Performance Assessment of Subsurface Drainage Systems

Case Studies from Egypt and Pakistan

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Abstract
A case study set-up for the performance assessment of subsurface drainage systems for agricultural land drainage has been developed and 76 case studies from Egypt and Pakistan have been prepared. Based on these case studies, performance indicators for subsurface drainage systems have been derived and the main lessons learned to assess the performance of these systems have been summarized.

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Keywords: Subsurface drainage, performance assessment indicators, planning, design, installation, operation and maintenance, Egypt, Pakistan

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Preface

Assessment of the performance of drainage systems is a component of the FAO-AGLW Regular Program. Outputs of this program are, among others, case studies in Mexico and Spain. These case studies will be used to prepare a FAO Irrigation and Drainage Paper on "*Performance assessment of land drainage systems*". To assist the FAO with this forthcoming publication, Alterra-ILRI has undertaken a study with the aims (i) to prepare a case study set-up with table of contents and method of reporting, and; (ii) to prepare case studies for respectively Egypt and Pakistan.

These case studies are based on Allterra-ILRI's assess to a vast source of grey literature on drainage projects in Pakistan and Egypt. In Egypt, the long-term cooperation with the Drainage Research Institute was in the framework of the Drainage Research Project (1994 – 2001) and preceding Pilot Areas and Drainage Technology Project (1981-1993). In Pakistan, the long-term cooperation with the International Waterlogging and Salinity Research Institute was in the framework of the Netherlands Research Assistance Project (1988-2000).

This study could not have been conducted without the data and support provided by these organisations and projects.

Summary

Performance assessment of a land drainage system can be defined as the systematic observation, documentation and interpretation of the management of the system with the objective of ensuring that the input of resources, intended outputs and required actions proceeded as planned.

This report presents the outcome of the study for the set-up of a framework for the evaluation of the performance of land drainage systems based on a review of case studies for respectively Egypt and Pakistan. Chapter 1 present the rationale and purpose of the study and the structure of the report. In Chapter 2, a general framework for the planning and implementation of performance assessments of subsurface drainage systems is presented. In this framework, the aims of performance assessment for the four main steps in subsurface drainage practices, i.e. identification, design, installation and operation & maintenance, are discussed. The framework was used to prepare an overview of the available indicators to assess the performance of subsurface drainage systems, differentiating between technical, socio-economic and environmental factors. In Chapter 3 and 4, this framework was used to prepare case studies for respectively Egypt and Pakistan. The format of the case studies is standardized, presenting the following information: subject, location/region, the used indicators, the stage in the subsurface drainage process, the background, the problem, the action/intervention undertaken to solve the problem, the main lessons learned and the references. Totally 76 case studies have been prepared, 51 from Egypt and 25 from Pakistan. In Chapter 5, the main performance indicators used in the cases studies and the lessons learned are summarized.

In a following phase, the outcomes of this study will used to prepare the above mentioned FAO Irrigation and Drainage Paper on performance assessment of land drainage systems. In this paper, the main framework will be worked out in more detail, discussing the theory and application of performance assessment in subsurface drainage systems.

1 Introduction

1.1 Background

Assessment of the performance of drainage systems is a component of the FAO-AGLW Regular Program. Outputs of this program are, among others, case studies in Mexico and Spain. These case studies will be used to prepare a FAO Irrigation and Drainage Paper on "*Performance assessment of land drainage systems*". To assist the FAO with this forthcoming publication, Alterra-ILRI has undertaken a study with the aims:

(i) To prepare a case study set-up with table of content and method of reporting, and;
(ii) To prepare case studies for respectively Egypt and Pakistan.

The study is based on Allterra-ILRI's assess to a vast source of grey literature on drainage projects in Pakistan and Egypt. In particular the long-term cooperation with the Drainage Research Institute, Egypt, in the framework of the Drainage Research Project (1994 – 2001) and preceding Pilot Areas and Drainage Technology Project (1981-1993) and with the International Waterlogging and Salinity Research Institute, Pakistan, in the framework of the Netherlands Research Assistance Project (1988-2000).

1.2 Rationale

Drainage is the removal of excess surface and subsurface water from the land to enhance crop growth, including the removal of soluble salts from the soil. Drainage of agricultural lands is an instrument for production growth, a safeguard for sustainable investment in irrigation, and a tool for conservation of land resources. Projections to meet the food and fibre need of the world show that food production has to be doubled in the next 25 years. The majority of this increase will have to come from investments in improved irrigation and drainage practices in existing agricultural lands. Presently, about 190 Mha, i.e. 13 % of the world's arable land, is provided with some sort of drainage (Table 1). About 130 Mha are in rainfed agriculture in humid regions and about 60 Mha in irrigated areas in semi-arid and arid regions (Schultz et al., 2005). Of these 60 Mha, about one fifth is in Egypt and Pakistan alone. In these countries, the majority of the population is still employed in the agricultural sector, of which irrigated agricultural is an important component. Most of the drainage systems are at least 30 - 40 years old. It is estimated that, in irrigated areas, existing systems have to be replaced/rehabilitated in about 30 Mha. Furthermore, to overcome irrigation induced waterlogging and salinity problems, in about the same area new systems have to be installed (Nijland et al 2005). It is expected that about 50% of these will be subsurface drainage systems. This will require an investment of about € 19 billion or € 750 million annually.

Table 1 Key indicators of the agricultural sector in Egypt and Pakistan (ICID 2003)

Indicator	**Unit**	**Egypt**	**Pakistan**	**World**
Total geographical area (TGA)	[Mha]	100	80	13 425
Arable & permanent cropped area (APC)	[Mha]	3.4	22.1	1 497
Population	[Million]	71	150	6 134
Population in Agriculture	[Million]	40	99	3 211
Population in Agriculture	[%]	57	66	52
Population Density with ref. to TGA	[No.km^{-2}]	70	188	45
Population Density with ref. to APC	[No.km^{-2}]	2 074	678	410
Food Production (Cereals)	[MT]	19	28	
Productivity for Cereals	[kg/ha]	7 249	2 302	
Gross national income per capita	[US$]	1.390	520	
Irrigated area	[Mha]	3.4	17.8	272
Irrigated Area	[% of APC]	100	80	18
Drained Area	[Mha]	3.0	6.0	190
Drained Area	[% of APC]	88	27	13

In this publication we define a subsurface drainage system an man-made system that induces excess water and salts to flow via the soil to wells, mole, pipe and/or open drains, from where it can be evacuated from the land to enhance crop growth (for other definitions see the Glossary).

Subsurface drainage has been practiced for thousands of years, large-scale introduction, however, only started around the middle of the last century, when the prevailing empirical knowledge of drainage and salinity control gained a solid theoretical foundation. Since then, the installation practices evolved from purely manual installation on individual farm plots to fully mechanised installation programmes covering thousands of hectares (Ritzema et al 2006). To make this rapid change possible, practical tools for the implementation had to be developed, starting with the introduction of new types of installation equipment, i.e. trencher and trenchless drainage machines. To optimize the use of these machines, a number of problems had to be solved. New materials for drain pipes and envelopes had to be developed to reduce the high transportation and installation cost of the traditional materials and to improve quality of construction. Next, the traditional method of quality control proved to be inadequate because of the increased speed and method of mechanical installation. And last but not least, staff had to be trained in these modernised drainage machinery and installation techniques, as well as in the planning and organisation of the implementation process. These developments are still going on to meet the specific needs of installation in developing countries, under climatic, physical and social conditions that differ from the ones for which they have been designed. Furthermore, the specific needs of drainage are also changes, particularly with regards to the quality of drainage water, that require changes in the drain system design and corresponding installation practices.

Performance assessment is a tool to improve subsurface drainage practices. Performance assessment in irrigation and drainage can be defined as the systematic observation, documentation and interpretation of activities related to agricultural water management with the objective of continuous improvement (after Bos et al 2005). Performance assessment can be done at various levels. Murray-Rust and Snellen (1993) distinguish between operational and strategic performance. The difference is perhaps best explained by management guru Peter Drucker (1910-2005), who said: "Before you wonder *'Am I doing things right?'* (= operational management) ask *'Am I doing the right things*?'"(= strategic management).

Small and Svendsen (1992) identify four different types of performance assessment, to which Bos et al (2005) added a fifth:

- Operational performance assessment: day-to-day, season-to-season monitoring and evaluation of scheme performance.
- Accountability performance assessment to assess the performance of those responsible for managing a scheme.
- Intervention assessment to study the performance of a scheme and, generally, to look for ways to enhance that performance.
- Sustainability performance to look at the long-term resource use and impacts.
- Diagnostic analysis seeks to use performance assessment to track down the cause, or causes, of performance in order that improvements can be made or performance levels sustained.

These different types can be used to assess the various aspects of subsurface drainage system, i.e.:

- Operational and accountability performance to study and/or improve operation & maintenance practices;
- Intervention assessment to look to improvement and rehabilitation measures to enhance the operation and drainage practices;
- Sustainability performance to analyse whether the objectives have been met and/or look into long-term resource use and impacts. The latter impacts are generally not specific defined in the (design) objectives but implicit taken into consideration during the design.
- Diagnostic analysis to analyse how the design and construction practices can be improved.

Based on these types of performance assessment, indicators for irrigation and drainage systems have been identified at regional and system level, see for example Bos et al, 2005. A performance indicator is a (dimensionless) indicator whose ratio includes both an actual value and an intended (target or critical) value of data on the considered key parameter. Major functions of performance indicators are (after Murray-Snellen, 1993):

- Policy or strategic: "*Am I doing the right thing?*"
- Operational: "*Am I doing things right?*"
- Diagnostic: "*Is the system performance according to the design criteria/objectives?*".

The purpose of performance assessment of subsurface drainage systems is to achieve an efficient and effective system performance by providing relevant feedback to the management of the drainage system at all levels. As such, it may assist the management in determining whether the performance is satisfactory and, if not, which and where corrective actions need to be taken in order to remedy the situation. Available resources in this context refer not merely to financial resources: they also cover natural resources (land and water) and the human resources to operate, maintain and manage the systems. Strategic management involves not only the system manager, but also higher level staff in agencies at the national planning and policy levels.

Performance assessment methods and the corresponding indicators, however, have not been applied widespread to field drainage systems. The lack of performance assessment for field drainage systems prevents a systematic evaluation of the effectiveness of this type of drainage. This limits the application of innovation in both the design and the management of these systems. To improve current and future subsurface drainage practices, there is a need to identify drainage system performance assessment indicators at a more detailed level, i.e. tertiary and farm level.

1.3 Purpose of this study

The overall objective of this study is to identify indicators for drainage system performance at the tertiary and farm level. Based on a literature review of case study materials from Egypt and Pakistan, performance assessment indicators for specific issues of subsurface drainage practices have been identified. The indicators have been grouped based on the stage of subsurface drainage practices they address, i.e.: (i) planning and organisation; (ii) design; (iii) installation, and (iv) operation and maintenance. Within these stages, the indicators are grouped under three headings: technical, socio-economic and environmental.

1.4 Structure of this report

In Chapter 2, a general framework for the performance assessment of subsurface drainage practices is presented. This framework is based on the four main stages that can be distinguished for subsurface drainage practices, i.e.: (i) Planning and organisation; (ii) Design; (iii) Installation, and (iv) Operation and maintenance. In Chapter 3 and 4, the subsurface drainage practices in Egypt and Pakistan are presented based on the case studies that are presented in Appendix A (for Egypt) and Appendix B (for Pakistan). These case studies are based on a literature review. For Egypt, the case studies are derived from the outcomes of the Drainage Research Project (1995–2001) (DRI, 2001), it's preceding Drainage Technology and Pilot Areas project (1982-1993) (DTPA, 1993) as well as outputs of the Water Quality Monitoring project (1995-2000). For Pakistan, the case studies are derived from the outcomes of the Netherlands Research Assistance Project (1988-2000) (Alterra, 2001 and Wolters, 2002). The format of the case studies is standardized, presenting the following information: subject, location/region, the used indicators, the stage in the subsurface drainage process, the background, the problem, the action / intervention undertaken to solve the problem, and the lessons learned. In Chapter 5, the most relevant indicators addressed in the case studies are summarized. These indicators and lessons learned so far are preliminary results; in a following study phase, they will be worked out in more detail.

2 Performance assessment of subsurface drainage systems

Subsurface drainage practices can be divided in four main steps (after Nijland et al, 2005):

1. **Planning and organization**: policy preparation, decision-making and technical, organizational and administrative preparation
2. **Design**: field investigations, design, planning and budgeting, tender preparation and tendering
3. **Installation**: procurement of materials and equipment, construction, quality control
4. **Operation and maintenance**.

Performance assessment can address one or more of these steps, for example, with the aim (Figure 1):

1. To improve planning and identification, e.g. by assessing whether the original objectives were realistic, whether they were realised or whether the environmental impacts were correctly assessed, whether there are long-term resource used or impacts not considered during the design, etc.;
2. To improve design practices;
3. To improve installation practices;
4. To analyse and improve (if appropriate) the operation & maintenance practices, or;
5. To develop rehabilitation measures to enhance the operation and drainage practices.

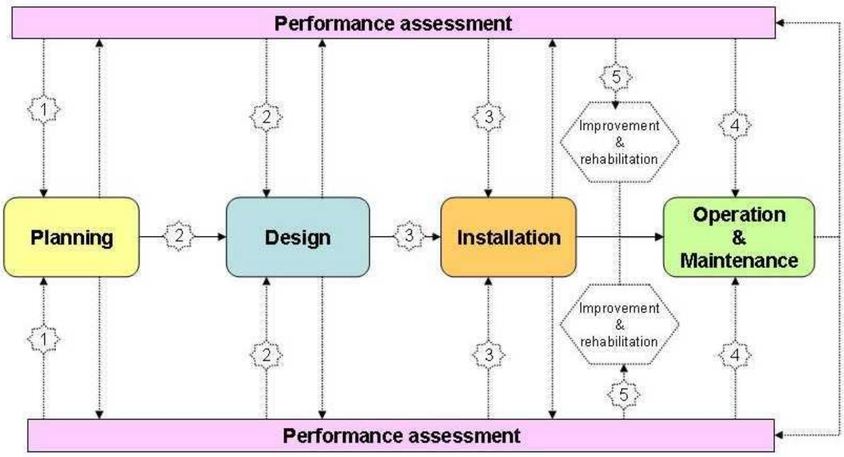


Figure 1 Performance assessment should focus on a specific aspect of subsurface drainage practices.

The focus can, of course, be further specified, e.g. improvement of installation practices can either focus on materials used for the installation or on installation equipment or on institutional arrangements, etc. To develop the performance indicators for these various aspects of subsurface drainage, we will to look into these various aspects in more detail, starting with the objectives of subsurface drainage.

Objectives of subsurface drainage

The objectives of agricultural subsurface drainage systems are to reclaim and conserve land for agriculture, to increase crop yield, to permit the cultivation of more valuable crops, to allow the cultivation of more than one crop a year/season, and/or to reduce the cost of crop production in otherwise waterlogged land (Oosterbaan 1994). An objective is defined as a broad goal that reflects the overall purpose of the irrigation or drainage system or the sector within the irrigation and drainage system falls. Typically, objectives are not precise, exemplified by such phrases as crop diversification, equity, adequacy, or sustainability (Murray-Rust and Snellen, 1993). Objectives represent the agricultural aims that are to be achieved; the social and economic factors are generally “hidden” in these objectives. The installation of a subsurface drainage system has generally two direct effects and a large number of indirect effects (Figure 2). The direct effects of installing a drainage system are:

- A reduction in the average amount of water stored on or in the soil, inducing drier soil conditions and reducing waterlogging;
- A discharge of water through the system.

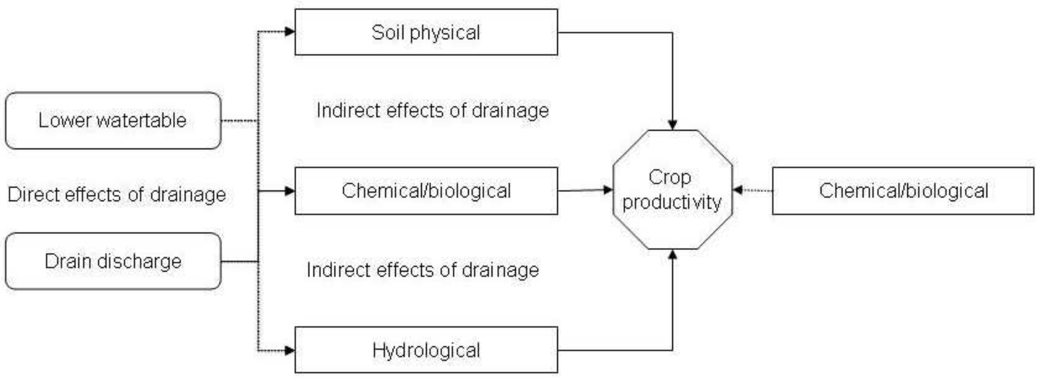


Figure 2 The installation of a subsurface drainage system trigger of a series of direct and indirect effects (after Oosterbaan 1994).

A complicating factor is that the objectives are not related to these direct effects but to the indirect effects. This is illustrated in the design process where the agricultural objectives of subsurface drainage systems, e.g. yield optimization, optimization of farm management practices, etc., cannot directly be applied in most design methods; they have to be expressed in design criteria or targets like: depth of the water table, maximum period of flooding, degree of waterlogging, dryness or wetness of the soil and/or soil salinity. A design criterion is a specific value by which an (agricultural) objective can be measured for value. Owing to its variation in time and space, these criteria have to be specified, e.g. in:

- An average depth of the watertable;
- Seasonally salinity levels in the root zone;
- A number of days that the land is workable during a critical period.

The direct effects are mainly determined by the hydrological conditions, the hydraulic properties of the soil, and the physical characteristics of the drainage system. The direct effects trigger a series of indirect effects. These indirect effects are determined by climate, soil, crop, agricultural practices, and the social, economic, and environmental conditions. The indirect effects can be physical, chemical, biological, hydrological and also social and financial. It is obvious that, in general, the direct effects are not the reason (objectives) why subsurface drainage systems are installed; these objectives are "hidden" in the indirect effects. Thus assessing whether the objectives have been obtained is much more difficult, but not less important, than assessing the direct effects. To make the assessment even more complicated, it should be realised that some of these indirect effect are intended (i.e. the objectives of drainage) and some are unintended. These unintended effects can be either positive or negative (Ritzema and Braun, 1994), i.e. a lower watertable can induce subsidence; an induces flow to the drainage system not only leaches the salts from the rootzone but also fertilizers, herbicides or pesticides, drainage effluents can result in downstream flooding, waterlogging or salinity problems, etc.

Soil and hydrological parameters

The soil and hydrological parameters are factors representing the given climatic, soil or hydrological conditions and water management practices under which the system has to function. Examples of these factors are irrigation, rainfall, the watertable, the water-transmitting properties of the soil, the natural surface or subsurface drainage, and the topography. Most soil and hydrological parameters vary in time and/or space. The challenge is to derive a representative value of the parameter that can be used in the design, e.g.:

- A rainfall event with a frequency of occurrence of 1-, 2- or 3-days or 1 in 5- or 10-year rainstorm.
- The conductivity of a soil based on an average or geometric mean value.
- A one-, two- or multi-layer soil profile, etc.

Engineering factors

The engineering factors are factors representing the technical and material components of the drainage system, e.g. the lay-out, the longitudinal- and cross-section of the drains, and the type and quality of materials. Each type of drainage system has its specific engineering factors, for subsurface drainage systems they are the length, depth, slope, spacing and dimensions of the field and collector drains and the materials and machinery used for the installation.

Design approach in subsurface drainage

In the design of a subsurface drainage system, the above mentioned (agricultural) objectives and the soil and hydrological parameters are used to calculate the required drain depth and spacing. Subsurface drainage designs are based on theoretical drainage equations based on a simplification of the complex reality in the field. The challenge is to simplify this complex real situation to such an extent that mathematical solutions can be derived without losing the essence of the problem. In subsurface drainage, designs are based either on a steady-state or on an unsteady state approach (Ritzema 1994). Both approaches simplify the complex reality in the field thus the resulting designed SSD-system is only an approximation and not an absolute solution for the complex reality.

Installation practices for subsurface drainage
The SSD-system than will finally be installed will again differ from the designed system. These differences are unavoidable, e.g. drain spacing and drain depth are rounded of avoid mistakes with setting out levels and actual spacings, depths and alignments will differ from the design as there will always be some inaccuracy in the work done by man and/or machine. For performance assessment of installation practices, the emphasis should be on lessons learned and how new projects can benefit from these experiences,

Operation and maintenance practices
Like all infrastructure, subsurface drainage systems require operation and maintenance. The operation of subsurface drainage systems is mostly limited to the operation of pumps if any. In some cases, where controlled drainage is practiced, the operations can also involve opening and closing of gates. Maintenance of subsurface drainage systems consists mainly of removing sediment from the pipes and manholes, repairing and – if necessary – replacing these pipes, manholes and outlets. Maintenance of the open (main) drains is mainly confined to removing sediment and weeds. Maintenance of the pipe (subsurface) drainage system can not be entirely separated from maintenance of the downstream open (main) drains and/or outlets: if the downstream open drainage system is not properly maintained, it will influence the functioning and maintenance of the pipe drainage systems. Generally speaking, the main objective of the maintenance of an open drainage system is to keep the water level below the outlet level of the pipe drainage system(s) at all times.

In summary, subsurface drainage practices include many aspects, thus depending on the aims of the performance assessment, a number of indicators has to be selected for quantify these aspects. In this report a distinction is made between technical, socio-economic and environmental indicators. Based on a review of a number of case studies in Egypt and Pakistan these indicators were identified for the four phases of subsurface drainage practices, i.e.:

- Planning and organisation
- Design
- Installation, and
- Operation and maintenance.

3 Egypt

3.1 History of irrigation and drainage in Egypt

The Nile River Basin is, like the Indus basin, one of the oldest agricultural areas in the world. As Egypt's average annual rainfall ranges from 1.5 mm in the south (near Aswan, about 900 km south of Cairo) to 150 mm in the north (in the coastal regions bordering the Mediterranean Sea, about 150 km north of Cairo), agriculture has always depended upon irrigation. The River Nile represents the only renewable source of water for Egypt's 3.4 million ha agricultural lands (Figure 3) (Amer and Abu-Zeid, 1989).

Figure 3 Agriculture in Egypt depends entirely on irrigation from the River Nile

Since the days of the Pharaohs until the 19th century, basin irrigation has been practiced. For this ancient method of irrigation, based on the natural regime of the Nile, the natural drainage capacity of the land was sufficient to protect the area against the twin problem of waterlogging and salinity. In the 19th century, new crops, i.e. cotton and sugarcane were introduced that required water when the Nile's water levels were low. This resulted in the construction of barrages in the River Nile and a network of irrigation canals and open drains. The completion of the Aswan High Dam in 1968 finally eliminated the Nile's season floods and allowed all agricultural lands to be brought under perennial irrigation. The main crops are cotton, sugarcane and paddy in summer and wheat and berseem (Egyptian clover) in winter.

The elimination of the seasonal fluctuation in the River Nile, however, resulted in higher piezometric pressure in the aquifer underlying the agricultural areas in the Nile Valley and Delta, reducing the natural drainage capacity (Wolters et al., 1986) (Figure 4). Together with the increased percolation from irrigation this gradually resulted in waterlogging and salinity problems in large areas in The Nile Valley and Delta. The open drainage systems, constructed since the second part of the 19th century, were not sufficient to overcome these problems and in the 1960's, The Egyptian Government embarked upon an ambitious programme install subsurface drainage systems in all agricultural lands by 2011 (Nijland 2000). On top of this, the rehabilitation of subsurface drainage systems older than 30 years was initiated covering about 0.44 million ha. Annually, about 63.000 ha are provided by new subsurface drainage systems while old drainage systems are rehabilitated in about 12.600 ha.

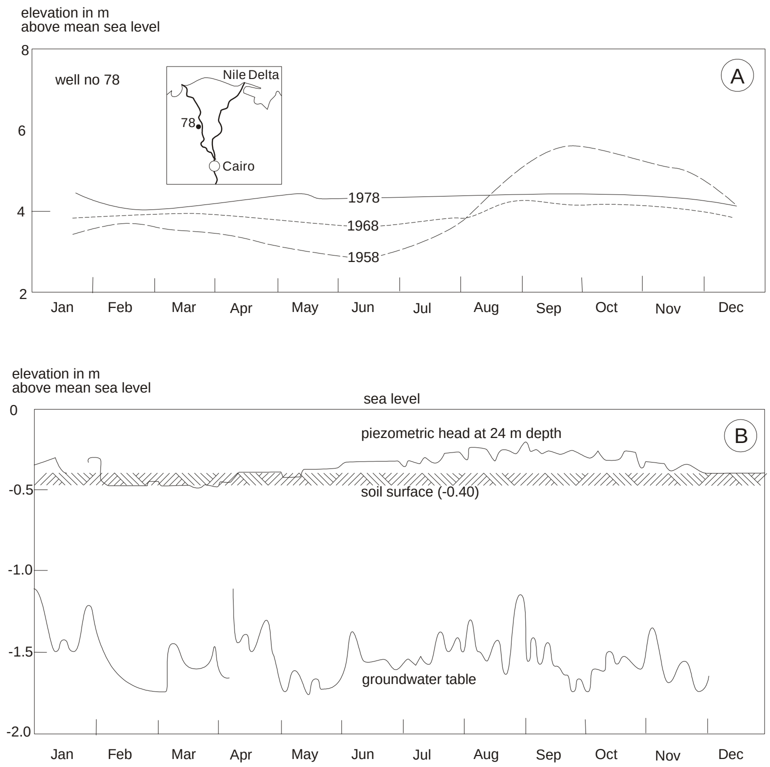


Figure 4 A: Fluctuation of the piezometric head in the Nile Delta Aquifer, before (1958) and after (1978) the construction of the Aswan High Dam (completed in 1967), and B: Piezometric head and the fluctuation of the groundwater table in Shereishra Pilot area (Bos and Wolters 1994).

