers levelled their fields in preparation for the subsequent crop season. A small
crew restored the bunds, drains and watercourses disturbed by the machinery. As-built construction drawings were prepared for operation and maintenance requirements. Under extreme wet conditions and during the monsoon season the work was suspended. Sometimes, however, it was required to pull the trencher by a bulldozer when and where local wet conditions prevailed. The trenchless installation under wet conditions caused smearing and clogging of the synthetic envelopes resulting in less than optimal performance of the drainage systems. In such cases, additional field drains had to be installed to alleviate wet conditions in the fields. The rate of installation varies from 500 m/day for the combined mechanical/manual installation to more than 5000 m/day for installation by trenchless drainage machine (Table 2).

Table 2  Installation rates of the different installation techniques achieved at RAJAD

<table>
<thead>
<tr>
<th>Method</th>
<th>Installation rate (m/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manual installation with one backhoe and 20 labourers</td>
<td>500</td>
</tr>
<tr>
<td>Installation by excavator</td>
<td>1500</td>
</tr>
<tr>
<td>Installation by trenchless drainage machine</td>
<td>5000 - 6000</td>
</tr>
</tbody>
</table>

Experiences gained during installation resulted in the following list of precautions:

- Construction management staff should be given comprehensive training in effective inspection and reporting techniques prior to the start of the installation;
- A Construction Management Organisation with the clear division of responsibilities is essential;
- Laboratory testing and field inspection of PVC pipe and fittings must be a continuous, well documented process of quality control to avoid installation problems and failures of the system;
- All faulty material should be rejected;
- Laser set-up should always be double checked against control points and ground elevations prior to starting the actual installation of the drain pipes;
- Grade control on collector and field drains is fundamental to the success of installation;
- Installation work should start from the outlet drain and installation should then proceed upstream to prevent drainage water collecting in trenches;
- Restoration work should start within 24 hours of the pipe installation.

6.2 Haryana Operational Pilot Project

Project objectives
The Haryana Operational Pilot Project (HOPP) for the reclamation of waterlogged and saline lands of Haryana came into being in 1994 with the assistance of the Government of the Netherlands. The long-term objective of the project was to "build and strengthen the capacity of the Department of Agriculture (DOA) of Haryana to implement the subsurface drainage technology in the
state and to create/act as a resource/knowledge base for the future interventions of subsurface drainage technology in waterlogged and salt affected areas of Haryana (and later in north-west India) including playing an active facilitating role in the development of a drainage policy in the state and possibly in neighbouring states. The specific (short-term) objectives were:

- Transfer of technology (equipment, knowledge and skills) relating to the reclamation of waterlogged and saline lands in Haryana;
- Construction and operation of two horizontal subsurface drainage schemes, each of about 1000 ha;
- Creation in Haryana of a nucleus organisation capable of:
  - Implementing subsurface drainage systems on about 2500 ha per year and maintaining the resulting drainage network;
  - Attracting sufficient funds for the purchase of additional equipment, the actual construction of drainage systems and for hiring the necessary staff.
- The participation of farmers in the planning, construction, operation and maintenance of the subsurface drainage systems;
- The environmentally sound disposal of the saline drainage effluent of the pilot areas.

**Project organisation**

The organisations responsible for managing and implementing the HOPP were the Department of Agriculture, Government of Haryana, India and the Directorate General of International Co-operation, The Netherlands. The overall supervision and guidance was in the hands of two committees whose members belonged to a number of organisations involved in drainage in Haryana (Department of Agriculture, Department of Irrigation, CSSRI, Haryana Agricultural University, and others), as follows:

- **Steering Committee** headed by the Secretary of Agriculture of DOA in Chandigarh, for guidance on policy matters meeting at least twice a year;
- **Technical Committee** headed by the Director of CSSRI in Karnal to guide the Haryana OPP on the technical details meeting at least four times a year.

Consultancy was provided by the Netherlands through an Indo-Dutch consortium of consulting companies. To implement HOPP an organisational unit under the DOA was established with deputations from other departments within Haryana (Figure 5). Based on a process approach, a Knowledge Management Unit (KMU) was established at Chandigarh together with a Technical Assistance Team to ensure the sustainability of the institutional memory from project experiences. In addition to assuming Monitoring and Evaluation (M&E) responsibilities, the KMU guided the implementing department (Subsurface Drainage Cell) to develop capacity building packages, co-ordinate training on data collection, work processing and planning, gender sensitisation and farmers participation for field teams, farmers and contractors. The KMU was also responsible for cultivating links with other agencies (e.g. Department of Irrigation) and assists in the development of drainage policy initiatives in Haryana and elsewhere as appropriate. The project activities were grouped under the following work components:

- Project management;
- Planning and design;
- Construction of subsurface drainage and other field activities;
• Machinery maintenance;
• Farmers participation and O&M;
• Monitoring and evaluation.

The work programme was designed to ensure that full integration of all the components took place and that human resource development and training was linked to all components.

Planning
Before HOPP started, CSSRI and Haryana Agriculture University conducted operational research on waterlogging and soil salinity in sandy soils of Haryana. The recommendations of these studies provided the required inputs for undertaking subsurface drainage construction under HOPP. The sequence of activities was as follows:

- Participatory Rural Appraisal (PRA) in the pilot areas, mapping the social landscape;
- Rough layouts for the blocks based on maximum size of the drainage blocks, boundaries of villages, minors, dirt roads, open drains and so forth;
• Motivational activities including the development of communication materials, orientation visits to nearby mini pilot schemes and farmer field days;
• Detailed designs;
• Verification of the designs in consultation with the farmers, changes in the designs were made when feasible;
• Obtain farmers’ consent for the construction of the subsurface drainage system;
• Formation of Farmers Drainage Societies including elections for the executive committee and official registration according to the Societies Registration Act (1860) and bye-laws. The executive committee included one ex-officio member of HOPP;
• Construction of the subsurface drainage system with conflict resolution by the Farmers Participation Section (FPS) staff;
• Handing over of (electric) pumps operation to the registered Farmer Drainage Societies.

The first subsurface drainage systems were installed in April 1997 in the Gohana area: in three seasons about 1000 ha divided into 23 blocks with one pumping unit in each block were provided with subsurface drainage. The drains were installed mechanically using imported trencher machines. All blocks were handed over to the farmers’ drainage societies in phases for operation and maintenance.

Then, the construction activities were shifted from government constructing units to a private contractor. Identification of areas requiring drainage, their prioritisation, undertaking investigations, design and planning were carried out by the government and its own staff, while the construction was carried out by contractors and the systems operated and maintained by the farmers’ drainage societies.

Layout
Composite subsurface drainage systems were installed with corrugated PVC pipes for both the field (Ø 80 & 100 mm) and collector (Ø 200 & 294 mm) drains. The field drains connect on both sides to a collector pipe that discharge into a sump. Each sump serves around 50 ha, an area of approximately 40 - 50 farmers being the maximum size of group that can organise themselves. From the sump, the drainage water is lifted by pumping and disposed of into a surface drainage system. To prevent the inflow of fine soil particles into the pipes, nylon socks (for the collectors) and polypropylene non-woven fibres (thicknes >2 mm and an apparent opening size $O_{90} > 300$ microns) are used for the collector and field drains, respectively. Both pipe and envelope materials were produced locally (Figure 6). The field drains are about 315 m in length and have an average depth of 1.7 m. The maximum depth of the collectors at the sump is 3 m. The design discharge is 2 mm/day, which has been reduced to 1.5 mm/day for the new projects, resulting in a drain spacing of 60 to 67 m.

Equipment
The Netherlands Government provided a trencher, with which about 1000 ha area has been covered so far (Figure 7).
PART III - CASE STUDIES

Figure 6  Wrapping the non-woven polypropylene envelope around the drain pipe

Figure 7  Trencher installing pre-wrapped corrugated drain pipe in Gohana area

Costs
Based on the actual expenditure for the first 983 ha in Gohana (1997-1999) the total cost of installing subsurface drainage amounted to € 770 per hectare at 2000 prices (Table 3).
Table 3  Actual cost of installing subsurface drainage systems in Haryana, India

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost per ha (€)</th>
<th>(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Materials</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Pipes</td>
<td>238</td>
<td>(31%)</td>
</tr>
<tr>
<td>• Envelopes</td>
<td>132</td>
<td>(17%)</td>
</tr>
<tr>
<td>• Structures a</td>
<td>59</td>
<td>(8%)</td>
</tr>
<tr>
<td>Machinery</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Fixed b</td>
<td>174</td>
<td>(23%)</td>
</tr>
<tr>
<td>• Variable c</td>
<td>131</td>
<td>(17%)</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>37</td>
<td>(5%)</td>
</tr>
<tr>
<td>Total</td>
<td>770</td>
<td>(100%)</td>
</tr>
</tbody>
</table>

a Structures include sump, pump house, pumps, electrification, manholes, labour, disposal (surface) drainage;
b Fixed machine costs include interest (15%) and depreciation based on a lifetime of 7 - 10 years. A working time of 70 machine hours have been used for one block with an average working time of the construction plant (trencher, excavator, bulldozer, tractors and trailers) of 800 hrs per year;
c Variable costs include spare parts (estimated over lifetime), repairs (partly estimated), diesel and oil (actual).

6.3 Indo-Dutch Network Project

This third project is not an example of large-scale implementation but of applied research and small-scale implementation. To support the research activities in subsurface drainage design and small-scale implementation, the Indo-Dutch Project for waterlogging and soil salinity was in operation for about 17 years (1985 - 2002). Between 1996 and 2002 this project was converted into a Network Operational Research Programme on Drainage and Water Management for Salinity Control in Canal Commands (IDNP). The overall objectives of the project were (i) to strengthen research capacity of CSSRI and the four State Centres, especially in the field of waterlogging and salinity control, and (ii) to enhance awareness on drainage and related water management for the control of waterlogging and soil salinity at State and Central level. The objective of the drainage pilot area research component was to conduct operational research on drainage methods for reclamation of waterlogged and salt affected agricultural land in different agro-climate zones of India. Eight pilot areas, ranging in size from 20-188 ha, were implemented in 5 agro-climate zones. Monitoring included one large-scale monitoring area of 2000 ha out of which nearly 1200 ha were provided with subsurface drainage.

Project Organisation

The IDNP project was implemented jointly by the Government of India through the Indian Council of Agricultural Research (ICAR) and the Government of the Netherlands through the Royal Netherlands Embassy (RNE) in India. The Implementing agencies in India were:

- Central Soil Salinity Research Institute (CSSRI), Karnal, Haryana (Box 1);
- Acharya N G Ranga Agricultural University (ANGRAU), Indo-Dutch Network Project, Bapatla, Andhra Pradesh;
- Gujarat Agricultural University (GAU), Soil and Water Management Research Institute, Navsari, Gujarat;
• University of Agricultural Sciences Dharwad (UASD), Agricultural Research Station, Bheemarayanagudi, Karnataka;
• Rajasthan Agricultural University (RAU), Agricultural Research Sub-Station, Hanumangarh, Rajasthan.

**Box 1 Central Soil Salinity Research Institute**

The Central Soil Salinity Research Institute (CSSRI), established in 1969 under ICAR, is a central research institute located at Karnal, Haryana. It is a leading research centre in India in the fields of salt affected soils and waterlogging. Besides the main centre at Karnal, the institute has regional stations at Canning Town in West Bengal for coastal soils, at Anand in Gujarat for black soils and at Lucknow in Uttar Pradesh for alkaline soils of the Gangetic plains. It is also the headquarters of the All India Coordinated Research Project on Management of Salt Affected Soils and Use of Saline Water for Agriculture, which has seven network centres located in different agro-climatic regions of the country. The multidisciplinary research at CSSRI is organised under the four following divisions:

- Drainage and Water Management Engineering;
- Soils and Crop Management;
- Crop Improvement, and;
- Technology Evaluation and Extension.

The research on drainage concentrates on development of design criteria, testing of drainage materials, recycling of drainage water and socio-economic aspects through field research and modelling.

CSSRI was the coordinating agency and focal point for all the other network centres and the International Institute for Land Reclamation and Improvement (Alterra-ILRI), Wageningen, The Netherlands, provided technical assistance to the project. The four state agricultural universities, often in cooperation with state departments or CADAs, had already started operational research.

**Output**

The project provided the guidance for identifying problems, developing research programme, undertaking pilot research in farmers’ fields, and analysis of results to develop solutions to waterlogging and soil salinity. Multidisciplinary scientific teams under a chief scientist at each centre conducted the studies. The outputs were synthesised into recommendations for field departments for implementation. The research activities resulted in major developments on the following issues (for more details see Bibliography):

- Two methodologies, one based on visual and one for digital interpretation, were recommended for the identification of waterlogging and soil salinity conditions using remote sensing: These were based on eight studies covering areas ranging between 5,000 and 350,000 ha in the Indo-Gangetic plains (3), heavy clay or black soils (3) and sandy soils (2);
- Recommendations on Waterlogging and Salinity Control were based on the research findings of 7 drainage pilot areas (of between 20 and 188 ha, Table 4), covering 5 agro-ecological sub-regions in India with soils ranging from sandy loam to heavy clay. Suggestions for open and pipe drains were presented for each sub-region specifications for subsurface drainage systems;
- Computer modelling for irrigation and drainage: four computer simulation models, SWAP, UNSATCHEM, SALTMOD and SURDEV, were tested to assess the short and long-term
impacts of water management options on the land and water productivity and the environment;
• Human resource development and the establishment of a training centre: the report included discussion of the adopted approach in technology transfer, capacity building and institution strengthening of the four network centres.

Table 4  Summary of the various drainage systems in the pilot areas

<table>
<thead>
<tr>
<th>Pilot Area</th>
<th>State</th>
<th>Size (ha)</th>
<th>Type of Drainage System</th>
<th>Outfall conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Konanki</td>
<td>Andhra Pradesh</td>
<td>20</td>
<td>• Composite pipe drainage</td>
<td>Gravity</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Composite open drainage</td>
<td></td>
</tr>
<tr>
<td>Uppugunduru</td>
<td>Andhra Pradesh</td>
<td>21</td>
<td>• Composite pipe drainage</td>
<td>Pumped</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Composite open drainage</td>
<td></td>
</tr>
<tr>
<td>Segwa</td>
<td>Gujarat</td>
<td>188</td>
<td>• Composite pipe drainage</td>
<td>Gravity</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Singular pipe drainage</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Composite open drainage</td>
<td></td>
</tr>
<tr>
<td>Sisodra</td>
<td>Gujarat</td>
<td>160</td>
<td>• Composite open drainage</td>
<td>Gravity</td>
</tr>
<tr>
<td>Gohana</td>
<td>Haryana</td>
<td>1200</td>
<td>• Composite pipe drainage</td>
<td>Gravity</td>
</tr>
<tr>
<td>Sampla</td>
<td>Haryana</td>
<td>100</td>
<td>• Composite pipe drainage</td>
<td>Pumped</td>
</tr>
<tr>
<td>Islampur/</td>
<td>Karnataka</td>
<td>180</td>
<td>• Composite pipe drainage</td>
<td>Gravity</td>
</tr>
<tr>
<td>Devapur</td>
<td></td>
<td></td>
<td>• Singular pipe drainage</td>
<td></td>
</tr>
<tr>
<td>Lakhwali</td>
<td>Rajasthan</td>
<td>75</td>
<td>• Composite pipe drainage</td>
<td>Pumped</td>
</tr>
</tbody>
</table>

Combined Mechanical and Manual Installation in Andhra Pradesh
In Andhra Pradesh in the Krishna Delta, two drainage pilot areas were constructed in 1999/2000: one in Konanki (22 ha) and one in Uppunguduru (21 ha). Installation was done semi-mechanically: the excavation and backfill was done by excavators, and activities like pipe-laying were done by hand.

First, the collector line was set out and the ends marked with ranging rods. Then, the field drains were set out perpendicular to the collector drain using an optical square and again the ends were marked with ranging rods. All lines were marked with white chalk powder to make certain that the trenches were dug as straight as possible.

The trenches were dug mechanically using an excavator, the drain pipes were installed manually and the backfill was done mechanically using a tractor with a front blade. The excavator had a bucket with a width of 40 cm. Cleaning and smoothening of the trenches was done manually.

The collectors, rigid PVC pipes (160 mm and 6 m length), were made watertight with solvent cement. The field drains (80 mm and 100 m length) were uncoiled on the ground and laid par-
allel to the trench and then the envelope (a geotextile and a nylon mesh) was wrapped around the pipe in the field before the pipe was placed in the trench. Four labourers could wrap and place about 250 m of pipe per day (Figure 8). Before the soil was backfilled it was crushed using the tractor blade.

Problems encountered during the installation and lessons learned were:

- It was hard for one labourer to do the wrapping, Therefore teams of four labourers were engaged to do the job;
- The binding wire used for wrapping the envelope material got easily twisted;
- Delays in installing the pipes were often caused as a result of standing water in the trenches. Pumping was required to discharge this excess water;
- Stability of the trench walls was poor and therefore the drain pipes needed to be installed as soon as possible after excavation.

Combined Mechanical and Manual Installation in Gujarat

In Gujarat in the Kakrapar irrigation command area, a 188 ha drainage pilot area was established in Segwa to test several layouts and configurations of subsurface drainage systems, namely, singular and composite systems and various drain depths and spacings. The following methods were tried:

- Manual installation in a 9.1 ha block: drains were installed manually at a depth of 0.90 m. The tools used for the manual installation included: hoes, sticks, hand scrappers, rope, metal and wooden compactors, metal buckets and vessels and bailing buckets;
- Semi-mechanical installation in two blocks (18.9 ha): an excavator was used to dig the trench up to 10-15 cm above the design level, all other activities such as levelling, grading, envelope wrapping, pipe-laying, backfill, were done manually (Figure 9).
Figure 9 In Segwa, the drain trench was excavated mechanically and all other activities were done manually: a) excavating the trench; b) checking the level; c) preparing the bed; d) checking the final level; e) checking the level at the outlet and f) laying the pipe
Time studies were conducted to establish the labour requirements (Table 5). The overall labour requirements in the manually installed block were 52 working days per 100 m drain (or 1.9 m/day). For preparatory activities like setting out the alignment and levels, the labour requirements were between 1 and 2 man-days per 100 m of drain, and for supporting activities like levelling, grading and smoothening the trench bottom, pipe-laying and backfill they were between 5 and 11 man-days. Thus the actual excavation of the drain trench took about 39 man-days per 100 m or 2.5 m/manday. The overall cost of installation of the completely manually installed system (approximately € 495/ha at 2000 prices) was 27% higher than the cost of the semi-mechanically installed system (approximately € 385/ha).

Table 5  Labour requirements for the manual installation of pipe drains in Segwa Pilot Area

<table>
<thead>
<tr>
<th>Labour requirements per 100 m of drain</th>
<th>Field drain</th>
<th>Collector drain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field drain</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Preparation:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Setting-out alignment</td>
<td>0.3</td>
<td>0.5</td>
</tr>
<tr>
<td>Pegging</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>Cleaning alignment</td>
<td>0.9</td>
<td>0.0</td>
</tr>
<tr>
<td>Marking</td>
<td>0.5</td>
<td>0.6</td>
</tr>
<tr>
<td><strong>Subtotal - Preparation</strong></td>
<td>1.8</td>
<td>1.3</td>
</tr>
<tr>
<td>Supporting activities:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Setting out levels</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Placement of boning rods</td>
<td>0.1</td>
<td>0.0</td>
</tr>
<tr>
<td>Levelling and smoothing trench bottom</td>
<td>6.2</td>
<td>0.0</td>
</tr>
<tr>
<td>Pipe inspection</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Laying of pipe</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Backfill</td>
<td>2.6</td>
<td>2.4</td>
</tr>
<tr>
<td>Compaction</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td><strong>Subtotal - Supporting activities</strong></td>
<td>11.1</td>
<td>4.6</td>
</tr>
<tr>
<td><strong>Excavation of drain trench</strong></td>
<td>39.2</td>
<td>Done by excavator</td>
</tr>
<tr>
<td><strong>Grand total</strong></td>
<td><strong>52.1</strong></td>
<td><strong>5.9</strong></td>
</tr>
</tbody>
</table>

| Additional activities:                |             |                |
| Wrapping envelope                     | 1.3         |                |
| Gypsum application $^a$               | 5.3         |                |
| Dewatering $^b$                       | 4.9         |                |

$^a$ In several trenches the backfill was mixed with gypsum to study the effect of gypsum application on sedimentation in the drain pipes in these unstable soils (high SAR).