3.2 Subsurface drainage practices in Egypt

3.2.1 Organisation

To implement this ambitious drainage programme several institutions were established within the Ministry of Water Resources and Irrigation (MWRI). In 1973, the Egyptian Public Authority for Drainage Projects (EPADP) was established. EPADP is 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. EPADP is organised in five regional divisions. The actual construction is done by public and private contractors. 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.

To assist EPADP with this programme, a new research infrastructure was set-up within MWRI. The Drainage Research Institute (DRI) was established in 1976 as part of the National Water Research Centre (NWRC) of MWR 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. Since its establishment, DRI has cooperated with Alterra-ILRI through a number of bilateral projects. The first project (1976-1979) established the Egyptian-Dutch Advisory Panel on Land Drainage, with various drainage research and capacity building components (Amer and De Ridder, 1989 and Van der Zel and Amer, 1983). It was followed by a series of bi-lateral technical assistance projects. In the first phase of this long-term cooperation, the emphasis was on technical cooperation (DTPAP, 1993). In the follow-up projects, the emphasis was on transforming DRI in a robust research organisation, capable of high quality work, recognised and sought after by clients nationally and internationally (DRI, 2001).

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. Finally, the Soils, Water and Environment Research Institute (SWERI) of the Ministry of Agriculture and Land Reclamation (MALR) conducts 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 sub-soiling and its effect on drainage enhancement.

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. 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, but are now fully owned by the Ministry 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, 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 started some forty years ago, 90% of the contractors were public contractors. Nowadays, the balance has shifted in favour of private contractors. Although, the Government of Egypt pre-finances the installation of subsurface drainage systems, the farmers pay back the full investment cost of subsurface drainage over 20 years without interest.

3.2.2 Description of the subsurface drainage system

The subsurface drainage system installed in Egypt consists of buried pipes, forming a regular pattern of field and collected drains (Figure 5). The field drainage system consists of subsurface field (lateral) and collector pipes that runs by gravity. The piped 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.

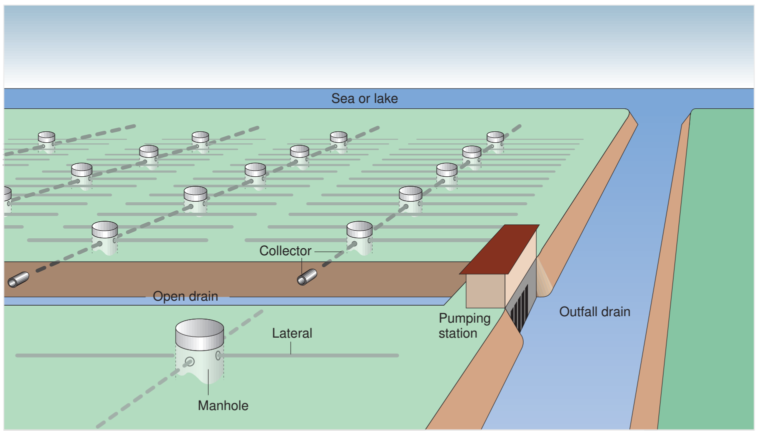


Figure 5 Schematic representation of the subsurface drainage system used in Egypt

The design criteria of the subsurface drainage system are based on the requirements of the most critical crop, which was considered to be cotton (Abdel-Dayem and Ritzema, 1990). In the Nile Delta, cotton is cultivation in rotation with other crops: berseem (Egyptian clover) and wheat in winter and rice and maize in summer (Figure 6).

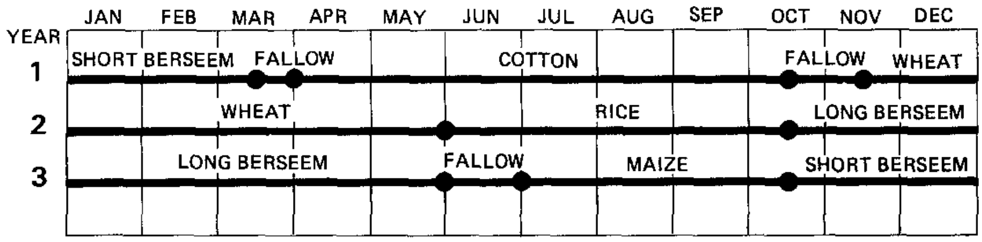


Figure 6 Example of the crop rotation in the southern part of the Nile Delta

The design criteria can be divided in agricultural and technical criteria. The agricultural criteria are based on the effect of land drainage on crop production under the prevailing agricultural and hydrological conditions. The technical criteria are related to the performance of the drainage system, and are based on the drain discharge, drain capacity, optimum drain depth, and the spacing, slope and diameter of the drains. The drainage design criteria currently used in Egypt are:

For the calculation of the depth and spacing of the field drains:

- A design depth of the watertable midway between the drains of 1.0 m to guarantee favourable soil-water conditions for the deep-rooting crops (cotton).
- A design discharge of 1.0 mm/day to maintain soil salinity levels below the critical levels for crop production. In the northern parts of the Nile Delta (north of the 3m+MSL-countour) this rate has been increased to 1.2 mm/d (Nijland 2000).

For the calculation of the diameters of the field and collector drains:

- A peak design discharge for the determination of drain-pipe capacity of 4 mm/d for rice areas and 3 mm/d for non-rice areas.
- A safety factor of 25 % in the design of the collector drains to take into account sedimentation and irregularities in the alignment.
- No overpressure in the system at discharges equal to the peak design rate.
- A maximum drain depth of 1.5 m for field drains and 2.5 m for collector drains.

On basis of these criteria, drain spacing are calculated using Hooghoudt's steady-state approach (Ritzema, 1994). In spite of the theoretical computations, a limit is imposed on the drain spacings: minimum 30m and maximum 60m (Nijland 2000). The field drains have an average length of 200 m and a design slope between 0.1 and 0.2%. Collector drains are spaced at 400 m and consists of pipes with increasing diameter. The diameters s are based on the Manning equation for transporting pipes (Vlotman 1994) using a roughness coefficient derived by Visser (Ven 1983).

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 piped systems can discharge by gravity in these main drains;
- Construction of piped field drainage systems consisting of field drains (named laterals in Egypt) and piped collector drains.

3.2.3 Disposal of the drainage effluent

The River Nile is not only the only source of irrigation water in Egypt, it also is the main disposal drain as all drainage effluent from the agricultural lands in the Nile Valley is discharged back to the river. This is possible as only about one third of the agricultural lands are located in the Nile Valley (Figure 3). 20×10^9 m^3/year of the total amount of water passing the Aswan High Dam (approximately 55×10^9 m^3/year) is used to irrigate these agricultural lands between Aswan and Cairo (approximately 0.9 Mha). Because all the drainage water is discharged back into the River Nile, the salinity of the Nile water increases in downstream direction (Table 2). This practice is safe and sustainable because the salinity of the water entering the Nile Delta is still so low (< 0.47 dS/m) that it can be used for irrigation. In the Nile Delta, however, a separate open main drainage system had to be constructed to discharge the drainage effluent directly in the sea as diverting this water back to the river would result in unacceptable high salinity levels. The increase in the total salt load between Cairo and the Mediterranean Sea is due to the leaching of deeper (saline) soil layers and the seepage of saline groundwater. Since 1930, 21 pumping stations have been built in the Nile Delta to pump part of the drainage water back into the irrigation system. Part of this drainage effluent is re-used: in the 1980's, approximately 2.9×10^9 m^3/year of drainage water with an average salinity of 1.45 dS/m was pumped back into the irrigation system, totalling approximately 15% of the crop water supply. At field level, farmers also re-use drainage water for irrigation by pumping it directly from the drains, again covering about 15% of the crop water requirements. A major disadvantage of this re-use is that, because the salinity of the re-used water is often high, it contributes more than proportionally to the total salt supply to the crop. It is estimated that the contribution of the 15% re-used water is about 46% of the total salts supplied through irrigation.

Table 2 Discharge, salinity, and salt load in the River Nile (Ritzema and Brain, 1994)

Location	**Discharge ($\times 10^9$ m^3/yr)**	**Salinity (dS/m)**	**Total salt load ($\times 10^9$ kg)**
Aswan High Dam	55	0.31	11.0
Delta Barrage (Cairo)	35	0.47	10.5
Mediterranean Sea	14	3.59	32.0

3.3 Case Studies

To develop a general framework for performance assessment of subsurface drainage systems, 51 case studies that highlight the SSD-practices in Egypt were selected (Table 3). The case studies are presented in Appendix A.

Table 3 Cases studies on subsurface drainage practices from Egypt

No.	Case Study	Step in the SSD project cycle addressed by the case study			
		Planning	**Design**	**Installation**	**O & M**
Eg-01	Egyptian Public Authority for Drainage Projects	● [a]	○	○ [a]	○
Eg-02	Advisory Panel on Water Management	●	○	○	○
Eg-03	Project planning and preparation	●			
Eg-04	Planning the execution of drainage projects	●		○	
Eg-05	Tendering and contracting	●		○	
Eg-06	Improvement of planning and implementation	●		○	
Eg-07	Large-scale execution of drainage projects	●			
Eg-08	Planning SSD in areas with heavy clay soils	●		○	
Eg-09	Capacity building	●	○	○	○
Eg-10	Investments in drainage – lessons learned	●		○	
Eg-11	Planning and managing research activities	●			
Eg-12	Planning field research	●	○		
Eg-13	Organisation of research activities	●			
Eg-14	Evaluation of research programmes	●			
Eg-15	Data information system	●			
Eg-16	Selection criteria for a drainage pilot area	●	○	○	
Eg-17	Capacity building for research	●			
Eg-18	Automation of the design process		●		
Eg-19	Simulation models for design and evaluation	○	●		
Eg-20	Verification of drainage design criteria		●		
Eg-21	Verification of drainage design criteria		●		
Eg-22	Selection of a drain envelope		●	○	
Eg-23	A modified layout for rice areas		●		○
Eg-24	Determining hydraulic conductivity		●		
Eg-25	Evaporation from brackish/saline open-water bodies	○	●		
Eg-26	Materials for pipe drains		○	●	○
Eg-27	Handling synthetic envelope materials		○	●	
Eg-28	Wrapping synthetic envelopes			●	
Eg-29	Field - collector drain connection		○	●	
Eg-30	Capacity of drainage machines	○		●	
Eg-31	Efficiency of drainage machines	○		●	
Eg-32	From manual to mechanical installation	○	○	●	
Eg-33	Installation using trenchless machines	○		●	
Eg-34	Laser technology			●	
Eg-35	Installation: hard rock	○		●	
Eg-36	Installation: upward pressure	○		●	
Eg-37	Quality control by rodding			●	○
Eg-38	Construction of drainage pilot areas	○		●	

No.	Case Study	Step in the SSD project cycle addressed by the case study			
Eg-39	Functioning of SSD		○		●
Eg-40	Assessing the functioning of SSD				●
Eg-41	Hydraulic performance collector drains		○	○	●
Eg-42	Controlled drainage and farmers participation	○	○		●
Eg-43	Managing SSD to save irrigation water	○	○		●
Eg-44	Leaching of nitrates	○			●
Eg-45	Safe disposal of drainage effluent		○		●
Eg-46	Maintenance SSD systems - flushing				●
Eg-47	Video inspection to assess maintenance needs				●
Eg-48	Monitoring drainage effects and impacts	○			●
Eg-49	Monitoring salinity with EM38	○	○		●
Eg-50	Performance assessment for rehabilitation criteria	○			●
Eg-51	Criteria for rehabilitation of SSD-systems	○			●

[a] ● : main activity addresses in the case study

○ : supplementary activity addressed in the case study

4 Pakistan

4.1 History of irrigation and drainage in Pakistan

Like the Nile basin, the Indus basin is one of the oldest and most populated agricultural areas in the world. The rainfall is rather erratic and does not follow the normal monsoon pattern experienced in the region further south. Subsequently, about 80% of the arable land is irrigated. Agriculture thrives when the rains are on time and properly spaced: then a good cotton crop is followed by a wheat crop. Before the introduction of the diversion-controlled irrigation in the 19th century a hydrological equilibrium existed between the recharge and discharge of groundwater, enabling a timely removal of excess water and the dissolved salts (Fahlbusch et al., 2004). The introduction of large-scale irrigation in the 19th century, however, resulted in a distinct rise of the groundwater (Figure 7). As a consequence waterlogging and salinity now are a serious threat to irrigated agriculture: of the 16.7 million hectare in the Indus Basin about 2 million hectare are waterlogged and 6 million hectare are salt-affected (Nijland et al 2005).

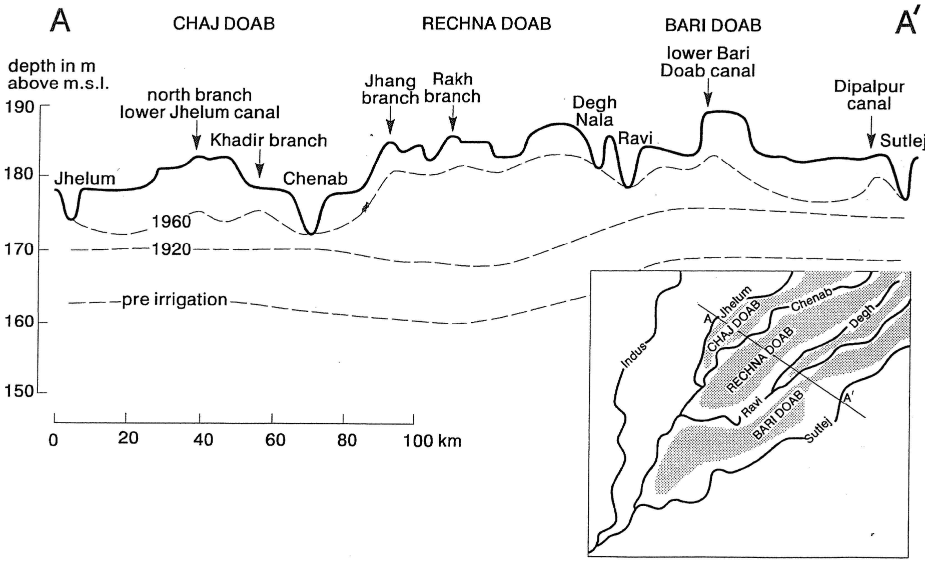


Figure 7 Groundwater profiles in north-eastern Pakistan (Bos and Wolters 1994).

To solve the problems of waterlogging and salinity, irrigation canals were lined, supplies were restricted and natural drainage channels that were interrupted by the construction of the irrigation network were restored. These measures, however, were not sufficient to overcome the above mentioned problems and in the 1960's the Government of Pakistan launched a comprehensive plan to control waterlogging and salinity through a series of Salinity Control and Reclamation Projects/SCARP's (Fahlbusch et al 2004). The Upper

Indus plain was divided into ten reclamation projects, ranging from 0.4 to 1.6 million ha, and sixteen projects in the Lower Indus, ranging from 0.3 to 0.8 million ha. Next to the construction of surface drainage system to restore the natural drainage capacity, "vertical" drainage was introduced through a network of tubewells with an average density of one tubewell per 2.5 square kilometre. By the turn of the century, 61 SCARP's were completed, covering about 8.98 million ha. In areas with saline groundwater, the use of tubewells, however, is not very successful because of serious operation and maintenance problems. In these areas, mainly located in Sindh, North West Frontier and Punjab Provinces, horizontal subsurface drainage systems are being considered more appropriate (Figure 8). The main problem in these areas is the disposal of the saline effluent. River flows only reach the sea for a few months per year, thus the disposal of saline effluent increasing the salt burden in the downstream irrigated lands. Alternative options, like the construction of evaporation ponds, are not environmentally sustainable and do not have sufficient capacities to handle the large quantities of salts imported by the irrigation water. The Left Bank Outfall Drain was constructed to drain approximately 0.5 million ha in the Sindh Province.

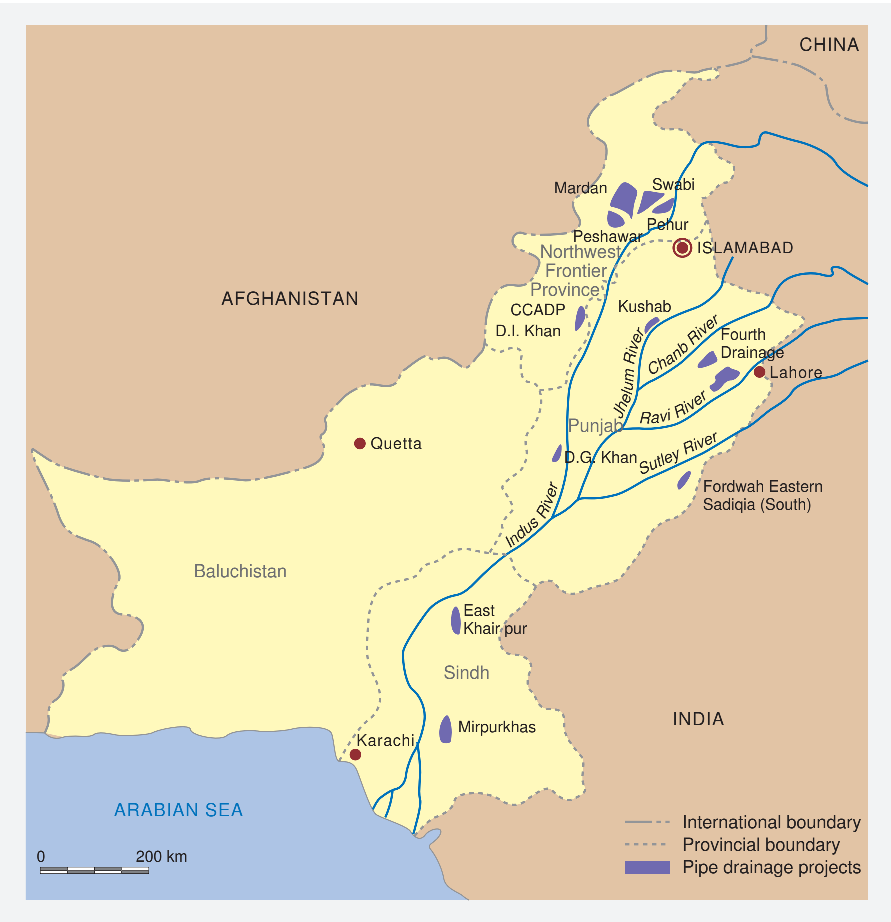


Figure 8 Subsurface drainage projects in Pakistan

4.2 Subsurface drainage practices in Pakistan

4.2.1 Organisation

The Water and Power Development Authority, established in 1958 as a part of the Ministry of Water and Power, is responsible for the subsurface drainage projects carried out in Pakistan. Subsurface drainage systems have been installed in areas with saline groundwater and cover about 220 000 ha. Installation is generally done by public or private consortia formed under the authority of WAPDA. The works are contracted to a specialized company.

In 1986, the International Waterlogging and Salinity Research Institute (IWASRI) was established. IWASRI, which is part of the WAPDA, has the mandate to conduct, sponsor, manage and undertake research on waterlogging and salinity in Pakistan. In 1988, the Netherlands Research Assistance Project was initiated, 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 (Alterra-ILRI, 2001). The project, which covered the period 1988-2000, had two main activities: work on technical aspects of drainage and the development of a participatory approach to drainage.

4.2.2 Description of the subsurface drainage system

The subsurface drainage systems installed in Pakistan typically consist of a composite system consisting of a buried collector and field drains. The major parts of the irrigated areas in Pakistan where waterlogging and salinity occur have little slope (basically "*one foot per mile*"), therefore pumped subsurface drainage systems are required and most collectors discharge into a sump from which the water is pumped into an open drainage network.

The drainage design discharge is a function of crop, water and leaching requirements and varies between 0.95 and 3.5 mm/d (Table 4). Drain depths are relatively deep, basically because of two reasons: (i) to reduce salinization of the root zone through capillary rise and (ii) deeper systems were cheaper because deeper drains allow larger drain spacings.

Table 4 Drainage design criteria for some major projects in Pakistan (Bhutta et al 1995)

Project	Designed	Constructed	Design parameters			
			Design discharge (mm/d)	Drain depth (m)	Design depth of watertable (m)	Hydraulic head (m)
East Khaipur Tile Drainage	1976	1986	2.5 – 3.5	1.95	1.0	0.95
MARDAN SCARP	1983	1992	3.0	2.40	1.05	1.20
Fourth Drainage	1983	1994	2.44	2.40	1.20	1.20
Chashma Command Area Development	1984	1994	1.2 – 2.6	2.10	1.40	0.90
Fordwah Eastern Sadiqia (South)	1994		1.5	2.10	1.20	0.90
Khushab SCARP	1990		1.8	2.10	1.20	0.90
Swabi SCARP	1994		2.0	1.80	1.00	0.80
Mirpurkhas II	1994		0.95	1.80 – 2.40		
DC Khan SCARP	1995		1.88			

Drainage in Pakistan is generally executed within the canal irrigation commands. The drainage projects are contracted to a special project organisation under the authority of the Water and Power Development Authority (WAPDA). WAPDA is responsible for the planning, design, tendering and contracting. In the past the Irrigation Department took over operation and maintenance. In 1997, however, the irrigation and drainage sector was reformed as the financial burden for O & M became too much for the Government. System management was decentralised with the establishment of autonomous Provincial Irrigation and Drainage Authorities (PIDA's). Area Water Boards (AWB's) and Farmers Organisations (FO's) were established to let farmers to take part in the system development and take over O & M. 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 to implement reforms (the responsibilities between the Irrigation Department and the PIDA's are not well defined); (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.

4.2.2 Disposal of the drainage effluent

Disposal of the drainage effluent is complicated because the majority of the agricultural lands, about 10.0 Mha of the total 16.7 Mha, are located in the Punjab in upper reach of the Indus River Basin (Figure 8). Not all drainage effluent from the agricultural lands in the Punjab, which a salinity that can vary between 4.7 and 15 dS/m, can be discharged back into the river system: the downstream salinity becomes too high. Attempts to dispose the drainage effluent in evaporation ponds have not been very successful because evaporation ponds need quite large area, between 10 and 15% of the land, and because of environmental constraints, i.e. seepage of saline drainage water, both from the unlined drainage canals as well as from the evaporation ponds itself, pollutes the groundwater reservoirs. To create a safe outlet, the Left Bank Outfall Drain has been constructed to discharge the drainage effluent of approximately 0.5 Mha directly into the Arabian Sea.

4.3 Case Studies

For the development of the general framework for the performance assessment on subsurface drainage systems, 27 case studies that highlight SSD-practices in Pakistan were selected (Table 5). The case studies are described in detail in Appendix B.

Table 5 Case studies on subsurface drainage practices from Pakistan

No.	Case Study	Step in the SSD project cycle addressed by the case study			
		Planning	Design	Installation	O & M
Pa-01	Organisation of the drainage sector	● [a]			
Pa-02	Organisation of SSD projects	●	○	○	
Pa-03	Participatory drainage development	●	○	○	○
Pa-04	Interceptor drains	●	○		
Pa-05	Improving the main drainage system	●			
Pa-06	Improving irrigation practices	●			○
Pa-07	Benefits of shallow drainage	●	○		
Pa-08	Benefits of research	●	○	○	○
Pa-09	Impacts of subsurface drainage	●			○
Pa-10	Improving SSD-design	○	●		
Pa-11	Modelling approach in field drainage design	○	●		
Pa-12	Groundwater approach to drainage design		●		
Pa-13	Optimizing the drainage design discharge	○	●		
Pa-14	Use of poor quality water for crop production		●		○
Pa-15	Gravel versus synthetic envelope		○	●	
Pa-16	Adapting envelope materials requirements	○	○	●	
Pa-17	Construction under wet conditions	○		●	
Pa-18	Trench backfill and pipe strech	○		●	
Pa-19	Costs of SSD-systems in Pakistan and Egypt	○		●	
Pa-20	Cost of subsurface drainage	○		●	
Pa-21	Farmers' participation in O & M	○			●
Pa-22	Drainage discharge and quality	○	○		●
Pa-23	Evaporation ponds	○	○		●
Pa-24	Performance of interceptor drains	○	○		●
Pa-25	Measuring soil salinity	○	○		●

[a] ● : main activity addresses in the case study

[b] ○ : supplementary activity addressed in the case study

5 Preliminary assessment of the indicators

A framework to assess the performance of subsurface drainage systems was introduced in Chapter 2. The framework is based on the four main steps in subsurface drainage practices i.e. (i) planning and organisation; (ii) design; (iii) installation, and (iv) operation and maintenance. Based on the analysis of the case studies from Egypt and Pakistan, the most important aspects (or subcomponent) of these four steps have been identified (Table 5). For each of these aspects a number of possible indicators have been selected. A further distinction between technical, social-economic and environmental indicators proved to be hardly possible and consequently has been refrained from the analysis. The indicators have been used to summarize the lessons learned from the case studies. These lessons are summarized in the following paragraphs.

Table 5 Indicators for subsurface drainage practices at field and tertiary level

Aspects or subcomponent	Step in the SSD process	Possible indicators to address this aspect
1. Objectives	Planning	Physical, social and economic conditions
2. Institutional set-up	Planning	Organization at national, provincial or project level
3. Stakeholders	Planning	Farmers, government, planning and implementation authorities, drainage contractors, suppliers of drainage materials and equipment
4. Capacity building	Planning	i) enabling environment; ii) institutional development, including community participation, and, iii) human resources development and strengthening of management systems
5. Implementation process	Planning	i) policy preparation and decision-making ii) technical, organizational and administrative preparation; iii) actual implementation: field investigations, design, planning & budgeting, tendering and construction, and iv) handing-over, operation and maintenance, including monitoring
6. Implementation mode	Planning	Specialized government entity or contracted to a specialized company
7. Costs and benefits	Planning	i) investment costs: staff, equipment, materials; (ii) pre-construction costs: field investigations, design, tender preparation & tendering; (iii) construction costs: materials, equipment, structures, staff, (iv) operational costs, and (v) maintenance costs, including monitoring Direct, associated or indirect (secondary) benefits
8. Area in need of drainage	Design	Soil & hydrological conditions, topography, outlet conditions
9. Drainage method	Design	Field drainage system: surface, subsurface or tubewell drainage; Main drainage system; interceptor drains, open or pipe drains; Pumped or gravity drainage
10. Drainage design	Design	Design depth of the (ground) watertable, design drain discharge
11. Drainage materials	Installation	Pipes, envelopes and structures
12. Drainage equipment	Installation	Excavators, trenchers, trenchless machines
13. Installation methods	Installation	Manual, mechanical or combined mechanical/manual
14. Quality control	Installation	Process, materials and installation
15. Operation	O & M	Controlled drainage, pumping, etc.
16. Maintenance	O & M	Preventive and/or repair or rehabilitation Regular and/or routine maintenance

5.1 Indicators for planning and organisation

Objectives

- Drainage is effective in controlling waterlogging and soil salinity in irrigated lands: it is highly profitable, for the (individual) farmers as wells as for the national economy (Eg-48, Pa-22).

Institutional set-up

- Large-scale implementation of drainage projects requires a specialized authority (Eg-01, Eg-07, Pa-01, Pa-02).
- The organisational set-up has to be adjusted from time to time to cope with changing (often increasing) responsibilities and circumstances (Eg-01, Eg-05, Eg-07, Pa-03).
- Institutional reforms in the organisation of the drainage sector are only successful if all stakeholders are involved (Eg-10, Eg-51, Pa-03).
- Without an appropriate legal framework reforms will not take place (Eg-51).
- Setting up sustainable farmers' organisations is not easy: at the start of the project, farmers have to agree among themselves on the structure, rules and tasks of the drainage organisation (Pa-03).

Stakeholder's participation

- Good cooperation and transparency between the various organisations is essential (Eg-04, Eg-07, Eg-08, Eg-16, Eg-18, Eg-37, Pa-03, Pa-08, Pa-21).
- Stakeholder's participation needs capacity building at all levels (Eg-08, Eg-14, Pa-03).

Capacity building

- Capacity building is required at all levels, i.e.
  - (i) To create an enabling environment (Eg-02, Eg-10, Eg-16, Pa-03, Pa-05, Pa-06, Pa-09);
  - (ii) For institutional development (Eg-01, Eg-10, Eg-51), and
  - (iii) For human resources development (Eg-05, Eg-09, Eg-17, Pa-03, Pa-11).
- The logical framework approach is a good tool to assess performance in capacity building projects. (Eg-14, Eg-17).
- Capacity building a never-ending process (Eg-18).

Implementation process

- To implement subsurface drainage projects on a large scale, policies have to be developed and institutional arrangements to be made (Eg-02).
- A high-level advisory panel, with members who are experts in various fields of experiences and head or share big public and private organisations, accelerated the implementation of drainage project mainly by advising the government on (future) water management strategies (Eg-02).
- A sound and well-balanced project preparation and planning system is required for the large-scale implementation of ssd-systems (Eg-03, Eg-04, Eg-05, Eg-08, Eg-10, Eg-37, Pa-02).
- The preparation and planning system should be flexible to adjust to changes in e.g. implementation methods, materials and equipment (Eg-03, Eg-10).
- Operational research is a effective tool for the following activities (Eg-06):
  - (i) Monitor the performance of individual projects;
  - (ii) Assess the performance of contractors and subsequently award new contracts;
  - (iii) Determine the number of machines needed for implementation, and;
  - (iv) Advise on the purchase of new machinery and equipment.

- In the successive steps of the implement process, a close cooperation between all stakeholders is required (Eg-04, Eg-07, Eg-08).
- A Management and Data Information System is a useful tool to support the managerial and technical activities (Eg-15).

Implementation mode

- There is no golden rule which implementation mode to apply: either a specialised public authority or special project organisations can be used (Eg-01, Pa-01, Pa-02).

Costs and benefits

- Subsurface is value for money (Eg-10)
- Pipe drainage systems, although more expensive, are better for the environment than tubewell drainage systems. Generally, the shallow groundwater quality in pipe drainage systems improves (or at least remains constant) whereas the deep groundwater quality does not change. In areas drained by tubewells the trend is that effluent quality decreases, except near canals (Pa-09).
- Research saves costs (Eg-08, Eg-14, Eg-20, Eg-21, Eg-22, Eg-23, Eg-42, Pa-04, Pa-05, Pa-07, Pa-08, Pa-10, Pa-11, Pa-12, Pa-13, Pa-16, Pa-24).

5.2 Indicators for design

Areas in need for drainage

- Soil and hydrological conditions are site-specified and should be fully understood (Eg-08, Eg-24, Eg-25, Eg-35, Eg-36, Eg-41, Pa-13, Pa-14, Pa-23).

Drainage method (Eg-08, Eg-14, Eg-20, Eg-21, Eg-22, Eg-23, Eg-42, Pa-04, Pa-05, Pa-07, Pa-10, Pa-11, Pa-12, Pa-13, Pa-16, Pa-24).

- Although theories form the basis of modern drainage system designs, there always remains an element of art in land drainage. It is not possible to give beforehand a clear-cut theoretical solution for each and every drainage problem. Sound engineering judgement supported by practical experience is still needed.
- Research has proven to be a cost-saving investment; new drainage materials were developed and and new installation methods tested.
- Stakeholder participation enhances the drainage system design.

Drainage design

- Drainage and irrigation are interrelated (Pa-06, Eg-43, Eg-44, Pa-14).
- Automation of the design process has increased the quality of the design process, from the field investigation to the storage of ready-made designs (Eg-18, Eg-19, Pa-10, Pa-11, Pa-13).
- Field research and computer simulations enhance each other (Eg-20).
- Research has enhanced to design process (Eg-21, Eg-22, Pa-22).
- Design remain local specific and for larger project verification in pilot areas is recommended (Eg-20, Eg-21, Eg-22, Eg-45, Pa-08, Pa-16).

5.3 Indicators for installation

Drainage materials

- New materials improves the quality of the installation and save costs (Eg-07, Eg-22, Eg-26, Eg-27, Eg-28, Eg-29, Eg-36, Pa-15, Pa-16, Pa-17, Pa-18, Pa-20).

Drainage equipment

- New and modified drainage equipment improves the quality of installation and saves costs (Eg-30, Eg-31, Eg-32, Eg-33, Eg-34).

Installation methods

- The implementation process should be flexible so that it can be adjusted to local conditions (Eg-08, Eg-09, Eg-10, Eg-26, Eg-28, Pa-15, Pa-17).
- A good coordination between all stakeholders is essential for a smooth work process (Eg-32, Eg-37, Eg-38, Pa-03, Pa-17).

Quality control

- Quality control enhances the implementation process (Eg-26, Eg-28, Eg-29, Eg-51, Pa-15).

5.4 Indicators for operation and maintenance

Operation

- Watertable drawdown curves are good indicators to assess the performance of ssd-systems (Eg-39, Eg-40).
- Operation can reduce environmental constraints (Eg-42, Eg-43, Eg-44).
- Monitoring can assess whether a ssd-system is in need for maintenance or rehabilitation (Eg-50, Eg-51, Pa-25).

Maintenance

- Medium pressure flushing machines have a high economic and technical efficiency to flush light textured soils (Eg-46).
- Video inspection is a useful, none-destructive, tool to assess the need for maintenance (Eg-47).

Appendix A - Case Studies from Egypt

Title: Egyptian Public Authority for Drainage Projects		**Case Study**: Eg-01
Country: Egypt	**Location/Project**: whole country	**Years**: 1973-onwards

Indicator(s) used in this case study: institutional set-up, implementation mode

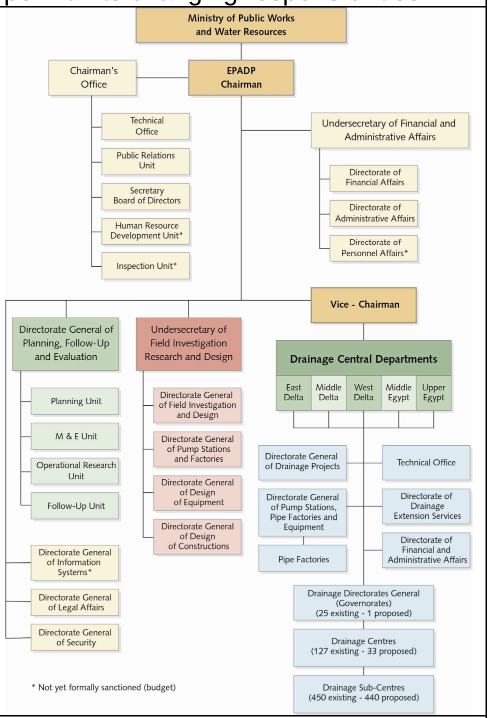
Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical	●	○	○	○
Socio-economical	●	○	○	○
Environmental	●	○	○	○

Background: In the 1960's, the Egyptian Government started an ambitious programme to drain all agricultural lands in Egypt to protect these against waterlogging and salinization. Large-scale drainage projects are complex and numerous stakeholders are involved, i.e. farmers, national or provincial government organizations, planning and implementation authorities, drainage contractors, suppliers of drainage materials and machinery.

Problem description: To implement this ambitious programme the Government of Egypt had to establish an appropriate institutional set-up. In principle, a choice had to be made out of two implementation modes: either a specialized government entity or contracted to a specialized company. Egypt decided to establish a specialized government organisation, the Egyptian Public Authority for Drainage Projects (EPADP). Since its establishment in the beginning of the 1970's, EPADP continuously improved its organisational set-up to cope with its changing responsibilities.

Action/intervention: Although, nowadays the implementation is done by public and private contractors, 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. 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 and, since 1992, EPADP was also given the responsibility for the maintenance of all open drains. EPADP is a semi-autonomous authority, headed by a Chairman with the rank of First Under-Secretary directly responsible to the Minister of Public Works and Water Resources. EPADP has one Vice-Chairman supported by five regional Departments, each headed by an Under-Secretary (Figure). 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.



Lessons learned:

1. Egypt successfully created a specialized authority (EPADP) that became responsible for the implementation of the national drainage programme.
2. The organisational set-up has from time to time been adjusted to cope with changing (often increasing) responsibilities.
3. In principle, two implementation modes can be used: either a specialized government entity or contracted to a specialized company, There is no golden rule which mode to apply, both methods have been used: e.g. in Egypt and the Netherlands specialised public authorities were established, but in Pakistan and India special project organisations were created

References: Fathi and Hamza (2000) and Nijland et al (2004)

Title: Advisory Panel on Land Drainage on Water Management		**Case Study**: Eg-02
Country: Egypt	**Location/Project**: Nile Delta 7 Valley	**Years**: 1975 – onwards

Indicator(s) used in this case study: institutional set-up, capacity building

Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical	●	○	○	○
Socio-economical	●	○	○	○
Environmental	●	○	○	○

Background: In the 1960's, the Egyptian Government started an ambitious programme to drain all agricultural lands in Egypt to protect these against waterlogging and salinization. Ultimately more than 2.5 million hectares will be provided with subsurface drainage systems.

Problem description: To manage these activities, policies had to be developed and institutions established. To assist the Egyptian Government in its efforts to accelerate the implementation of drainage project the Egyptian-Dutch Advisory Panel on Land Drainage was established in 1975. Later, the scope of the panel was widened to include all aspects of water management.

Action/intervention: The Egyptian-Dutch Advisory Panel on Water Management has six Egyptian and six Dutch members and is chaired by the Egypt's Minister of Water Resources and Irrigation (MWRI). All members are experts in many different fields of experiences and head or share big public and private organisations. The Egyptian members are appointed by the MWRI and the Dutch members by the Netherlands Embassy (RNE). The main objective of the panel is to advise the Egyptian Government on (future) water management strategies. The Panel meets once a year, alternating between Egypt and The Netherlands. The five-day events include three days of meetings, one day for a Panel Workshop in which matters are addressed more thoroughly and one day for an excursion to view a local water management project. The Secretariat (Centre APP support by Alterra-ILRI, Wageningen University and Research Centre, The Netherlands) is responsible for gathering the issues the Panel will discuss, to prepare the meetings and the follow-up, including the dissemination of all information and knowledge. In this respect, the Panel is a good link between the Egyptian Ministry of WRI, the RNE, and the whole water sector and particular the Dutch financed projects. For more information on the Egyptian Panel, see www.app-wm.com .

Lessons learned:

1. To implement subsurface drainage projects on a large scale, policies have to be developed and institutional arrangements to be made.
2. A high-level advisory panel, with members who are experts in many different fields of experiences and head or share big public and private organisations, accelerated the implementation of drainage project mainly by advising the Egyptian government on (future) water management strategies.

References: APPWM (2003), Nijland et al (2004)

Title: Project planning and preparation — **Case Study**: Eg-03

Country: Egypt | **Location/Project**: | **Years**: 1973 - present

Indicator(s) used in this case study: implementation process

Stage(s) in SSD practices addressed in this case study :

	Planning	Design	Installation	O & M
Technical	●			
Socio-economical	●			
Environmental	●			

Background: In Egypt, the Egyptian Public Authority of Drainage Projects (EPADP) is responsible for design, implementation, maintenance and rehabilitation of drainage system. 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.

Problem description: About 30 000 ha of subsurface drainage systems are installed each year. This requires a strict and well-balanced project preparation and planning, which was developed and modified over the years.

Action/intervention: The following preparation and planning cycle is used:

- **Identification and planning** includes four steps: (i) *Identification stage*: the type of the drainage problem is identified on the basis of available information, augmented by minor analysis (ii) *Pre-feasibility stage*: information is collected through reconnaissance type field investigation, serving to make a preliminary diagnosis of the problem and to give a rough outline of possible solutions; (iii) *Feasibility stage*: all relevant information is collected through a semi-detailed type of field investigations (map scaled: 1: 10 000, 1: 25 000) and final solution is chosen and (iv) *Final stage*: collection of information through detailed field investigations and elaboration of detailed plans to serve as working documents for implementation, i.e. detailed designs and construction drawings, specifications and planning of the execution.
- **Investigation and design** 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.
- **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.

Lessons learned:

1. A sound and well-balanced project preparation and planning system enables EPADP to install subsurface drainage systems at a rate of 30 000 ha/year.
2. Over the years, the preparation and planning system has been adjusted to changes in the implementation.

References: Amer et al (1989), Nijland et al (2004) and Menshawy et al (2000a)

Title: Planning the execution of drainage projects		**Case Study**: Eg-04
Country: Egypt	**Location/Project**:	**Years**: 1970-onwards

Indicator(s) used in this case study: implementation process

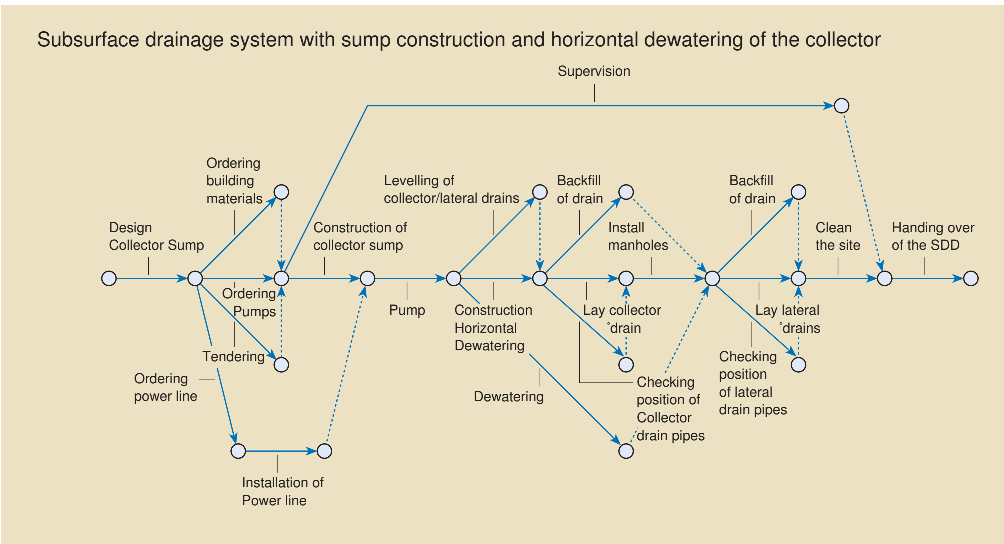
Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical	●		○	
Socio-economical	●		○	
Environmental				

Background: In Egypt, subsurface drainage systems are installed at a rate of about 75,000 ha/year. 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.

Problem description: These large-scale drainage projects are complex because numerous stakeholders are involved, including the farmers, government organizations, drainage contractors, suppliers of drainage materials and machinery. It is important to schedule and co-ordinate the various activities, which include the installation of field drains, remodelling and construction of open drains and renewal of pumping stations.

Action/intervention: The schedule time analysis and the co-ordination between different activities are related to planning at the national and regional levels using a network planning and analysis technique. The network diagram indicates the sequence in which the activities will be implemented and the interdependency of the activities (Figure)



Lessons learned:

1. Large-scale drainage projects are complex because numerous stakeholders are involved.
2. It is important to schedule and co-ordinate the various activities.
3. Network planning is a useful tool to plan the sequence of the activities and their interdependency.

References: Amer (1989), Menshawy et al (2000a) and Nijland et al (2004)

Title: Tendering and contracting | **Case Study**: Eg-05

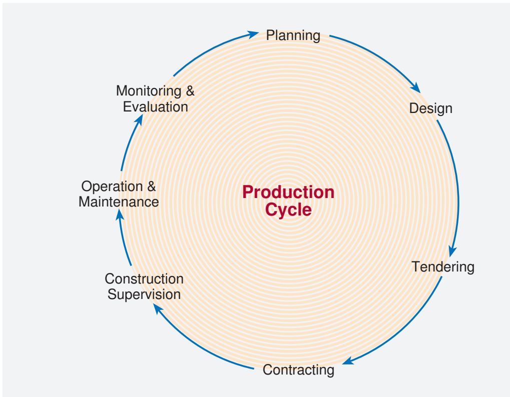
Country: Egypt | **Location/Project**: nation-wide | **Years**:

Indicator(s) used in this case study: implementation mode

Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical	●		○	
Socio-economical	●		○	
Environmental				

Background: In Egypt, the Egyptian Public Authority for Drainage Projects (EPADP) is responsible for the implementation of drainage projects. Most activities, i.e. the planning, data collection, preparation of designs, drains, maintenance, monitoring of the impact of drainage, budgeting, etc are done the EPADP, but the actual installation of the subsurface drainage systems is contracting to public and private companies. 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.



Problem description: Over the years, tendering and contracting practices have to be adjusted to cope with the changing national policy and installation methods and practices.

Action/intervention: 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. A contractor is selected by tender based on a tender document prepared by EPADP. After being approved by the World Bank, the tender is advertised. Tenders are judged on their responsiveness to the pre-set specifications and conditions an on the total price. The contract is awarded to the lowest bidder. The whole procedure takes about 15 months. To guarantee good quality staff of contractor can be trained and the EPADP Training Centre in Tanta (Case Eg-09).

Lessons learned:
1. The execution of drainage project has gradually changed over the past 20 years with a shift from public to private contractors.
2. The tendering and contracting procedure takes about 15 months.
3. To improve the quality of construction, contractor's Staff can also be trained at EPADP's Training Centre at Tanta.

References: Menshawy et al (2000a), Nijland et al (2004)

Title: Operational research to improve the planning and implementation		**Case Study**: Eg-06
Country: Egypt	**Location/Project**: Nation-wide	**Years**: 1993-onwards
Indicator(s) used in this case study: implementation process, drainage equipment		

Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical	●		○	
Socio-economical				
Environmental				

Background: 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 activities:

- 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.

Problem description: To improve planning and implementation activities accurate data on existing practices is essential. To obtain this information ORU has conducted a number of studies.

Action/intervention: After its establishment in 1993, ORU conducted a number of operational research activities, i.e. an inventory of all drainage machine working all over Egypt was made to quantify the machine specifications, the project-related data and the performance. The performance of the machine was classified as *good*', '*moderate*', '*bad*' or '*beyond repair*'. A good relation could be established between the performance of the machine and its age. Time and motion studies were conducted to quantify the effective working time of the machines (Case Eg-31) and calculate the capacity of the field and collector machine (Case Eg-30). The results are used to improve the planning of the execution of the drainage projects, both in time and manpower as it is now known:

- The number of machines that were operational: 59% of the field drainage machines and 76% of the collector drainage machines were operational.
- The effective life. 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.
- The effective time about 198 working days per year and 3 and 4 hours per day for respectively collector and field drainage machine
- Installation capacity. 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 90 m/h, respectively.

The results are also used to select supplies of new machines as they can be assesses on the performance of machines bought in the past.

Lessons learned:
Operational research is a effective tool to

1. Monitor the performance of individual projects;
2. Assess the performance of contractors and subsequently award new contracts;
3. Determine the number of machines needed to implement EPADP's annual plans;
4. Advise the Mechanical Department on the purchase of new machinery and equipment

References: Nijland et al (2004) and Menshawy (2000b&e)

Title: Drainage technology developments for the large-scale execution of drainage projects		**Case Study**: Eg-07
Country: Egypt	**Location/Project**: Nation-wide	**Years**: 1950-2000

Indicator(s) used in this case study: institutional set-up, implementation process, capacity building

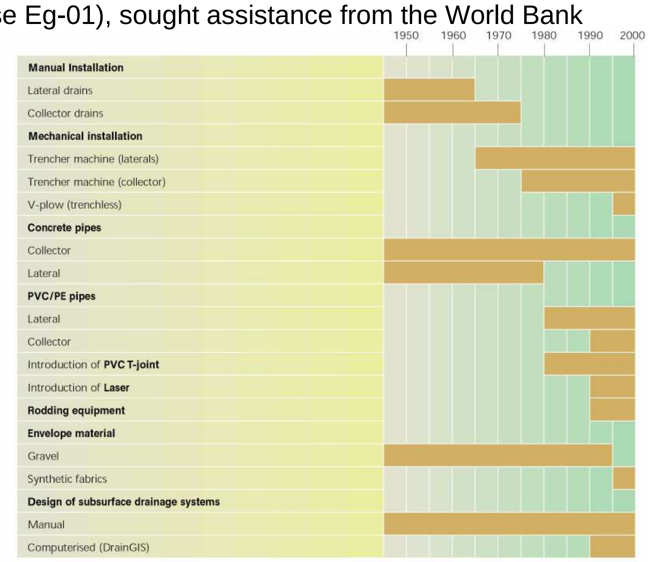
Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical	●			
Socio-economical	●			
Environmental	●			

Background: In the 1960's, the Egyptian Government started an ambitious programme to drain all agricultural lands in Egypt to protect these against waterlogging and salinization. Ultimately more than 2.5 million hectares will be provided with subsurface drainage systems.

Problem description: To implement this ambitious drainage programme, new innovations in drainage equipment, materials, installation techniques and procedures had to be developed.

Action/intervention: Since the start of the large-scale execution of drainage projects in the beginning of the 1970's, much emphasis was put on the development of new drainage materials, including drain envelopes, installation techniques and the associated improvements in the planning, design and implementation techniques. To achieve this, the Egyptian Government has set-up a specialized agency, the Egyptian Public Authority for Drainage Projects (EPADP, Case Eg-01), sought assistance from the World Bank (Case Eg-10) and, among other, The Netherlands through a bilateral advisory panel (Case Eg-02), several research organisations (Case Eg-13) and over the years put much emphasis on building up capacity (Case Eg-09). That Egypt has nowadays one of the largest and most modern subsurface drainage programmes in the world can be attributed to this institutional set-up and the good cooperation between the various organisations. This is especially remarkable, because the developments in Egypt took place in a relatively short period: over a period of 40 years manual installation practices were almost completely mechanised, including the introduction of new materials.