$^b$ In several trenches dewatering was required because of the inflow of excess irrigation water.
The major problems encountered with the manually installation of the pipe drains, the adopted methods to overcome these problems and the lessons learned were:

- In the block where the system was installed semi-mechanically, the installation of the pipes could not follow the digging of the trenches. This problem was caused by the rather high labour requirements for supporting activities (5 - 11 labour days per 100 m of drain, see Table 5) as well as insufficient labour availability;
- Extra time was needed to train the labours in the specific tasks, like wrapping, grading & smoothening the trench bottom, pipe laying and backfill. It was difficult to find enough skilled labourers;
- A high labour input requires a higher input in supervision. The large number of labourers and the long distances in the field necessitated the use of walkie-talkies;
- The soils in Segwa Pilot area are rather heavy (clay content about 44%), when these soils dry up manually excavation is hard and difficult. It was especially hard to get good quality (fine and crumbled soil particles) for the backfill on top of the pipe;
- On the other hand, these soils become sticky under wet conditions. Therefore, to avoid waterlogged conditions, installation was not done in the monsoon season, but only in the summer season (January - May) when rainfall is limited;
- Neighbouring farmers did not want to interrupt their irrigation practices, which on several occasions resulted in inflow of water in the trenches;
- In the deeper trenches or those parts of the area where the groundwater table was high, trench walls were unstable due to in-flowing groundwater. This resulted in sudden collapse of (part) of the trench, which not only caused extra work but also created a safety hazard for the labourers working in the trench.

Manual Installation in Karnataka

In Karnataka, 180 ha operational research pilot area was constructed in Islampur-Devapur along the Naraynapur Left Bank Canal. A singular open and pipe drainage system was installed in a 14.9 ha block and a composite pipe drainage system in a 14.4 ha block. All installation activities, namely, excavation of the trench, laying of the pipes and backfill, were done by local labours. PVC corrugated pipes (Ø 80 and 100 mm) were installed at a spacing of 30 and 50 m, a depth varying between 1.1-1.2 m (for the field drains) and 1.4-1.5 m (for the collector drains) and wrapped with nylon socks in part of the area. The installation technique was similar to the method used in Segwa (see above), again with special emphasis on grade control. The only major difference was that topsoil was used for the first layer of backfill (0.20 to 0.30 m on top of the pipe), as this was more stable than the excavated subsoil. This layer was compacted lightly using wooden flats. Overall labour requirements for the installation of the composite system in the 14.4 ha block was 127 days/ha at a cost of Rs. 5200 to Rs. 5500 per ha (1999-2000 prices). Labour requirements per 100 m of drain line corresponded to the Segwa Pilot area, namely, 49.8 man-days per 100 m for Islampur-Devapur (Table 6) and 52.1 man-days per 100 m for Segwa (Table 5).
Table 6  Labour requirements for the manual installation of a composite pipe drainage system in 14.4 ha in Islampur-Devapur Pilot Area

<table>
<thead>
<tr>
<th>Activity</th>
<th>Labour input [man-days]</th>
<th>Labour requirement [man-days per 100 m of drain]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Men</td>
<td>Women</td>
</tr>
<tr>
<td><strong>Land clearing:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Collector line and outlets</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>- Field drain lines</td>
<td>75</td>
<td>75</td>
</tr>
<tr>
<td><strong>Installation:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Field drains (2890 m)</td>
<td>510</td>
<td>430</td>
</tr>
<tr>
<td>- Collector drains (782 m)</td>
<td>234</td>
<td>234</td>
</tr>
<tr>
<td><strong>Construction of outlets and manholes:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Mason</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>- Labour</td>
<td>60</td>
<td>50</td>
</tr>
<tr>
<td>Transport of pipes &amp; materials</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Watchman on site</td>
<td>90</td>
<td>90</td>
</tr>
<tr>
<td>Assistance to engineers (setting out levels etc.)</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td><strong>Miscellaneous</strong></td>
<td>30</td>
<td>50</td>
</tr>
<tr>
<td><strong>Grand Total</strong></td>
<td>1224</td>
<td>605</td>
</tr>
</tbody>
</table>

On average a male labourer could install 6 to 8 m of field drain (excavation, installation and backfill) per day and 4 to 5 m of collector drain. A couple (consisting of a female and male labourer) could install 9 to 11 m of field drains per day. The labour requirements doubled on rainy days.
Case Study - The Netherlands
Case Study - The Netherlands

1 Background

1.1 Historical developments

In the Netherlands, 25% of the land is below sea level and about 65% of it would be flooded where it not for the dykes (Figure 1). The climate is relatively mild with an average annual rainfall of about 750 mm and an annual evaporation of about 475 mm. The removal of excess rainfall in combination with the low elevation, the lowest area is 6.5 m below mean sea level, requires an intensive drainage system to keep one’s feet dry, both man and crops. The expansion of agriculture in the Netherlands started some 1000 years ago with a gradual change from shifting cultivation towards a more permanent development and occupation of the land. Farmers had to learn to organise themselves to mobilise enough labour and capital under evolving authorities: abbeys (1000-1200 AD), feudal rulers (1200-1500), locally organised groups (1300-1500) and water boards (1300-present). Moreover the water management was influenced by private or municipal land reclamation companies and peat mining companies (1500-1700), companies to drain and reclaim lakes (1500-1900), and governmental services to reclaim lakes, swamps and heath lands (1900-2000). Field drainage has always been the responsibility of the land user and the main drainage systems the responsibility of the above-mentioned institutions. Exceptions are the large-scale, government-supported, land reclamation and land consolidation projects in the second half of the 20th century: in these projects both the field and main drainage systems were implemented.

1.2 Large-scale reclamations in the 20th century

The generally felt need for better agricultural production conditions in the 20th century resulted in a number of government-financed, long-term programmes in which the construction of subsurface drainage systems was a significant part. Important programmes were the land reclamation programme in the former Zuiderzee area and the rural development programmes on the ‘old lands’, the so-called land consolidation projects. The public organisations involved in these programmes were the IJsselmeerpolders Development Authority (for the newly reclaimed areas) and the Government Service for Land and Water Use (for the “old lands”). Both organisations were multi-purpose organisations whose tasks included drainage installation. The IJsselmeerpolders Development Authority carried out most of the works themselves in forced account. The construction of drainage systems in the land consolidation projects was carried out by consultants and contractors under contract with Government Service for Land and Water.

1.3 Commonly used subsurface drainage system

In the Netherlands, subsurface drainage systems are used in almost all agricultural lands, except in the peat areas, where a high groundwater table is require to reduce subsidence and only shal-
low open drainage systems are used. The most commonly installed subsurface drainage system is a singular system with piped field drains discharging into open collector drains (Figure 2). The main function of the field drains is to control the watertable level. The corrugated plastic field drains ($\Phi$ 60 mm) are installed at a depth of 1.0 to 1.3 m. In fine or reduced (risk of ochre formation) soil layers, voluminous organic (coconut fibres) envelopes were used in the past, but they have been replaced by synthetic pre-wrapped envelopes. Depending on the drain depth and soil texture, installation is done by either trencher or trenchless drainage machines (Part I Figure 5.8). The discharge from the subsurface field drains and the surface runoff is removed by gravity through a system of open collector drains.

1.4 Present status of drainage in the Netherlands

As mentioned above, an intensive drainage programme was carried out in the Netherlands during the second part of the 20th century. In total some 750 000 ha in the “old lands” and 150 000 ha
In the new polders were equipped with subsurface drainage systems. Generally speaking all agricultural lands that require drainage have been provided with subsurface drainage, except the peat lands. The peat lands that are mainly used for pasture can only be superficially drained to avoid oxidation and the subsequent subsidence. Therefore these areas are only equipped with a shallow open drainage system that maintains water levels at around 0.5 m below the surface. Currently, most of the drainage installation in the Netherlands is replacement of defunct systems, improvements of drainage in case change of land use and drainage of urban and industrial sites.

2 Organisation of the water management

2.1 Water Boards

Water boards emerged in the 13th Century when land reclamation and protection against flooding became essential for survival. These water boards are an example of an effective and sustainable self-managed organisation for the construction, management and maintenance of dykes and drainage systems. Protection against floods and the agricultural development in many parts of the Netherlands was accomplished through cooperation among groups of landowners with a common interest in drainage, thus engaged in community undertakings to remove excess water from their holdings. These efforts eventually resulted in the creation of water boards. Within the water board organisation, the farmers and landowners are responsible for the local water management engineering works such as the smaller dykes, watercourses and roads.
Overall responsibility for proper water management throughout the country rests with the national government that exercises authority over the provinces. The national government, in the person of the Minister of Transport, Public Works and Water management, is responsible for water management affairs of national concern. This Ministry has its own executive body for this job: the Directorate General for Public Works and Water management. The local and regional responsibility for water management, as laid down in the constitution, rests with the water boards. The provincial governments supervise the work and the finances of the water boards: they set up and abolish water boards, determine the water management tasks to be undertaken by the water board, the area in which it will work, the composition of the governing body and how its members will be elected.

Traditionally, the tasks of the water boards in the Netherlands were:

- Flood protection;
- Conveyance and disposal of drainage water;
- Maintaining of agreed minimum and maximum water levels in the drainage system.

These tasks have now been extended to include water quality management, ecological management, water conservation and flood prevention. Nowadays, the water boards may be charged with the following tasks:

- **Water control:** providing protection against flooding by means of dunes, dykes and quays;
- **Water quantity:** managing the amount of water and ensuring that it is kept at the right level;
- **Water quality:** combating water pollution and improving the quality of surface waters;
- **Management of the inland water ways and roads.**

The role of the water boards as far as subsurface drainage is concerned is a normative and a controlling one. If a farmer or a group of farmers wants to install a subsurface drainage system they need to obtain permission from the water boards. An application for the installation of a subsurface drainage system is judged on the basis of the following criteria:

- The effect on the neighbouring areas;
- The discharge;
- The quality of the drainage water.

Water boards always had to serve the interests (= functions of water) of different groups. In the past, little conflict arose between agriculture and other sectors because the pressure on the land was not yet dominant. If any conflicts presented between agriculture and peat mining, for instance, an extensive jurisprudence offered a verdict most of the time. Potential conflicts between sub-sectors of agriculture over water management urged farmers to participate and de facto they became the only interest group represented in the water boards. During the 20th century, the parallel interdependency in drainage has grown considerably and water boards are now the arena of decision making on all functions of water, in which besides the farmers all concerned parties, like households, municipalities, industries, recreation and nature organisations have a say.
2.2 Government Service for Land and Water Use

The main task of the Government Service for Land and Water Use is the planning, preparation and supervision of the execution of land consolidation projects. These projects embody multiple aims: besides improving the production conditions for agriculture, they include the preservation and development of nature, improvement of living conditions in rural areas, and development of green belts around cities. Sectoral improvement of water management and a more rational arrangement of agriculture land use is part of the programme. Central to the objectives to improve the water management is meeting water control requirements for agriculture and nature areas. Adjustments have to be made to the groundwater level as both land use and drainage requirements change as years go by. Lowering the groundwater level is important in order to increase productivity when growing agricultural crops. In addition, it increases the load-bearing capacity of the soil to accommodate the heavier agricultural machines driven on the land, even during wet periods. Conversely, in certain areas where the soil is sensitive to drought, it may be necessary to maintain high groundwater levels in order to maximise crop growth, taking into account (adjacent) nature areas that usually require a higher groundwater level than the surrounding agricultural land. In a rural development project, both agriculture and nature interests are considered in the planning process. An appropriate water control system is designed for the project area to achieve the desired groundwater levels by means of fixed or moveable weirs, thereby ensuring the best possible water levels in the drainage system (Figure 3). The field drainage is usually improved by constructing a new subsurface drainage system or modifying the existing one, but it also includes enlarging watercourses and renovating existing pumping stations.

2.3 IJsselmeerpolders Development Authority

Initially, the IJsselmeerpolders Development Authority had no other task than to cultivate the newly reclaimed land. Over the years, its task has evolved from land reclamation primarily for agriculture, to an integrated development of agriculture, urban settlement, forests, recreational facilities and nature reserves. This experience has given the IJsselmeerpolders Development Authority worldwide recognition in the reclamation and development of new lands.

Reclamation Process
The first step in reclaiming land for the sea or lakes includes the construction of a ring dike, one or more pumping stations and the dredging of the main drainage channels to the pumping...
Figure 3 Fixed (a), adjustable (b) and movable (c) weirs are used to maintain the water level in the open drainage system at the desired level.
stations. After these works are completed, the water is pumped out of the new polder. Once the polder is drained, the land developers take over from the civil engineers. The tasks of the land developers are to prepare the new land for agriculture (Land Use Department) and to pave the way for further development (Urban Development Department and the Socio-Economic Development Department). The Land Use Department is responsible for the rural development and for the implementation of the works in the agricultural sector, including the land drainage systems, infrastructural works, rural roads and bridges, mechanised farming and afforestation. The next step is preparing the land for agriculture that starts with the aerial sowing of reed on the exposed mud flats. Reed speeds up the ripening process of soil with the result that the area becomes accessible on foot and at a later stage by vehicle. The third and final step is the progressive implementation of the field drainage system, an essential measure to further ripen the soil and to progressively transform the reclaimed area into agricultural land. The first field drains are open ditches usually spaced at intervals of 48 m. These ditches facilitate the drainage of surface water and the water in the surface layers. One year before cultivation starts, extra ditches are dug between existing ones at intervals of about 12 m. Finally, after a few years of cultivation, the ditches are replaced by subsurface drainage pipes (Figure 4).

Finally the drainage of the polders consists of the following elements:

- Open ditches that after some years were replaced by piped subsurface drainage;
- Open collector drains;
- Secondary drains;
- Primary drains;
- Pumping stations.

2.4 The Drainage industry

The activities in both the large land consolidation projects and the reclamation of the IJsselmeer polders prompted the development of modern mechanised drainage techniques. The need for efficient and reliable installation of pipe drains in large areas coupled with increasing labour cost and labour scarcity facilitated and gave an economic basis to the development of modern drainage trenchers and later trenchless drainage machines. The switch from the cumbersome heavy tile drains to the corrugated plastic drain pipes was made in the same period thanks to the development of the plastic industry and the large volumes of pipes required that made investment in development and production of machinery attractive. The development of pre-wrapped envelopes, first made of voluminous coconut fibres and later on of voluminous synthetic fibres, was prompted by the need for envelopes in most soils and the high price of gravel.

These developments were the result of a rather unique cooperation between the government services, the research departments of universities and of these government services, the machine building industry, the plastic industry, the land development companies and consultants. This cooperation resulted in:

- Modern drainage techniques that with adjustments are now applied world-wide;
- A specialised industry for the production of drainage machines;
Figure 4  Sequence of drainage measures during the reclamation of Southern Flevoland
• Specialised drainage contractors, and;
• A specialised industry for the production of drain pipes and accessories as well as pre-wrapped envelopes.

2.5 Drainage Contact Group

To enhance cooperation between the various partners involved in agricultural land drainage the so-called Drainage Contact Group was formed. This group organised study and extension meetings on a regular basis to ensure that all parties are kept up-to-date with the latest developments in the sector and that their interests were taken into consideration. While the initiative to organise these meetings came from (semi-) government organisations, farmers, manufacturers and consultant organisations also played an important role. During the meetings they had the opportunity to express their views on recent developments, new rules and regulations and discuss the difficulties encountered by the implementation. The (semi-) government organisations, on the other hand, could sound out the general feeling for proposed changes in the existing rules and regulations and got feedback on new developments. The Drainage Contact Group also played an important role in setting up applied research, and improving the quality of work and setting higher quality standards.

2.6 Research institutes

An important factor in the resources management system is the scientific knowledge complex, through which new and existing knowledge from research is disseminated via education, publications and extension services. This scientific knowledge complex (including drainage research) has changed considerably over the past decades as itemised below:

• The number of research institutes has been drastically reduced through successive rounds of mergers: for instance, in Wageningen, the main centre for agricultural research in the Netherlands, the seven research institutes and the departments of Wageningen Agricultural University involved in agricultural water management have merged into one Knowledge Centre under the umbrella of Wageningen University and Research Centre, of which Alterra-ILRI is part of;
• The same applies to the institutions for secondary and higher vocational training, which also have gone through a round of mergers and concentration;
• Research programmes have evolved from single-disciplinary research on basic plant-soil-water relationships to interdisciplinary research involving all aspects of the effects of interventions in the complex natural resources systems;
• The change from a government-sponsored and owned research complex in to a privatised organisation where research programmes have become demand driven instead;
• The integration of research and education and society as a whole. The introduction of demand-driven research has improved the representation of all stakeholders and reduced the accumulation of power (as knowledge is power) with only a few privileged groups left.
The mandate of Alterra-ILRI is to collect and disseminate knowledge for better and sustainable use of land and water resources. This includes the following tasks:

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

2.7 Farmers

As mentioned before, farmers always have been responsible for the installation of a subsurface drainage system on their land. A farmer who wants to install a system needs to obtain permission from the Government, in particular the water board. The water board will check whether the proposed system is in line with the current regional rules and regulations that, for example, stipulate that the system should not exceed the maximum permissible lowering of the water table, quantity and quality of drainage. Once permission has been obtained, the farmer will engage a drainage contractor. The drainage contractor guarantees that the drainage system is installed according to the Standard Rules and Regulations for the implementation of drainage works.

3 Drainage materials

3.1 Pipes

The diameter of the PVC corrugated pipes used for subsurface drains ranges between 50 and 200 mm. As the length of the field drains of the singular systems used in the Netherlands is most times limited to about 200 mm, pipes of 60 and 80 mm diameter are mainly used. Dimensions, quality criteria and testing methods are standardised, under the authority of the "Nederlands Normalisatie Instituut" (Netherlands Normalisation Institute). There are several standards available for drain pipes and envelopes (Table 1). Quality certification is done by an independent organisation: ‘Stichting voor Onderzoek, Beoordeling en Keuring van Materialen en Constructies/KOMO’ (Institute for Research, Judgement and Testing of Materials and Constructions).

<table>
<thead>
<tr>
<th>Standard</th>
<th>Subject</th>
</tr>
</thead>
<tbody>
<tr>
<td>NEN 7036</td>
<td>Corrugated unplastised PVC pipes for sub-soil drainage</td>
</tr>
<tr>
<td>NEN 7047</td>
<td>Wrapping material made of coconut fibre for land drainage pipes</td>
</tr>
<tr>
<td>NEN 7048</td>
<td>Wrapping material made of peat-fibre for land drainage pipes</td>
</tr>
<tr>
<td>NEN 7090</td>
<td>Wrapping material made of polypropylene fibres for land drainage pipes</td>
</tr>
</tbody>
</table>

Table 1   Netherlands standards for drain pipes and envelopes (in Dutch) a

a Nederlands Normalisatie Instituut, P.O. Box 5059, 2600 GB Delft, The Netherlands
3.2 Envelopes

Most of the soils in the Netherlands require an envelope. Apart from their hydraulic and filter function, envelopes are also useful in areas where the formation of iron ochre is likely to occur. The most widely used envelope materials were organic materials such as coconut and peat fibres, but they have been gradually replaced by voluminous envelopes made of polypropylene fibres. On a smaller scale, especially on sandy and loamy soils, thin synthetic envelopes are also used. Gravel envelopes are only used in exceptional cases, e.g. in urban and industrial sites and in areas where quick sand problems are encountered (Box 1), as gravel is scarce in the Netherlands and hence the supply and transport is very expensive. Similar to drain pipes, the composition, quality and testing methods are standardised (Table 1).