Technical developments in the large-scale implementation of drainage projects in Egypt since over the last 40 years.

Lessons learned:

1. A tailor-made institutional set-up and the good cooperation between the various organisations enabled Egypt to carry out its ambitious programme to provide subsurface drainage to 2.5 million of its agricultural lands.

References: Amer and de Ridder (1989), Nijland (2000), Nijland et al (2004) and Ritzema et al (2006)

Title: Subsurface drainage in areas with heavy clay soils		**Case Study**: Eg-08
Country: Egypt	**Location/Project**: Northern Nile Delta	**Years**: 1970 -2000

Indicator(s) used in this case study:

Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical	●		○	
Socio-economical	●		○	
Environmental	●		○	

Background: Immediately after the Second World War, Egypt started with reclamation of areas surrounding the lakes in the Northern Delta. By the mid seventies, about 109 000 ha of these heavy clay soils were reclaimed, but waterlogging was still prevalent.

Problem description: These problematic heavy clay soil have a clay content above 40% clay, low hydraulic conductivity (<0.1 m/d) and problems such as salinity, alkalinity, hard pans and saline groundwater with possibly upward seepage. Installation of SSD systems proved to be difficult in these sticky clays. Low crop yields could not only be attributed to drainage problems but also to poor water, soil, agronomical and environmental conditions.

Action/intervention: Research was conducted in eight areas to develop soil reclamation and improvement scenarios, leading to the following results: (i) SSD systems with drain depths of 1 – 1.5 m did not perform well in unripe soils; (ii) SSD systems do no work in virgin or unripe (heavy) clay soils; (iii) shallow surface drains in combination with sub-soiling or mole drains allow effective reclamation of the top 60 cm; (iv) mole drains (at 50–70 cm depth and 1–3 m spacing) in combination with a subsurface field drains at 1–1.5 m depth and 20–40 m spacing work satisfactorily when saturated hydraulic conductivity of the soil is greater than 0.1 m/d; (v) when hydraulic conductivity is less than 0.1 m/d traditional SSD system does not work well; (vi) the (old) believe that clay soils should have deep drains is not deemed valid anymore with the latest knowledge of reclamation techniques and crop growth needs.

Lessons learned:

1. Land reclamation techniques and agronomic practices should be dependent on the stage of development: **Stage 1** (1-3 years): surface drainage/irrigation growing true halophytes combined with gypsum or other amendments to improve of the top 10-20 cm of the soil profile; **Stage 2** (3-5 years): mole and surface drainage and gypsum applications to grow salt resistant/tolerant crop to improve soil structure and fertility by nitrogen fixation, have strong root system up to 50- 60 cm; **Stage 3**: SSD in combination with the existing surface drainage to growth less salt-tolerant and more profitable crops.
2. In the successive stages a close cooperation between technical (infrastructure, drainage and soil improvement), agronomic and social disciplines is needed.
3. Field drainage should be managed by farmers and the surface drains should be constructed by them: appropriate technologies should be made accessible to farmers.
4. Only for ripened (heavy) clay soil with hydraulic conductivity greater than 0.1 m/day have the potential for SSD systems at economical spacings.
5. Mole drains constructed up to 60 cm remove salts during the reclamation process.

References: Croon (1997), DRP (2001) and Nijland et al (2004)

Title: Capacity building to improve the quality of the SSD-systems | **Case Study**: Eg-09

Country: Egypt | **Location/Project**: Nation-wide | **Years**:

Indicator(s) used in this case study: capacity building

Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical	●	○	○	○
Socio-economical				
Environmental	●	○	○	○

Background: To implement its ambitious drainage programme, EPADP has continually introduced new innovations in drainage equipment, materials, installation techniques and procedures.

Problem description: To implement these new innovations requires that all persons involved are properly trained. Next to formal education and training to obtain basic knowledge, experience with large scale projects shows that for the practical skills and procedures on-the-spot training is the most practical and effective approach. The approach is based on the principle that the trainers go to the field instead of the field staff going to the trainers.

Action/intervention: EPADP established the Drainage Training Centre (DTC) in Tanta in 1991. The Training Centre is the result of a long-term co-operation between the IJsselmeerpolders Development Authority of the Netherlands and EPADP. Those two organisations cooperated in the Drainage Executive Management Project/DEMP. When the DEMP project commenced there was no former training programme. The project started with training of EPADP staff in the Netherlands. At the same time, Dutch instructors together with their Egyptian counterparts started to visit and train the staff of EPADP and the staff of the contractors in the directorates all over Egypt. This training programme was known as "*in-service training"*, and became a regular event. 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 for quality control, such as using laser equipment and rodding equipment. After some years it was felt, however, that the range of training was still too limited. The need for more specific training courses became evident and the visits of EPADP staff to vocational training centres in the Netherlands convinced the EPADP management of the need for a permanent training centre in Egypt. This led to the establishment of the DTC. The training activities at the DTC focus on personnel of the EPADP organisation and contractors, in order to: (i) increase their skills for the job; (ii) obtain essential knowledge to perform their job, and; (iii) improve the quality and the quantity of their performance. The DTC has all the facilities to conduct practical training courses. 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.

Lessons learned:

1. To implement new innovations in drainage equipment, materials, installation techniques and procedures requires that all persons involved are properly trained.
2. Experience showed that for the practical skills and procedures on-the-spot training is the most practical and effective approach.
3. To conduct practical training courses for both its Staff and the Staff of the contractors EPADP established a vocational training centre.
4. That Egypt has nowadays one of the largest and most modern subsurface drainage programmes in the world can, to a large extend, be attributed to its capacity building activities. This is especially remarkable, because the developments in Egypt took place in a relatively short period: over a period of 40 years manual installation practices were almost completely mechanised, including the introduction of new materials

References: Nijland (2000), Nijland et al (2004) and Ritzema et al (2006)

Title: Investments in drainage – lessons learned		**Case Study**: Eg-10
Country: Egypt	**Location/Project**: Nile Delta and Valley	**Years**: 1993 – onwards

Indicator(s) used in this case study: benefits, implementation process, capacity building

Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical	●		○	
Socio-economical	●		○	
Environmental	●			

Background: Through a series of projects called the National Drainage Program, i.e. NDP I (1993-2001, project cost US$160 million) and NDP II (2001-2007, total project cost US$278.4 million), the World Bank and partners, such as the German Development Bank and the Netherlands Government, are working with the Government of Egypt to introduce gradual reforms to introduce technologies and improve the management of irrigation and drainage systems. Goals are to enhance agricultural productivity and the incomes of smallholder farmers by improving drainage conditions, reclaim land lost to waterlogging and salinity, and improve the institutional capacity of the Egyptian Public Authority for Drainage Projects (EPADP). A second objective is to redress the negative environmental effects of the discharge of untreated industrial and domestic waste into open drains.

Problem description: While the immediate need is for drainage system improvement, the projects also needed to focus on creating institutional and community mechanisms for the long-term development and maintenance of the systems, and the systems for cost recovery.

Action/intervention: During NDP I, EPADP organized farmers into drainage associations (Collector User Associations, CUAs) to facilitate interface with the end-users. By 1999, 2,269 CUAs were formed. NDP II will continue the development of CUAs. Additionally the project will develop two pilot schemes to explore the potential of integrating irrigation associations (Water User Associations, WUAs) with CUAs. Beneficiaries pay for drainage investments over a 20-year period with no interest charged, effectively amounting to about 45 percent of the cost in real terms. All major objectives of the first phase of the project have been achieved. Over 248,000 hectares have been provided with new subsurface drainage. Including renewal areas, subsurface drains have been installed on more than 311,000 hectares. On this area, yields of major crops increased by up to 20 percent. Estimates show that improved drainage accounts for 15 to 25 percent of this yield increase. Many farmers switched to higher-value crops as a result of this project, particularly in the Nile Valley and the Delta region. Reuse of drainage water in irrigation, guided by appropriate criteria and guidelines, has resulted in one of the highest water use efficiencies in the world. Different Egyptian public sector agencies have improved their management capacity, such as EPADP which monitors and evaluates both the technical aspects of drainage (see also Case Eg-48), and important social and institutional issues. Cost recovery for drainage investments and maintenance has improved, as is reflected in a 25-year time frame for full recovery of capital costs, shared between government (50-55 percent) and beneficiaries (40-45 percent).

Lessons learned:
1. Flexibility in implementation is the key to guaranteeing success in this type of project.
2. Although EPADP has improved its institutional capacity, further institutional building is needed, especially support to computerize various aspects of its daily activities.
3. Compensation for crops damaged during subsurface drainage installation should be incorporated into the drainage installation contract, to be paid directly to farmers by contractors. This will circumvent the delays farmers experience in getting compensation when a government agency manages the compensation.
4. Drainage has often been a neglected component of irrigation system development, but can have a substantial effect on crop yields and system sustainability. Institutional innovations, training, and capacity building may be needed to reorient irrigation agencies and farmers from new irrigation investments to equally important drainage issues and investments.

References: World Bank (2004)

Title: Planning and managing research activities		**Case Study**: Eg-11
Country: Egypt	**Location/Project**: Research Institute. Cairo	**Years**: 1994-2001

Indicator(s) used in this case study: institutional set-up, capacity building, drainage design

Stage(s) in SSD practices addressed in this case study :

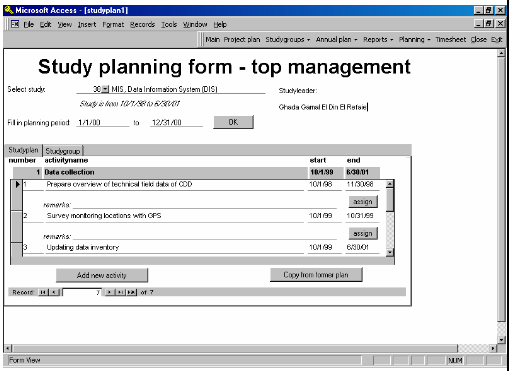
	Planning	Design	Installation	O & M
Technical	●			
Socio-economical	●			
Environmental	●			

Background: To verify and optimize the drainage design criteria and installation practices, the Drainage Research Institute in Cairo is conducting numerous research activities in experimental fields, pilot areas and farmer's fields.

Problem description: Research activities tent to be open-ended and continue year after year, mainly because the objectives have not clearly been defined at the beginning.

Action/intervention: A standard study descriptions was introduced for all research activities carried out by the Drainage Research Institute, including the following:

- Basic data: Subject, duration & period, client, cooperating agencies, budget, start date and revision date(s);
- Introduction and background: description of the state-of-the art, main problems/research questions;
- Past research carried out at the Institute: use the knowledge that is already in-house
- Justification: why is this research needed, is it not a repetition from past research activities;
- Research objectives: overall and specific (desk, laboratory and/or field research) objectives;
- Activities and work plan: specifying desk-, laboratory and field research activities;
- Study output: when, what and where;
- Evaluation and dissemination: workshops, (intermediate) reports to client, papers to (inter)national platforms (workshops, symposia, journals);
- Staffing: Study leader, client liaison, technical advisors and team members, i.e. scientists, technician and observer
- Requirements: transport, equipment, materials and labourers
- Cost estimate: Staff, procurement and investment and operational costs



Since 1997, these study descriptions are put in a data base (see Figure and Case Eg-15.

Lessons learned:

1. To good planning of research activities save time and money and reduce the risk of never-ending research activities than are done for the shake of research and not so much focus on real-life problems.

References: DRP (2001), DTPAP (1993), DRI (1992a&c)

Title: Planning field research: from fully-controlled experiments to large-scale monitoring.		**Case Study**: Eg-12
Country: Egypt	**Location/Project**: Zankalon, Mashul, Nile Delta	**Years**: 1987 – 1990

Indicator(s) used in this case study: implementation process, capacity building, stakeholder participation, drainage method

Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical	●	○		
Socio-economical	●	○		
Environmental	●	○		

Background: In Egypt, crop rotation is practised with wheat and berseem in winter, and cotton, maize, and rice in summer. The SSD system is installed irrespectively of the crops cultivated in the area. Of the crops, rice is an exception as it needs standing water in the field; consequently rice fields suffer huge water losses through the SSD system. As a reaction, farmers block the drainage system to save irrigation water, which on its turn results in waterlogging conditions for the upstream “dry-foot” crops. To overcome these problems the concept of a modified drainage system was developed. This modified drainage system is designed and installed in such a way that it enables the closure of the sub-collectors serving areas cultivated with rice without restricting the drainage of the blocks cultivated with dry-foot crops

Problem description: Before the concept of the modified system can be introduced on a large scale it had to be verified under the prevailing conditions in the Nile Delta. Research was conducted at three levels, namely: (1) fully controlled experiments at three experimental stations; (2) in-depth studies in farmers’ controlled fields, and (3) large-scale monitoring programmes in three project areas.

Action/intervention: In the experimental plots, water and salt balances studies under fully-controlled conditions were conducted to assess the potential of the modified system: irrigation water savings, drainage discharge rates and salinity’s, types and performance of closing devices, changes in soil salinity, crop yields etc. Fully-controlled conditions are needed because crop yield depends on some many factors that without control over the inputs conclusive results are very hard to obtain. In the pilot areas, the results obtained in the experimental fields were verified under normal farmers’ operation conditions. The modified concept was introduced and farmers were asked and agreed to use it. The farmers had full control of the in- and outputs, e.g. irrigation water application, opening of the blocked sub-collectors, etc. O&M practices were established involving a multi-disciplinary team of stakeholders, i.e. the farmers, Drainage Authority and Ministry of Agriculture. Finally, large-scale monitoring programmes were conducted to verify the crop consolidation practices and the operation of the closing devices. At all three levels, the same research activities were also conducted in areas drained according to the traditional system. In this the influence of autonomous developments, like new crop varieties, or farming practices, could be accounted for.

Lessons learned:

1. Before new concepts can be introduced on a large scale, research at three levels is required: (i) in experimental fields to verify the concept under fully-controlled conditions; (ii) in pilot areas to verify if the concept works under farmers’-controlled conditions, and finally; (iii) in project areas to monitor whether the foreseen benefits are actually achieved.
2. Had the research only be conducted in experimental plots, pilot areas or monitoring programmes not all research questions could have been answered.

References: Amer and de Ridder (1989), DRI (1993), DRP (2001), DTPAP (1993), El-Atfy et al (1990) and El-Guindi et al (1987)

Title: Organisation of research activities		**Case Study**: Eg-13
Country: Egypt	**Location/Project**: Nation-wide	**Years**: 1976 onwards

Indicator(s) used in this case study: institutional set-up, capacity building

Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical	●			
Socio-economical	●			
Environmental	●			

Background: In the 1960's, the Egyptian Government started an ambitious programme to drain all agricultural lands in Egypt to protect these against waterlogging and salinization. Ultimately more than 2.5 million hectares will be provided with subsurface drainage systems. To implement this ambitious drainage programme, new innovations in drainage equipment, materials, installation techniques and procedures have to be developed.

Problem description: A new research infrastructure had to be set-up within the Ministry of Water Resources and Irrigation to implement this ambitious research programme.

Action/intervention: Three research organisations are involved in research on subsurface drainage:

- 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.

That Egypt has nowadays one of the largest and most modern subsurface drainage programmes in the world can also be attributed to these research organisations. This is especially remarkable, because the developments in Egypt took place in a relatively short period: over a period of 40 years manual installation practices were almost completely mechanised, including the introduction of new materials.(see also Case Eg-07)

Lessons learned:

1. The Government of Egypt has, within the Ministry of Water Resources and Irrigation, created a sound research infrastructure to support its ambitious programme to provide all its agricultural lands with ssd-systems.
2. This research infrastructure is required to innovate drainage equipment, materials, installation techniques and procedures.

References: Amer and de Ridder (1989) and Nijland et al (2004)

Title: A logical framework approach to evaluate research programmes		**Case Study**: Eg-14
Country: Egypt	**Location/Project**: Research Institute, Cairo	**Years**: 1994-2001
Indicator(s) used in this case study: capacity building		

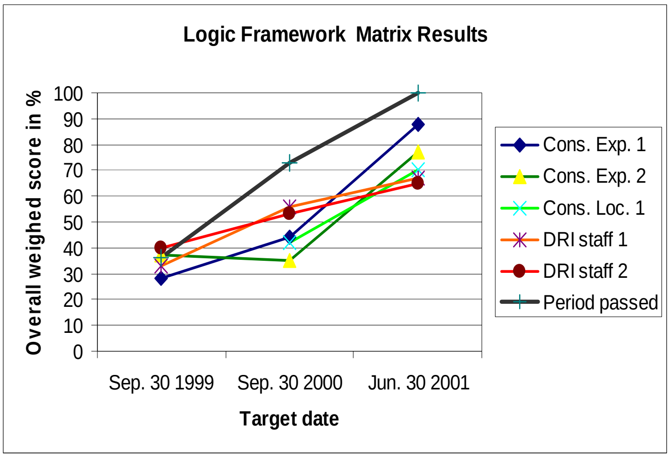
Stage(s) in SSD practices addressed in this case study :

	Planning	Design	Installation	O & M
Technical	●			
Socio-economical	●			
Environmental	●			

Background: The Drainage Research Programme (DRP), a bilateral project between the Governments of Egypt and the Netherlands started in December 1994 and was completed in June 2001. One of the project objectives was to increase the market-orientation and self-sustainability of the Drainage Research Institute (DRI). The emphasis was on transforming DRI in a robust research organisation, capable of high quality work, recognised nationally and internationally, and sought after by clients nationally and world wide. The main objectives were to enhance (i) internal communication and reporting; (ii) human resources development; (iii) planning, monitoring and evaluation and (iv) technical data base facilities for planning, to develop marketing strategies and public relations activities, to improve the planning, management and quality of research and to train staff in these activities and new topics, especially related to IWRM.

Problem description: Details of the project activities were based on the logic framework matrix that was set-up for the project during the inception phase. The most critical pre-conditions to succeed are: (i) sufficient number of key management staff involved; (ii) commitment of all staff levels to organisational changes, and (iii) acceptance of the staff appraisal system by DRI's management. The question was how to assess whether these pre-conditions were met during the project implementation.

Action/intervention: To assess the overall performance of project on a yearly basis, project staff was asked to assess the status of the project using the logic framework (Figure 1). Key staff of the project rated the final achievement of the project at an average of 73%. Over time the division of difference in assessment between (expatriate and local) consultants staff and DRI staff switched from the consultants having a lower sense of achievement during the first two target dates than the DRI staff, to one higher than that of the DRI staff in the end.



Lessons learned:

1. The logical framework approach is a good tool to assess performance in capacity building projects.
2. Special attention is needed to keep the local project staff motivated, especially in the later phases of long-term projects when the initial excitement and commitment has worn out.

References: DRP (2001)

Title: Data Information System at the Drainage Research Institute		**Case Study**: Eg-15
Country: Egypt	**Location/Project**: Research Institute. Cairo	**Years**: 1997 – onwards

Indicator(s) used in this case study: implementation process, capacity building

Stage(s) in SSD practices addressed in this case study:

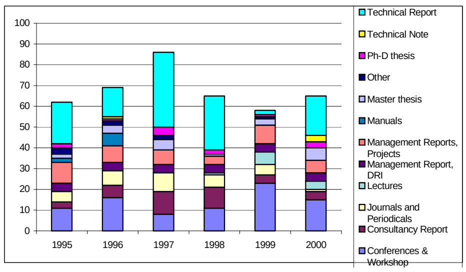
	Planning	Design	Installation	O & M
Technical	●			
Socio-economical	●			
Environmental	●			

Background: 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.

Problem description: To manage this large number of Staff involved in numerous research project and activities us a cumbersome and time-consuming task. Since 1997, DRI has a good computer network, which made it possible to implement the Management and Data Information System to support the managerial and technical activities.

Action/intervention: The Management Information System (MIS) consists of six databases. It was completed during the DRP I & II projects which were financed by the Government of The Netherlands. Each database serves a specific management task for which specific information is required. These databases are:

- Financial database (Findat)
- Publications database
- Human Resource database
- Inventory database
- Contacts database
- Activity database



Each of these data base serve a specific management task. With the MIS, it is easier to perform managerial tasks, as it supplies all the information needed to make good decisions. For example, the Publications database is a good tool to keep track of DRI publications and search for other publications in different libraries (Figure) and the Inventory database is a useful method to keep track of project and government inventories at DRI (Case Eg-11). The Human Resource database is a helpful information technology method to organize all DRI information and employees' information to help managers' decision-making related to the Human Resources at DRI (Case Eg-17).

Lessons learned:

1. A Management and Data Information System is a very useful tool to support the managerial and technical activities.

References: DRP (2001)

Title: Selection criteria for a drainage pilot area | **Case Study**: Eg-16

Country: Egypt | **Location/Project**: Mit Kenana, eastern fringes of the Nile Delta | **Years**: 1991-1992

Indicator(s) used in this case study: implementation process, soil and hydrological conditions, stakeholder participation

Stage(s) in SSD practices addressed in this case study :

	Planning	Design	Installation	O & M
Technical	●	○	○	
Socio-economical	●	○	○	
Environmental	●	○	○	

Background: The eastern fringes of the Nile Delta north of Cairo are characterised by sandy, unstable sub-soils. They occupy about 210.000 ha and are newly reclaimed. The most important reason to establish a drainage pilot area in this region was to find out how to deal with the specific problems that are encountered during the installation of the subsurface drainage systems in unstable sandy subsoil with high water tables. Consequently, the research objectives were (i) to get experience regarding the technological aspects of subsurface drainage in the areas for which it is representative and ii) to obtain data on the effectiveness of subsurface drainage in these areas using different design criteria and materials. Previous experiences with the construction of Sherashra pilot area learned that a careful planning can avoid disappointing experiences (see also Case Study Eg-38 and Eg-32).

Problem description: How to find an area where the research can be done and that, at the same time, is representative for the prevailing conditions in eastern fringes of the Nile Delta?

Action/intervention: Based on the research objectives and the characteristics of the prevailing conditions in the study area, selection criteria were formulated. These selection criteria including aspects related to

- The problem: the presence of (i) unstable, sandy subsoil; (ii) a high water table or even waterlogging, and; (iii) high soil salinity.
- The possibility to install a SSD-system: an open drain should be present with a water level and capacity allowing for the installation of a subsurface drainage system;
- The possibility to do research: (i) the area should be accessibly by car; (ii) the farmers should be in favour of subsurface drainage system and thus be co-operative, and; (iii) the nature of the crops in the area should allow for the installation of subsurface drainage. This means that an area largely covered by orchards would not be suitable.

Based on these criteria, the Mit Kenana Area, 40 km north of Cairo, was selected. It measures 270 ha and the water table depth varies between 0.30 and 1.0 m. In some parts, soil salinity reached up to 15 dS/m. Low piezometric pressure heads in the layers underneath the clay cap cause substantial downward leakage.

Lessons learned:

1. Formulating precise criteria for the selection of a drainage research area avoid disappointments during installation, implementation of the research and application of the research findings.

References: DRI (1992b), DRI (1987c), Nijland et al (2004).

Title: Capacity building for research		**Case Study**: Eg-17
Country: Egypt	**Location/Project**: Cairo	**Years**: 1994-2001
Indicator(s) used in this case study: capacity building		

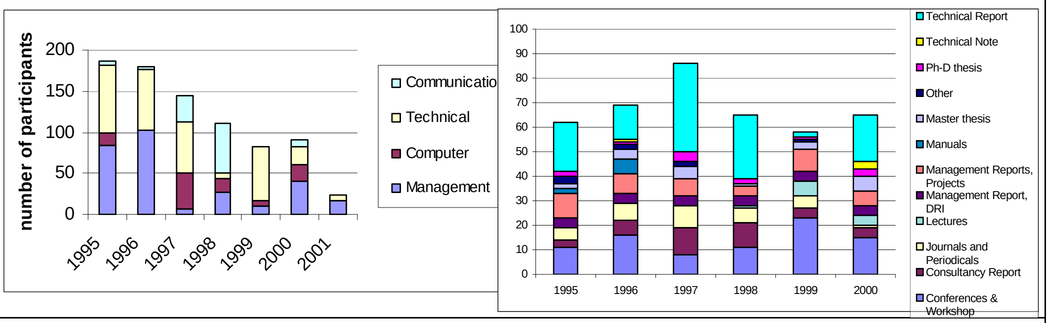
Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical	●			
Socio-economical	●			
Environmental	●			

Background: 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.

Problem description: To keep up to date, a continuous programme of capacity building is required. One of the objectives of the Drainage Research Programme Project (1994-2001) was to enhance the capabilities of the staff of DRI.

Action/intervention: Capacity of DRI was enhanced through different types of training, such as short-courses in-country and overseas, tailor made courses in-country, attendance of conferences and workshops, locally organised workshops and one-to-one training (e.g. report writing assistance by the British Council, which they refer to as surgery sessions). These training activities focussed on communication skills (languages, report writing), computer skills, management skills and technical skills (Figure - left). To evaluate the output of the capacity building activities, outputs were monitored and stored in a data base (see also Case Eg-15). The outputs included technical reports, technical notes, PhD- and MSc-theses, other publications, manuals, management reports, lectures and papers in Journals and for conferences (Figure – right).



Lessons learned:

1. A combination of different type of courses at different levels and different skills is an appropriate and efficient method to keep the capacity of an institute up-to-date.
2. Encouraging research staff to attend workshops, conferences and symposia is a good method to enhance their skills and the overall skills and the overall name and standing of the institute they are working for.
3. Capacity enhancement can be monitored by recording outputs, i.e. technical reports, technical notes, PhD- and MSc-theses, other publications, manuals, management reports, lectures and papers in Journals and for conferences.

References: DRP (2001), DTPAP (1993) and Nijland et al (2004)

Title: Automation of the design process		**Case Study**: Eg-18
Country: Egypt	**Location/Project**: nation-wide	**Years**: 1986-1997

Indicator(s) used in this case study: drainage design, implementation process, institutional set-up, capacity building

Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical		●		
Socio-economical		●		
Environmental		●		

Background: EPADP's Field Investigation and Research Department (FIRD) is responsible for the design of ssd-systems. The designs are based on the five-year and annual execution plans prepared by the Planning Department (Case Eg-04). 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.

Problem description: In the 1960's and 1970's design were made by hand but the computerization of (part) of the design was gradually introduced.

Action/intervention: 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. In the design process a number of activities can be distinguished, i.e. (i) planning of design activities; (ii) preparing maps; (iii) preparing the field investigations; (iv) field investigations; (v) processing the field data, and; (vi) preparing the design. In a 10-year period, the design process was gradually computerized. The objectives were to increase accuracy; to enforce consistency; to save time; to improve data storage, data evaluation and the quality of maps; to optimise designs; to enable an easier implementation of new design rules; to increase the data storage (especially maps) for future use and to provide management information. In 1987, computers were introduced. In 1988, Staff was trained in the use of PC's (this training continues of the following years). In 1988-1990, the automation started with (i) set-up of computer programmes for drainage design; (ii) processing of field data, and (iii) computing the longitudinal profile. In the following years, the automation was gradually expanded, but the designing the layout was still done manually. In the period 1993 to 1997, GIS was gradually introduced to computerize the mapping.

Lessons learned:

1. Automation of the design process has increased the quality of the design process, from the field investigation to the storage of ready-made designs.
2. An important factor for the successful introduction of automation practices is the working environment: offices have to be updated to enable the use of sophisticated but vulnerable equipment.
3. The introduction of new equipment and techniques requires new skills. Training should be an integral part of the automation process.
4. The gradual introduction of the automation increase the confidence and support of the staff, enabled the automation of local-specific methods and procedures and at a later phase gave design engineers options that could not be done manually.
5. Automation is a never-ending process as both developments in automation and developments in drainage will continue. Thus follow-up is needed and should be planned.

References: Khalaf et al (2000a & b) and Nijland et al (2004).

Title: Use of a simulation model for design and evaluation of SSD systems.

Case Study no.: Eg-19

Country: Egypt | **Location/Project**: Zankalon, Nile Delta | **Years**: 1989 – 1997

Indicator(s) used in this case study: drainage design, soil and hydrological parameters, costs & benefits

Stage(s) in SSD practices addressed in this case study :

	Planning	Design	Installation	O & M
Technical		●		
Socio-economical	○	●		
Environmental				

Background: The reliability of DRAINMOD-S for simulating water management in irrigated lands under actual field conditions was tested against data sets from Zankalon Experimental Field (ZEF) in the Eastern Nile Delta in Egypt. Climate, groundwater table depth, drain discharges and irrigation water quantities and their salinities, crop data and soil salinities for 15 cm increments of the soil profile down to 150 cm below the soil surface are available for the cropping season 1989-1991.

Problem description: For design purposes, drain depth and drain spacing can be determined for a given set of conditions in an irrigated area. These conditions are represented by irrigation practices, quality of irrigation water, soil physical properties, initial salinity distribution in the soil profile, climatic data, crop rotation and other general information as the drain radius and depth to impermeable layer. To test different irrigation scenarios in the field is cumbersome and time-consuming; especially for the prevailing cropping practices in the Nile Delta very various crops are cultivated in a 3-year crop rotation, i.e. cotton, wheat, rice, berseem, maize, and berseem. Using a simulation model, like DRAINMOD-S can save time and money, but first the model has to be verified for the prevailing soil and hydrological conditions.

Action/intervention: The model was tested using the depth of the groundwater midway between two field drains. The correlation coefficient (R^2) of the measured and simulated watertables was in the range of 0.8 - 088 for all the tested data sets. The calibrated model was used to simulate soils salinities at three layers. The results indicate that the effect of the salt concentration of the irrigation water on the soil salinity is more pronounced in the surface layer than in the deeper layers. The differences become less as time progresses, until the soil salinity is reduced to almost the same level as irrigation water salinity irrespective of its initial salinity. Good agreement was also observed between the simulated and the measured drain effluent salinity. The model was also used to simulate the optimum drain spacing for various irrigation scenarios for crops in a crop rotation. In this case, the designer has to assess the performance through either adjusting the irrigation practices of some crops in the rotation to eliminate stresses caused by the irrigation inputs (if possible) or selecting the spacing on the basis of economic analysis (cost and benefits). Market prices of crops and interest rates play an important role in the latter case.

Lessons learned:

1. Computer simulation can help the designer to select the most optimum drain depth/spacing combination for crops in crop rotation under various irrigation scenarios.
2. Market prices of crops and interest rates play an important role in selecting the spacing on the basis of economic analysis.

References: Abdel-Dayem (1997), Kandil et al. (1992), Workman and Skaggs (1990).

Title: Verification of drainage design criteria: a mix-between desktop and field research.		**Case Study no.**: Eg-20
Country: Egypt	**Location/Project**: Mashtul Pilot Area, Nile Delta	**Years**: 1985-90

Indicator(s) used in this case study: drainage design, soil and hydrological parameters

Stage(s) in SSD practices addressed in this case study :

	Planning	Design	Installation	O & M
Technical		●		
Socio-economical				
Environmental		●		

Background: In the 1960's, the Egyptian Government started an ambitious programme to drain all agricultural lands in Egypt to protect these against waterlogging and salinization. Ultimately more than 2.5 million hectares will be provided with subsurface drainage systems. To verify the drainage design criteria, drainage pilot areas were established. In Mashtul Pilot area, a comprehensive monitoring programme was conducted to establish all components of the water & salt balance: in- and outflow of irrigation and drainage water and the corresponding salinities were measured, groundwater tables and piezometric levels were monitored, soil salinity and meteorological data collected. To verify the measured data the overall, 3-year average water and salt balance were estimated. A three 3-year period was considered because of the crop rotation practices (see for example Figure 3.3 in Chapter 3.2.2).

Problem description: Not all components of the water and salt balance could be measured, e.g. the natural drainage and its salinity. The natural drainage was estimated using piezometer readings. Although the corresponding water balance fits nicely, the salt balance shows a huge surplus: much more salts were removed than were imported by the irrigation water. It was assumed that this difference could be attributed to the continuous leaching of salts from the soil layers below drain level.

Action/intervention: To verify these results the model SALTMOD was used. SALTMOD is a computer program for the prediction of the salinity of soil moisture, ground water and watertable depth and drain discharges in irrigated agricultural lands. The model was calibrated using the seasonal average depth of the watertable. The simulated drain discharges varied between 0.10 and 0.15m in summer and 0.05 and 0.10 m in winter and the natural drainage was in the range 0.10 and 0.20 m/year. Although this result is not very accurate it is in the same order as magnitude as the field measurements. After these calibrations, the salinity in the rootzone, in upper part of the deeper soil layers (transition zone) and the salinity of the drainage water were simulated. These simulations confirm that the leaching of the deeper layer lacks behind of the leaching in the root zone:

Water balance (m/year)		Salt balance (t/ha/year)	
Irrigation	1.24	Salts brought in by Irrigation	8.0
Crop evapotranspiration	0.91		
Subsurface Drainage	0.15	Salts removed by subsurface drainage	12.8
Natural Drainage	0.18	Salts removed by natural Drainage	18.7
Change in storage	0		-23.5

Lessons learned:
1. Measuring water and salt balances to verify drainage design criteria is a complex and time-consuming activity.
2. For reliable results, all components should be monitored, but in practice this is often complicated (e.g. the natural drainage or its salinity).
3. Computer simulation can help to overcome these problems as the models can be used (i) to verify the input data; (ii) to estimate those components of the water & salt balance that are too complicated to measure in the field, and (iii) to simulate long-term effects.

References: Abdalla and Ritzema (1990), Abdel-Dayem and Ritzema (1990), DRI (1990b) and DTPAP (1993)

Title: Pilot areas research to verify drainage design criteria		**Case Study**: Eg-21
Country: Egypt	**Location/Project**: Mashtul, Nile Delta	**Years**: 1977-1990

Indicator(s) used in this case study: drainage design, soil and hydrological parameters

Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical		●		
Socio-economical		●		
Environmental		●		

Background: Since the beginning of the 20th century, the use of water per unit area in the Nile Delta of Egypt has increased sharply with the gradual introduction of perennial irrigation. Consequently, the natural drainage could no longer cope with the increased percolation losses and land became waterlogged and/or salt-affected. To overcome these problems, the Egyptian Government is implementing an intensive programme to provide all agricultural lands (2.5 million ha) with subsurface drains. The design criteria were established in the early sixties, i.e.:

- For the calculation of the drain depth and spacing: a depth of the watertable of 1.0 m and drain discharge of 1.0 mm/d.
- For the calculation of the drain pipe capacity: a discharge of 4 mm/d for rice areas and 3 mm/d for non-rice areas with a 25% safety factor and no overpressure.

Problem description: To verify and update these criteria, pilot areas representing the prevailing soil, hydrological and socio-economic conditions in the delta were established and long-term monitoring programmes were initiated to assess all components of the water & salt balance: in- and outflow of irrigation and drainage water and the corresponding salinities were measured, groundwater tables and piezometric levels were monitored, soil salinity and meteorological data.

Action/intervention: A drainage pilot area was constructed in the south-eastern part of the Nile Delta to verify the design criteria for SSD systems for the prevailing conditions in the region. The monitoring programme showed that: (i) crop yields increased significantly: 10% for rice, 48% for berseem, 75% for maize and more than 130% for wheat; (ii) the relation between crop yield and watertable shows that the design depth of the watertable can be reduced to 0.8 m in combination with a discharge of 0.9 mm/d; (iii) for drain pipe capacity a design discharge rate of 1.7 mm/d is sufficient for field drains and 2.3 mm/d for collector drains.

Lessons learned:

1. SSD-systems installed using the original design criteria had a significant positive effect on all crops cultivated in the Nile Delta.
2. The original design criteria are on the safe site, adding an additional safety to the system from about 30% for the field drains to 40% for the collector drains.

References: Abdel-Dayem and Ritzema (1990), DRI (1990 a&b), DRI (1987a), DRP (2001) and DTPAP (1993)

Title: Selection of a drain envelope		**Case Study**: Eg-22
Country: Egypt	**Location/Project**: Nile Delta, Egypt	**Years**: 1978-2001
Indicator(s) used in this case study: drainage design, soil and hydrological , drainage materials		
Stage(s) in SSD practices addressed in this case study:		

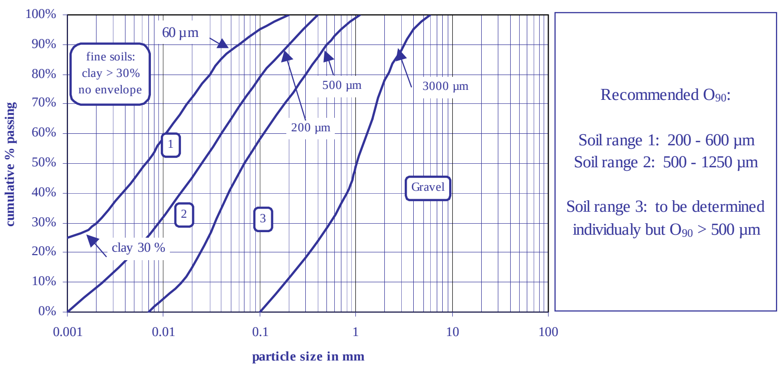
	Planning	**Design**	**Installation**	**O & M**
Technical		●	○	
Socio-economical		○	○	
Environmental				

Background: In Egypt, annually about 63.000 ha are provided by new subsurface drainage systems while old drainage systems are rehabilitated in about 12.600 ha. Traditionally, a graded gravel envelope was used in areas with a clay content of 40% or less. 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.

Problem description: As gravel envelopes were costly and difficult to apply, research to use pre-wrapped synthetic envelopes started in the late 1970's. Before pre-wrapped synthetic envelopes could be introduced on a large scale, research was conducted to develop guidelines for the pre-drainage investigation, design, production and installation.

Action/intervention: Based on a review of available wrapping methods, the method using loose materials with yarn was recommended as this method is more flexible and easier for maintenance and operation compared to sheet wrapping units and it can be used for all pipe diameters (up to 200 mm outside diameter). In September 1991, a Horman band wrapping machine BWK 200T was installed at the Tanta pipe factory of EPADP.

Locally produced materials were tested and guidelines for storage, transportation, sampling and testing were prepared. Research was conducted in the laboratory, in pilot areas and during normal installation practices to establish the relevant O_{90} ranges for the envelopes for the typical range of problems soils that prevail in Egypt (Figure).



Ranges of selected d_{90} values for use in the Egyptian Nile Delta

Lessons learned:

1. Guidelines for design, manufacturing, wrapping, storage, transportation, handling, in the field and construction of pre-wrapped synthetic envelope under local conditions were established.
2. Savings in cost up to 50% on the material and installation costs are achieved when gravel is replace with a synthetic envelope: the additional cost for envelope construction is 200 LE/fed for synthetic envelopes and 402 LE/fed for gravel envelopes (1995 prices).

References: DEMP IV (1995), DRP (2001), DTPAP (1993), EPADP (1998), Nijland et al (2004|), Menshawy et al (2000c) and Vlotman and Omara (1998).

Title: A modified layout of the subsurface drainage system for rice areas in the Nile Delta, Egypt		**Case Study**: Eg-23
Country: Egypt	**Location/Project**: Nile Delta	**Years**:

Indicator(s) used in this case study: drainage design, drainage method, soil and hydrological criteria, stakeholder participation

Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical		●		○
Socio-economical				
Environmental		●		○

Background: In the Nile Delta in Egypt, rice is cultivated in rotation with "dry-foot" crops. The implementation of conventional free-flowing subsurface drainage systems serving a mixed pattern of crops including rice caused excessive drainage from the rice fields.

Problem description: To reduce water losses from areas cultivated with rice without restricting drainage from other areas, a modified layout of the subsurface drainage system has been developed. In the modified layout, the drainage from rice fields is restricted by closing the sub-collectors serving these fields, while the outflow from sub-collectors served fields with “dry-foot” crops is not restricted.

Action/intervention: The principles of the modified layout have been investigated in experimental fields under fully controlled conditions as well as in farmers' controlled fields. In addition, the performance of the modified layout was monitored in two areas of around 2000 ha each. The study covered a six-year period, running from 1983 to 1988.

Lessons learned:
The introduction of the modified layout of the subsurface drainage system in rice-growing areas in the Nile Delta resulted in:

1. Savings in irrigation water up to 30%. This irrigation water would otherwise be lost through the subsurface drainage system: the difference in drainage rates from rice fields between the conventional and modified drainage system amounts of 1 to 3 mm/day over a growing season of approximately 100 days;
2. Protection of the drainage system from justifiable, although unauthorized and improper, interference by farmers to stop irrigation water losses from rice fields through the subsurface drainage system, and thus reduce the maintenance requirements;
3. Protection of crops other than rice from the damaging effects of improperly blocked conventional collector drains.
4. These benefits were obtained without any negative effects on either soil salinity or crop yield and with no increase in costs compared with the conventional system.

References: El Atfy et al. (1991)

Title: Determining the hydraulic conductivity from a pF-curve		**Case Study**: Eg-25
Country: Egypt	**Location/Project**: El-Genina, North-eastern Nile Delta	**Years**:

Indicator(s) used in this case study: drainage design, soil and hydrological conditions

Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical		●		
Socio-economical				
Environmental		●		

Background: The Integrated Soil and Water Improvement Project (ISAWIP)In Daqahleya Governorate, Nile Delta, Egypt aims towards improving the irrigation, drainage and soil conditions in an area of about 70 000 feddan (30 000ha). The project is located in the most north-eastern region of the Nile in an area with special soil and hydrological conditions.

Problem description: To design the SSD system a representative value of the hydraulic conductivity had to be obtained. A pilot area was established in El-Genina to test the drainage design criteria in that project.

Action/intervention:
The saturated hydraulic conductivity was measured with two methods: (i) in the laboratory using undisturbed soil samples taken in cores at 10, 50 and 100cm, and (ii) in the field using the auger-hole method. The results clearly show a wide range and high standard deviation. However, part of the differences between the hydraulic conductivity of the top meter of the profile and the deeper soil might be attributed to the measuring procedures. The results of the auger-hole measurements reveal that the hydraulic conductivity decreases with soil depth:

Method	Depth (m)	Average k_{sat} (cm/h)	Standard dev.	Range (cm/h)
Laboratory	0.0-0.1	0.20	0.18	0.09-0.21
Laboratory	0.1-0.5	0.15	0.04	0.05-0.21
Laboratory	0.5-1.0	0.15	0.03	0.09-0.18
Field (auger-hole method)	1.5	0.63	0.32	0.13-1.08
Field (auger-hole method	2.0	0.49	0.31	0.08-1.08
Field (auger- hole method	3.0	0.31	0.19	0.04-.83

The unsaturated hydraulic conductivity was calculated using the soil moisture characteristic curves. A highly significant correlation have been found between k_{sat} and k_{unsat} at pF=2 (log suction head of 100cm water): $k_{nsat-100} = 1.6 \times 10^{-3} K^{0.626}{}_{sat}$ ($r^2 = 0.98$).

Lessons learned:

1. Hydraulic conductivity measurements show a wide range and high standard deviation, not only between methods but also within a method.
2. A good correlation could be established between the saturated and unsaturated hydraulic conductivity.

References: Abdel-Ghany et al (1990), Oosterbaan and Nijland (1994).

Title: Estimating evaporation from brackish/saline open-water bodies		**Case Study**: Eg-25
Country: Egypt	**Location/Project**: Lake Qarum	**Years**:

Indicator(s) used in this case study: drainage design, soil and hydrological conditions

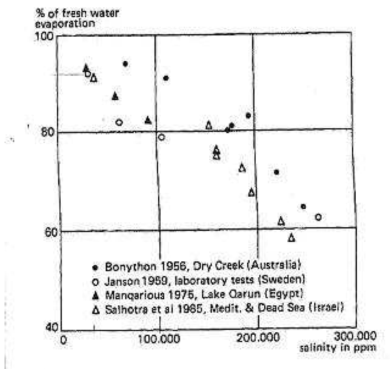
Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical	○	●		
Socio-economical				
Environmental	○	●		

Background: Lake Qarum, a salt-water lake in the Fayoum depression, has no natural outlet. Its size (at present about 247 sq km) and its water level (on average 43.4 m below MSL) depend on the delicate balance between inflow and evaporation. There is seasonal variation in water level of about 45 to 60 cm because of high evaporation in summer with limited inflow. The evaporation from the Lake depends not only on its surface area, but also on the salinity of its water. This salinity is increasing with time because salts do not evaporate. Annually, the drainage water caries about 500 000 tons of salts to the Lake. In 1979, 650 samples of the Lake showed an average salinity of 37.6 g/l. The evaporation from saline water bodies is lower than from the same water bodies without salinity because dissolved salts reduce the free energy of water molecules and thus the saturation vapour pressure over saline surface.

Problem description: Under the same meteorological conditions, evaporation from an open water body decreases when the salinity concentration of the water increases.

Action/intervention: Evaporation depends on the salinity of the water: in water with a salinity of more than 200 g/l, evaporation is only about 60% of fresh water evaporation (Figure). For Lake Qarun, with an average salinity of 37.6 g/l, the reduction is about 9 to 10%. Expressing the evaporation of saline water as a percentage of the evaporation of fresh water, depending only on salinity, is not entirely correct because the ionic composition of the water has an effect on the reduction of the saturation vapour pressure.



Lessons learned:
1. Evaporation depends on the salinity of the water: it more or less linearly decreases to 60% for water with a salinity of 250 g/l.
2. Calculating the evaporation of saline water based on its salinity is not entirely correct because the ionic composition of the water has also an effect on the reduction of the saturation vapour pressure.

References: Wolters et al. 1989

Title: Materials for pipe drains		**Case Study**: Eg-26
Country: Egypt	**Location/Project**:	**Years**: 1970 – onwards

Indicator(s) used in this case study: drainage materials, installation method

Stage(s) in SSD practices addressed in this case study:

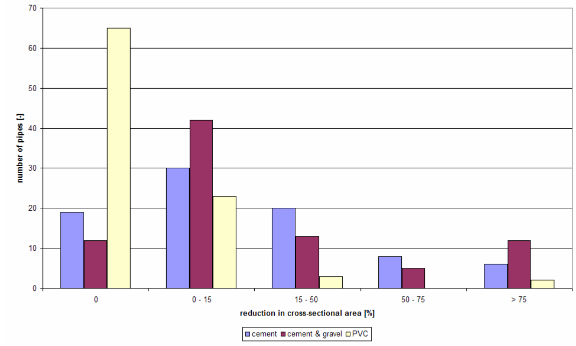
	Planning	Design	Installation	O & M
Technical		○	●	○
Socio-economical				
Environmental				

Background: Traditionally, clay pipes with a length of about 0.30 m and a diameter of 100mm were used. In the 1950's, cement pipes with the same diameter but 0.50 m in length were introduced. These pipes were installed manually.

Problem description: The introduction of mechanical laying, in the early 1960s for filed drains and in the 1970's for collector drains, required different types of pipes.

Action/intervention: At first, shorter cement pipes of length 0.30 m were introduced as they were more convenient both for handling and for providing additional water entry surface.

The introduction in 1979 of corrugated plastic PVC pipes 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. A large-scale excavation programme, carried out in the Nile Delta in Egypt, revealed that sedimentation was significantly reduced after the introduction of plastic pipes for field drains.



Concrete collector drains have the same sedimentation problem as the clay pipes. Sedimentation levels in concrete collector drains, with diameters up to 500 mm, reduced the effective cross sectional area by about 35%. Thus it is not surprising that plastic collector drains perform better than concrete drains, mainly because the lower sedimentation rates that offset the higher roughness coefficient caused by the corrugations. However, the introduction of larger diameter plastic pipes (150 < Ø < 300 mm) for collector drains took much longer than the introduction of smaller diameter pipes for field drains, mainly because of the complex manufacturing process. The biggest obstacles that had to be overcome for the introduction of corrugated plastic pipes were: (i) the complex manufacturing process, (ii) making the pipes strong enough and flexible, and at the same time keep the weight per metre low, and (iii) the logistic problems, because plastic pipes are more sensitive to temperature and ultra-violet radiation. Especially when exposed to sunlight, the pipes trends to become brittle. Existing standards were updated to include specifications for the new materials from which the pipes are manufactured. These standards, originating from countries with a long drainage history, were adapted to specific, local conditions and circumstances.

Lessons learned:

1. The introduction in 1979 of corrugated plastic PVC pipes significantly helped to boost the progress of Egypt's large-scale drainage projects.
2. The introduction of plastic pipes significantly reduced sedimentation.
3. The biggest obstacles that had to be overcome for the introduction of corrugated plastic pipes were: (i) the complex manufacturing process, (ii) making the pipes strong enough and flexible, and at the same time keep the weight per metre low, and (iii) the logistic problems, because plastic pipes are more sensitive to temperature and ultra-violet radiation.

References: Abdel Dayem et al (1989), Abdel-Dayem (1986), El Atfy et al (1990b), Nijland et al (2004), Ritzema et al (2006), Ritzema and Abdel Alim (1985)

Title: Handling and storage of synthetic envelope materials		**Case Study**: Eg-27
Country: Egypt	**Location/Project**:	**Years**: 1994-1997

Indicator(s) used in this case study: drainage materials, installation method

Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical		○	●	
Socio-economical				
Environmental				

Background: Since 1991, synthetic envelope materials are used in Egypt to pre-wrapped drain pipes.

Problem description: Synthetic envelope materials must be protected against direct sunlight to prevent degeneration of pre-wrapped coils. Recently, it is found that even ultraviolet stabilized materials need protection because they will be affected sooner or later by ultraviolet radiation.
Drainage Research Institute (DRI) study the safe storage period of exposed pre-wrapped coils in direct sunshine (outdoor) and also storage period under shelter (indoor) to avoid their deterioration. These results were disseminated to Egyptian Public Authority for Drainage Projects (EPADP) in Egypt to help in storing the huge amount of synthetic envelopes used by EPADP yearly.

Action/intervention: Synthetic envelope samples (PP290, PP430, PP310, PP360, and PP260) were exposed for 6 months to natural weather conditions with direct protection from ultraviolet radiation (UV) to represent indoor or outdoor storage. The materials used in this research were stored in three locations: outdoor (on the roof of the laboratory building at the Delta Barrage and exposed directly to sunshine), indoor (inside the laboratory and not covered with black sheet), and indoor (inside the laboratory and covered with black sheet). Every three months an evaluation made by carrying out standard tests on the stored envelope material.