**Box 1 Planning the supply of gravel for subsurface drains in the Lauwerszee project area**

The planning of the gravel supply in a subsurface drainage area is illustrated by an example of the installation of subsurface drains in the Lauwerszee project area in the northern part of the Netherlands. Gravel was used because of the unique soil and hydrological conditions (quick sand) and the proposed land use (recreation and military training ground). The gravel had to be transported by ship to the project area over a rather long distance, more than 250 km (Figure 5). The gravel was a by-product of the gravel used for housing and road construction and its availability is limited. The supply rate of gravel was less than the amount needed during the period of drain installation. Therefore, a rather large amount of gravel had to be in kept in stock (Table 2 and Figure 6). The required amount of gravel was based on envelope of 40 cm of gravel around a drain of 200 m length. The amount of gravel required was 26 m³, namely, 9 loads of 3 m³ each drain. The calculation shows that at least 3600 m³ of gravel had to be in stock before the drain installation could start and that the supply had to start at least 12 weeks before the drain installation begins.

**Table 2 Calculation of amount of gravel needed in Sub-area no.5 Lauwerszee**

<table>
<thead>
<tr>
<th>Total drain length</th>
<th>60 km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average amount of gravel needed per km</td>
<td>100 m³</td>
</tr>
<tr>
<td>Total amount of gravel</td>
<td>6000 m³</td>
</tr>
<tr>
<td>Drain installation per week</td>
<td>7.5 km</td>
</tr>
<tr>
<td>Amount of gravel per week</td>
<td>750 m³</td>
</tr>
<tr>
<td>Supply of gravel per week</td>
<td>300 m³</td>
</tr>
<tr>
<td>Duration of drain installation</td>
<td>8 weeks</td>
</tr>
<tr>
<td>Duration of gravel supply</td>
<td>20 weeks</td>
</tr>
</tbody>
</table>

From the temporary storage the gravel was transported to the drainage machine in so-called dump-carts and via a gravel trailer with a conveyor belt into the container on the trench box of the drainage machine. The speed of the gravel trailer needed to be the same as the speed of the drainage machine, because stopping the drainage machine waiting for gravel supply had to be avoided, as this had a negative effect on the drain alignment. The total number of equipment needed and the time needed for the supply of gravel from temporary storage to the drainage machine is presented in Figure 7.

*Figures of box 1 on the next pages.*
Figure 5  The Lauwerszee project area and the location of the gravel supply site
Figure 6  Duration of gravel transport from the gravel pit to the project area

Figure 7  Schedule of activities of gravel supply equipment and duration
3.3 Structures

As was mentioned before, most subsurface drainage systems in the Netherlands are singular, thus only a limited number of structures are needed, mostly confined to special conditions, such as:

- Drain bridges, and;
- Manholes for flushing and control.

The other accessories for pipe drains are standardized:
- Couplings to connect pipes with the same and different diameters;
- T-joint and cross-joints;
- End caps;
- End chutes to avoid erosion of the banks of the collector drain (Figure 8).

![End chute to protect the side slope of the open collector drain against erosion](image)

Figure 8   End chute to protect the side slope of the open collector drain against erosion

4 Installation

4.1 Manual installation

Nowadays, manual installation of pipe drains is obsolete in the Netherlands, but in the first half of the 20th century, most drains were installed by hand. In that period a wealth of experience with manual installation was built up and realistic and precise standards for a large variety of conditions were developed. The amount of earthwork a labourer can handle varies considerably from place to place, mainly depending on the type of soil (Table 3). On average, digging a trench requires a labour input of about one labourer-day per metre per hour. A word of caution: in other countries, especially in the tropics, conditions are often much more difficult, so these figures serve only as a guideline.
Table 3 Guidelines for labour input earth movement using manual labour

<table>
<thead>
<tr>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work type</td>
</tr>
<tr>
<td>Labour input hours/m³</td>
</tr>
<tr>
<td>Sand Cl</td>
</tr>
<tr>
<td>Excavation, including loading the spoil in a wheelbarrow:</td>
</tr>
<tr>
<td>• Up to 0.75 m depth</td>
</tr>
<tr>
<td>• 1.0 - 1.5 m depth</td>
</tr>
</tbody>
</table>

4.2 Mechanical installation

Mechanized drain laying was introduced in the 1950s. Initially American wheel diggers were experimented with. These machines had a low production per hour and therefore soon chain digging machine were developed. The performance and the capacities of trenchers has been further improved and developed since then (Figure 9). A modern trencher with laser control can install 400 - 500 m of corrugated drain pipe (Ø 60 mm) per hour, at a depth of 1-1.4 m.

Figure 9 Development of drainage machines in The Netherlands
The use of trenchless drain techniques has expanded since the 1980s. Approximately 2/3 of lateral drains are installed by trenchless drainage machines. With trenchless installation 500 to 750 m of drain can be installed per hour. Large part of the agricultural land in the Netherlands is used as pasture. Trenchless drain installation is causing very little damage to the grass land. Moreover, installation costs are lower and the production is higher.

In newly reclaimed areas trenchers are preferred. Clay in the reclamation areas is highly saturated with water. Leaving the trench open for some time after digging will increase evaporation and the ripening process is accelerated. The trenchers are equipped with a knife at the trench box to scrape off a small portion of the ripened topsoil into the trench ("blinding") on top of the drain pipe (Figure 10).

Figure 10  Trencher operation in reclamation area with blinding knife at the trench box
5 Quality control

5.1 Certification

In The Netherlands, a system of certification has been set up for quality control of the drainage materials. The quality check of the production is carried out by an independent inspection institute. Manufacturers can participate on a voluntarily basis and if they do and their products constantly meet the quality standards they have the right to market their products as certified by the institute. To the implementation authority this quality certificate means a guarantee of the quality of the product. The manufacturers are obliged to check the quality of their products continuously and the results are entered in a logbook. An inspector from the inspection institute visits the manufacturing plants about 6 times a year. These visits are unexpected and irregular. During these visits the inspector makes random checks of the production quality, and compares the results with those in the logbook. As the visits are unexpected, the manufacturer needs to ensure that the quality is good at all times. The cost of this certification system amounts to about 0.5% of total drainage costs. Nowadays, these standards include an internal quality control system based on the international standard ISO 9000-series.

5.2 Organisation of Quality Control

In large-scale drainage projects (100 - 1000 km of drains) the (semi-) government organisations usually commissions the implementation works. The work is put out to tender and carried out according to specifications that also include the quality standards. Certification is the most appropriate way of guaranteeing that the materials are up to standard. Checking the workmanship by means of rodding or continuous depth recording is also be specified on the basis of random checks. If errors are detected in the random checks the intensity of the random checks is increased according to fixed rules. The consulting company in charge of supervision of the work normally does these checks. An indication of the cost involved based on experiences in the Netherlands is presented in Table 4.

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost of checking all drains (%)</th>
<th>Intensity of random checks (%)</th>
<th>Cost of random check (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Certification of materials</td>
<td>0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rodding</td>
<td>6</td>
<td>15</td>
<td>0.9</td>
</tr>
<tr>
<td>Continuous depth recording</td>
<td>50</td>
<td>3</td>
<td>1.5</td>
</tr>
<tr>
<td>All three methods</td>
<td></td>
<td></td>
<td>3</td>
</tr>
</tbody>
</table>

* Excluding cost of internal quality control by manufacturer.
In small-scale projects commissioned by private farmers (2.5 and 10 km of drain), the tender documents normally do not include rules and regulations concerning the quality of the work. This may result in poor quality work. To improve the quality the Government Service for Land and Water Use issued a model for a standard contract for private drainage works in 1984. This standard contract contains the quality control methods discussed above. In another development, the farmers’ and drainage contractors’ organisations decided in 1987 - on the farmers’ initiative - to establish a foundation to improve the quality of drainage work. The procedure is more or less analogous to the procedure for certification of materials discussed above. Contractors have their work supervised by this foundation and if their work is up to standard they receive a certificate. The cost of this system comes to about 2% of drainage costs. The possibility to apply this system in the whole of the Netherlands is being studied.
Case Study - Pakistan
Case Study Pakistan

1 Background

Waterlogging and salinity is a serious threat to irrigated agriculture in Pakistan: of the 16.7 million ha in the Indus Basin about 2 million ha are waterlogged and 6 million ha salt affected. The major parts of the irrigated areas in Pakistan where drainage is needed have little slope. Therefore the disposal of the drainage effluent by gravity is in general not possible. The standard subsurface drainage system is a composite system, with buried field and collector drains. Sumps are used to pump the drainage water from several collector drains in open main drains. Figure 1 shows the location of the major pipe drainage projects in Pakistan.
PART III - CASE STUDIES

2 Organisation

2.1 Historical developments

Drainage in Pakistan is generally executed within the canal irrigation commands. In 1958, the Water and Power Development Authority (WAPDA) was established as the agency responsible for the coordination of design, construction and initial operation of the engineering works. After decades of irrigation development, the enormous protective irrigation systems of Pakistan began to experience problems with rising groundwater tables caused by inefficient water delivery systems and inequitable water distribution. In the 1960's WAPDA launched some 51 Salinity Control and Land Reclamation projects (SCARP's) to provide vertical drainage to combat these problems. The SCARP projects were initiated with loans from the World Bank. WAPDA was responsible for the design, construction and initial operation and monitoring of these deep tubewell projects, after which the Provincial Irrigation Departments (PID's) took over operation and maintenance.

As the drainage fees cover only around 20% of the actual expenses of O&M, the financial burden to operate and maintain the public tubewell systems became gradually too much for the PID’s. These problems were aggravated because the life expectancy of most SCARP’s proved to be less than half the expected life time. To overcome these problems, the irrigation and drainage sector was reformed and in 1997 Provincial Irrigation and Drainage Authorities (PIDA’s) were established in all four provinces. System management is to be decentralised and farmers are to take part in the system development and to take over O & M. This is realised by the creation of Area Water Boards (AWB’s) and Farmer Organisations (FO’s). PIDA’s facilitate and promote the formation of AWB’s, which compose of farmers, government and PIDA representatives. AWB’s on its turn facilitate and promote the formation of FO’s. The PIDA’s are responsible for the planning, construction, operation and maintenance of the system at main and secondary level. At tertiary level, the FO’s are responsible for O & M of the system. All these organisations have to become financial autonomous by levying water charges and drainage fees. The establishment of FO’s and AWB’s is however hampered by (i) a lack of farmers’ involvement in policy reforms; (ii) the weak legal framework (the PIDA Acts) to implement reforms; (iii) lack of knowledge within the FO’s and AWB’s to develop and implement strategies to deal with the systems’ problems and (iv) to make the shift from engineering to institutional solutions.

2.2 International Waterlogging and Salinity Research Institute

To counteract the waterlogging and salinity problems, the Ministry of Water and Power, under the umbrella of WAPDA, and with the assistance of the UN, established the International Waterlogging and Salinity Research Institute/IWASRI, in Lahore, Punjab in 1985. The overall objectives of IWASRI are to co-ordinate and to conduct research on waterlogging and salinity in Pakistan. Over the years IWASRI’s mandate has evolved but its intentions and functions have largely remained the same. End-users of IWASRI’s research include farmers, planners and designers, policy makers, national research institutes and the drainage industry.
To assist IWASRI, The Governments of Pakistan and The Netherlands in 1988 initiated the Netherlands Research Assistance Project/NRAP, a collaboration between IWASRI and Altera-ILRI. The main aim of NRAP, which covered the period 1988-2000, was to conduct a multidisciplinary research programme on waterlogging and salinity with special attention to drainage engineering, groundwater hydrology and land reclamation. In the second phase of the project, the development of a participatory approach to drainage was included. The project yielded valuable results in the following fields:

- **Technical lessons learned**, in particular: (i) design criteria for gravel and synthetic envelope materials; (ii) drainage design with computer simulations; (iii) drainage design criteria; (iv) salinity measurements by magnetic induction; (v) interceptor drainage; (vi) groundwater approach to drainage design; (vii) operation and maintenance of drainage systems (viii) benefits of shallow drainage, and (ix) the use of poor quality water for crop production and reclamation;
- **Participatory drainage development**: lessons learned on development and implementation of Bahawalnagar Subsurface Drainage Pilot Area (112 ha) in the Fordwah Eastern Sadiqia Irrigation and Drainage Project;
- **Institutional development**, including capacity building at ISWARI, through training and the execution and dissemination of research.

### 2.3 Implementation of subsurface drainage projects

Most subsurface drainage works are implemented on the project basis. For each project a consortium is formed under the authority of WAPA. Such a consortium normally consists of a private (most times foreign) or public contractor and a consulting engineering firm (both local and foreign) to assist with the design and supervision. Salient features of some major projects are discussed in Chapter 5.

### 3 Drainage materials

**Field drains**

In Pakistan, corrugated perforated PVC pipes are used for subsurface field drains. As the hydraulic conductivity of the soil is relatively high (e.g., in Mardan Scarp in the Northwest Frontier Province the hydraulic conductivity ranges between 1 and 3 m/d), the spacing between field drains is large and consequently the pipe diameters are rather big (> 100 mm, Table 1).
Table 1  Materials used in some major drainage projects in Pakistan

<table>
<thead>
<tr>
<th>Project</th>
<th>EKTDP  a</th>
<th>FDP  b</th>
<th>Mardan</th>
<th>Khusab</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size of the unit</td>
<td>280 - 450 ha</td>
<td>380 - 400 ha</td>
<td>100 - 300 ha</td>
<td>100 &amp; 150 mm PVC pipe</td>
</tr>
<tr>
<td>Field drains</td>
<td>100 mm corrugated PVC pipe</td>
<td>100 - 200 mm PVC pipe</td>
<td>100 mm PVC pipe</td>
<td>Gravel mainly but for some collectors</td>
</tr>
<tr>
<td>Envelope</td>
<td>Gravel</td>
<td>Natural river run gravel with Hydraulic Conductivity &gt;15 m/d</td>
<td>Mainly gravel but for some collectors with synthetic fabric envelope was used</td>
<td>Synthetic envelope was used on one sump</td>
</tr>
<tr>
<td>Collector drains</td>
<td>Perforated 250 - 375 mm PVC pipes</td>
<td>Perforated 100, 150, 188, 250 &amp; 300 mm PVC pipe</td>
<td>Outflow was by gravity and therefore no Sump required</td>
<td>100, 150, 200, 250, 300 &amp; 380 mm PVC pipe</td>
</tr>
<tr>
<td>Sumps</td>
<td>Pumps provided</td>
<td>79 numbers circular 3.05 m diameter masonry well on RCC base slab. One to three pumps of each 2.25 cfs capacity</td>
<td>Total 56 sumps. 45 circular and 11 rectangular</td>
<td></td>
</tr>
</tbody>
</table>

a  East Khairpur Tile Drainage Project, Sindh Province  
b  Fourth Drainage Projects, Faisalabad, Punjab Province

Collector drains

In the first major subsurface drainage project, EKTDP, concrete pipes were used as collectors but their installation under the prevailing high water table and unstable subsoil conditions proved to be extremely difficult and the work progressed slowly. The concrete collector drains did not always perform well due to dislocation of the pipes. Therefore, perforated large diameter PE pipes with gravel envelope were installed in the remaining part of the EKTDP project. In all the following projects, perforated plastic PVC pipes are being used. Nowadays, plastic T-joints are used to connect the field and collector drains (Figure 2).

Envelopes

Most soils in Pakistan are fine-textured (silty loam, sandy loam, silty clay etc.) and require an envelope material. No well-established criteria to determine the need and type of envelope existed, mainly gravel envelopes were installed (Table 1) generally based on design criteria developed in the USA (USBR, SCS and others). Serious problems occurred with the crushed rock envelope at the FDP although it was designed according to the specifications (Chapter 5.4). River-run gravel envelopes (having rounded particles) of the same specifications performed better, stressing the need for local verification of these rather site-specific criteria.
Figure 2 Before the field drains are installed, the field drain is connected to the collector drain using a plastic T-joint

Sumps
Sumps are provided for the collection of effluent from the collectors. These sumps are generally a circular brick masonry structure, with a depth of 5 to 7 m (15 to 20 feet) below the soil surface. One to three pumps are installed in a sump for the evacuation of drainage effluent to the surface drain. Electric sensors are provided for automatic operation of the pumps.

4 Installation

Dewatering
Subsurface pipe drains are generally installed when the groundwater table is high. Moreover, in large areas the soil conditions are such that the subsoil is unstable. Therefore, before the construction at a particular unit starts, the contractor will install dewatering equipment (vertical well pointing) and diesel pumps to dewater the site of the sump. The sump is constructed before laying the collector and field drains. Dewatering of the sump starts immediately when the installation of the collector starts. Diesel pumps are also operated to dewater the sites where connections between field drains and collector are made.

Installation of Gravel Envelopes
As the field drains have a comparatively large diameter (Chapter 1.3) it was observed that gravel was not laid uniformly around the pipe in the earlier projects. Therefore, a modification was made in the trench box with an addition of auger which was moving around the pipe below the gravel box feeder (Figure 3). The speed of the gravel auger is automatically adjusted to the speed of the trencher during drain installation. This modification was first time introduced in Fourth Drainage Project and subsequently in the Chashma Command Development (CCAR) (Chapter 5.3) and
the Fordwah Eastern Sadiqia South (FESS) projects. The results were encouraging and gravel was laid comparatively uniformly.

Installation of Deep Collector Drains
In the Fourth Drainage Project, drain spacing is wide and consequently the collector drains are very deep, up to 4 m below the ground surface, especially at the downstream sections near the sumps. It was not possible for the trencher to lay the collector drains at that depth. For these particular sections, the top layer of about 0.30 m was scraped away from alignment of collector drain.
Trench Backfill and Pipe Stretch
In several projects, sink holes appeared after the installation of drains. The reasons were that, although the consolidation of the top layer was reasonably good after backfill, the conditions immediately above the drain pipe were poor and did not improve in time. This was because:

- Consolidation of the backfill on top of the drain pipe in semi-saturated conditions was not possible, as no equipment would go deeper than 1.5 m;
- Just after installation, the trench often collapsed resulting in large humps of soil on top of the drain pipe leaving big voids.

The sink holes appeared as the result of piping after irrigation and rainfall events. Sink holes appeared even after two to three years after construction especially when the trench backfill had not been exposed to irrigation and/or a heavy rainfall event which are needed to consolidate the trench properly.

Sink holes damaged or misplaced pipe couplings and gravel envelopes. To reduce the risks of sink holes, excessive gradients were avoided by reducing pumping from the sumps during construction. Pumping was resumed only after trench backfill has been exposed to one cropping season irrigation and/or to a heavy rainfall event. Furthermore, additional measures like rollers (Figure 4), puddling, extra soil, blinding, slow water table draw down and deep tillage were used to overcome this problem.

Figure 4
Rollers to compact the backfill were used in the Mardan SCARP project: (a) site view; (b) detail roller and (c) rear view.
5 Salient features of some large-scale drainage projects

5.1 East Khaipur Tile Drainage Project

East Khaipur Tile Drainage Project (EKTDP) was the first major subsurface drainage project to combat waterlogging and salinity in Pakistan. This World Bank-financed project covered 18,000 ha in the Sindh Province, of which 14,000 ha were provided with subsurface drainage systems. The subsurface drainage system of a unit (varying in size between 280 and 450 ha) consists of plastic field drains, concrete collector drains and a sump through which the excess drainage water is pumped into a shallow open main drain. The project execution started in 1981 and was completed in 1986.

Figure 5  Dewatering of collector drain section, (a) horizontal dewatering by diesel pumps (b) and installation of concrete collector pipes (c) in the EKTDP project area

PART III - CASE STUDIES

The corrugated PVC field drains (Ø 100 mm) were manufactured in Pakistan and were installed at an average depth of 1.8 m with an average spacing of 115 m (range between 50 and 175 m). All field drains were installed with a trench drainage machine and provided with a gravel envelope (0.1 m³/m). The concrete collector pipes were manufactured also locally but within the project area. The diameters ranged between 230 and 460 mm and the maximum installation depth at the outlet was 3 m. Installation was done by a hydraulic excavator after previous dewatering.

The total installation cost, excluding extra and indirect costs, was about € 1183/ha at 1981 prices (Table 2). The extra and indirect costs totalled 44%; i.e. contingencies (10%), contractor’s overhead (10%), contractor’s profit & risk (10%), foreign technicians (2%), supervision and accounting (5%) and crop compensation for farmers (7%).

Table 2  Cost of subsurface drainage system in EKTDP (1981 prices)

<table>
<thead>
<tr>
<th></th>
<th>Cost</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(€ per m of drain)</td>
<td>(€ per ha)</td>
</tr>
<tr>
<td>Field drains:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pipe material (ex factory)</td>
<td>2.25</td>
<td></td>
</tr>
<tr>
<td>Transport of pipes to site</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td>Gravel filter including transport</td>
<td>1.95</td>
<td></td>
</tr>
<tr>
<td>Installation pipe &amp; gravel</td>
<td>0.95</td>
<td></td>
</tr>
<tr>
<td>Land clearing and backfill</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td>Repair of crossings with roads, canals, etc.</td>
<td>0.25</td>
<td></td>
</tr>
<tr>
<td>Transport of equipment</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td>Sub-total field drains</td>
<td>5.74</td>
<td>603</td>
</tr>
<tr>
<td>Collector drains:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dewatering</td>
<td>13.30</td>
<td></td>
</tr>
<tr>
<td>Concrete pipes</td>
<td>5.75</td>
<td></td>
</tr>
<tr>
<td>Transport</td>
<td>1.60</td>
<td></td>
</tr>
<tr>
<td>Excavation, installation and backfill</td>
<td>7.05</td>
<td></td>
</tr>
<tr>
<td>Land clearing and levelling</td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>Sub-total collector drains</td>
<td>28.20</td>
<td>412</td>
</tr>
<tr>
<td>Manholes (connections field - collector drains)</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Sumps and pumping stations</td>
<td>43</td>
<td></td>
</tr>
<tr>
<td>Open main drains:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Excavation</td>
<td>12.00</td>
<td></td>
</tr>
<tr>
<td>- Structures</td>
<td>20.00</td>
<td></td>
</tr>
<tr>
<td>Sub-total open drains</td>
<td>32.00</td>
<td>106</td>
</tr>
<tr>
<td>Total per hectare</td>
<td>1,183</td>
<td></td>
</tr>
</tbody>
</table>
Lessons learned
The installation of the concrete collector drain pipes was a cumbersome and costly job. Prior to the installation of the collector pipes sections of the collector line had to be dewatered by horizontal dewatering and some sections even by vertical well pointing due to the unstable soil conditions in the area. It became clear after the installation and operation of a number of collector units that the performance of the concrete collector drain pipes was unsatisfactory. The unstable subsoil caused dislocation of the concrete pipes, sink holes appeared, and costly repairs were necessary. So, it was decided to install large diameter perforated PE pipes with a gravel envelope in the remaining collector units (Figure 6). The PE pipes had to be imported, as large diameter PE or PVC pipes were not yet locally made. The installation and performance of the PE collector drain pipes proved to be successful in unstable soil. So, in unstable subsoil no concrete drain pipes are to be used but only perforated collector drain pipes with envelope material.

5.2 Mardan Salinity Control and Reclamation Project

The Mardan Salinity Control and Reclamation Project encompasses 52 000 ha of the Lower Swat Canal Command in the Northwest Frontier Province, of which about 30 000 ha were provided with subsurface drainage. The project was funded by the Governments of Pakistan and Canada through a World Bank loan and a Canadian International Development Agency (CIDA) grant. The project was carried out under a general agreement for consulting engineering services between WAPDA (representing the owners) and two associated Canadian and Pakistan Engineering Companies (Engineer). Actual implemented was done under contract; the first contract utilized Canadian contracting practices, while the second followed an international contracting format. The overall project consisted of an extensive program of civil works, including the construction of surface and subsurface drainage, irrigation canal remodelling, road improvements, land level-

Figure 6  Installation of large diameter perforated corrugated PE collector drain pipe with gravel envelope
The project started in 1987 and was completed in 1991. The main activities and players in the implementation of the subsurface drainage systems are presented in Table 3. Prior to the installation of subsurface drainage the area had relatively high water tables: pre-drainage water tables fluctuated between 0.3 and 1.2 m.

Table 3  Main activities and responsible actors in the implementation of MARDAN SCARP

<table>
<thead>
<tr>
<th>Activity</th>
<th>Responsible actor/player</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Pre-construction:</strong></td>
<td></td>
</tr>
<tr>
<td>1.1 Acquisition of construction access</td>
<td>Owner</td>
</tr>
<tr>
<td>1.2 Drain layout surveys</td>
<td>Contractor</td>
</tr>
<tr>
<td>1.3 Layout adjustment (if required)</td>
<td>Engineer</td>
</tr>
<tr>
<td>1.4 Certification of layouts</td>
<td>Engineer</td>
</tr>
<tr>
<td>1.5 Control of irrigation water</td>
<td>Owner - Irrigation Department</td>
</tr>
<tr>
<td>1.6 Supply of drain pipes</td>
<td>Owner</td>
</tr>
<tr>
<td>1.7 Supply of gravel envelope</td>
<td>Owner</td>
</tr>
<tr>
<td><strong>2. Construction:</strong></td>
<td></td>
</tr>
<tr>
<td>2.1 Site stockpiling drain pipes and gravel envelope materials</td>
<td>Contractor</td>
</tr>
<tr>
<td>2.2 Clearing trees from drain lines</td>
<td>Contractor</td>
</tr>
<tr>
<td>2.3 Smooth and prepare right of way for installation</td>
<td>Contractor</td>
</tr>
<tr>
<td>2.4 Installation of drain pipes and gravel envelope</td>
<td>Contractor</td>
</tr>
<tr>
<td>2.5 Restoration of disturbed lands and water canals</td>
<td>Contractor</td>
</tr>
<tr>
<td>2.6 Construction of related structure, i.e. outlets, culverts, manholes, etc.</td>
<td>Contractor</td>
</tr>
<tr>
<td>2.7 Inspection of all works to verify construction in accordance with contract</td>
<td>Engineer</td>
</tr>
<tr>
<td><strong>3. Post-construction:</strong></td>
<td></td>
</tr>
<tr>
<td>3.1 Measurement of all installed items</td>
<td>Engineer</td>
</tr>
<tr>
<td>3.2 Invoice for interim payments</td>
<td>Contractor</td>
</tr>
<tr>
<td>3.3 Check of all measurements (3.1) and certify invoices for payment</td>
<td>Engineer</td>
</tr>
<tr>
<td>3.4 Approve and payment of contract invoices</td>
<td>Owner</td>
</tr>
</tbody>
</table>

**Drainage Materials**

Corrugated PVC pipes were used for both the field and collector drains, varying in size from 100 to 300 mm. Gravel envelopes were used for the field drains and a thin synthetic envelope for the collector drains. The gravity system had relatively deep field drains (1.8 - 2.0 m) resulting in wide spacing (> 100 m) and very deep collectors (up to 3 m).
Equipment

For the installation of the field drains (Ø 100 mm) two types of drainage machines were used:

- A trenchless plough: a double roller, imaginary hitch-point type with gravel box and drain pipe chute mounted on a crawler tractor (410 HP). Due to the traction conditions, tow services of an additional crawler tractor (300 HP) were normally required (Figure 7);
- A chain-type trencher.

For the installation of the collector drains (Ø 160 - 300 mm) two chain-type trenchers with gravel box and pipe chute were used. Under wet ground conditions a crawler-type tow tractor had to be used to provide extra power.

All these machines were equipped with laser controlled hydraulic systems. The average rate of drain pipe installation varied from 2,500 m/day for the field drainage machines and 540 m/day for the collector drainage machines.

Quality control during installation

As poor construction quality was regarded as one of the main causes of drain failure, an intensive inspection routine was pursued. The inspection team, which included a survey team, undertook the following activities:

- Grade inspection at 30 m intervals along the installed field and collector lines. Although all the drainage machines were laser controlled, numerous deviations were observed mainly due to the response time required for the adjustment of the trench box and to a less extent due to adjustment of the laser and system control linkages;
• Visual inspection of the pipe couplings, end caps either on the surface (pipe couplings and end caps) or in excavations (field· collector drain couplings, see Figure 2);
• In the second contract, inspection also included the pulling of a ball (with a diameter 12.5 mm less than the diameter of the pipe) through the line to check for loose couplings and deformed (compressed) pipe sections;
• In-situ measurements of the thickness of the graded gravel in inspection pits.

Jointly procedures and measurements between the Engineer and the Contractor were introduced, although not contractually required, to minimize later disputes.

Lessons learned
Some of the major lessons learned during the installation of subsurface drainage in the Mardan SCARP are:
• Discontinuation of irrigation a few days before and during installation is required to obtain sufficient grip for the drainage machines;
• In areas that are intensively cropped and have many (small) farm holdings, a good coordination between the landowners, farmers, contractor and engineer is essential for a smooth work process;
• Frequent and jointly organised (between the contractor and the engineer) inspections are essential to ensure good quality installation practices;
• Specifications of construction requirements, inspection procedures, etc. have to fully and carefully define the requirements of the works. They must also address any unique problems that are likely to be encountered during the work. Again these specifications should be developed in close cooperation between the consultant and the contractor.

Effects of the subsurface drainage system
The waterlogged conditions reduced considerably after the project was completed: a monitoring programme revealed that the post drainage watertable fluctuates between 1.2 and 2.5 m, compared to a pre-drainage fluctuation between 0.3 and 1.2 m.

5.3 Chashma Command Area Development Project

The Chashma Command Area Development (CCAD) Project encompasses about 60 000 ha served by the Chashma Right Bank Canal (CRB) in the Dera Ismail Khan District of the Northwest Frontier Province. Three types of subsurface drainage were installed to combat the waterlogging and salinity problems:
• Interceptor drains along an unlined section of the CRB Canal in the upstream part of the project area (7 700 ha);
• Subsurface pipe drainage systems in the middle section of the project area (29 000 ha), and;
• Surface drainage in combination with subsurface drainage in the perched watertable zones in the downstream section of the command (23 000 ha).
Organisation
The executing agency was the Water and Power Development Authority and an international consultant consortium served as consultants during the implementation. The project was financed by the Asian Development Bank using international competitive bidding with pre-qualified contractors. Three contractors tendered for the job and the tender was awarded to the 2nd lowest bidder as the lowest bidder was declared non-responsive. The project started in 1985 and was completed in 1995.

Subsurface drainage system
The subsurface drainage system consists of locally produced PVC corrugated field and collector drains of 150, 200, 250, 300 and 350 mm diameter. The field drains were installed at a minimum depth of 1.70 m and 610 m spacing, only in the fine-textured soils of the downstream part spacings of 200 to 300 m were used. A river-run gravel envelope (thickness 100 mm), based on Soil Conservation Services (SCS) criteria, was placed around the drains. The collector drains convey the water into a circular reinforced brick masonry sump (Ø 3.0 & 3.6 m, with a 7.7 m depth) form where the water was pumped in to a disposal drain using electric pumps.

Equipment
A specially designed drainage trencher was purchased: with a 464 horsepower Caterpillar, hydraulic motor-driven gravel compacting screw, wide tracks, a track-mounted gravel feeder and laser control. Track-mounted feeders and trailers with float tyres for maximum bearing were used to transport the gravel to the drainage machine (Figure 8). The manufacturer provided the contractor an experienced expatriate trenching machine operator for in-service training of local machine operators.

Figure 8    Track-mounted gravel feeders and gravel trailers with float tyres for maximum bearing were used in the Chashma CAD Project
The equipment suffered excessive wear and tear due to the extremely wet conditions. The digging chains and allied parts of the trencher machine wore very rapidly due to the abrasive action of sand. Replacement of these digging chains in the CCAD project was eight times more than for similar projects in Pakistan: after digging 3.5 - 4 km of trench in the CCAD project area compared to e.g. 30 km of trench in Nawabshah. Another reason for this was the contractor’s procurement of locally manufactured chains. Replacement of a digging chain costs 2 working days.

Lessons learned

- Because of the emergency from flooding and the resulting local pressure on the Government to initiate the works, a feasibility study was not conducted and the project was commissioned based on the limited available information. Investigations, surveys and designs were only carried out after the project execution started. This resulted in many changes of the original plans. Although this delayed the project for several months, millions of rupees were saved that would otherwise have been wasted on unnecessary drains if the project had been in its original scope;
- Contracts also started without adequate surveys, acquisition of land rights, or complete plans and specifications, seriously hampering the construction activities later on;
- The surveys of the large area were very time consuming and were not always very accurate. This resulted in poor quality base maps and unreliable topographical maps;
- The deep installation depth of the drain caused frequent breakdowns of the trencher, excessive dewatering efforts and slow installation rates. These problems were rectified only after the design was revised to reduce depth of drains by splitting the larger sump units to smaller ones (170 - 250 ha);
- The initial implementation schedule developed by the Engineer was not realistic: time required to import equipment, the assembly and adjustment to local soil conditions should have been included;
- A visit of the manufacturer of the trencher to the site at a early stage in the project resulted in valuable modifications to the equipment to make them more suitable for the local conditions, e.g. wider tracks and the introduction of the power auger for the gravel placement;
- The supply of gravel under the wet conditions encountered in the project area was problematic: although the trencher with its wide tracks performed satisfactorily, the performance of the auxiliary equipment like gravel trailers and excavators was poor. The option to use a much lighter synthetic envelope instead of gravel should be considered under such wet conditions;
- The contract was awarded to the second lowest bidder, although this bid was considerable lower than the highest. During construction the contractor who was awarded the job always complained of heavy financial losses and had constant difficulties to make sufficient funds available to procure sufficient materials and auxiliary equipment, resulting in many delays. The contractor who submitted the highest bid had gained experience in similar projects (Mardan SCARP) and should probably have completed the project in time. Thus in contracts requiring specialized services, the bidder’s experience in similar works should also be weighed during the tender evaluation.
• A monitoring programme, in particular on watertables (and soil salinity) should be initiated at the start of the project and continue afterwards to assess the benefits of drainage.

5.4 Fourth Drainage project

The Fourth Drainage project (FDP) located in the Faisalabad District of the Punjab included the installation of subsurface drainage in an area of 31,500 ha. The project was launched by WAPDA in 1984 and only completed after many delays in June 1994. One of the main problems faced was due to the use of crushed gravel as envelope. The subsurface drainage system consists of corrugated plastic (PVC) field (Ø 100, 150 & 200 mm) and collector (Ø 250, 300 & 375 mm) drains. The design specifications, which were based on the United Stated Bureau of Reclamation (USBR) criteria, specified that well-graded gravel with a minimum thickness of 100 mm should be placed around all field and collector pipe drains. The contract stated that “the envelope material shall consist of a uniform well graded mixture of sand and gravel. It should be sound, stable, clear, free of vegetable matter, clay and other deleterious matter. The minimum hydraulic conductivity of the envelope shall be 50 ft. per day (15 m/d)”. Normally river-run gravel is used in Pakistan, but because river-run gravel was not available in the vicinity of the FDP area, the use of crushed gravel was proposed by the contractor and accepted by the engineer. Soon after installation started it became clear that the drain lines for which the crushed gravel was used did not perform satisfactorily: drain pipes were choked by soil that had entered the pipe. The execution was stopped to investigate the cause of the problem. Drains were excavated and it was discovered that a lot of fine soil had moved into the drains (Figure 9). Subsequent laboratory tests revealed that the hydraulic conductivity of the crushed gravel (> 900 m/d) was much higher than river-run gravel (75 - 250 m/d) of the same gradation. It was concluded that the resulting higher hydraulic gradient had allowed the finer soil particles to enter the pipe.

Figure 9 Fourth Drainage Project: excavations revealed that the drain pipes were blocked by fine sediments
Following these field and laboratory tests, the designers reviewed the specifications and, although the gravel gradation was kept according to its previous graduation, it was decided that only river-run material should be used. Different quarries were visited and gravel samples were collected for laboratory and field tests. After these tests proved to be successful three new quarry sites were selected and the use of river-run gravel was specified for the remaining part of the contract. The consequences on the project implementation process were that:

- The temporary stoppage of the execution delayed the project by about 5 months;
- The cost of gravel increased about 3 times due to the longer haulage distance.

Lessons learned
The main lesson learned from this experience is that specifications based on knowledge that was developed elsewhere (in this case the USBR criteria) should be locally verified during the project's preparation phase.
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**Bibliography**

**Drainage of clay soils**


This bulletin discusses the drainage of clay soils. The book starts with a discussion of the physical and chemical properties of clay soils, the movement of water and salts in these soils and then reviews the techniques to drain and reclaim heavy clay soils. Case studies of drainage of heavy clay soils in Yugoslavia, Portugal, Spain and Egypt are included.

**Drainage design**


This volume on open drainage channels consists of two parts: Part I is devoted to a general review of the design aspects of open drainage channels: system lay-out, design capacity, channel shape, roughness coefficient, permissible channel velocity, longitudinal channel slope, side slope; Part II contains the country reports of Australia, Bangladesh, Canada, Colombia, Czechoslovakia, Egypt, France, Federal Republic of Germany, German Democratic Republic, Great Britain, Greece, India, Iraq, Ireland, Japan, Malaysia, Morocco, Portugal, Saudi Arabia, Sudan, and the U.S.A.


This manual, which is based on an expert consultation, gives 28 questions and answers regarding drainage design factors.


The manual contains the engineering tools and concepts that have proven useful in planning, constructing, and maintaining drainage systems for successful long-term irrigation projects. Although the manual is not a textbook, it provides drainage engineering with a ready reference and guide for making accurate estimates of drainage requirements. All the methods and techniques covered in the manual have proven to be very satisfactory through observed field conditions on irrigated lands in the USA but also in other parts of the world.

**Drainage guidelines**


This paper provides research results for and experiences with agricultural drainage and related subjects. It has been developed to guide Bank staff, consultants, and borro-
wing-country technicians as they work through the project cycle, seeking to assist planners and designers, as well as those responsible for implementation and follow-up, when projects involve drainage measure.

These guidelines give general criteria and recommendations for the construction of horizontal subsurface drainage systems. The book starts with an inventory of subsurface drainage systems and then briefly reviews design aspects. It gives attention to drainage materials and to equipment to install the drains. It then recommends construction methods, and describes operation and maintenance. Finally, it treats the cost benefit analysis of projects. Includes a glossary.

This publication covers the historical, technological, economic, and environmental aspects of agricultural drainage in the USA. The main purpose is to review the evolution of modern farm drainage and to identify farm drainage objectives for agricultural extension specialists and agents, environmental specialists, drainage consultants, installation contractors, and educators. Farm production, water management, and other benefits and costs associated with the drainage of wet soils on farms are described within the context of existing USDA programs and other Federal policies for protecting wetlands. The publication, which draws from the combined knowledge of academic and USDA professionals, covers subjects: 1) A framework for future farm drainage policy: the environmental and economic setting; 2) A history of drainage and drainage methods; 3) Advances in drainage technology: 1955-85; 4) Purposes and benefits of drainage; 5) Preserving environmental values; 6) Principles of drainage; 7) Drainage system elements; 8) Planning farm and project drainage; 9) Drainage for irrigation: managing soil salinity and drain-water quality; 10) Drainage institutions; 11) Economic survey of farm drainage; 12) Drainage potential and information needs, and; 13) Drainage challenges and opportunities.

Gives guidelines for the main text of a feasibility study, which provides the answers to questions that might be raised in the course of project appraisal.

Drainage materials

The book is a compilation of the most recent information on how to design and select envelope materials for agricultural drains. It is especially valuable for drainage engin-
eers, contractors, drainage equipment manufacturers, students, teachers, and researchers who need to understand soil hydraulic conditions and how to prevent soil particles from moving into drains so that they can design successful subsurface drainage systems. The publication consists of two parts. In part one, guidelines for the design of envelopes for subsurface drains are presented, it includes the following subjects: the needs for a drain envelope, material selection, design, cost, implementation, maintenance and evaluation. Part two, the “resources” section, presents the background of drain envelope design, the theory and testing of existing design criteria and experiences.

This paper provides practical information to drainage engineers and contractors for the selection, installation and maintenance of drainage materials as well as specifications and standards for such materials. In addition, the manual also contains practical guidelines for the implementation of laboratory and field investigations to evaluate the performance of drainage materials.

This manual gives an overview of the materials used in the construction of pipe drainage systems.