Lessons learned:

1. The thickness, mass/area, and pore size index of envelopes stored outdoor decreased over time by respectively: 13, 20 and 14%, compared to 2, 7 and 24% indoors.
2. The two main properties affected by exposing synthetic materials to ultraviolet radiation (UV) are tensile strength and elongation. Therefore, these two tests should be carried out in the future to determine the deterioration of the exposed materials while stored in the pipe factory of EPADP.
3. After six months of storage, the materials made from polypropylene became rough, brittle and fell apart upon touch. Also the colour of these materials changed.
4. Under Egyptian conditions, the total annual radiation is 6.86 GJ/m^2, therefore the maximum storage period in direct sunshine is about 6 months in winter and about 3 months in summer.
5. It is recommended to test wrapped coils in the future tenders for ultraviolet radiation using Xenon-Arc type apparatus according to the standard test method ASTM-D4355 (1996).

References: Omara and Abdel-Hadi (1997)

Title: Purchase of a wrapping units for drain envelopes		**Case Study**: Eg-28
Country: Egypt	**Location/Project**:	**Years**: 1991-1995

Indicator(s) used in this case study: drainage materials, installation method, quality control

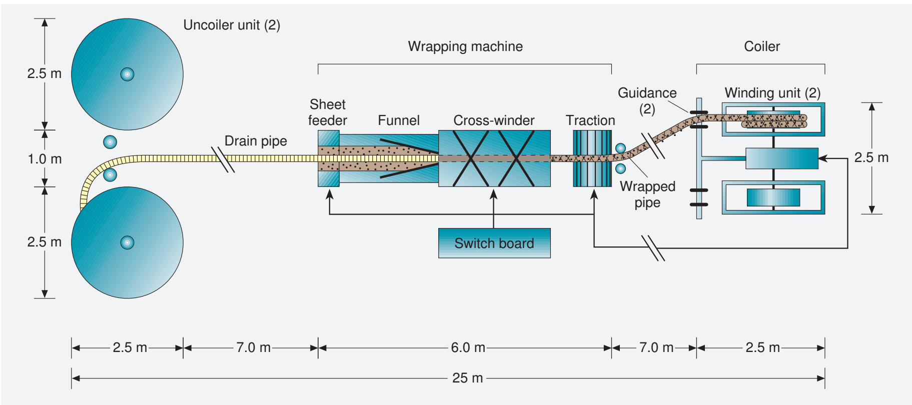
Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical		○	●	
Socio-economical				
Environmental				

Background: In the 1960's, the Egyptian government started an ambitious programme to drain all agricultural lands. Initially, 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 tile 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.

Problem description: As gravel envelopes were costly and difficult to apply, alternatives like pre-wrapped synthetic envelopes were tested and found to be functional (Case Eg-22). However, before these synthetic envelopes could be introduced on a large scale, production facilities had to be created.

Action/intervention: Based on the types of synthetic envelope materials best suited to the Egyptian conditions (Case Eg-22), the Drainage Research Institute reviewed the type of envelope machinery that were commercially available and advised EPADP on: (i) the possibilities to produce synthetic envelope materials locally, and (ii) the most suitable technology to wrap envelopes around the drain pipe. Various suppliers were visited and not only the available machinery and technology was assessed, but also the assistance offered by the suppliers to support the set-up of local production facilities, including the training of local staff. Based on this assessment, it was recommended to select a loose fibre-wrapping machine and to purchase a wrapping-unit consisting of manually-operated uncoiler and winding unit and an engine-operated sheet feeder, funnel and cross-winder:



Lessons learned:
1. Production of a synthetic envelope is a specialised job, thus the know-how of the process is as important as the machinery.
2. Selection of the machinery not only depends on the latest available (most sophisticated) technologies but also on the local absorption capacity.
3. Quality control is a prerequisite for a successful introduction of pre-wrapped envelopes. The establishment of a quality control laboratory at the production site is recommended.

References: Man and Man (1991), Nijland et al (2004), Menshawy et al (2000c), Ritzema and Zeijts (1991)

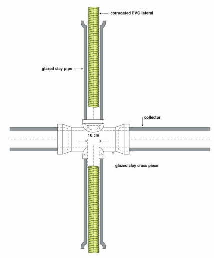
Title: Development of the T-joint to improve the field - collector drain connection.		**Case Study**: Eg-29
Country: Egypt	**Location/Project**: Nation-wide	**Years**: 1980's

Indicator(s) used in this case study: drainage materials, installation method

Stage(s) in SSD practices addressed in this case study:

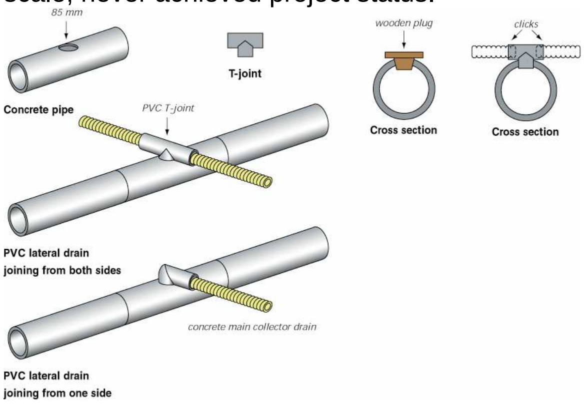
	Planning	Design	Installation	O & M
Technical		○	●	
Socio-economical				
Environmental				

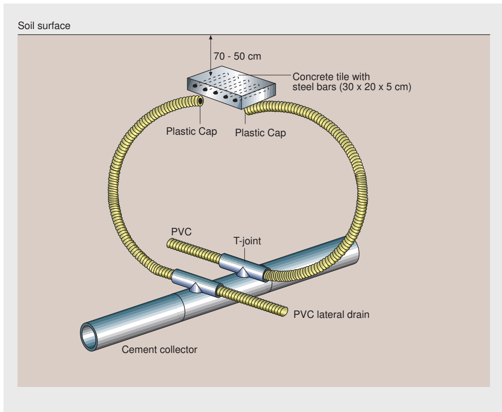
Background: Traditionally, glazed crosspieces were used to connect the field drains with the smaller-diameter collector pipes and buried manholes for the larger-diameter pipes.



Problem description: The installation of these connections required considerable excavation and dry working conditions. Consequently, installation practices were below standard and often sedimentation considerably reduced the performance of the system. An excavation programme carried out in Mashtul Pilot area showed that sedimentation levels in concrete collector drains, with diameters up to 500 mm, reduced the effective cross sectional area by about 35%.

Action/intervention: In the 1980s, after research conducted by the Drainage Research Institute, an improved connection using a plastic T-joint was introduced. The T-joint is clicked into a hole drilled in the concrete collector pipe and than connected to the field drain. The holes in the concrete collector pipes have to be made with an electric drill. Later on, the T-joints were modified so that they also can be used for corrugated plastic collector drains. These T-joint were further modified to enable flushing. However, these flushing inlets, although successfully tested on a pilot scale, never achieved project status.





Lessons learned:

1. The introduction of a plastic T-joint greatly improved the connection between the field and collector drains.
2. Dry conditions, however, are still required to drill a hole in the collector drain.
3. Further improvements to create a flushing inlet, although successfully tested on a pilot scale, never achieved project status.

References: Nijland et al (2004), Nijland et al (2000) and Ritzema and Abdel Alim (1985)

Title: Capacity of drainage machines		**Case Study**: Eg-30
Country: Egypt	**Location/Project**: Nile Delta & Valley	**Years**: 1994-2000

Indicator(s) used in this case study: drainage equipment, implementation process

Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical	○		●	
Socio-economical				
Environmental				

Background: In Egypt, subsurface drainage systems are installed at a rate of about 75,000 ha/year, this implies the installation of approximately 1850 km of collector drain and 18 500 km of field drains.

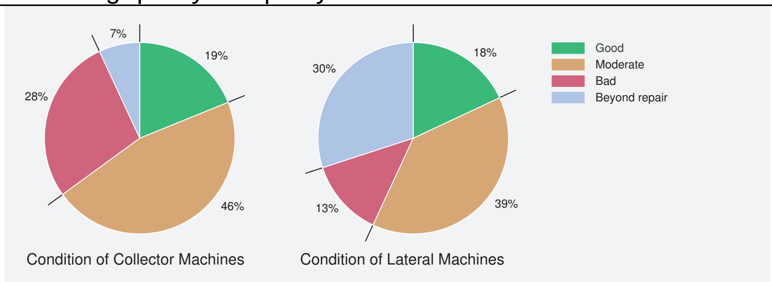
Problem description: One of the main factors affecting the implementation rate of subsurface drainage is the number, productivity, and quality of the drainage machines. Inventories of data were made on the efficiencies and capacities of the various types of drainage machines operational in Egypt collected 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.

Action/intervention: 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 by time and motion studies. 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.



Results of the inventory conducted in 1994: condition of drainage machines

Lessons learned:

1. Time and motion studies are an effective tool to assess the actual capacity of drainage machines.
2. The efficiency of the machines has a close relationship with the age of the machines: the older the machine the lower the efficiency: the efficiency of 15-years old machines is only about 50% of new machines.
3. Results of time and motion studies can be used for planning of drainage projects as the capacity of machines is a decisive factor for the implementation rate of drainage projects.

References: Menshawy et al (2000b) and Nijland et al (2004).

Title: Efficiency of drainage machines		**Case Study**: Eg-31
Country: Egypt	**Location/Project**: Nile Delta & Valley	**Years**: 1994 -onwards

Indicator(s) used in this case study: drainage equipment, implementation process, costs and benefits

Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical	○		●	
Socio-economical	○		●	
Environmental				

Background: In Egypt, subsurface drainage systems are installed at a rate of about 30,000 ha/year, this implies the installation of approximately 1850 km of collector drain and 18 500 km of field drains.

Problem description: To effectively plan the execution of drainage projects (see also Case Eg-04) it is, among others, important to know the efficiency of the drainage machines: how many effective working hours per day, how much time is needed for (daily) maintenance and what is the overall capacity, etc.

Action/intervention: To answer these questions, the Operational Research Unit of EPADP conducted time motion studies. The studies clearly showed a difference between collector-laying and field drain-laying machines: 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).

Time	**Collectors**		**Field drains**	
	%	**(hours)**	**%**	**(hours)**
Non-available time:				
* Field condition	16	1.4	9	0.8
* Technical breakdown	13	1.2	17	1.6
Subtotal non-available	29	2.6	26	2.4
Available time:				
* Non-effective				
- Maintenance	7	0.7	12	1.0
- Meal time	11	1.0	10	0.9
- Organisation	20	1.8	8	0.7
Subtotal available	38	3.5	30	2.6
* Effective time	33	2.9	44	4.0
Total time	**100**	**9.0**	**100**	**9.0**

Lessons learned:

1. The effective time of drainage machines varies between 33% for collector-laying machines to 44% for field drain-laying machines.
2. 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.
3. 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.
4. Selection of supplies can be done based on the performance of machines bought in the past.

References: Menshaway et al (2000b) and Nijland et al (2004)

Title: Installation methods: from manual to mechanical installation		**Case Study**: Eg-32
Country: Egypt	Location/Project: Nation-wide	**Years**: 1970's onwards

Indicator(s) used in this case study: drainage equipment, installation methods, implementation process

Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical	○	○	●	
Socio-economical				
Environmental				

Background: 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 marking the beginning of Egypt's modern drainage. 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 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, imported by the government, is handed over to the contractors and paid back in instalments 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 contractors mostly to the private sector have resulted in most contractors now being able to buy their machines directly from the market, although the original arrangement is still a viable option.

Problem description: All drainage machine used in Egypt are imported. To adjust these machines to the local conditions, a number of modifications and improvements were required.

Action/intervention:

- To reduce resistance of the cohesion forces of the sticky clays, the machines were equipped with a water tank to spray water on the cutting blades of the trencher chain and along the sides of the trench box.
- The width of the crawlers was adjusted to produce adequate pressure for the bearing capacity of the Egyptian soils. Similar adjustments were made to the length of the tile trench box, the arrangement and design of blades on the revolving machines and so forth.
- Laser equipment was introduced in the late 1980s. In the 1990s the use of laser equipment became a compulsory condition of the construction contract (Case Eg-34).
- 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.
- 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.
- To improve the quality of construction, EPADP has established a vocational training centre where also contractor staff is trained on the latest methodologies, materials and equipment (Case Eg-09).

Lessons learned:

1. Co-operation between EPADP, contractors and machine suppliers proved to be successful in developing and implementing improvements to adjust the imported drainage machines to the local conditions.
2. Implementing these modification and improvements is a gradual and never-ending process as technologies and implementation requirements are continuously changing over time.

References: Nijland et al 2004, Nijland et al (2000)

Title: Installation of field drains using trenchless machines		**Case Study no.**: Eg-33
Country: Egypt	**Location**: Haress Pilot Area, Nile Delta	**Year**: 1996

Indicator(s) used in this case study: drainage equipment, installation methods, implementation process

Stage(s) in SSD practices addressed in this case study :

	Planning	Design	Installation	O & M
Technical	○		●	
Socio-economical				
Environmental				

Background: With the start of the World Bank funded projects in 1970, mechanical installation of pipe field drains was introduced on a large scale in Egypt. Heavy trenchers are used to install field and collector drain pipes with diameters of up to 250 mm. Imported machinery is adjusted and modified to suit local conditions.

Problem description: Subsurface drainage installation encountered problems in unstable light-textures (sandy) soils at the fringes of the Nile Delta and Nile Valley. These problems were aggravated with the presence of high water table or upward artesian pressure. Collapsing trench walls caused misalignment problems and permanent damage to the drainpipes. High water tables during construction led to an inflow of sediment-rich water into the plastic drain pipes resulting in floating pipes.

Action/intervention: In the summer of 1996, a trenchless drainage experiment using a V-plough machine was conducted to install pipe field drains in irrigated fields. A total of 142 km of field drains were installed in (heavy) clay and loamy sand soils, at depths between 1.2 and 1.7 m. The hydraulic performance of the installed SSD systems was compared against those installed by trenchers. Watertable drawdown curves, measured 5 m from the drain, were used as indicator of the hydraulic performance of the drainage systems. The results show that: (i) when using trenchless machines the cost per km is approx. 25% lower compared to trenchers; (ii) the V-plough can install drains up to a depth of 1.8 m; (iii) the average net installation speed was approx. 2350 m/hr and the average gross speed, including loading pipes, travel between lines, etc., 615 m/hr; (iv) the special Apex-tracks allow pipe drain installation in fields that have recently been irrigated: only 3 to 12% of the drain lines could not be completed in fields irrigated 0-4 days beforehand; (v) only 1% of the total 660 filed drains could not be completed, due to slipping tracks or have to cross ditches that were too wide, the V-plough experiences problems when a ditch full of water was close to and almost parallel to the drain alignment, and (vi) although, the watertable drawdown rate during the first two years after construction was lower compare to trencher-constructed drains, the drawdown rate was well within the criterion that the watertable should be at design depth six days after an irrigation event.

Lessons learned:

1. V-plough trenching techniques can be used to install drain pipes in (heavy) clay and loamy soils under irrigated conditions.
2. The V-plough experienced problems when a ditch full of water was close to and almost parallel to the drain alignment. This problem could be easily solved by slightly adjusting the location of the upstream end of the drain.
3. The research resulted in draft guidelines for the use of V-plough trenchless drainage machine under Egyptian conditions. These guidelines include specifications for tendering: i.e. machine requirements, ground pressure, maximum installation depth, installation speed and installation after irrigation and on quality control.

References: DRI (2001), Nijland et al (2004) and Menshawy et al (2000d).

Title: Laser technology: its introduction and acceptance		**Case Study**: Eg-34
Country: Egypt	Location/Project: Nation-wide	**Years**: 1990-1992

Indicator(s) used in this case study: drainage equipment, installation method, quality control

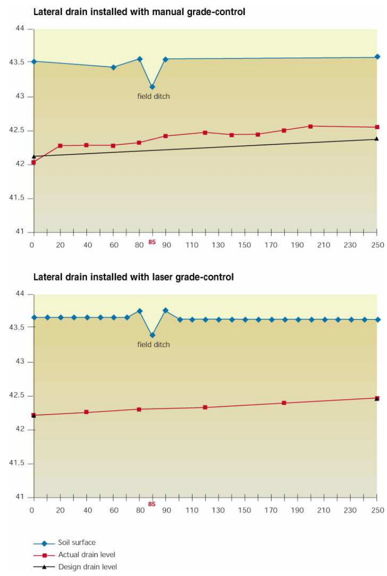
Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical			●	
Socio-economical				
Environmental				

Background: Installing a drain or collector pipe at the proper grade (slope) is essential for the functionality of the drain. Traditionally, this was done manually during or immediately after installation by measuring the level of the top of the drain pipe every 5 m.

Problem description: To improve the quality of the installed drainage systems and to increase the efficiency of the drainage machines, grade control by laser technology was an option.

Action/intervention: Laser equipment for drainage basically consists of two components: (i) a transmitter**,** which is positioned in the field, and: (ii) a receiver mounted on the trench box of the drainage machine. The receiver is electrically connected to the hydraulic system of the lifting cylinders of the trencher and is programmed in such a way that it automatically adjusts the depth of the trench box to the preset grades stored in the memory of in the transmitter.



There are also indictor lights on the operator's display (receiver display) so that he can check the system continuously. The main benefits of laser control are: (i) continuous level control during installation; (ii) better and easier grade-control by operator; (iii) obstacles such as irrigation ditches and field bunds can be crossed without affecting the slope; (iv) less preparation time (staking out sight bars in the field). Introduction of laser control resulted in a higher quality of the work, better system performance and less maintenance (Figure). Laser grade-control, however, also requires that due attention is paid to:

- Periodic calibration and proper maintenance of this sophisticated, vulnerable, equipment
- The transmission speed of the laser had to be reduced to less than 300 rpm to avoid that the hydraulic system of especially some of the older drainage machines is not affected.
- The hydraulic system of some of the older machine could not cope with the sudden changes in levels when crossing a bund or irrigation ditch.

Lessons learned:

1. The introduction of laser control resulted in a higher quality of the work, better system performance and less maintenance.
2. Training of the machine operators, mechanics, observers and engineering (supervising staff) was crucial for the successful introduction on a large-scale.

References: Nijland et al (2004), Rashed et al (2000) and Ritzema et al (2006)

Title: Installation of a SSD system under adverse conditions: hard rock		**Case Study**: Eg-35
Country: Egypt	**Location/Project**: Fringes of the Western Nile Delta	**Years**: 1970's

Indicator(s) used in this case study: drainage equipment, installation method, soil and hydrological conditions, implementation process

Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical	○		●	
Socio-economical				
Environmental	○		●	

Background: The field conditions in Egypt, namely, type of soil and agro-hydrologic conditions are rather uniform. The soil consists of relatively deep alluvial soils with a high clay and silt content. In the Western Nile Delta, some areas are characterised by calcareous hard rocks in the subsoil (Nubariya).

Problem description: Special arrangements have to be made to install subsurface drainage in these "problem" areas.

Action/intervention: 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 watertable 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.

Lessons learned:

1. A special type of trencher with a more powerful engine and a different design and material for the digging mechanism was developed to install subsurface drainage systems in areas with calcareous soils and intersecting hard rock.
2. A partnership and cooperation between the contractor and the machine supplier proved to be successful in developing and implementing these improvements.

References: Nijland et al (2004)

Title: Installation of a SSD system under adverse conditions: upward pressure		**Case Study**: Eg-36
Country: Egypt	**Location/Project**: Sherashra and Haress, West Nile Delta	**Years**: 1979 and 1994

Indicator(s) used in this case study: installation method, soil and hydrological conditions, drainage materials

Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical	○		●	
Socio-economical				
Environmental	○		●	

Background: The field conditions in Egypt, namely, type of soil and agro-hydrologic conditions are rather 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.

Problem description: Special arrangements have to be made to install subsurface drainage in these "problem" areas. 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 ground water 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, in the Sherashra Pilot Area, revealed the prevalence in the area of a piezometric head around soil surface, 1 to 1.5 m above the groundwater table. 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.

Action/intervention: 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. Using new materials and installation techniques, a pilot area was constructed in 1993-1994: pre-wrapped PVC corrugated plastic pipes were used for the field drains and corrugated imperforated HDPE pipes for the collectors. The field drains were installed successfully and their performance was adequate. However, the results were not entirely satisfactory due to problems with the installation of the gravel envelope. The installation of the collector drains at a greater depth (2.0-2.5 m) also proved to be problematic: groundwater rising under pressure in the trench behind the trencher machine made the non-perforated 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 (Case Eg-33).

Lessons learned:

1. To install collector drains under conditions with upward pressure it is recommended to use pre-wrapped perforated collectors.

References: DRI (1992c), DTPAP (1993), Nijland et al (2004.)

Title: Quality control of subsurface drains by rodding		**Case Study**: Eg-37
Country: Egypt	**Location/Project**: Nile Delta	**Years**: 2000
Indicator(s) used in this case study: quality control, drainage equipment		

Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical			●	○
Socio-economical				
Environmental				

Background: Rodding equipment is used in Egypt for checking the damaged drain pipes, misalignment of the drain pipes or sedimentation inside the drain pipes. The equipment consists of a rodding head, which is pushed into the drain pipe by means of a long fibre-glass rod. The length of the rod is 300m. The rodding head consists of a rigid metal bar, at the front end provided with a torpedo- shaped 'go-gauge'. At the end of the fibre- glass rod, 'go-gauges' of different diameters can be attached, as well as a sound of radio detection. The fibre -glass rod is wound on a reel. The reel can be transported, either attached to a tractor or it can be rolled over the ground surface on the outer ring of the cage in which is wound.

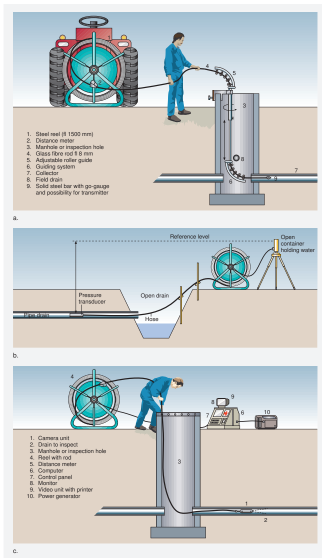
Problem description: Pipes drains, especially those install by trenchless drainage machine cannot be checked visual, thus quality control during installation is difficult. Rodding is a non-destructive method to check the quality.

Action/intervention: The equipment could be used as follows:

- The reel is put in position at the beginning of the drain line that is to be checked;
- The glass -fibre rod is pushed into the drain by hand;
- If the rodding head get stuck, the spot where this happens can be located by means of the counter (distance measurement) on the fibre-glass rod or by the sound (a small radio emitter) in the rodding head, which produces a signal;
- The site of the disturbance has to be marked in the field and /or map. Its location can then be traced later on for repair or excavation.

Lessons learned:

1. If the drain has been correctly installed, the rod can pass unhindered.
2. The required pushing force increases slightly with the length of the drain. However, if the drain spirals, the required pushing force increases with the length of the drain.
3. The required force should not exceed a pre-set limit.
4. If the rod cannot pass a particular point in the drain, there is a fault in the installation and the drain has to be excavated at this point.
5. Drains up to a length of 400 m can be checked by rodding.
6. In principle, every single drain can be tested but this will prove to be rather expensive. It is therefore recommended to randomly test only a limited number of drains, for instance, 10% of the drains. Testing can be increased if more than a prescribed percentage of drains fail the test.
7. The number of drains to be tested, the method and whether or not the contractor has to replace malfunctioning drains must be specified in the contract.
8. Rodding is also a useful means of making sure that the drain will be accessible for flushing.
9. Although rodding is a useful tool to check whether there are disturbances in the drain line, the method cannot be used to check the slope of the drain line. To do this continuous depth recording is required.



References: El-Sherbiny and Nijland (2000), Nijland et al (2004) and Ritzema and Alim (1986).

Title: Lessons learned from the construction of drainage pilot areas		**Case Study**: Eg-38
Country: Egypt	**Location/Project**: Nile Delta	**Years**: 1976-2001

Indicator(s) used in this case study: installation method, implementation process, stakeholder participation

Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical	○		●	
Socio-economical	○		●	
Environmental	○		●	

Background: Since its establishment in 1976 the Drainage Research Institute (DRI) has designed and implemented a number of pilot areas to conduct field research in farmer's fields, among others, Sherashra (1979), Mashtul (1980), Haress (1993-94), Mit-Kenana (1992).

Problem description: Designing and implementing a new pilot area is always a new challenge as, per definition, new and unknown circumstances are encountered. A careful planning, based on past experiences, increase the changes of success and reduce the risks for failures, like in Sherashra.

Action/intervention: To keep a good record of past experiences costly mistakes can be avoided.