Drainage planning, design and management
New edition of the publication Land Drainage (published in 1983). The book is based on traditional drainage methods for rainfed agriculture in the humid temperate zone. Significant parts are devoted to drainage for salinity control of irrigated lands in (semi-)arid zones, and to drainage of rice land in the humid tropics. Institutional, management and maintenance aspects are covered, as well as the mitigation of adverse impacts of drainage interventions on the environment. Moreover, various applications for drainage design and management are treated. The book is intended for use both as a university level textbook and as a professional handbook.

The text discusses the diagnosis of agricultural drainage problems and their solutions, based on an understanding of the physical principles involved. Land drainage is treated as being a field of applied soil physics and applied hydrology. All major drainage problems are covered, each in its particular environment and field of application: Groundwater Drainage; Watertable Control; Surface Drainage of Sloping and Flat Lands; Shallow Drainage of Heavy Land; Drainage for Salinity Control in Irrigated Land; Drain-
BIBLIOGRAPHY

age and Reclamation of Polders; Drainage for Seepage Control; Main Drainage: Design Discharges, Canal Design, Outlets. The book stresses the universal relationships between the main design variables and soil, climatology, and other relevant environmental conditions.

**Drainage principles and applications**


This completely revised second edition on drainage principles and applications is based on lectures delivered at the International Course on Land Drainage, which is held annually by the International Institute for Land Reclamation and Improvement, Wageningen, The Netherlands. The book presents the basic principles of land drainage with applications. The book provides a coverage of all the various topics useful to those engaged in drainage engineering. Includes a glossary.

Also available is a Spanish version published in 1977, entitled: *Principios y Aplicaciones del Drenaje* (en cuatro volúmenes).

**Drainage systems**


This monograph summarises the information developed during the past two decades and deals with the many aspects of contemporary agricultural irrigation and drainage systems, placing these systems into the perspective of comprehensive water management. It can serve as the scientific basis for decision-makers in developing management strategies to improve the soil conditions of the field and protect water quality from contamination by cropping practices. The 42 chapters which contributions from 71 scientists and professions are presented in 12 sections: I) Introduction; II) Overview of drainage and crop production; III) Soil water movement in drained lands; IV) Movement and fate of solutes in drained lands; V) Modelling in the performance of drainage systems; VI) Drainage for salinity control and reclamation; VII) Water table control; VIII) Hydrology and water quality impacts of drainage; IX) Planning and design of drainage systems; X) Drainage methods and materials; XII) Special drainage problems; XII) Determination of soil properties for drainage design, and; XII) Socio-economic impacts of agricultural water management systems.

**Drainage testing**


This publication gives guidelines on how to test the functioning and adequacy of single drains and drainage systems.

**Drainage training manuals**

Drainage of Irrigated Lands is the ninth in a series of training manuals on irrigation. The manual is intended for use by field assistants in agricultural extension services and irrigation & drainage technicians at the village and district levels who want to increase their ability to deal with farm-level irrigation and drainage issues. It discusses the needs for drainage in irrigated areas, focusing on drainage at farm level. It reviews the systems that are available to drain irrigated lands and explains which factors of soil and hydrology influence drainage. It touches briefly upon the design, construction, operation and management of field drainage systems.

**Case studies**

**China**  
This publication gives an overview of the status of irrigation and drainage in China and the developments since the Chinese revolution in 1948.

This publication summarises the research and observations on, and the experiences with the implementation of the research results over a period of 20 years with controlling waterlogging and salinity in the North China Plain. One of the conclusions is that with a proper waterlogging and salinity control, the effects of drought can be substantially reduced.

**Egypt**  
The booklet published through the Secretariat of the Egyptian-Dutch Advisory Panel on Water Management, on the occasion of the Third World Water Forum, March 2003, presents an overview of an unique 27-year cooperation between the Governments of Egypt and the Netherlands in the Egyptian-Dutch Advisory Panel on Water Management. This bilateral cooperation on water started, in 1975, on drainage, with a main focus on design and implementation of large-scale drainage systems. Throughout the years of the bilateral co-operation, the Advisory Panel successfully widened its scope from drainage specific issues to water management topics and gradually changed from technical support to policy advice. The main objective of the Panel in its present set-up is to assist the Ministry of Water Resources and Irrigation in carrying out its responsibilities towards managing the quality and quantity of Egypt’s freshwater resources more efficiently and effectively. This task is accomplished with an Annual Panel Meeting, Workshops, consultant missions (local and international), Working Group Meetings, Task Forces, etc., coordinated by a Secretariat, based in Cairo, Egypt, and Wageningen, The Netherlands.
In the booklet the ‘nuts and bolts’ of the Panel as well as many of the achievements of the last 27 years are described in 13 interviews with Panel members, Officials of the Netherlands Embassy in Cairo, and the Panel’s Secretariat.

2003
The proceedings highlight the results of the long-term, 27 years from 1975-2002, Egyptian-Dutch cooperation on water management. The objectives of the Seminar were threefold:
• To highlight the achievements of more than 25 years of Egyptian-Dutch cooperation;
• To reflect on the evolution of the cooperation programme from technology transfer in land drainage towards integrated water management and planning, institutional reform, capacity building and environmental management;
• To exchange experiences, lessons learned, vision for the future of Egypt’s water sector and coordination issues of donor cooperation.
The proceedings include the critical success factors for such a bilateral cooperation programme as well as the Main Findings and Recommendations of the Seminar. A CD with all papers and presentations completes the Proceedings.

2001
The report presents the results of the long-term co-operation of drainage research in Egypt between the Drainage Research Institute (DRI), Egypt and the International Institute for Land Reclamation and Improvement (ILRI), the Netherlands. After a brief sketch of agriculture and agricultural research in Egypt, with emphasis on the activities by DRI, the achievements in the field of design criteria are described in 6 sections: I) Project details; II) Research on design criteria; III) Monitoring and evaluation; IV) Research on drainage technology; V) Crop production and water management; VI) Research Management. The report concludes with a list of publications by the project.

2000
This publication presents the achievements of 15 years of co-operation on institutional and technical aspects of Agricultural Land Drainage in Egypt between the Egyptian Public Authority of Drainage Projects (EPADP) and the Netherlands Directorate General of Public Works and Water Management (RWS). It presents various aspects of large-scale implementation of drainage, covering subjects that are technical, economic, and organisational, or that concern operation research, and institutional and human resources development. The contributions of 40 authors are presented in 5 parts: I)
Drainage in Egypt and The Netherlands; II) Training; III) Planning and Organisation; IV) Information Technology, and; V) Drainage Technology.

1989 Amer, M.H. and N.A. de Ridder (Eds.) Land Drainage in Egypt. Drainage Research Institute, Cairo, Egypt and the International Institute for Land Reclamation and Improvement (ILRI), The Netherlands, 377 p.

The project presents the achievements of 14 years of technical co-operation between Egypt and The Netherlands on agricultural land drainage. The book summarises the knowledge gained in research studies that were conducted to combat waterlogging and salinity in the Nile Delta and Valley with the aim to provide some 2.1 million hectares with subsurface drainage systems. The results are presented in seven: 1) Drainage survey and design practices; 2) Drainage technology; 3) Operation and maintenance of drainage systems; 4) Vertical drainage feasibility in the Nile Valley; 5) Reuse of drainage water for irrigation; 6) Economic evaluation of drainage projects, and 7) Institutional and management aspects of drainage projects. The book provides in depth guidance to practising engineers in planning and designing drainage systems.


This report presents the findings of the Indo-Dutch Network Project on research on the control of waterlogging and salinization in irrigated agricultural lands in India. The project, covering the period 1995 - 2002, was a collaboration between the Central Soil Salinity Research Institute, Karnal, the four State Agricultural Universities of Andhra Pradesh, Gujarat, Karnataka and Rajasthan and Alterra-ILRI. The four volumes of the report cover the following issues:

- A methodology for identification of waterlogging and soil salinity conditions using remote sensing: Based on eight studies covering areas ranging from 5 000 to 350 000 ha in the Indo-Gangetic plains (3), heavy clay or black soils (3) and sandy soils (2), two methodology, one based on visual and another for digital interpretation are recommended;
- Recommendations on Waterlogging and Salinity Control based on pilot area drainage research: presenting the research findings of 7 drainage pilot areas (ranging in size from 20 to 188 ha), covering 5 agro-ecological sub-regions in India with soils ranging from sandy loam to heavy clay. For each sub-region specifications for subsurface drainage systems, both open and pipe drains, are presented;
- Computer modelling in irrigation and drainage: four computer simulation models, SWAP, UNSATCHEM, SALTMOD and SURDEV, were tested to assess the short and longterm impacts of water management options on the land and water productivity and the environment;
• Human resource development and the establishment of a training centre: the report discusses the adopted approach in technology transfer, capacity building and institution strengthening of the four network centres.

The report presents an intensive review of the present state of scientific knowledge and technology in the subsurface drainage research activities undertaken by the Rajasthan Agricultural Drainage Research Project (RAJAD) during 1991-1994. These activities have resulted in the development of criteria and guidelines for subsurface drainage installation to assist with the formulation of large-scale subsurface drainage procedures for the installation of subsurface drainage in about 25,000 ha in the Chambal Command Area, Kota, Rajasthan, India. The information is presented in 10 chapters: 1) Project description; 2) Background information on Chambal Command Area; 3) Salinity and waterlogging; 4) Description of the experimental drainage test sites; 5) Subsurface drainage design criteria development; 6) Multidisciplinary aspects of subsurface drainage; 7) Hydraulics of subsurface drainage systems; 8) Subsurface drain envelope requirements; 9) Subsurface drainage installation costing procedures; 10) Design guidelines for subsurface drainage.

The Netherlands
Man-made lowlands presents a comprehensive and richly illustrated picture of the way the Dutch have made and kept their lowlands habitable. A indispensable standard work for anyone interested in the Dutch history of water management and land reclamation. The publication covers subjects: 1) The Netherlands, the country and its inhabitants; 2) Water management from about 800 to about 1250; 3) Water management from about 1250 to about 1600; 4) Water management from 1600 to about 1800; 5) The Netherlands, its inhabitants and water management administration from 1800 till present; 6) Water management in ‘Laag-Nederland’ from about 1800 till present; 7) Water management in ‘Hoog-Nederland’ from about 1800 till present; 8) Improvement of the large rivers; 9) The Zuiderzee and the Delta projects; 10) Epilogue and the prospects of water management in the Netherlands.

Pakistan
This is the final report of the Netherlands Research Assistance Project, a joint undertaking by the International Waterlogging and Salinity Research Institute (IWASRI), Lahore, Pakistan and the International Institute for Land Reclamation and Improvement (ILRI), Wageningen, The Netherlands. The project, with covered the period 1988-2000,
had two main activities: work on technical aspects of drainage and the development of a participatory approach to drainage. The report discussed three main issues.

1. Technical lessons learned, in particular: (i) envelope materials; (ii) drainage design with computer simulations; (iii) drainage design criteria; (iv) salinity measurements by magnetic induction; (v) interceptor drainage; (vi) groundwater approach to drainage design; (vii) operation and maintenance of drainage systems; (viii) benefits of shallow drainage; and (ix) the use of poor quality water for crop production and reclamation;

2. Participatory drainage development: lessons learned on development and implementation, and;

3. Institutional development, including capacity building through training and the execution and dissemination of research.

1984 MARDAN SCARP. 1984. MARDAN SCARP Subsurface Drainage Design Analysis. Water and Power Development Authority, Pakistan, 224 p. This reports presents the subsurface drainage design analysis for the Mardan Salinity Control and Reclamation Project (SCARP) carried out by the Pakistan Water and Power Development Authority (WAPDA) and consulting engineering companies Engineering with assistance by the Canadian International Development Agency (CIDA). The Mardan SCARP project encompasses 123 600 acres of the Culturable Command Area of the Lower Swat irrigation canal in the Northwest Frontier Province of Pakistan. The achievements are presented in 8 chapters: 1) Background information; 2) Design drainage rates, drain depths and spacings; 3) Subsurface drainage pipework; 4) drain envelopes; 5) Cost estimates; 6) Economic analysis; 7) Subsurface drainage plans, and; 8) Evaluating the performance of subsurface drainage.
Glossary

Alignment
(1) The fixing of points on the ground in the correct lines for setting out a canal, drain or pipeline, etc. (2) A ground plan showing a route, as opposed to a profile or section, which shows levels and elevations.

Augerhole method
A technique to determine the saturated hydraulic conductivity of a soil at a certain depth by augering a cylindrical hole in the soil, bailing water from it, and measuring the rate of water-level rise in the hole.

Backfill
Soil excavated from a drain trench that is to be placed back into the trench after the drain pipe has been installed.

Backfilling
Replacement of excavated material from a trench into the trench directly after the drain pipe has been installed. Backfilling is a three-step operation: blinding (backfilling directly after installation to fix the pipe in its position) - backfilling - compaction.

Bar chart schedule
A chart on which the start and finish of activities are represented as bars on a time scale. A bar chart schedule is a simplification of the planning prepared in a network planning or an independent planning method (see also Network planning).

Benchmark
A relatively fixed point whose level is known and used as a reference for levelling.

Bill of quantities
List of specifications of activities, including labour and materials, for a project or work to be carried out, expressed in measurable quantities, e.g. area (ha, m^2), length (m, km), weight (kg, ton) or volume (litres, m^3), labour days, including simplified technical specifications of the materials and methods to be used and references to the more elaborate technical specifications.

Blinding
First step in backfilling a trench by carefully replacing the excavated soil around and over the drain pipe, mainly used to fix the drain pipe in its position.

Boning Rod
A rod or stake with a cross bar with variable length to indicate a reference level (Figure C 1301).
**Critical path**
The longest path of the network in terms of time requirements for a sequence of activities that have to be implemented one after another (see also **Network planning**).

**Centrifugal pump**
A roto-dynamic pump with radial flow, its inlet opening being near the centre of the impeller and its outlet along its periphery. The water follows the curved impeller vanes away from the centre.

**Collector drain**
A drain that collects water from the field drainage system and carries it to the main drain for disposal. It may be either an open ditch or a pipe drain.

**Compaction**
Artificial increase of the dry density of a granular soil by mechanical means such as rolling the surface layers.

**Composite drainage system**
A drainage system in which both field drains and collectors are buried.

**Concrete**
A mixture of water, sand, stone and a binder (nowadays usually Portland cement) which hardens to a stone like mass.

**Consultant**
A registered architect, chartered engineer or specialist who acts for a client. For construction projects the duties of a consultant often go much further than giving advice. The consultant and his staff can provide the complete design and supervision of the construction (acting as the Clients or employers representative) up to and including final handing-over of the project.

**Contract**
Binding agreement (between persons, groups, states) to supply goods or equipment, to carry out works, etc. at a fixed price.

**Contractor**
A person who signs a contract to carry out certain specified work at certain rates of payment, generally within a stated time.

**Culvert**
A square, oval, or round closed conduit used to transport water horizontally under a highway, railway, canal, or embankment.

**Deflection**
The deflection or elastic change of a pipe under stress or pressure.
Deformation
The deformation or plastic, non-recoverable, change of a pipe which is under stress or under extreme temperatures.

Design discharge
A specific value of the flow rate that, after the frequency and the duration of exceedance have been considered, is selected for designing the dimensions of a structure, a drainage system, or a part thereof.

Drain
A channel, pipe, or duct for conveying surface water or groundwater.

Drain pipe
See Drain.

Drain spacing
The horizontal distance between the centre lines of adjacent parallel drains.

Drainage base
The water level at the outlet of a drained area.

Drainage basin
The entire area drained by a stream in such a way that all stream flow originating in the area is discharged through a single outlet.

Drainage coefficient
The discharge of a drainage system, expressed as a depth of water that must be removed within a certain time.

Drainage criterion
A specified numerical value of one or more drainage parameters that allow a design to be calculated with drainage equations.

Drainage effluent
The water flowing out of a drainage system which must be disposed of, either by gravity flow or by pumping.

Drainage gate
A gravity outlet fitted with a vertically moving gate or with a horizontally hinged door or plate (flap gate).

Drainage sluice
A gravity outlet fitted with vertically-hinged doors, opening if the inner water level is higher than the outer water level, and vice versa, so that drainage takes place during low tides.
**Drainage survey**
An inventory of conditions that affect the drainage of an area, made at various levels, ranging from reconnaissance to design level.

**Drainage system**
(1) A natural system of streams and/or water bodies by which an area is drained. (2) An artificial system of land forming, surface and subsurface conduits, related structures, and pumps (if any), by which excess water is removed from an area.

**Drainage techniques**
The various physical methods that have been devised to improve the drainage of an area.

**Dumpy level**
See Level.

**Elongation**
See Deflection.

**Entrance resistance**
The extra resistance to water flow in the vicinity of a drain pipe, due to a decreased permeability of the material around the drain and/or to a contraction of the flow lines resulting from the small drain openings.

**Envelope**
Filter material placed around pipe drains to serve one or a combination of the following functions: (i) to prevent the movement of soil particles into the drain; (ii) to lower entrance resistances in the immediate vicinity of the drain openings by providing material that is more permeable than the surrounding soil; (iii) to provide suitable bedding for the drain; (iv) to stabilise the soil material on which the drain is being laid.

**Evaluation**
The assessment of the degree of success of a planned project or process, often undertaken at a specific moment (e.g. upon or after completion).

**Excavator**
A power-driven digging machine, mounted on crawler tracks or wheels. The backacter, dragline, face shovel, grab, and skimmer are fittings which can be attached to give a different function to the jib of the standard excavator.

**FIDIC**
"Federation International des Ingenieurs Conseil" (International Federation of Consulting engineers) an international organisation that has prepared standards contracts often referred to as FIDIC contracts.
Feasibility study
A study of the existing and future parameters of a drainage or other project in such detail that a reasonable estimate of its profitability can be made.

Field drain
(1) In surface drainage, a shallow graded channel, usually with relatively flat side slopes, which collects water within a field. (2) In subsurface drainage, a field ditch, a mole drain, or a pipe drain that collects groundwater within a field.

Field drainage system
A network that gathers the excess water from the land by means of field drains, possibly supplemented by measures to promote the flow of excess water to these drains.

Field lateral
See Field drain.

Filter
A layer or combination of layers of pervious materials designed and installed so as to provide drainage, yet prevent the movement of soil particles in the flowing water (see also Envelope).

Flushing
Method by which sediment is removed by flushing a pipe drain from the downstream end with water.

Free water surface
See Watertable.

Grade
See Gradient.

Gradient
The rise or fall per unit horizontal length of a pipe.

Granular envelope
See Gravel envelope.

Gravel envelope
Envelope made of untreated or only slightly washed, rounded, natural building aggregate, larger than 5 mm, graded to a pre-described texture to match the prevailing soil type.

Gravity outlet structure
A drainage structure in an area with variable outer water levels, so that drainage can take place by gravity when outside water levels are low.
**Grey Literature**
Written information that is not officially published and has a limited distribution, e.g. project reports, feasibility studies, research reports, etc. Often the content of these reports is confidential.

**Groundwater**
Water in land beneath the soil surface, under conditions where the pressure in the water is equal to, or greater than, atmospheric pressure, and where all the voids are filled with water.

**Horizontal drainage**
A method of groundwater drainage in which low watertables are maintained by pipe drains or open ditches.

**Hydraulic conductivity**
The constant of proportionality in Darcy’s Law, defined as the volume of water that will move through a porous medium in unit time, under a unit hydraulic gradient, through a unit area, measured at right angles to the direction of flow.

**Hydraulic excavator**
See Excavator.

**Impact test**
A test to measure the brittleness of the pipe material, in particular its sensitivity to the notch effect.

**Interflow**
Water that has infiltrated into a soil and moves laterally through the upper soil horizons towards ditches or streams as shallow perched groundwater above the main groundwater level.

**Irrigation**
Controlled applications of water to agricultural land to allow the cultivation of crops, where otherwise, owing to a deficiency of rainfall, agriculture would be impossible.

**K-value**
See Hydraulic conductivity.

**Land reclamation**
Making land capable of more intensive use by changing its general character: (1) by draining excessively wet land; (2) by reclamation of submerged land from seas, lakes, and rivers, and; (3) by modification of its saline, sodic, or acid character.
**Laser equipment for drain installation**
Equipment consisting of a transmitter which emits a plane of invisible light, horizontal or under a slope, and a mast with receptors on the drainage machine. The receptors are connected to the hydraulics of the drainage machine. The transmitted light assures semi automatically the installation grade and level of the drainage pipe is according to the set plane of the transmitter.

**Layout**
A drawing showing the general arrangement of a proposed drainage system.

**Level**
(1) The elevation of a point; (2) an instrument with a telescope and bubble tube which enable the surveyor to take level sights over considerable distances, shots of 30 - 50 m being normal practice.

**Levelling staff**
Staff with a graduation in centimetres used in combination with a level (or levelling instrument) to determine the level of a spot removed from the levelling instrument.

**Longitudinal profile**
An annotated design drawing of a canal along its centre line, showing original ground levels, canal bank levels, design water levels, bed levels, and other relevant engineering information.

**Main drain**
The principal drain of an area, receiving water from collectors, diversion drains, or interceptor drains, and conveying this water to an outlet for disposal outside the area.

**Main drainage system**
A water conveyance system that receives water from the field drainage systems, surface runoff, interflow, and groundwater flow, and transports it to the outlet point.

**Manhole**
An access hole to a pipe collector, just large enough for a man to enter. It is normally covered with a concrete cover.

**Mechanical analysis**
Determining the particle size distribution of a soil or gravel envelope by screening, sieving, or other means of mechanical separation.

**Mean Sea Level (MSL)**
The average water level in a tidal area.
GLOSSARY

**Mole drain**
An unlined underground drainage channel, formed by pulling a solid object, usually a solid cylinder with a wedge-shaped point at one end, through the soil at the proper slope and depth, without a trench having to be dug.

**Network planning**
Planning method in which all activities are placed in a diagram in such a way that all activities are listed in a realistic order (some activities can only start when other activities have been completed).

**Observation well**
A small diameter pipe, at least 25 mm in diameter, in which the depth of the watertable can be observed. It is placed in the soil and perforated over a length equal to the distance over which the watertable is expected to fluctuate.

**Open drain**
A channel with an exposed water surface for removing and/or conveying surface and groundwater.

**Outlet**
The terminal point of the entire drainage system, where it discharges into a major element of the natural open water system of the region (e.g. river, lake, or sea).

**Outlet drain**
A drain that conveys collected water away from the drained area or project, either in the form of a natural channel or as a constructed drain.

**Overland flow**
Water flowing over the soil surface towards rills, rivulets, channels, and rivers. It is the main source of direct runoff.

**Peg**
A wooden or metal pin, usually pointed at one end, used to mark the location and/or level of an item to be constructed (same as stake).

**Performance assessment**
A tool to determine the functioning of a drainage system compared to the design criteria and to identify the causes of malfunctioning (if applicable).

**Piezometer**
A small diameter pipe used to observe the hydraulic head of groundwater. It is placed in, or driven into, the subsoil so that there is no leakage around the pipe. Water can only enter the pipe through a short screen at the bottom of the pipe, or through the bottom only.
Pipe drain
A buried pipe - regardless of material, size, or shape - which collects and conveys drainage water from a piece of land to a collector or to a main drain.

Pre-wrapped envelope
Envelope, often a synthetic envelope, which is pre-wrapped around the drain pipe before it is delivered to the site. Pre-wrapping is normally done in the factory.

Ranging Rod
A bar or stick of 2-3 m height that is used by surveyors to mark an alignment in the field. Ranging rods are often painted red and white each colour part indicating a height of 50 cm (Figure C 1301).

Reconnaissance study
An initial, exploratory study into the conditions affecting an existing problem. Its results should allow the extent of the problem to be weighed and possible solutions in general terms to be found.

Rodding
A method to check a newly installed drain line by pushing a glass fibre rod through the pipe outlet into the drain pipe over its entire length.

Sighting rod
A rod or stake with a cross bar at the top (Figure C 1301).

Singular drainage system
A drainage system in which the field drains are buried and discharge into open collectors.

Soil survey
The systematic examination of soils in the field, including the laboratory analysis of specific samples, their description, and mapping.

Soil texture
The relative proportions of the various sized groups of individual soil grains in a mass of soil. Specifically, it refers to the proportions of clay, silt, and sand below 2 mm in size (fine earth fraction).

Specifications
Written description of work to be done. Specifications form part of a contract and describe the quality of material mode of construction and also giving dimensions and other information not shown in the drawings.
**Stake**
A strong, pointed length of wood or metal (to be) driven into the ground to indicate in the field the location and/or level of an item to be constructed (same as peg).

**Subsurface drainage**
The removal of excess water and salts from soils via groundwater flow to the drains, so that the watertable and rootzone salinity are controlled.

**Subsurface drainage system**
A man-made system that induces excess water and salts to flow via the soil to wells, mole drains, pipe drains, and/or open drains, and be evacuated.

**Sump**
A pit often made of pre-cast concrete rings or brickwork, in which water collects before being pumped out.

**Supervisor**
Person who supervises and directs the work carried out by the contractor.

**Surface drainage**
The diversion or orderly removal of excess water from the surface of the land by means of improved natural or constructed channels, supplemented when necessary by the shaping and grading of land surfaces to such channels.

**Surface drainage system**
A system of drainage measures such as channels and land forming meant to divert excess surface water away from an agricultural area in order to prevent waterlogging.

**Survey**
(1) Examine the general condition of an area, a drainage system, structure, etc.; (2) Measure and map out the position, level, size, boundaries, etc. of an area; (3) A map or drawing showing the layout of an area.

**Synthetic envelope**
Envelope made of artificial (often plastic) material, nowadays most times pre-wrapped in the factory.

**Tender**
Statement of the price which one offers to supply goods or services, or to undertake a specific work.

**Tender procedure**
Process in which suppliers or contractors are invited to make an offer (to carry out work, supply goods, etc) at a stated price.
**Terms of Reference (TOR)**
Scope or range given to a person or authority specifying the duties to be performed.

**Textural class**
The name of a soil group with a particular range of sand, silt and clay percentages, of which the sum is 100% (e.g. sandy clay is: 45 - 65% sand, 0 - 20% silt, 35 - 55% clay).

**Tidal drainage**
The removal of excess water from an area, by gravity, to outer water which has periodic low water levels owing to tides.

**Tile drain**
See **Pipe drain**.

**Total float**
The difference in time between the time that is available for implementing an activity and the time needed to do this activity (see also **Network planning**).

**Trench box**
Part of the trencher that holds the trench sides apart and contains guides for the pipes and envelope material (sometimes called tile box).

**Trencher**
A drainage machine that digs a trench in which a drainpipe and if required a pre-wrapped envelope or gravel filter are laid.

**Trenchless machine**
A drainage machine that instead of digging a trench uses a plough to lift up the soil to make room for the drain pipe.

**Tubewell drainage**
The control of an existing or potential high watertable or artesian groundwater through a group of adequately spaced wells.

**Vertical drainage**
See **Tubewell drainage**.

**Vertical plough**
Trenchless drainage machine equipped with a vertical plough that acts as a subsoiler.

**V-plough**
Trenchless drainage machine equipped with a V-plough that lifts a triangular ‘beam’ of soil while the drain is being installed.
**Watertable**

The locus of points at which the pressure in the groundwater is equal to atmospheric pressure. The watertable is the upper boundary of groundwater.
A
Advisory Panel Project, 472, 476
Alignments & levels, 126, 317, 318
collectors, 318, 399
cost, 139, 326
cost of levelling, 168, 174
evacuation by excavator, 380
field drains, 318, 398
field preparation, 120, 166, 168,
317, 321
manual installation, 299, 373
misalignment, 416
smoothing, 321
starting level collector drain, 344
quality control, 139, 298, 397, 417
setting-out costs, 168
vertical alignment, 141
APEX plates, 102
Area boundaries, 33
As-built drawings, 147, 174, 191, 231,
235, 512
Asian Development Bank, 47, 49, 55
project in Pakistan, 560
Auger, 96, 240, 246, 249, 250, 551
Auxiliary equipment, see Support equipment
Available time, 197, 491, 495

B
Backfill, 132, 283, 355, 359, 360, 383, 400
compaction, 377, 382
costs, 174, 555
dry soil, 361
equipment, 113
manholes, 355
manual installation, 377, 382, 522
quality control, 139, 400
trench, 132, 312, 359, 400, 553
wet soil, 361
Backhoe, 93, 486, 511, 512
Bar chart, 43, 195
Base material, 71, 215
costs, 159, 169
collector drains, 75
clay pipes, 77
field drains, 71, 164
granular envelope, 82, 83
synthetic envelope, 169, 170, 395
Beneficiaries, see also Farmers
cost estimates, 154
role in implementation process, 27
Benefits of drainage, 17, 143, 154, 156,
166, 195, 549, 562
associated benefits, 157
direct effects, 157
indirect effects, 153, 157
secondary benefits, 17, 157
‘with drainage’ case, 157
‘without drainage’ case, 157
Bidding, 46, 485, 560
documents, 55
Bill of quantities, 36, 37, 39, 51, 156, 168,
175, 189, 190
Bio drainage
China, 456
Blades, 102
check, 246
replacement, 249, 250
subsoiler, 102
trenchless machine, 102
V-plough, 104
Blind pipe, 332, 339, 350
Blinding, 98, 132, 355, 360, 506, 542, 553
Boning rod, 127, 227, 229, 234, 299, 301,
312, 347
Bonus, 136, 207
Budget, 27, 29, 168, 476, 488
cost control, 43
output preparation process, 35
planning, 43, 153, 156, 158
Build-up time, 197
Capacity, 197, 198, 201
drainage machinery, 106, 492
gravel trailer, 112
pipe production, 162, 165
supporting equipment, 108
trencher, 95, 197
Capacity building
Egypt, 498
India, 517
Pakistan, 548
The Netherlands, 529
Case study, 447
China, 451
INDEX

Egypt, 467
India, 501
Pakistan, 545
The Netherlands, 525
Cement pipe, see also Concrete pipe, 74, 479
cost raw material, 215
quality control, 392
Central Soil Salinity Research Institute, 517, 518
Certification, 137, 141
The Netherlands, 536, 543
Chashma Command Area Development Project, 559
Checking
functionality, 143, 233, 403, 404, 423
routine, 148, 421
China, 451
Clay pipe, 20, 70, 76, 392, 479, 506
collector, 80
history, 20
India, 506
installation, 92, 129, 375, 541
maintenance, 148
production, 77
quality control, 77, 392
standards, 78
transport, 77
Cleaning, see also flushing, 423, 428
Collector drain, 24, 57, 550
alignment starting level, 318, 344
alignment, 318
checking performance, 404
composite system, 62, 285
concrete pipes, 81
costs calculation, 163, 173, 555
flushing, 435
function, 80, 403, 412, 424
grade control, 407
installation, 299, 341, 353, 524, 552, 558
layout options, 57
manholes, 314
manual installation, 382
material, 34, 69, 80
open, 57
outlet, 89
output design process, 39
Pakistan, 550
pipe, 57, 80
plastic pipes, 80, 130, 556, 557
quality control, 397
singular system, 60
slope, 63
starting level for operator, 342, 347
sump, 341
type of pipes, 57, 80
Collins apparatus, 141, 417
Combined mechanical and manual installation,
91, 115, 116, 512
advantages & disadvantage, 117
India, 519, 520
Command Area Development Authority, 505
Command panel, 242, 267
Compaction, 133, 360, 361, 377, 400, 522
manual, 382, 383
trench, 132, 361
Composite drainage system, 22, 62, 220
advantages & disadvantages, 63
backfill of trench, 359
bill of quantities, 175, 190
China, 462
equipment requirements, 119
flushing provisions, 131
functionality, 403, 421
implementation requirements, 229
information requirements, 219
installation of manholes, 349, 355
installation of pipe connectors, 353
installation of sump, 341, 355
monitoring, 424
outlet, 89
performance, 315, 403, 423, 403
preparatory activities, 313
site clean up, 363
staff requirements installation, 121, 230
starting level installation, 343
Concrete collector drain, 81, 382, 399, 550,
554, 555, 556
quality control, 399
Concrete field drain, 74
base material, 75
diameters, 74
maintenance, 148
production, 75
quality control, 75
Concrete pipe, 20, 71, 74, 81, 480, 506, 550
costs, 170, 555
installation, 130, 328, 376, 382, 400
production in Egypt, 481
standards, 76
Connections, see also Joints, 353
Construction, 37, 44, 181
activities, 192
backfill, 132
cost subsurface drainage, 153
costs, 153, 168, 175
grade control, 126
instruction sheets, 183
manholes, 130
outlet, 125
partners in construction process, 44
placing envelopes, 130
placing pipes, 129
planning, 189
post construction checking, 413
preparation process, 44
pumps, 174
quality control, 135
setting out alignments & levels, 126
site clean-up, 133
staff requirements, 120
steps during installation, 124
trench excavation, 128
Construction department
task requirements planning, 119
role implementation process, 54
Construction process, 27, 189
quality control, 135
Consultant, 45, 48
pre-qualification tender, 48
role implementation, 27, 37, 54
Contingencies, 175, 191, 212
Continuous depth recorder, 141, 413, 417
Contract, 45, 207
awarding the tender, 54
conditions of payment, 156
procedure, 46
standards, 55
specifications for quality control, 136
transport, 213
Contract department
instruction sheets, 183
role in implementation process, 54
Contracting
procedures, 46
Egypt, 478
Pakistan, 556, 560
Contractor, 44, 48
Egypt, 485
handing-over site, 307
instruction sheets, 183
role during the implementation, 44
role quality check, 137
specifications tender documents, 44
tender procedure, 48
role in implementation process, 45
tender preparation, 53
Controlled drainage
O & M requirements, 145
Corrugated plastic pipe, 71
costs, 164
diameters, 72
handling during installation, 326
history, 20
installation, 263
production, 72
quality control, 73, 391
reel, 98
standards, 74
transport, 73
Cost calculation, 153, 165, 205
equipment, 172, 209, 207
example, 172, 173, 212
raw materials, 215
staff, 207
transport, 213
Cost components, 207
Cost control, 41, 153, 156
Cost estimate, 39, 145, 159, 205
drainage installation unit, 163
unit costs, 160
accuracy, 155
during planning process, 155
methodologies, 160
pre-drainage soil survey, 166
principles, 159
Cost of transport, 213
Cost recovery, 159
Costs, 153
crop compensation, 123
construction, 168, 517
contingencies, 175
depreciation, 210
drainage industry, 158, 161
equipment, 207, 517
levelling drain-line, 169
financing costs, 153
fixed costs, 209, 517
flushing, 151
general costs, 174
India, 516
interest rate, 210
investment costs, 153
maintenance, 60
minimising operational costs, 259
O & M, 151
O & M in Pakistan, 548
on-farm investments, 159
operational costs, 60, 209
overhead, 160
Pakistan, 555
pre-construction activities, 165
profit and risk, 175
quality control The Netherlands, 543
raw materials, 215
recurrent costs, 153
staff, 205
staff training, 161
subsurface drainage systems, 153
trencher, 261
total costs, 175
Couplers, 78, 326
Crawler tracks, 95, 239, 260
Critical depth, trenchless machine, 104
Critical path, 41, 194
Crop compensation
during installation, 107, 123
Egypt, 485
Crop rotation
China, 455
Crop yield, performance indicators, 144
Crossings, 62, 66, 173, 321
O & M, 177

D
Deep collector drains
Pakistan, 552
Depreciation, 160, 210
Depth control, 93, 107, 299, 321, 325
Design, 39, 37, 89
China, 461
criteria, 33
conditions, 55
cost estimates, 154, 156
costs, 153, 167
department, 45
Egypt, 478
input requirements, 39
layout options, 57
preparation process, 39, 311
required for planning, 189
output preparation process, 39, 189
site verification, 308
terms of reference, 39
Design department
role in implementation process, 54
Detection rod, 349, 408, 409
Dewatering equipment, 109
elementary network planning, 193
Pakistan, 551
vertical well-pointing technique, 126
well-sinking technique, 126
Diameters, 72, 74, 77
field drains, 72, 479, 506, 536, 549
collector drain, 74, 81, 480, 550
clay pipes, 77
Discharge site, 58
Digging chain, 95, 249
adjustment, 253
flat digger chain, 99
knives, 96
reduction of wear, 259
replacement, 249
vertical digging chain, 110
Digging knives, 96, 100, 249
adjustment, 254
replacement, 249
Digging mechanism, 95, 96, 99, 264, 268
Direct effective time, 198, 201
Discharge, 57, 58
at outlet, 35, 144
composite system, 62
in manhole, 144
singular system, 60
site, 58
sump, 87
Double-wall pipe, 72
Drain
collector drain, 57, 80
extended field drain, 63
field drain, 57
mole drain, 22
open drain, 22, 60
pipe drain, 22, 62
Drain bridge, 322, 324, 540
Drain envelopes, see also Envelope, 81
INDEX

costs, 173
design, 39
function, 81
geo-textiles, 82
granular, 82, 83
installation, 128, 130
investment in production plant, 165
machine attachments, 96
materials, 81
organic, 82
planning, 69
pre-wrapped, 83, 85
production of granular materials, 83
quality check, 139
standards, 83
standards granular envelopes, 83
synthetic, 82, 84
synthetic, pre-wrapped, 85
synthetic, production, 84
synthetic, quality control, 86
synthetic, standards, 86
voluminous, 82
Drain installation
preparatory activities, 307, 311
sequence of activities, 311
specialised machinery, 108
support equipment, 111
steps in installation, 124
Drain level & grade, 325, 373, 403, 407, 413
visual inspection, 139, 398
Drain line performance
post construction verification, 140, 141, 413
vertical alignment, 141
visual inspection, 424
Drain pipe, see also Pipe, 70
base material, 71
China, 463
diameters, 72
Egypt, 479
gravel envelope installation, 365
handling of corrugated pipes, 326
India, 506
installation, 263, 325
installation, steps, 124
installation of connections, 353
investment production plant, 164
manual installation, 376, 385
The Netherlands, 536
Pakistan, 549
quality control, 391
plastic, 71, 479
poor performance, 438
post construction verification, 413
watertight joints, 357
Drain slope, see also Drain grade, 61, 63
grade control, 126
quality control, 139, 141, 408
Drain trench
back fill, 132, 360
excavation, 94, 117, 128
manual installation, 373
Drainage
benefits, 17
China, 453
costs, 29
effects, 28
Egypt, 469
history, 18
impact, 29
India, 503
mole, 22
need, 17
objectives, 16
open, 22
pipe, 22
Drainage Contact Group, 535
Drainage criteria
output of preparation process, 33
Drainage developments
China, 459, 464
Drainage equipment, see also Equipment
investment costs, 158
Drainage Executive Management Project, 498
Drainage industry, 28, 44
cost estimate, 155
implementation mode, 35
investment costs, 155, 158, 161
The Netherlands, 533
quality control by certification, 137
quality control of drain pipes, 73
role in implementation, 27, 44
role in preparation process, 27
Drainage installation unit, 92, 118, 120, 122
cost estimate, 163
organisation, 120, 231, 233, 307
quality control, 136
Drainage machinery, see Equipment
Drainage material, 69, 219
  China, 456
cost estimate, 159
cost of quality control, 174
cost of raw material, 215
costs, 169
  Egypt, 478
effect on O & M, 148
for collector drains, 69
for field drains, 69
  India, 506
information requirements, 32
information requirements for envelopes, 34, 81
  India, 511
information requirements pipes, 34
manufacturers, 44
output of preparation process, 34
  Pakistan, 549, 555, 557, 560, 562
procurement, 219
quality control in the field, 138
quality control, 137, 391
selection, 69
  suppliers, 44, 69
  The Netherlands, 536
Drainage methods, 20, 57
  China, 454, 461
  Egypt, 469
  India, 511, 515
  Pakistan, 555, 557, 559
  The Netherlands, 527
Drainage policy
  preparation, 27, 28, 30, 154
  Egypt, 470
Drainage project
  cost estimate, 159
  financing, 159
  planning, 193
Drainage Research Institute, 470
Drainage system, 20, 57
  China, 461
  composite, 22, 219, 229
  Egypt, 469
  field, 20
functioning, 143, 403, 421
  impacts, 143
  India, 511, 515, 519
  Installation, 217, 305
malfunction, 143, 147, 438
  open, 60
organisation of implementation, 223
  Pakistan, 555, 557, 559
  performance, 140, 403
  periodic checking, 149
  singular, 22, 219, 227
  The Netherlands, 527
tubewell, 22
E
  East Khaipur Tile Drainage Project, 554
  Economic life time, 158, 162
  Effective time, 107, 197, 198
  Effects of drainage, 16, 28, 143, 156
  Pakistan, 559
  Efficiency, 108, 197
    machinery in Egypt, 490
  Egypt, 467
  Egyptian Public Authority for Drainage Projects, 473
  Element, 197
  End cap, 78, 175, 190, 353, 540
  End chute, 540
  Engine
    reduction of wear, 260
  Engine power, 98, 12
  Engineers estimate, 153, 156
  Envelope, 81, 365, 373
    China, 463
    costs, 170
    costs of granular, 165
    costs of synthetic, 165
    design criteria in India, 506
    design in Pakistan, 562
    development in China, 464
  Egypt, 482
    function, 81
    granular, 83, 365, 375, 399
    gravel trailer, 303
  India, 506
    information requirements, 34
    installation granular envelope, 130, 303, 365, 375, 377, 382, 551
    installation organic envelope, 130
    installation synthetic envelope, 130
    investments, 164
    manual installation, 381
    manual wrapping in the field, 385
    materials, 81, 215
  Pakistan, 550, 551, 557, 560, 562
    planning of gravel transport, 537
INDEX

placing, 130, 365
production plant, 164
quality control, 137, 393, 394, 398, 399
quality control installation, 139
synthetic, 84, 394
tasks of gravel manager, 236
The Netherlands, 537
wrapping, 385
Equipment, 91, 237, 262
accessibility costs, 168
backfill equipment, 113
capacity, 106
capacity in Egypt, 489, 492
cost calculation, 172
cost estimate, 160, 209
dewatering equipment, 109
economic lifetime, 162
efficiency in Egypt, 489
Egypt, 487
excavator, 93
flushing, 428, 439, 443
gravel trailer, 112
India, 509, 511, 515
information requirements, 32
investment costs, 162
maintenance requirements, 93, 245, 275
Pakistan, 551, 558, 560
planning, 91
purchase in Egypt, 495
operation, 263, 283
operational costs, 259
orchard trencher, 109
output of preparation process, 34
requirements, 93, 118
rock trencher, 108
selection criteria, 91
special-purpose, 108
support, 111
survey sheet, 201
The Netherlands, 541
transport, 113, 213
transport costs, 169
trencher machine, 91, 239
trenchless machine, 100, 271
European Union
tender procedure, 56