Lessons learned:

1. All persons involved in the pilot area research, i.e. research team, farmers, local authorities like Water Users Associations, Extension Services, Irrigation Department, Village Councils, etc. should know: (i) why the pilot area is constructed: objectives, activities and expected outcomes; (ii) who is the main client for the result of the research, and; (iii) when the results of the research work are needed.
2. The pilot area must be representative for the project area. If the project area is not homogeneous or uniform, the establishment of two pilot areas should be considered.
3. It is required that the pilot area can be reached the whole year around. Thus it should be constructed near all-weather roads. Remember that it is of utmost importance that the functioning of the drainage system during extreme rainfall conditions can be monitored.
4. Farmers must realise the importance of the pilot area and they must be involved in the design phase of the drainage system. A channel of communication and trust must be created between the farmers and the research team through non-official and social meetings. Key-person, with a social status among the farming community, can play an important role in this respect.
5. Care should be taken during the pre-investigation phase to prevent any misleading or biased results. E.g., in El Serw Pilot area, sand lenses at drain depth were discovered during the construction of the subsurface drainage system in spite that all the survey results indicated that the soil type predominantly clay and that pipe drains without envelope materials could be used.
6. Quality control and quality assurance must be regarded during the construction of the pilot area. Checking materials, drain levels, slopes, pipe connections, envelope materials, etc. must be done regularly according the specifications.
7. Any mistakes during the construction must be corrected immediately to prevent any harmful effect on the soil and plant afterwards. This is essential as the research team has to gain the trust of the farmers.
8. The monitoring programme for measurements must be planned and discussed several times with the team to achieve good results within the planned time.
9. Observers should be well trained and researchers must coach them and regularly check the results.
10. Data processing and analysis and reporting should be finished according the planned time to make the client satisfy.

References: DRP (2001), DRI (1992a&c), DRI (1990a&b), DRI (1987c), DTPAP (1993), Nijland et al (2004)

Title: Watertable drawn-down curves to assess the functioning of SSD

Case Study:Eg-39

Country: Egypt | **Location**: Mashtul, Nile Delta and Fayoum | **Year**: 1992-1996

Indicators addressed in this case study: Operation, monitoring, soil and hydrological conditions

Stage(s) in SSD practices addressed in this case study :

	Planning	Design	Installation	O & M
Technical		○		●
Socio-economical				
Environmental				

Background: In Egypt, the fluctuation of the water table is being monitored to assess the performance of subsurface drainage systems. Data collected in pilot areas was used to select an appropriate indicator.

Problem description: Watertables fluctuate in time: it rises after rainfall or irrigation and falls due to crop evaporation and/or groundwater flow to drains. To study how the watertable drawdown curves can be used to assess the performance of SSD, data sets from the Fayoum and various pilot areas in the Nile Delta were analyses.

Action/intervention: Data were grouped according drain depth, drain spacing and initial depth of the water table. For these data sets the upper and lower boundary-lines of the drawdown curves were established. If a draw-down curve from a selected plot falls within the upper and lower boundary lines, the system performs according to the design (If the point falls above the line, the drain is not working well.

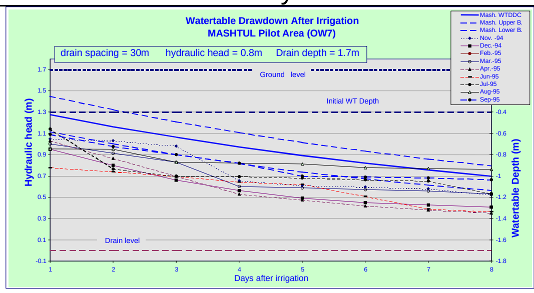


Figure Draw-down curves in Mashtul Pilot Area

In case that the data falls below the line the system or drain was probably over-designed. Other factors that are not directly related to the functioning of the drain line or drain system may also cause a rapid water table drop. Equally so, if the data point falls above the upper boundary, the cause of this may not be the individual drain line, but could be a blockage further downstream. Hence the curves are highly suited for the preliminary PA, but for cause analysis more data are needed.

Lessons learned:

1. From all the watertable drawdown-curves reviewed during the study, the design water table depth was achieved approximately six days after irrigation. This then may serve as the target value or target rate for typical drainage systems in Egypt.
2. Watertable drawdown-curves are highly suited for the preliminary Performance Assessment, but for cause analysis more data are needed.

References: DRI (1990b), DRI (1987a), DRP (2001), DTPAP (1993), Eissa (2001) and Eissa et al (1996)

Title: Watertable as function of area as an indicator to assess the performance of SSD-systems.

Case Study: Eg-40

Country: Egypt

Location/Project: Mashtul, Nile Delta and Fayoum

Years: 1992-1996

Indicator(s) used in this case study: Operation, monitoring, soil and hydrological conditions

Stage(s) in SSD practices addressed in this case study :

	Planning	Design	Installation	O & M
Technical				●
Socio-economical				
Environmental				

Background: Traditionally, the depth of the watertable has been used in Egypt as an indicator for the performance of a SSD-system. This indicator was used in World Bank projects.

Problem description: The indicator lacks a clear definition of the period during which the observations should be taken. Also the area to be considered is not clearly defined. To study how this indicator can be improved, data sets from the Fayoum and various pilot areas in the Nile Delta were analyses.

Action/intervention:
The data was plotted in contour maps and from these the area under certain water table depth can be determined. Besides hard statistical data this method also gives a visual image of the extent of water logging. If during a critical growing period, under Egyptian conditions, 75% of the area has a water table less than 100 cm below the surface, it could be concluded that the SSD-system is performing less than the design standard.

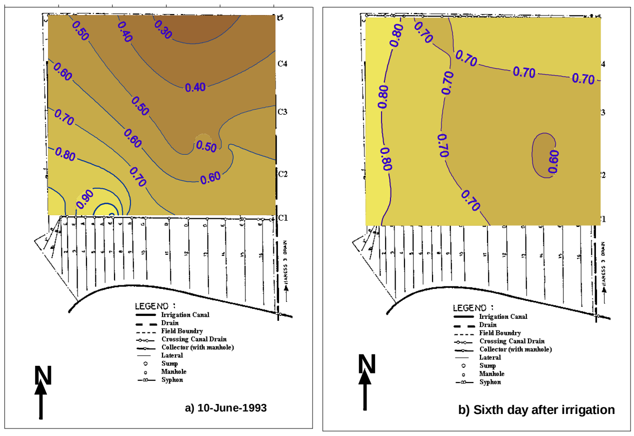


Figure Application of the water table as function of area indicator at Haress Pilot Area

Lessons learned:

1. In all cases, all measurement locations in the grid should be measured preferably on the same day. In this research, the data of the 6th day from irrigation is taken as resulted from the watertable draw down curve of the study area.
2. Observations could be on a grid of 500 x 500 m. If it is needed to assess the need for maintenance or rehabilitation or a real idea about the performance assessment of an area the observations should be on a grid of smaller scale.

References: DRP (2001), Eissa (2001) and Eissa et al (1996)

Title: Hydraulic performance collector drains		**Case Study**:Eg-41
Country: Egypt	**Location/Project**: Balaktar, Mahmoudiya, Masanda and Roda/Nashart areas in the Nile Delta	**Years**: 1984-1989

Indicator(s) used in this case study: Operation, monitoring, drainage design

Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical		○	○	●
Socio-economical				
Environmental				

Background: Pipe diameters of the collector and field drains are calculated with steady-state equations (Manning) with the criterion that no overpressure occurs at the beginning of the field drain. The design discharge for collectors in non-rice areas is taken as 3 mm/d, including a safety factor of 2. In rice-growing areas, a drainage coefficient of 4 mm/d is used, including a safety factor of 33%.

Problem description: The hydraulic performance of the collector and field drains depends not only on the design criteria but also on the quality of construction. To verify the design criteria and the standard installation practices adopted by the Egyptian Public Authority of Drainage Project (EPADP) a monitoring programme to quantify:(i) the assumptions in the design equations, i.e. applied reduction factors, roughness coefficient, full-flow conditions, etc.; (ii) the actual alignment of the drains, and (iii) obstructions in the drains, i.e. roots, sediments, etc., which reduce the effective cross-section area.

Action/intervention: A four year monitoring programme was conducted in four areas in the Nile Delta to check the hydraulic performance of collector drains. A period of 4 years was selected to include the 3-year cropping pattern that is commonly practiced in the Nile Delta. The study covered rice-growing areas in the western (Balaktar) and northern (Nashart/Roda) Nile Delta and non-rice areas in the northern (Masanda) and eastern (Mahmoudiya) Nile Delta. Discharges, salinities and (over)pressures were monitored and excavation programmes were carried out. The following conclusions could be derived: (i) the discharges were significantly smaller than the design rates, i.e. between 0.7 and 1.0 mm/d in the non-rice areas and 1.0 and 2.7 mm/d in the rice-growing areas; (ii) the discharge in the rice-growing areas were proportional to the area cultivated with rice; (iii) despite the relative low discharge rates, overpressure occurred in rice-growing areas; (iv) overpressure mainly occurred in the upstream parts of the collector-lines with discharges below the design rate (v): excavation programmes revealed that the reduction in the cross-sectional area reduced the effective cross-sectional areas up to 35%; (vi) sedimentation in plastic pipes was significantly lower compared to cement pipes: (vii) hydraulic performance greatly improved after maintenance (viii) salt concentrations were much higher in the north of the Nile Delta compare to the south, probably due to presence of natural drainage in the south and upward (brackish) seepage in the north.

Lessons learned:

1. Discharge rate were smaller than the design rate and are proportional to the area cultivated with rice.
2. Overpressure occurred mainly in the upstream sections of the collector lines, caused by sedimentation and/or root growth.
3. Root growth takes place at places where the collector line crosses a line of trees.
4. Maintenance can effectively reduce overpressure by removing sediment and or roots.
5. Roots can be removed by rodding but not by flushing.

References: DRI (1989), DRI (1986a&b), El-Atfy et al (1991 & 1990b), Ritzema et al (2006) and Ritzema and Alim (1986)

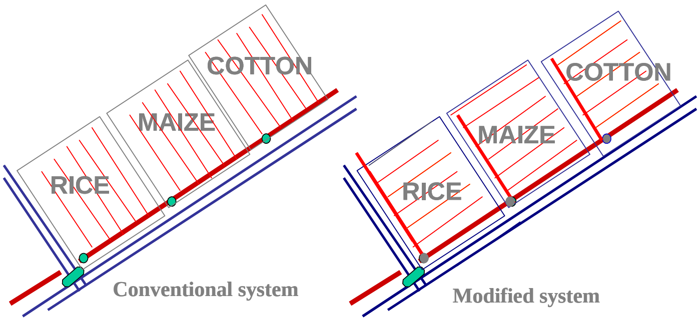
Title: Controlled drainage and farmer participation. | **Case Study**: Eg-42

Country: Egypt | **Location/Project**: Balaktar area, Western Nile Delta | **Years**: 1995-1998

Indicator(s) used in this case study: operation, drainage method, stakeholder participation, costs and benefits

Stage(s) in SSD practices addressed in this case study :

	Planning	Design	Installation	O & M
Technical	○	○		●
Socio-economical	○	○		●
Environmental	○	○		●



Background: Water scarcity will become a major concern in the near future in the Nile Delta. Already during the early eighties the, a modified drainage system for rice areas was introduced to closed part of the system during the rice season (Figure and Case Eg-12). Water savings of up to 30% or more and considerable time savings for the farmers were achieved. The modified SSD system requires crop consolidation in the sub-catchments of the drainage system, adjustments in the traditional drainage design (more sub-collectors), willingness of farmers to consolidate, and passing on of the savings to the farmers by water user associations.

Problem description: To increase awareness about the benefits of the modified SSD-system among farmers and acceptance of the technique by farmers and the drainage authority, in 1995 DRI re-introduced modified drainage as controlled drainage, through traditional field trials, new Participatory Rural Appraisal techniques, and advertising the opportunities with all stakeholders. Emphasis was put on: (i) farmers involvement on operation, and; (ii) savings in irrigation water supply.

Action/intervention: Farmers were organized on voluntary basis to consolidate the rice areas and the collectors were provided with closing devices. Observations were also made along two other collector drains where farmers did not consolidate rice areas. The results show that the average irrigation water supply for the modified system is 1805 m^3/ha and 3169 m^3/ha for conventional collectors. This means that the modified drainage system saves about 43% of irrigation water compared to the conventional system, reducing the costs of renting pumps with the same percentage. The reduction in irrigation water supply did not result in a yield decrease (the average yield in the modified SSD-plots was 2.7 t/ha compared to 2.6 ton/ha in the conventional plot). The decrease in soil salinity indicated that although the subsurface drainage in the modified SSD-plot is restricted, the leaching requirements are still met. Based on the findings, guidelines to help with appropriate design and water management have been prepared.

Lessons learned:

1. Farmers nicely adjusted themselves in the application of the modified SSD-system. As a result the farmers in the modified-plot used up to 43% less irrigation water (saving the same percentage in pumping costs).
2. Controlled drainage is not only important to reduce water use during the rice-growing season, but will become an essential water management tool during water scarce situations for all crops. Downstream environmental impacts can also be controlled and minimised.

References: Abdel Ghany et al (1997), DRI (2000), DRI (2001), DTPAP (1993) and ILRI and DRI (2001)

Title: Managing subsurface drainage to save irrigation water		**Case Study**: Eg-43
Country: Egypt	**Location/Project**: Nile Delta	**Years**: 1987 - 1990 - 2005

Indicator(s) used in this case study: operation, drainage method, stakeholder participation, costs and benefits

Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical	○	○		●
Socio-economical	○	○		●
Environmental	○	○		●

Background: In Egypt more than2 million ha of irrigated lands have been provided with a subsurface drainage system to control waterlogging and salinity. These systems have been designed based on criteria for the design depth of the watertable and corresponding discharge (Case Eg-21). These original design assumptions only occur for short periods and so for most of the time excessive drainage occurs. With the result that approximately 7.2BCM of water is drained from areas provided with SSD-systems. In the 1980's, a modified lay-out for areas with rice in the cropping pattern was developed to, among other, reduce drain discharges from these areas (Case Eg-12). Based on trials in farmers operated fields it could be concluded that up to 25 % of irrigation water could be saved with the introduction of the modified system.

Problem description: To investigate whether controlled drainage could also save irrigation water during the season non-rice crops are cultivated while maintaining a favourable water- and salt balance, the simulation model DRAINMOD-S was applied for the western Nile Delta to test new easily adoptable management measures.

Action/intervention: Various management concepts to control effective drain depth and spacing in combination with reduce irrigation water supply during the growing season were tested, i.e. drain spacings were doubles by blocking alternate drains and watertables were raised by controlling outflow. The results show that with controlled drainage irrigation volumes can be reduced without sacrificing yields. Application of controlled drainage has the potential to maintain and even increase yields while increasing irrigation water use efficiency by 15 to 20%.

Lessons learned:

1. Controlled drainage, in combination with improved irrigation practices, has the potential to increase irrigation water efficiency by 15 to 20%.
2. Low-cost and easily controlled options can be introduced to improve subsurface drainage management.
3. Controlled drainage requires coordination and training between irrigation authorities, drainage authorities and farmers.

References: El-Atfy et al (1990a), Wahba et al (2005)

Title: Leaching of nitrates through subsurface drainage.		**Case Study no.**: Eg-44
Country: Egypt	**Location/Project**: Mashtul, Nile Delta	**Years**: 1989 – 1992

Indicator(s) used in this case study: operation

Stage(s) in SSD practices addressed in this case study :

	Planning	Design	Installation	O & M
Technical	○			●
Socio-economical				
Environmental	○			●

Background: The common fertilizers used in Egypt are urea, calcium nitrate, potassium, sulphate, super phosphate and ammonium sulphate. Generally, the fertilizer applications, especially calcium nitrate and ammonium sulphate, are applied in two doses separated by about one month.

Problem description: The drainage effluent is re-use for irrigation after mixing it with irrigation water to reduce the salinity. As the drainage effluent not only contains dissolved salts but also dissolved fertilizers, it is important to know the concentration of these dissolved fertilizers. .

Action/intervention: In a drainage pilot area in the South East of the Nile Delta, the leaching of agro-chemicals form fields with various crops and drain intensities (drain depth/spacing combinations) was monitored. In each field, three observation wells were installed midway between the field drains a depth of 2.0 m below ground level, groundwater samples and water samples from the outlets of the field and collector drains were collected every fortnight. The results show that the concentration of nitrates fluctuates during the seasons with remarkable increase after each application of fertilisers. Pollution of the shallow groundwater with nitrates (NO_3) during both the winter and summer season is very similar to the pollution of the drainage water (discharge from the field drains). The concentration of nitrates in the drainage water, however, is very much influenced by the drainage intensity. The concentration in drainage water from fields with deeper drains (1.50m) and narrow spacing (15m) reached higher peaks than those of the other more shallower and wider drain depth/spacing combinations. The nitrates concentration in the groundwater and drainage water during winter is small and seldom exceeded 25 ppm, because berseem is not fertilised with nitrates. Consequently, the nitrate concentration in the collector and open main drains was small. The nitrate concentration in the drainage water of rice fields is relatively less compare to the other summer crops. Continuous flooded crops produce lower concentrations than intermittently irrigated crops probably due to dilution and denitrification.
The concentration of nitrates in the drainage water is also reduced as the drainage water flows from the field drains into the collectors and then to the main drain. The peak nitrates concentration during summer at the outlet of the closed collector and the open main drain were 152 and 89 ppm, respectively. In the collector system, the field drainage water from different field crops gets mixed together. The open main drain usually receives fresh irrigation water losses and surface runoff which cause further dilution of the Nitrates concentration. This concentration, however, is sufficient to encourage and enhance the aquatic weed growth in the Egyptian drains.

Lessons learned:

1. Remains of dissolved nitrates are leached out through the SSD-system. The concentration depends on the applied dozes, which vary per crop and the time of application.
2. Dilution takes place as the drainage effluent flows from the field drains n the collector drains, as the later also receive drainage effluent from fields with different crops. The effluent is once-more diluted when discharged in the open drain as open drains also receive irrigation water losses and surface runoff. Despite this dilution, the concentration of nitrates is still so high that it enhances weed growth.

References: Abdel-Dayem and Abdel Ghani (1992) and Bouwer (1987)

Title: Safe disposal of drainage effluent		**Case Study**: Eg-45
Country: Egypt	**Location/Project**: Nile Delta & Valley	**Years**:

Indicator(s) used in this case study: operation, drainage method

Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical				
Socio-economical				
Environmental		○		●

Background: Agriculture in Egypt depends almost entirely on irrigation from the river Nile. With the year-round availability of water, 2 or 3crops a year can be grown. Under the present cropping pattern, the quantity of irrigation water applied to a representative area in the Nile delta is about 1200 -1500 mm/year. Although the irrigation water is of good quality (0.3 dS/m), it brings salts into the soils at a rate of 2 to 3 ton/ha/year. To guarantee sustainable land use, this amount of salts is leached from the soil profile through the subsurface drainage system.

Problem description: The River Nile is not only the only source of irrigation water it also acts as its main drain as all drainage effluent from the agricultural lands in the Nile Valley is discharged back to the river, increasing the salt load in the downstream direction.

Action/intervention: To assess whether this is a sustainable method, the overall water and salt balance was calculated. Of the amount of water passing the Aswan High Dam (approximately 55×10^9 m^3/year), part is used to irrigate the Nile Valley between Aswan and Cairo (approximately 0.9×10^6 ha). Because all the drainage water is discharged back into the River Nile, the salinity of the Nile water increases in downstream direction (Table). This practice is safe and sustainable because the salinity of the water entering the Nile Delta is still acceptable low (< 0.47 dS/m). In the Nile Delta, however, a separate open main drainage system had to be constructed to discharge the drainage effluent directly in the sea as diverting this water back to the river would result in unacceptable high salinity levels. The increase in the total salt load between Cairo and the Mediterranean Sea is due to the leaching of deeper (saline) soil layers and the seepage of saline groundwater. Since 1930, 21 pumping stations have been built in the Nile Delta to pump part of the drainage water back into the irrigation system. In the 1980's approximately 2.9×10^9 m^3/year of drainage water with an average salinity of 1.45 dS/m was pumped back into the irrigation system, totalling approximately 15% of the crop water supply. Farmers also re-use drainage water by pumping it for irrigation directly from the drains. On the basis of a measuring program and simulations with the SIWARE integrated water-management model, it is estimated that, in the eastern part of the Nile Delta, 15% of the crop water is supplied from groundwater and on-farm re-use. A major disadvantage of this re-use is that, because the salinity of the re-used water is often high, it contributes more than proportionally to the total salt supply to the crop. In this case, the contribution of the 15% re-used water is about 46% of the total salts supplied through irrigation.

Location	Discharge (x 10^9 m^3/yr)	Salinity (dS/m)	Total salt load (x 10^9 kg)
Aswan High Dam	55	0.31	11.0
Delta Barrage (Cairo)	35	0.47	10.5
Mediterranean Sea	14	3.59	32.0

Lessons learned:

1. In its upper reaches (up to Cairo), the River Nile can be used for safe disposal of drainage effluent: although its salinity increases it is still safe source for irrigation water.
2. More downstream, the Nile Delta, irrigation and drainage systems have to be separated, to avoid a too high salt concentration in the irrigation water.
3. Water and salt balances are a good tool to assess the safe disposal of drainage water in rivers. Lakes or other open water bodies.

References: Abdalla et al (1990), Abdel Gawad et al (1991), El Quosy (1989) and Ritzema and Braun (1994)

Title: Maintenance of subsurface drainage systems – flushing | **Case Study**: Eg-46

Country: Egypt | **Location/Project**: EL Gorn, El Lawaya and Harrara in Beheira Governorate, Western Nile Delta | **Years**: 1997-1998

Indicator(s) used in this case study: maintenance, soil and hydrological conditions, drainage equipment

Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical				●
Socio-economical				●
Environmental				

Background: Maintenance of SSD systems has become a major concern in Egypt because of the large areas provided with such systems yearly. EPADP has maintenance Departments, Centres and Sub-Centres. Each drainage sub-centre is responsible for the routine and preventive maintenance of the subsurface drains in an area of 5,000 feddan (2100ha). The Sub-Centre Staff, working in close consultation with the farmers, use flushing machines and inspection and cleaning tools. In principle, the subsurface drainage system should be flushed twice every year. When farmers notice any malfunctioning of the system, they report to the staff of the maintenance Centre to carry out the necessary corrective repair and flushing if necessary. The first trials for maintenance of the system were done in the past by pushing a jointed bamboo rod through the pipes to loosen deposits. Nowadays, jet flushing is a very effective technique for cleaning drainpipes and improving their performance. It removes sediments and obstructions and cleans the perforations of the drainpipes. The large volume of water flushes the loosened sediments to the down stream end of the pipe or the downstream manhole of collector pipes. Since 1984, high-pressure (HP) flushing machines, of about 80 bar pressure at the pump, have been used to remove sediments in subsurface drain laterals.

Problem description: High-pressure machines, however, may cause disturbance problems in the soil around the field drains, resulting in even more sedimentation after flushing. Moreover, it is difficult to maintain a uniform speed for the movement of the flushing hose during the flushing process, which decreased the flushing efficiency. Therefore, medium pressure (MP) machines of 20 – 40 bar pressure at the pump have been suggested to replace the high pressure ones.

Action/intervention: An experimental field study to compare and evaluate the use of medium and high-pressure flushing machines was conducted in three areas. The selection of the areas was done in cooperation with EPADP to represent different soil textures and pipe materials in EL Gorn, El Lawaya and Harrara in Beheira Governorate, Western Delta. The results were:

- Sediment removal efficiency achieved by using MP pressure flushing machine is about 100%. For the HP machine this efficiency was about -150 to 75% (the negative sign means the increasing of sedimentation inside drain pipe after flushing).
- Soil stability around the drainpipe as affected by the different pressures was not clearly identified by field measurements. This may be due to the complex nature of such phenomenon, which is controlled by different parameters. The drains flushed with the HP machine had again sediments in the pipe after flushing while this was less the case with the MP machine.
- MP machine had almost regular speed of advance and withdrawal of the flushing hose through the drain pipes, while the movement of the flushing hose with the (HP) flushing machine was irregular with significant reduction in the withdrawal speed; the operating pressure dropped to only 25% of design pressure during hose withdrawal.
- The total costs of the (MP) flushing machine (LE 0.13/m) was about 33% less than the costs of the (HP) flushing machine (LE 0.20/m). Manpower, fuel and crop damage costs are the main causes for such difference.

Lessons learned:

1. Medium pressure flushing machines perform better under Egyptian conditions, especially in light textured soils, having a higher economic and technical efficiency.

References: Bons and Van Zeijts (1991), Hanafy, Abdel Ghany and El-Salahy (1998), Nijland (2000), Nijland et al (2004) and Ritzema and Alim (1986).

Title: Video inspection of field and collector drains to assess the need for maintenance

Case Study: Eg-47

Country: Egypt

Location/Project: Abu Matamir, Western Nile Delta

Years: 1994-2001

Indicator(s) used in this case study: maintenance, soil and hydrological conditions, drainage equipment

Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical				●
Socio-economical				
Environmental				

Background: Egypt is in the process to install SSD-systems on all its agricultural lands (about 2.5 million ha). To keep these systems in good working order, assessing the maintenance need is a major concern (see also Case Eg-46).