Excavation of trench,
by excavator, 93, 116, 128, 381
manual, 128, 374, 375
Excavator, 93, 229
advantages & disadvantage, 94
capacity, 107, 512
tasks of operator, 93, 234
Extended field drains, 63
advantages & disadvantages, 64
China, 462

F
Farmers
cost estimates, 154
instruction sheets, 183
role in implementation process, 27, 145
role in O & M, 9, 145, 149, 151, 421, 427
role in policy-preparation & decisions-making, 28
role in handing-over process, 44, 406
role in The Netherlands, 536
Feasibility study, 155
preparation, 165
FIDIC, 51
tender procedure, 49, 55
Field allowance, 207
Field drain, 20, 57
alignment, 318
checking performance, 406
clay pipe, 77
diameters clay pipes, 77
quality control clay pipes, 77
transport of clay pipes, 77
composite system, one-sided, 62
composite system, two-sided, 62
cement pipe, base material, 74
cement pipe, diameters, 74
cement pipe, production, 75
cement pipe, quality control, 75
cement pipe, standards, 76
cement pipe, transport, 75
diameters of clay pipes, 77
diameters of plastic pipes, 72
extended, advantages & disadvantages, 64
extended, 63
flushing, 439, 443
function, 70
grade control, during and after installation, 335, 407
INDEX

installation from open drain, 339
corrugated pipes, 72
from manhole, 314
from open drain, 335
layout options, 57
manholes, 341, 350
material, 70
outlet, 335, 339, 349
starting level for operator, 347
Pakistan, 549, 555, 557, 560
pipe, 57
plastic pipe, 71
plastic pipe, base material, 71
plastic pipe, diameters, 72
double wall pipes, 72
plastic pipe, perforations, 72
plastic pipe, production, 72
plastic pipe, quality control, 73
plastic pipe, standards, 74
plastic pipe, transport, 73
quality control, 397
required level of manhole, 345
singular system, one-sided, 60
singular system, two-sided, 60
smooth plastic pipe, 72
starting level, 343
trenchless machine, 285
types of pipes, 57, 70
Field drainage system, 20
Field investigations, 38, 166
cost estimates, 154
costs, 166
during the preparation process, 37
output of preparation process, 38
purpose, 38
Field manager, 120, 231
description of activities, 183
instruction sheets, 183
tasks, 120
tasks description, 231
Field preparation unit, 120, 122
Field staff, 120
description of activities, 183
instruction sheets, 183
tasks, 231
Financers, 45
role in implementation process, 45
Financing costs, 153, 160
Fixed costs, 209
Flat-digging-chain trencher, 99

Flushing, 149, 427, 433, 435, 439, 443
collector drain, 435
costs, 151, 177
damaged pipes, 438
equipment, 428
field drain from manhole, 443
field drain from open drain, 439
high pressure, 433
maintenance, 147, 149, 151
method, 427
principles, 427
provisions during construction, 131, 150
Forced account basis, 43
Fourth Drainage Project, 562
Fuel consumption, 146, 210, 212
Fuel price, 210

G
General costs, 155, 174
Geo-textiles, 82, 85
Government
Egypt, 470
financing of drainage projects, 159
India, 504
Pakistan, 548
role in implementation process, 27
role in policy-preparation & decisions-making, 28
The Netherlands, 529
Grade control, 93 126, 325
checking during installation, 407
during installation, 291
equipment, 287
management, 291
manual, 299
post construction verification, 417
problems, 292
test in the field, 297
tips for operation of laser, 291
Granular envelope, 83
application, 365
China, 462
costs, 165, 170
equipment requirements, 303, 366
installation, 130, 551, 562
manual installation, 377, 382
planning, The Netherlands, 537
quality control, 139, 393
staff requirements, 366
Gravel, 20, 82, 130, 214
Indo-Dutch Network Project, 517
Information requirements, 30
decision-making, 28
equipment, 32
maps, 31
materials, 32
objectives, 31
outlet conditions, 31
preparation research data, 33
rules and regulations, 32
Installation, 115, 217, 305
additional manholes, 314
bottlenecks, 123
by excavator, 379
China, 462
clay pipes, 328
cleaning the site, 363
collector drain, starting level, 344
combined mechanical and manual, 116, 520
composite drainage system, 227
corrugated pipes, 326
costs, 170
cost of quality control, 174
depth and grade control, 325
drain pipe, 325, 353
Egypt, 487
equipment, 91, 237
field drain, starting level, 345
from open drain, 335
gravel application, 365, 551
gravel management, 370
in saturated soils, 331
in standing water, 321, 333
in unstable soils, 331
information requirements, 219
instruction sheets, 183, 219, 220
logistics, 123
manhole, 355
manual, 115, 373
manual using excavator, 379
mechanical, 118
method, 115
operation of laser, 291
operation of trencher, 263
organization, 119
outlet, 339, 341
Pakistan, 551, 554, 558, 561
post construction verification, 413
preparatory activities, 307
pre-wrapped envelope, 381
quality control, 135, 391, 397
saturated soil, 331
season, 123
setting out field, 317
singular system, 223
site cleanup up, 363
staff requirement, 119
standing water, 333
steps, 124, 311
sump, 341, 355
T-joint, 353
unstable soils, 331
Installation capacity
China, 460
Egypt, 469, 489
India, 512
Instruction sheets
contents, 220
subjects, 183
target group, 183
Instructions to tenderers, 51
Insurance, risk and profits, 160, 207, 210
for installation, 220
Interest rates, 210
International financiers
role in implementation process, 45
International transport costs, 213
Investigation
costs, 153, 164
Egypt, 478
field investigations, 31, 37, 38, 45
Irrigation, 17, 58
installation during irrigation, 307, 333, 361
winter irrigation in China, 456
irrigation canal crossing, 321
International Waterlogging and Salinity Research Institute, 548
J
Joints, 77, 78, 130, 353, 357
costs, 173
installation, 129, 130, 170, 353
quality control, 139, 148, 392, 397, 398
watertight joints, 80, 357, 401
L
Labour costs drainpipe installation, 171
Labour requirements
manual installation, India, 512, 522, 524,
Labourers tasks description, 235
Land reclamation
The Netherlands, 527, 531
Landowners, 37
investment costs, 159
Large-scale projects, 17
China, 460
costs, 153
Egypt, 478, 484
India, 509, 512
Pakistan, 554, 556, 559, 562
The Netherlands, 527, 531
Laser equipment, 93, 287
batteries, 294
beam level, 295
description, 287
control using two machines, 293
extension mast on trencher, 295
grade control, 287
horizontal adjustment, 297
level of beam, 295
maintenance, 294
mast on trencher, 295
principle, 287
receiver, 287
tips for operation, 291
transmitter, 287
Layout, 57, 219
collector, 424
comparison of options, 65
composite system, 62
considerations, 65
Egypt, 469
elements of a system, 57
extended field drains, 63
India, 511, 515, 519
instruction sheets, 219
manhole, 402
options, 57
output of preparation process, 34
Pakistan, 555, 557, 560
quality control, 397
subsurface field drains, 57
pumped outlet, 59
singular system, 60
soil conditions, 59
The Netherlands, 527
Legislation, Egypt, 470
Lessons learned, 5

China, 459, 464
Egypt, 485, 487, 494
India, 512, 520, 523
Pakistan, 549, 556, 559, 561, 563
The Netherlands, 544
Levelling staff, 408
Levelling instrument, 93, 126, 409
Levels, quality control, 397
Life time, 158, 210, 212
Local transport costs, 213
Logistics, 123, 271
Lubricants cost, 210, 211, 212

Machine costs drainpipe installation, 158,
170, 171
Main drain, 57
layout option, main drain, 57
O & M requirements, 145
Main drainage system, 20, 57
investment costs, 159
Maintenance, 145, 419
activities, 177
checking performance, 421
cleaning composite systems, 423
costs, 63, 151, 177
flushing equipment, 433
frequency estimation, 148
gravel trailer, 303
integral check, 149
minor, periodic, 149
objectives, 146
periodic cleaning, 149
preventive, 151
process, 147
repairs, 151
routine check, 148
requirements drainage machine, 93
subsurface drainage system, 147
staff, instruction sheets, 183
trencher machine, 245
trenchless machine, 275
Management, cost estimate, 160
Manholes, 34, 87, 130, 350, 355, 402
completion of installation, 355
costs, 173
determining the level, 343
Egypt, 483
installation, 314, 349, 355
installation costs, 173
INDEX

<table>
<thead>
<tr>
<th>Page</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>349</td>
<td>installation in field drains</td>
</tr>
<tr>
<td>400</td>
<td>installation, quality control</td>
</tr>
<tr>
<td>357</td>
<td>installation watertight joints</td>
</tr>
<tr>
<td>343, 344</td>
<td>levels</td>
</tr>
<tr>
<td>349</td>
<td>levels, composite system</td>
</tr>
<tr>
<td>320</td>
<td>location</td>
</tr>
<tr>
<td>357</td>
<td>lid or cover, installation</td>
</tr>
<tr>
<td>140</td>
<td>quality control</td>
</tr>
<tr>
<td>148</td>
<td>routine checking</td>
</tr>
<tr>
<td>151</td>
<td>repairs</td>
</tr>
<tr>
<td>422, 423</td>
<td>sedimentation</td>
</tr>
<tr>
<td>86</td>
<td>selection</td>
</tr>
<tr>
<td>115, 373, 379</td>
<td>Manual installation</td>
</tr>
<tr>
<td>462</td>
<td>China</td>
</tr>
<tr>
<td>487</td>
<td>Egypt</td>
</tr>
<tr>
<td>520, 523</td>
<td>India, labour requirements</td>
</tr>
<tr>
<td>512, 522, 524</td>
<td>The Netherlands, organisation</td>
</tr>
<tr>
<td>540</td>
<td>using excavator</td>
</tr>
<tr>
<td>116</td>
<td>tool</td>
</tr>
<tr>
<td>385</td>
<td>wrapping the envelope</td>
</tr>
<tr>
<td>119</td>
<td>using machinery</td>
</tr>
<tr>
<td>223</td>
<td>organisation</td>
</tr>
<tr>
<td>512</td>
<td>India, information requirements</td>
</tr>
<tr>
<td>547</td>
<td>Pakistan, drainage fee</td>
</tr>
<tr>
<td>527</td>
<td>The Netherlands, flushing of field drains</td>
</tr>
<tr>
<td>31, 38</td>
<td>Network diagram</td>
</tr>
<tr>
<td>41, 189</td>
<td>Network planning</td>
</tr>
<tr>
<td>197</td>
<td>non-available time</td>
</tr>
<tr>
<td>198</td>
<td>non-effective time</td>
</tr>
<tr>
<td>16</td>
<td>Objectives of drainage</td>
</tr>
<tr>
<td>457</td>
<td>China</td>
</tr>
<tr>
<td>469</td>
<td>Egypt</td>
</tr>
<tr>
<td>512</td>
<td>India</td>
</tr>
<tr>
<td>547</td>
<td>Pakistan</td>
</tr>
<tr>
<td>527</td>
<td>The Netherlands</td>
</tr>
<tr>
<td>38</td>
<td>Network diagram</td>
</tr>
<tr>
<td>193</td>
<td>Network planning</td>
</tr>
<tr>
<td>169, 170, 175, 190, 192, 321</td>
<td>On-site camp</td>
</tr>
<tr>
<td>169, 190</td>
<td>On-site storage</td>
</tr>
<tr>
<td>169</td>
<td>gravel, costs</td>
</tr>
<tr>
<td>190</td>
<td>pipes, costs</td>
</tr>
<tr>
<td>57, 60</td>
<td>Open collector drain</td>
</tr>
<tr>
<td>20, 22, 32, 57</td>
<td>Open drain</td>
</tr>
<tr>
<td>22, 57, 60, 160</td>
<td>Open drainage system</td>
</tr>
<tr>
<td>27, 44, 145, 146</td>
<td>Operation</td>
</tr>
<tr>
<td>435</td>
<td>flushing of collector drains</td>
</tr>
<tr>
<td>427</td>
<td>flushing of drains</td>
</tr>
<tr>
<td>443</td>
<td>flushing of field drains from manhole</td>
</tr>
<tr>
<td>145</td>
<td>Operation &amp; maintenance</td>
</tr>
<tr>
<td>145</td>
<td>unit, tasks</td>
</tr>
<tr>
<td>95, 108, 264</td>
<td>Operation in stony soils</td>
</tr>
</tbody>
</table>

N

National government see also Government
decision-making, 154
policy-preparation, 154
Need for drainage, 17
China, 453
Egypt, 469
India, 503
Pakistan, 547
The Netherlands, 527
Network diagram, 38, 193
Network planning, 41, 189
Non-available time, 197
Non-effective time, 198

O

Objectives of drainage, 16, 31
China, 457
Egypt, 469
India, 512
information requirements, 31
maintenance, 146
On-farm investments, 159
On-site camp, 169, 170, 175, 190, 192, 321
On-site storage
gravel, costs, 169
pipes, costs, 169, 190
Open collector drain, 57, 60
Open drain, 20, 22, 32, 57
Open drainage system, 22, 57, 60, 160
Operation, 27, 44, 145, 146
costs, 60, 151, 153, 177, 209, 211
liftable trench box, 267
trencher, 259
trenchless machine, 283
Operation & maintenance, 27, 44, 145, 146, 245, 275, 263, 419
cost estimates, 154
costs, 151, 153, 177
drain, 439
drainage fee, Pakistan, 548
flushing of collector drains, 435
flushing of drains, 427
flushing of field drains from manhole, 443
flushing of field drains from open
objectives, 145
planning, 145
unit, tasks, 121
Operation in stony soils, 95, 108, 264

Bib-Glos.qxp  9-2-2005  14:39  Pagina 598
Operational costs, 146, 209, 211
Operational research, 108
drainage machinery, 108
Egypt, 488
Operator, 94, 106, 122, 233
assistant tasks description, 234
description of activities, 183
excavator tasks description, 234
starting level for collector installation, 347
instruction sheets, 183
starting level for field drain installation, 347
tasks description, 236
trencher, 233
Orchard trencher, 109
Organisation, 27, 45, 119, 181, 223
China, 456
Egypt, 470
India, 504
mechanical installation, 119
overhead, 174
Pakistan, 548
quality control, 543, 558
The Netherlands, 529
Organisation of implementation, 223, 227
Egypt, 473, 478, 484
India, 509, 513
Pakistan, 554, 556, 560
Organisation of research
Egypt, 476
India, 517
Pakistan, 548
The Netherlands, 535
Outlet, 31, 34, 58, 59, 89, 125, 126, 146, 339
composite drainage system, 89
conditions, 31, 422
construction, 125
costs, 173
gravity, layout option, 58, 125
installation, 339
layout options, 58
O & M, 146, 177
pumped, layout option, 58, 126
pipes, 79
quality control, 140, 422
repairs, 151
singular drainage system, 89
Overhead, 155, 160, 174, 207, 208
cost estimate, 160
Overtime, 207
Owing costs, 211
P
Pakistan, 545
Participatory approach, Pakistan, 549
PE-pipes, 20, 71, 74, 82, 164
cost of raw material, 164, 215
Penalties, 43, 136
Perforations, plastic pipes, 70, 72, 74, 391
Performance, 140, 197
check, 140, 315, 421
collector drain, 403
composite drainage system, 403
equipment, 197
Performance assessment, 143
Egypt, 494, 496
Performance bond, 51
Performance indicators, 144
Performance methods, 403, 421
continuous depth recording, 417
rodding, 413
Personnel costs, 146, 210, 211
Pipe drain, 22
accessories, costs, 169
collector drain, 57, 80
costs, 169
connectors, installation, 353
field drain, 57, 70
information requirements of preparation, 34
installation, 129
installation costs, 170
location of factory, 164
mobile production line, 164
production plant, capacity, 164
production plant, costs, 164
quality control, 137, 397
repair of end-pipe, 151
steps in installation, 124
transport costs, 164
Pipe fitting
couplers, 78, 353
drain cap, 78
outlet pipe, 79
standards, 80
T-joint, 78, 353
transport, 79
Y-joint, 78
Pipe production line, 72, 158, 164
INDEX

investment costs, 158
Pipe stretch, Pakistan, 553
Pipe-joint, see also Joints
    installation costs, 173
    quality control, 139
Piping, 132, 355, 359
Placing envelopes, 82, 124, 130
Placing pipes, 92, 115, 124, 128, 129
Planning, 27, 37, 40, 45, 123, 183, 189
    bar chart, 195
    critical path, 194
    Egypt, 477
    gravel supply, 537
    India, 505, 510, 514
    information requirements, 189
    need for planning, 40
    O & M requirements, 145
    quality control, 543
    selection of drainage materials, 69
    selection of manholes, 86
    selection of pumps, 86
    selection of structures, 86
    tools, bar charts, 43
    tools, network planning, 41, 189
Planning & budgeting, 27, 153
    cost estimates, 154
    during the preparation process, 40
Planning authority, 27, 38, 154, 155
    cost estimates, 154
    role in implementation process, 27
    role in preparation process, 27
Planning department
    description of activities, 183
    role in implementation process, 54
Planning tools, 41, 195, 494
Plastic drain pipe, 20, 71, 169, 170
    costs, 169
    Egypt, 479
    installation, 129
    installation, quality control, 397
    production, China, 463
    India, 506, 511, 515
    quality control, 391
Policy-preparation, 28
    cost estimates, 154
Post construction verification, 143, 156, 431
Post-installation quality control, 140, 403, 413
Power grid system, connection, 358
Power supply, 22, 60, 73
Pre-construction activities, costs, 155, 165, 167, 223
Pre-drainage survey, costs, 166
Pre-fabricated structures, 86
    quality control, 137, 395
Pre-installation quality control, 138
Preparation activities, 30, 223
    costs, 165
    setting out field, 317
    site preparation, 321
Preparation costs, summary, 167
Preparation, information requirements
    equipment, 32
    maps, 31
    materials, 32
    objectives, 31
    outlet conditions, 31
    research data, 33
    rules and regulations, 32
Preparation process, 27, 30, 45, 123, 153, 165
    construction, 37
    costs, 155
    design, 37
    field investigations, 37, 168
    handing-over specifications, 35
    input information, 31
    lay-out options, 57
    planning & budgeting, 37
    policy, 27, 28
    output, area boundaries, 33
    output, budget, 35
    output, drainage criteria, 33
    output, drainage materials, 34
    output, equipment, 34
    output, implementation mode, 35
    output, layout, 34
    output, outlet, 34
    output, pumping requirements, 34
    output, type of system, 34
    tender preparation, 37, 50, 51, 167
Press pulley, 96, 130, 240
Preventive maintenance, 147, 151
Pre-wrapped envelope, 20, 32, 85, 100, 170
    China, 464, 463
Problem soils
    China, 453
    Egypt, 485
    hard rock, Egypt, 486
quick sand, Egypt, 485
upward pressure, Egypt, 486
Process control, 40
Production, 150
clay pipes, 71, 77, 80
cement pipes, 71, 81
cost production line, 158, 165
capacity production line, 164
drainage materials, 32, 34, 59, 69, 169
investments envelope production, 165
investment pipe plant, 164
granular envelopes, 83
plastic pipes, 72, 80
quality control, 392
synthetic envelopes, 83, 84
Profit and risk, 155, 160, 175
Project organisation, 223
Egypt, 473, 478, 484
India, 504, 509, 513, 517
Pakistan, 548, 556, 560
The Netherlands, 527, 531
Proposal
Financial, 48
Technical, 48
Public goods, 159
Pumps, 59, 86, 90, 124
c costs, 60, 174, 177
diesel, O & M requirements, 146
diesel-driven, 90
electric, O & M requirements, 146
electrically-driven, 90
installation costs, 174
layout considerations, 58
O & M requirements, 145
operational costs, 146
preventive maintenance, 151
quality control installation, 402
repairs, 151
selection, 86
Pump house, installation, 87, 357
Pumped drainage, power supply, 60, 126
Pumped outlet, 58
Pumping, China, 464
Pumping requirements, output of preparation
process, 34
Purchase price, 210
PVC pipe, 20, 70, 71, 164, 215
cost of raw material, 215
joints, 78, 80
Q
Quality control, 135, 387
active, 136
after installation, 139
clay pipes, 77, 392
cement pipes, 392
Collins apparatus, 141
composite drainage system, 403
continuous depth recorder, 141
costs, 174
data processing, 410
drainage material, 391
drainage material, procedure, 137
during installation, 138
envelope, 137
grades of installed pipes, 407
gavel envelope, 393, 562
hydraulic performance, 140
installation, 138, 397
installation of gravel envelope, 366
materials, 387
organisation, The Netherlands, 543
Pakistan, 558
passive, 136
performance assessment, 143
pipe, 137
planning phase, 136
plastic pipes, 73, 391
post installation, 140, 413
practical aspects, 387
prefabricated manhole, 400
prefabricated structures, 395
prefabricated sump, 400
process, 135
requirements, 136
rodde, 140
role during implementation, 44
standards, 137
structure, 137
synthetic envelopes, 86, 394
total quality system, 135
tracking, 143
unit, tasks, 121
video inspection, 135, 140, 496
Quality of installation, 135, 148, 397
effect on O & M, 148
standing water, 333
Quick sand conditions, Egypt, 485
R
Rajasthan Agricultural Drainage Research Project, 509
Reclamation process, 17, 31, 58
The Netherlands, 527, 531
Record sheet
O & M trencher machine, 250
O & M trenchless machine, 279
Recurrent costs, 153
Re-fuelling
trencher machine, 247
trenchless machine, 275
Regional government, see also Government
cost estimates, 154
Rehabilitation need, 33, 143
Repairs, 151, 211
composite drainage system, 423
singular drainage system, 421
Reporting functionality, 422
Research, 31, 33, 183, 197, 413
application of results, Egypt, 494
China, 456
Egypt, 476, 488
India, 504, 512, 517, 522
operational research 108, 488
organisation, The Netherlands, 535
Pakistan, 548
information requirements, 33
research department, 183
Residual value, cost, 210, 211
Right of way, 308
Rock trencher, 108
Rodding, 140, 413
Rules and regulations, 32, 51, 54, 55
S
Safety rules, flushing, 433
Salary, 207
Salinity, 17, 28, 31, 140, 157, 166
China, 455
India, 503
Pakistan, 547
Saturated soil, installation method, 331
Secondary benefits of drainage, 15, 17, 157
Sedimentation, 141, 144, 147, 428
maintenance needs, 149
performance indicators, 144
Setting out
alignments and levels, 120, 124, 126, 168
field, 317
level of manhole, 320
levels, 380
manually, 373
perpendicular line, 319
Shelter, cost, 210
Singular drainage system, 22, 60, 219, 315, 421
advantages & disadvantages, 62
backfill of trench, 359
checking performance, 315, 421
China, 462
equipment requirements, 119
implementation requirements, 227
information requirements, 219
installation, 335
installation, staff requirements, 122
installation of outlet, 335
installation, trenchless machine, 283
minor repairs, 421
The Netherlands, 527
outlet, 89
preparatory activities, 312
site clean up, 363
Sink hole, Pakistan, 553
Site
clean-up, 133, 363
costs, 174
discharge, 58
preparation, 54, 308, 321
setting out field, 317
Site-specific conditions, 147
Site preparation, costs, 166
Spare parts, costs, 160, 210
Specifications, see also Standards, 136, 186
drainage machinery, 107
handing-over, 57
in tender documents, 51
Sprockets
reduction of wear, 259
replacement, 250
Staff, 119, 231
cost calculation, 172, 207
cost estimate, 159
costs, 207
field manager, 120
field preparation unit, 120
implementation requirements, 229
instruction sheets, 183
mechanical installation, 119
INDEX

O & M unit, 121
requirements installation, 121, 227
task description, 231
installation preparation, 123
installation equipment, 91
installation method, 115
layout options, 57
maintenance activities, 147
O & M objectives, 146
O & M requirements, 146
Outlet, 58
periodic checking, 149
pumped outlet, 58
repairs, 151
steps in installation, 124
sub-main drain, 57
The Netherlands, 527
Sump, 86, 87
costs, 173
determining the required level, 344
function, 87
in-situ installation, 342
installation, 341, 355
installation costs, 173
installation, quality control, 400
Pakistan, 551
prefabricated sump installation, 341
types, 87
Supervisor, 44, 121, 136, 232
description of activities, 183
instruction sheets, 183
role during implementation, 44
tasks description, 232
Suppliers, see also Manufacturers, 27, 44, 215
transport, 214
role during the implementation, 44
Support equipment, 111
capacity, 106
gravel trailer, 303
Surface drain, crossing, 126, 321
Survey
pre-drainage survey, costs, 166
soil survey, costs, 166
topographic survey, costs, 166
survey sheet, 201
survey unit, tasks, 120
Surveyor
instruction sheets, 183
tasks description, 235
Synthetic envelope, see also Envelope
costs, 165, 170

Standards, 49
certification, 137
clay pipes, 78
concrete pipes, 76
drain envelopes, 86, 536
granular drain envelopes, 83, 562
pipe fittings, 80
plastic pipes, 74, 507, 536
synthetic envelopes, 83, 86, 507, 536
tender documents, 51
The Netherlands, 536
Stone mulching, 455
Storage
flushing equipment, 434
gravel, 169, 366
laser equipment in winter, 294
pipes, 169
trencher machine in winter, 248
trenchless machine in winter, 277
Sub-main drain, 57
Subsoiler blade, 102, 107, 250
Subsurface drainage system, 20, 55
checking performance, 421
China, 461
collector drain, 57
cost price, 153
costs, 153
Egypt, 469
field drain, 57
flushing, 150, 427
flushing of damaged pipes, 438, 442, 446
gravity outlet, 58
India, 511, 515, 519
installation bottlenecks, 123
installation planning, 123
installation preparation, 123
installation equipment, 91
installation method, 115
layout options, 57
maintenance activities, 147
O & M objectives, 146
O & M requirements, 146
Outlet, 58
periodic checking, 149
pumped outlet, 58
repairs, 151
steps in installation, 124
sub-main drain, 57
The Netherlands, 527
Sump, 86, 87
costs, 173
determining the required level, 344
function, 87
in-situ installation, 342
installation, 341, 355
installation costs, 173
installation, quality control, 400
Pakistan, 551
prefabricated sump installation, 341
types, 87
Supervisor, 44, 121, 136, 232
description of activities, 183
instruction sheets, 183
role during implementation, 44
tasks description, 232
Suppliers, see also Manufacturers, 27, 44, 215
transport, 214
role during the implementation, 44
Support equipment, 111
capacity, 106
gravel trailer, 303
Surface drain, crossing, 126, 321
Survey
pre-drainage survey, costs, 166
soil survey, costs, 166
topographic survey, costs, 166
survey sheet, 201
survey unit, tasks, 120
Surveyor
instruction sheets, 183
tasks description, 235
Synthetic envelope, see also Envelope
costs, 165, 170

Standards, 49
certification, 137
clay pipes, 78
concrete pipes, 76
drain envelopes, 86, 536
granular drain envelopes, 83, 562
pipe fittings, 80
plastic pipes, 74, 507, 536
synthetic envelopes, 83, 86, 507, 536
tender documents, 51
The Netherlands, 536
Stone mulching, 455
Storage
flushing equipment, 434
gravel, 169, 366
laser equipment in winter, 294
pipes, 169
trencher machine in winter, 248
trenchless machine in winter, 277
Sub-main drain, 57
Subsoiler blade, 102, 107, 250
Subsurface drainage system, 20, 55
checking performance, 421
China, 461
collector drain, 57
cost price, 153
costs, 153
Egypt, 469
field drain, 57
flushing, 150, 427
flushing of damaged pipes, 438, 442, 446
gravity outlet, 58
India, 511, 515, 519
installation bottlenecks, 123
installation planning, 123
installation preparation, 123
installation equipment, 91
installation method, 115
layout options, 57
maintenance activities, 147
O & M objectives, 146
O & M requirements, 146
Outlet, 58
periodic checking, 149
pumped outlet, 58
repairs, 151
steps in installation, 124
sub-main drain, 57
The Netherlands, 527
Sump, 86, 87
costs, 173
determining the required level, 344
function, 87
in-situ installation, 342
installation, 341, 355
installation costs, 173
installation, quality control, 400
Pakistan, 551
prefabricated sump installation, 341
types, 87
Supervisor, 44, 121, 136, 232
description of activities, 183
instruction sheets, 183
role during implementation, 44
tasks description, 232
Suppliers, see also Manufacturers, 27, 44, 215
transport, 214
role during the implementation, 44
Support equipment, 111
capacity, 106
gravel trailer, 303
Surface drain, crossing, 126, 321
Survey
pre-drainage survey, costs, 166
soil survey, costs, 166
topographic survey, costs, 166
survey sheet, 201
survey unit, tasks, 120
Surveyor
instruction sheets, 183
tasks description, 235
Synthetic envelope, see also Envelope
costs, 165, 170

Standards, 49
certification, 137
clay pipes, 78
concrete pipes, 76
drain envelopes, 86, 536
granular drain envelopes, 83, 562
pipe fittings, 80
plastic pipes, 74, 507, 536
synthetic envelopes, 83, 86, 507, 536
tender documents, 51
The Netherlands, 536
Stone mulching, 455
Storage
flushing equipment, 434
gravel, 169, 366
laser equipment in winter, 294
pipes, 169
trencher machine in winter, 248
trenchless machine in winter, 277
Sub-main drain, 57
Subsoiler blade, 102, 107, 250
Subsurface drainage system, 20, 55
checking performance, 421
China, 461
collector drain, 57
cost price, 153
costs, 153
Egypt, 469
field drain, 57
flushing, 150, 427
flushing of damaged pipes, 438, 442, 446
gravity outlet, 58
India, 511, 515, 519
installation bottlenecks, 123
installation planning, 123
installation preparation, 123
installation equipment, 91
installation method, 115
layout options, 57
maintenance activities, 147
O & M objectives, 146
O & M requirements, 146
Outlet, 58
periodic checking, 149
pumped outlet, 58
repairs, 151
steps in installation, 124
sub-main drain, 57
The Netherlands, 527
Sump, 86, 87
costs, 173
determining the required level, 344
function, 87
in-situ installation, 342
installation, 341, 355
installation costs, 173
installation, quality control, 400
Pakistan, 551
prefabricated sump installation, 341
types, 87
Supervisor, 44, 121, 136, 232
description of activities, 183
instruction sheets, 183
role during implementation, 44
tasks description, 232
Suppliers, see also Manufacturers, 27, 44, 215
transport, 214
role during the implementation, 44
Support equipment, 111
capacity, 106
gravel trailer, 303
Surface drain, crossing, 126, 321
Survey
pre-drainage survey, costs, 166
soil survey, costs, 166
topographic survey, costs, 166
survey sheet, 201
survey unit, tasks, 120
Surveyor
instruction sheets, 183
tasks description, 235
Synthetic envelope, see also Envelope
costs, 165, 170

INDEX

installation, 130
quality control, 394

T
Taxes and duties, 160, 207
Tender, 44, 45
Asian Development Bank, 55
advantages & disadvantages, 49
advertisement, 53
costs, 167
direct, 47, 48, 50, 52
documents, contents, 44
documents preparation, 51
documents, 48
European Union, 56
evaluation, 54
FIDIC, 55
International, 46
National, 47
preparation, 44, 51, 53, 167
preparation, cost estimates, 154
pre qualification, 47, 50, 52
price consultation, 47
procedure, 45, 50
procedure in Egypt, 478
restricted, 47
submission, 54
World Bank, 55
Tenderers, 46, 47, 51
tender preparation, 51, 53
pre-qualification, 52
Terms of Reference, 36, 38
FIDIC tender, 51
for design, 39
for field investigations, 38
The Netherlands, 525
Tile drain, see also Pipe drain
tiles, see Clay pipe, 15, 22, 70
time and motion study, 201
Egypt, 490, 492
time registration sheet, 200
time standard, 197
time study, 199
Egypt, 494
Installation, India, 512, 522, 524
T-joints, see also Joints, 78, 130, 353, 540
Egypt, 483
installation, 130, 353
Tool, manual installation, 92, 115, 374
Tools and instrument costs, 207
Topographic survey, 31, 38, 139, 166
costs, 166
Total machine time, 197
Total quality system, 135
Tracking, quality control, 141, 143
Tracks, trenchless machine, 95, 101
Tractor driver
instruction sheets, 183
tasks description, 236
Training, 161
costs, 153, 161
Centre in Egypt, 499
Transmitter, 119, 295
Transport, 169, 207
clay pipes, 77
costs, 213
equipment, 111, 113, 169
gravel, 367
pipe fittings, 79
plastic pipes, 73
pipes, costs, 164, 169
trencher machine, 260
Trench, backfill, 132, 359
evacuation, 128
Pakistan, 553
Trench box, 95
adjustment, 253
changing, 264
dimensions, 96
installation from open drain, 335
liftable box, 267
Trencher machine, 94, 239
accidental stopping, 264
advantages & disadvantage, 99
auger, 240
bucket-wheel type, 99
capacity, 106, 489
Chinese-made, 459, 465
command panel, 242
composition, 95
costs comparison, 106
description, 239
digging chain, adjustment, 253
gable power, 98
extension of laser mast, 295
flat-digging-chain type, 99
gravel management, 370
hard-rock type, 108
laser mast, 295
implementation requirements, 229
installation of drain pipes, 263
maintenance, 245
maintenance precautions, 250
modifications, Egypt, 487
operation, 263
operation in stony soils, 264
operational costs, 259, 517
operator tasks description, 233
orchard-type, 109
performance monitoring, 197
press pulley, 240
reduction of wear, 260
sizes, 98
starting level manhole, 343
specifications, 107
transport wear, 260
trench box adjustment, 253
types, 99
water tank, 241
winter storage, 248
Trenchless machine, 100, 271
advantages & disadvantage, 104
capacity, 100, 106, 512
composition, 101
costs comparison, 106
critical depth, 104
description, 271
driver, tasks, 236
electric power, 102
ingineer power, 102
installation blades, 102
maintenance, 275
maintenance precautions, 275
operation, 283
specifications, 107
tracks, 101
Trenching unit, tasks, 121
Triple gouser plates, 101
Tubewell drainage, 22, 456
Type of pipe
  field drains, 70
collector drains, 80
replacement of parts, 278
Video inspection, 141, 413, 496
Visual inspection, 74, 76, 93, 107, 139, 140, 141, 149
backfill, 400
during installation, 398
composite drainage system, 423
gavel, 393, 399
pipes, 391
singular drainage system, 421
V-plough, 19, 100, 107, 271, 511
  blade, 104
replacement of parts, 278
W
Warping, 455
Water board, The Netherlands, 529
Water level, manhole, 144
Water ponding, performance indicators, 144
Water tank, 98, 241
Waterlogging, 16
  China, 453
  India, 504
Wear of machine during transport, 260
Wheel tractor, 99
driver, tasks, 236
Work standard, 197
calculation form, 203
  Egypt, 493
World Bank
  project in Egypt, 487
  project in Pakistan, 554
tender procedure, 55
Wrapping, 385
Wrapping machine, 85, 170
Y
Y-joint, see also Joints, 78
  installation, 130, 354
U
Unit costs, 51, 160
Unstable soil, 86, 94, 107, 116
  installation method, 331
V
Vertical plough, see also Subsoiler, 19, 100, 102, 271, 511
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Drainage of agricultural lands is an instrument for production growth, a safeguard for sustainable investments in irrigation and a tool for conservation of land resources. Subsurface pipe drainage is a form of drainage that was widely introduced in Europe and North America in the twentieth century. Among the developing countries, Egypt has the largest area provided with subsurface drainage (about 2.5 million ha). Subsurface drainage has also been installed in large tracts of irrigated land in Pakistan, China, Turkey and India. In many other countries piped subsurface drainage has been introduced on a smaller scale.

A wide range of lessons has been learned from experience in implementing subsurface drainage systems across the globe, which has offered ample opportunity for identifying best practices. While technological advances and scientific research have paved the way for innovations in subsurface drainage, practical installation methodology and organizational and institutional aspects of drainage projects prove to be equally important to achieving the development objectives. Most of this knowledge and experience however is hidden in the so-called “grey literature” (unpublished reports) and in the minds of few experts who have not had the opportunity to collate this vast experience and to offer it to the next generation of projects.

The purpose of this handbook is to make the wealth of acquired knowledge and experiences readily available to those persons involved in the planning, installation and management of pipe drainage systems, i.e. planners, operational managers and field and office staff of both public and private organizations. The handbook gives practical guidelines for the planning, the implementation and the organisation of the implementation process of piped subsurface drainage systems with the focus on developing countries. It is composed of three parts:

• Part I discusses the planning of the implementation process of pipe drainage systems;
• Part II gives practical guidelines for the actual implementation, and;
• Part III presents the salient features of the history and present practices of the implementation in a number of countries.

The handbook of 608 pages contains 56 instruction sheets, 230 figures and illustrations, a glossary, a bibliography and an index.

About the authors

Henk Nijland has been involved in land drainage since 1976 and has worked on international land and water development projects for over 25 years. The implementation practices of subsurface drainage systems have always been an area of special interest to him. He was project manager of the Drainage Executive Management Project in Egypt for many years. He has lectured on land drainage for courses in several countries and for the International Course on Land Drainage (ICLD).

Frank W. Croon graduated from the Agricultural University in Wageningen, The Netherlands. He has been involved in drainage and salinity control for more than 35 years. His activities focused on planning, design, implementation, organization and maintenance of irrigation and drainage systems, often in salt affected areas. Training and transfer of technology was often a major part of his tasks.

Henk Ritzema obtained an MSc in Civil Engineering in 1980. He has twenty-three years of experience in design, construction, research and education in drainage-related water management for agricultural land. He is primarily interested in the organization, management and implementation of research and training activities in drainage-related management, including capacity building through the dissemination of knowledge.

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