Problem description: Visual inspection of pipe drains is not possible in a none-destructive way. One of the new technologies to inspect SSD-systems is the use of video equipment. With such equipment inspection of pipe lines (both field and collector drains) is possible over their full length without laborious excavations.

Action/intervention: A video camera attached to a rod is inserted into the drain and a video image can be viewed on a television screen on site and/or recorded on a video tape. In such way the pipe could be inspected for damages and blockages such as sediments and root penetration.

Based on the video the following recommendations for maintenance were derived:

- *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.

Photo: Video camera attached to a rod

Lessons learned:

1. Video inspection is a useful, none-destructive, tool to assess the need for maintenance: blockage such as sedimentation or root penetration can be observed without laborious excavations.

References: DRP (2001), El-Sherbiny and Nijland (2000) and Nijland et al (2004)

Title: Monitoring drainage effects and impacts		**Case Study**: Eg-48
Country: Egypt	**Location/Project**: Nile Delta and Valley	**Years**: 1994 - 2001

Indicator(s) used in this case study: operation, costs and benefits, implementation process

Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical	○			●
Socio-economical	○			●
Environmental	○			●

Background: In the 1960's, after the completion of the Aswam high Dam, Egypt started one of the largest drainage programmes in the world, so far 2 million ha of irrigated farmland have been provided with subsurface drainage systems.

Problem description: To assess whether the investments in subsurface drainage are profitable both for the national economy and farmers, a country-wide monitoring and evaluation project had to be developed to assess the effects of drainage on groundwater tables and soil salinity and the impacts on yields and farm incomes.

Action/intervention: In 1994, EPADP developed a systematic and replicable monitoring methodology. Country-wide, 15 sample areas were selected in both the Nile Delta and Valley, covering highly, slightly and non-saline areas. These sample areas are about 400 ha, usually including five to eight collectors. A long-time monitoring programme, from 3 years before to 5 years after drainage, was initiated. Three parameters were measures: (i) the depth of the groundwater table related to the number of days after irrigation; (ii) the salinity of the groundwater, and (iii) the soil salinity. Crop yields were determined by crop cuttings, a method applied by the Ministry of Agriculture and Land Reclamation all over Egypt. This facilitated easy comparison of site-specific data collected in the sample areas with village, district or governorate levels. The following conclusions could be derived from the monitoring programme:

(i) Average (ground) watertable (5 days after irrigation) significantly decrease from about 0.6 m before drainage to about 0.9 m 4 years after drainage:
(ii) Areas with saline soils decreased from 80% (before drainage) to 30% (4 years after drainage) in saline areas and from 40% (before) to 5% (after) in non-saline areas
(iii) Yield for all crops yields increased, possibly more than expected, although individual crops reacted differently,
(iv) Gross (GPV's) and Net Production Values were calculated for a traditional farm (0.4 ha) with the traditional cropping pattern, i.e. 80% wheat + 20% broad beans in winter and 30% maize + 30% cotton + 20% rice + 20% fallow in summer). GPV's improved about US$ 500-550/ha and the annual net farm income of the traditional farm increased by US$375/ha in non-saline areas to US$200/ha in saline areas. Compare to an overall cost of installation (including remodelling the open drains, planning, design and supervision) of about US$750/ha (and US$550/ha for rehabilitation) and an annual maintenance cost of US$10/ha/year. Assuming, that two-third of the incremental income can be attributed to drainage (a conservative estimate), the pay-back period is no more than 3-4 years, and;
(v) The impact of drainage on the national agricultural production is also significant; drainage contributes to about 8% of the production in the agricultural sector. The contribution to the gross domestic product is estimated at about US$0.9 billion per year.

Lessons learned:

1. Drainage is effective in controlling waterlogging and soil salinity in irrigated lands in Egypt
2. Drainage is highly profitable for both farmers and the national economy.
3. In monitoring, a distinction should be made between measuring direct effects and indirect-effects or impacts.
4. Drawdown of the watertable and soil salinity are good indicators for the direct effects and crop yield for the indirect effects both for the national economy and the farmer.

References: Ali et al (2001) and EPADP (2001)

Title: Monitoring salinity with EM38		**Case Study**: Eg-49
Country: Egypt	**Location/Project**: Hamoul, Middle Delta	**Years**: 1999-2000

Indicator(s) used in this case study: operation, soil and hydrological conditions

Stage(s) in SSD practices addressed in this case study :

	Planning	Design	Installation	O & M
Technical	○	○		●
Socio-economical				
Environmental	○	○		●

Background: The soil salinity is measured in Egypt on large scale during the pre-drainage investigations. Soil samples at 0.1 m to 2 m depth are taken from the auger holes in two locations of a 500X500 m grid.

Problem description: Human errors in collection and sampling of such large amount of soil samples are a problem. The laboratory method to measure EC_e is accurate, but time consuming and errors also can be expected. Furthermore, volumes sampled are relatively small, and the confidence that such small volume is representative for entire areas is rather small. The electromagnetic induction (EM) technique is an alternative for the determination of the soil salinity and has been successfully tested in several countries. However, the EM-38 device needs to be calibrated for different soil, salinity, moisture and temperature conditions.

Action/intervention: The objectives of this study were (i) to introduce the EM38 technique at DRI; (ii) to compare the use of EM38 technique with the traditional soil sampling method (cost, operation and accuracy), and; (iii) to give guidelines for the use of the EM38 device.
A two-week training program for 6 engineers was conducted. The training was done in two areas with different soil texture and salinity, i.e. at 25 locations in the. The soil salinity samples were analysed in the DRI laboratory for extracted past soil salinity (EC_e) and compared with the readings of EM38 (EC_a). Two methods were used to establish a relationship: (i) the average EC_e versus EM38 (EC_a) and; (ii) average EC_e in horizontal and vertical direction for different moisture classes. The first method did not yield a specific trend. The second method gave a better regression: moisture class no. 2 (32- 39%) gave the best correlation (r2 = 0.85) followed by class no. 3 (see Table). This can be attributed to the fact that the moisture contents in classes no. 2 and 3 are near the field capacity of the tested soil.

Moisture		n	Regression Equation (Vertical Mode)	R^2	Regression Equation (Horizontal Mode)	R^2
Class	Range (%)					
1	26 - 32	5	$EC_e = 1.633 + 3.464\ EC_a$	0.5	$EC_e = -\ 3.281 + 4.953\ EC_a$	0.6
2	32 - 39	5	$EC_e = 1.281 + 2.129\ EC_a$	0.9	$EC_e = -\ 3.182 + 1.877\ EC_a$	0.7
3	39 - 46	10	$EC_e = 2.945 + 2.027\ EC_a$	0.7	$EC_e = 3.139 + 1.982\ EC_a$	0.7
4	46 - 52	5	$EC_e = -\ 0.643 + 2.125\ EC_a$	0.7	$EC_e = -\ 0.335 + 2.299\ EC_a$	0.7

Lessons learned:

1. Calibration should be done following standardized procedures that resulted in the equations given by Rhoades (1999) and Vlotman (2000).
2. If no satisfactory regression coefficient results (at least 0.7 but values in the range 0.8 – 0.9 should be possible), then (i) it should be checked whether common errors with operation of the EM38 have not occurred; (ii) procedures of determining EC_a and EC_e should be checked, and (iii) it should be checked whether, temperature, soil moisture content, and percent clay were within acceptable deviations.
3. For the prevailing soils in the test area, soil moisture had a significant influence.

References: Abdel Ghany et al (2000), McNeill (1986), Rhoades et al (1999) and Vlotman (2000).

Title: Performance assessment to assess the need for rehabilitation

Case Study: Eg-50

Country: Egypt | **Location/Project**: Nile Delta & Valley | **Years**: 1994 -2000

Indicator(s) used in this case study: operation, soil and hydrological conditions, implementation process

Stage(s) in SSD practices addressed in this case study:

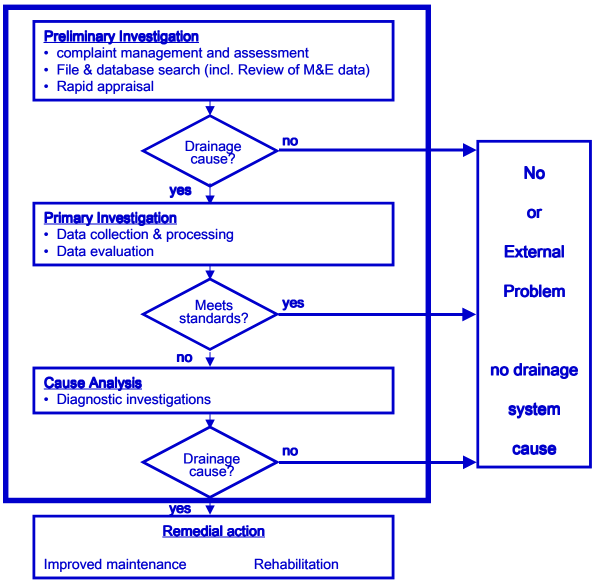
	Planning	Design	Installation	O & M
Technical	○			●
Socio-economical	○			●
Environmental				

Background: In the 1960's, the Egyptian Government started an ambitious programme to drain all agricultural lands in Egypt to protect these against waterlogging and salinization. Ultimately more than 2.5 million hectares will be provided with subsurface drainage systems.

Problem description: A methodology was needed to establish the need for rehabilitation of a drainage system.

Action/intervention: The performance assessment (PA) is used to establish the need for rehabilitation. The performance assessment involves three sequential steps:

1. *Preliminary investigation based on existing information* (complaints, age of the system, crop yields) in combination with a *r*apid appraisal: a short field survey to assess the drainage conditions.
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.
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.



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.

Lessons learned:
1. Performance assessment is a useful tool to establish the need for rehabilitation of subsurface drainage systems.
2. Performance assessment methodologies, however, can only be used when appropriate indicators have been developed (see Case Eg-51).

References: DRP (2001), Nijland et al (2004) and Smedema et al (2006).

Title: Criteria for rehabilitation of subsurface drainage systems		**Case Study**: Eg-51
Country: Egypt	**Location/Project**: Nile Delta & Valley	**Years**: 1994 - 2000

Indicator(s) used in this case study: operation, soil and hydrological conditions, implementation process

Stage(s) in SSD practices addressed in this case study:

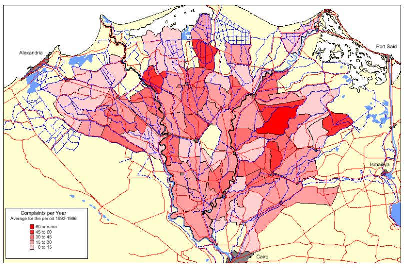
	Planning	Design	Installation	O & M
Technical	○			●
Socio-economical	○			●
Environmental				

Background: In the 1960's, the Egyptian Government started an ambitious programme to drain all agricultural lands in Egypt to protect these against waterlogging and salinization. Ultimately more than 2.5 million hectares will be provided with subsurface drainage systems.

Problem description: The economic lifetime of theses systems varies between 25 and 30 years, thus the systems that were installed in the 1960's and 1970's have reached their economic lifetime, resulting in increasing maintenance costs. Criteria were needed to assess whether these systems have to be rehabilitated and renewed.

Action/intervention: The Drainage Research Institute, in close collaboration with the Egyptian Public Authority for Drainage Projects, has investigated a number of indicators to find out whether these indicators can be used to assess whether a SSD-system is in need for rehabilitation, i.e.:

- *Age of the system*. Not surprisingly, the recently installed systems have fewer complaints, but the oldest systems (constructed from 1960 to 1977) have the same number of problems as the systems constructed 10 to 15 years ago.



- *Number of farmer complaints* (Figure, the darker the colour the higher the number of complaints). In the areas that were selected for rehabilitation based on their age, the number of complaints was low (Table), thus age alone is not enough as indicator.
- *Depth of the watertable* 6 days after irrigation: is a good indicator, but quite cumbersome to monitor (see also Case Eg-39).
- *Groundwater salinity*: in most areas the average salinity of the groundwater did not exceed 2.0 dS/m, thus not a good indicator.
- *Maintenance costs*. Is a good indicator, but does not tell which part of the system is in need for maintenance.

	No. of complaints per sub-drainage area (divided in class of 10 complaints)						
Class of complaints	**Mehallet-Rouh**	**Shenrak**	**Shubrakas**	**Ekhnawa**	**Tukh Mazyed**	**Belkeem**	**Mit Haway**
0 – 10	22	28	46	35	42	50	31
11 – 20			4	2	8	2	
21 – 30			2	1	2		
31 – 40			1				

Lessons learned:

1. To assess whether a SSD-system is in need for rehabilitation, one indicator is not sufficient.
2. A combinatory of number of indicators, e.g., the age of the system, the number of complaints, the depth of the watertable and maintenance cost, can be used to assess the need.
3. Groundwater salinity is not a good indicator to ass the need for rehabilitation under Egyptian conditions
4. The watertable drawdown curve after irrigation is a good indicator to assess the performance of a SSD-system.

References: DRP (2001), DRI (1993), Rady (1993), Ragab and Lashin (1998), Ragab and Abdallah (2000), Ragab et al (1998), Salman (1995), Smedema et al (1996),

Appendix B - Case Studies from Pakistan

Title: Organisation of the drainage sector		**Case Study**: Pa-01
Country: Pakistan	**Location/Project**: nation-wide	**Years**: 1958-onwards

Indicator(s) used in this case study: institutional set-up, stakeholder participation, capacity building

Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical	●			
Socio-economical	●			
Environmental	●			

Background: 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. 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 is responsible for the design, construction and initial operation and monitoring of the projects, after which the Irrigation Department took over operation and maintenance.

Problem description: 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 Government. These problems were aggravated because the life expectancy of most SCARP projects proved to be less than half the expected life time.

Action/intervention: To overcome these problems, the irrigation and drainage sector was reformed and in 1997 autonomous 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 to implement reforms (the responsibilities between the Irrigation Department and the PIDA's are not well defined); (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.

Lessons learned:

1. Institutional reforms in the organisation of the drainage sector will be only successful if all stakeholders, especially the farmers who are not only the main beneficiaries but also have to pay for the system, are involved.
2. Without an appropriate legal framework these reforms will not take place.
3. Capacity building at all levels is a prerequisite to make a shift from engineering to institutional solutions.

References: Alterra-ILRI (2001) and Nijland et al (2005)

Title: Organisation of a subsurface drainage project		**Case Study**: Pa-02
Country: Pakistan	**Location/Project**: Lower Swat Canal Command, North West Frontier Province	**Years**: 1987-1991

Indicator(s) used in this case study: implementation mode, implementation process, stakeholders participation

Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical	●	○	○	
Socio-economical	●	○	○	
Environmental	●			

Background: 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 overall project consisted of an extensive program of civil works, including the construction of surface and subsurface drainage, irrigation canal remodelling, road improvements, land levelling, reclamation and agricultural development programmes.

Problem description: Many stakeholders were involved in the project preparation and implementation. 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.

Action/intervention: Joint procedures and measurements between the Engineer and the Contractor were introduced, although not contractually required, to minimize later disputes.

Lessons learned:

1. Discontinuation of irrigation a few days before and during installation is required to obtain sufficient grip for the drainage machines;
2. 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;
3. Frequent and jointly organised (between the contractor and the engineer) inspections are essential to ensure good quality installation practices;
4. 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.

References: Mardan Scarp (1984), Nijland et al (2004)

Title: Participatory drainage development		**Case Study**: Pa-03
Country: Pakistan	**Location/Project**:	**Years**: 1995-2000

Indicator(s) used in this case study: implementation mode, implementation process, stakeholder participation

Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical	●	○	○	○
Socio-economical	●	○	○	○
Environmental				

Background: Traditionally, the Water and Power Development Authority (WAPDA) was responsible for the design, constructed and initial operation and maintenance of drainage projects, after which the Provincial Irrigation Departments (PID's) took over O & M (see also Case PA-01).

Problem description: Due to financial constraints the PID's could not manage and in 1997 the sector was reformed and the system management had to be decentralised and farmers are to take part in the system development and to take over O & M.

Action/intervention: To develop and implement an on-farm ssd-system with participation of the beneficiary farmers and to ensure that these farmers operate and maintain the ssd-system after completion, a pilot project was initiated by the Netherlands Research Assistance Project (NRAP). A 112 ha pilot area in the FESS project area was selected based on a topographic survey and a participatory rural appraisal. Meeting with the farmers and the involved government agencies were organised to agree on the farmers' contributions. Farmers agreed to (i) assist with data collection; (ii) provide unskilled and semi-skilled labour; (iii) cash payments and (iv) organise work and tasks. Farmers were involved in designing the system: they had a major say in selecting the location of the sump, and the layout of the field drains was adjusted so that more farmers could benefit. Initially it was agreed that the drains should be installed manually, but high groundwater tables made this impossible and the ssd-system was consequently installed mechanically. Farmers, however, dug "dewatering" trenches along the drain line to prepare the top soil for the weight of the drainage machines. During the actual project implementation some farmers appeared to be more motivated than others, because of various reasons like total land holding, extent of the waterlogging and salinity problem, farmers' dependency on agriculture, conflicts between farmers, lack of leadership etc. A Farmers' Drainage Organisation was established in 1997, which gradually took over its responsibilities. A gender programme was included to emphasis the role of women, mainly as motivators of their men to participate in and contribute to the project. During the implementation of the project, training courses were organised for the farmers, project staff and staff of the NGO's. These training courses were highly practical and designed too transfer information between the stakeholders with the overall aim to make the operation of the drainage system easier. The cost of the system is Rs 3,180,863 for 112 ha. This is equal to a very reasonable Rs 28,400 per ha (with 1 US$ equal to Rs 54, this implies US$ 526 per ha). The contribution of the farmers, including e.g. labour and foregone crop compensation, amounts to Rs 212,100.

Lessons learned:
1. The participatory drainage development programme resulted in less waterlogging and less salinisation.
2. A participatory drainage programme required a long-term process to build up mutual trust between all parties involved and to learn each others background, capacities and preferences.
3. Training at all levels is needed: for the farmers to understand the technical aspects, for the engineers to understand the socio-economic settings, etc.
4. Setting up sustainable farmers' organisations is not easy: at the start of the project, farmers have to agree among themselves on the structure, rules and tasks of the drainage organisation.

References: Knops and Siddiq, 1997, Knops et al., 1999, Rafiq et al. (2000), Alterra-ILRI (2001), Knops et al (1996), Nijland et al (2004)

Title: Interceptor drains to minimise drainage requirement		**Case Study**: Pa-04
Country: Pakistan	**Location/Project**: Fordwah Eastern Sadiqia	**Years**: 1995-1998

Indicator(s) used in this case study: drainage method, implantation process, soil and hydrological conditions

Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical	●	○		
Socio-economical				
Environmental	●			

Background: Irrigation agriculture of Pakistan is suffering from serious problem of waterlogging and salinity. Seepage from irrigation canals is often quoted as one of the main causes of waterlogging. The interceptor drains are installed i) to intercept a significant part of canal seepage to reduce drainage requirement and ii) to provide supplementary water for irrigation.

Problem description: IWASRI was asked to study the effectiveness of the interceptor drains at two branch canals (Malik & Hakra) and one distributary (3-R Khatan) in FESS.

Action/intervention: Five rows of observation wells were installed perpendicular to the canal to observe groundwater gradient towards the irrigated land. Three rows were installed in an area with an interceptor drain and two rows outside the interceptor drain command. Nested piezometers were placed on the top of the interceptor drain, next to the drain and a distance of 0.5 m and 1.75 m respectively. A ponding test was performed along Malik branch canal to measure seepage loss during 1998. The measured seepage rate appeared to be in the order of 1% of the inflow only. Monitoring results of the interceptor drainage pilot area along (1800 m on one side of) the Malik Branch canal of the FESS project shows that only about 19 % of the seepage water was intercepted. There is no interception of seepage when groundwater table is not connected with the water body of the canal.
A groundwater model study shows that seepage contributes about 0.31 mm/d, or about 20% of the drainage design discharge of 1.5 mm/d. Thus if all seepage water can be intercepted, the drainage requirement could be taken 20 % lower. Thus the net intercepted seepage at FESS is ineffective to reduce the drainage requirement.

Lessons learned:

1. Interceptor drains in the flat plains of the Indus do not significantly reduce the drainage requirements (or in other words, cannot prevent the need for the installation of a drainage system).
2. Installation of interceptor drains under those conditions would lead to excessive operation cost, thus the effects of such interceptor drains therefore do not justify the large investments involved.
3. When the canal water body is not ‘connected’ with the groundwater, interceptor drains do not at all intercept the percolation canal water as observed in various locations (in CRBC, FESS, and LBOD).
4. When the canal water body is ‘connected’ with the groundwater, interceptor drains induce seepage. The induced seepage should be pumped back into the canal to prevent (additional) suffering for tail-end farmers.
5. Before interceptor drains are installed the following should be investigated: (1) lithology of the soil; (2) hydraulic conductivity testing (at proper depth); (3) seepage flow lines; (4) groundwater level perpendicular to the irrigation canal.

References: Abid Bodla et al (1999), Abid Bodla et al (1998), Javed et al (2002), Niazi, et al (1998), Salaam Bashir (1997, 1996 & 1995), Seghal (1977)

Title: Improving the main drainage systems to reduce SSD requirements

Case Study: Pa-05

Country: Pakistan

Location/Project: Fourth Drainage Project (FDP) Faisalabad

Years: 1994-2000

Indicator(s) used in this case study: drainage method, implantation process, soil and hydrological conditions

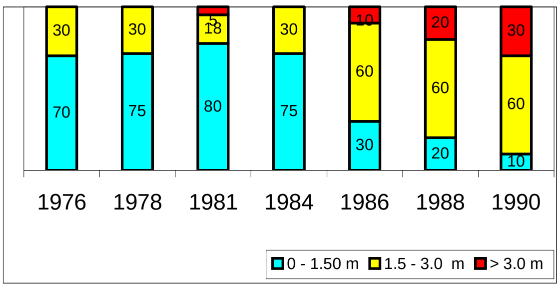
Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical	●			
Socio-economical				
Environmental	●			

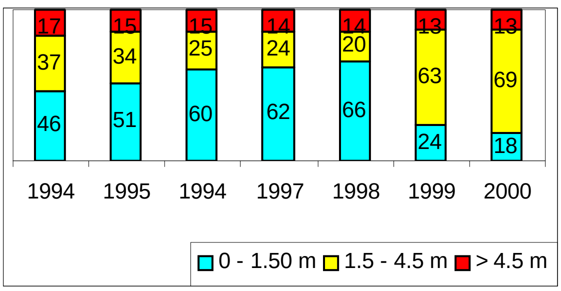
Background: In Pakistan, the general perception of engineers is that surface drains are only useful for disposal of rainfall run-off and pumped drainage effluent. However, surface drains also have a considerable effect as groundwater drains. In Fourth Drainage Project (FDP) Faisalabad, the area suffered from both the problems of waterlogging and salinity. One of the first actions in the implementation of the FDP was the improvement of the main drainage system in 1984-85. In this improvement, the drains were desilted, and the steepest possible slopes were provided to achieve maximum silt carrying capacity. At some locations, banks were provided to guide possible overland flow to the drains proper inlets.

Problem description: A monitoring programme was initiated to assess the effect of the improved surface drainage on the subsurface drainage requirements.

Action/intervention: A network of 125 observation wells was used, spaced some 4-5 km apart. Watertable depths were measured in all the observation wells in a fixed sequence each month from June 1994 to June 2000. In 1999 the surface drainage system became operational. The 'Kriging' interpolation of the software package Winsurf was used to prepare depths to watertable contour maps.
The data clearly shows that after the main drainage system was improved in 1999, the watertables were significantly lower. Similar results were obtained in the Fourth Drainage Project, where after the installation of a surface drainage system (1985), watertables also were significantly lower.



Watertables classes in FESS



Watertables in Fourth Drainage Project

Lessons learned:
1. A proper functioning main drainage system can significantly reduce the (area in) need of subsurface drainage.
2. A deep open drain has not only a function to dispose of rainfall-runoff, but acts as a groundwater drain as well
3. Open main drains are a neglected part of the solution of waterlogging and salinity problems of Pakistan.

References: Khan et al (1997)

Title: Improving irrigation practices to reduce SSD requirements		**Case Study**: Pa-06
Country: Pakistan	**Location/Project**: nation-wide	**Years**:

Indicator(s) used in this case study: drainage method, implantation process, soil and hydrological conditions

Stage(s) in SSD practices addressed in this case study: irrigation, crop water requirements

	Planning	Design	Installation	O & M
Technical	●			○
Socio-economical				
Environmental	●			○

Background: Pakistan is a land excess and water deficit country. A typical water supply of its large-scale, low-supply, irrigation schemes would be 3.5 cusecs/1000 acres, which equals 2 mm/d. This supply is by far not enough to satisfy the crop demand and therefore the systems are characterised as *'protective irrigation'*, based on proportionate division of water over available land.

Problem description: A great improvement in productivity is expected of better matching irrigation supplies with crop demand there are continued attempts to include this in all kinds of projects, as in FESS. In the Integrated Research Plan for FESS there are studies to attempt a closer match of water deliveries with crop water requirements by improved scheduling of delivery of water through introducing structural, operational and management improvements. But the efforts towards crop-demand based supply have so far only resulted in recommendations towards irrigation based cropping.

Action/intervention: IWASRI/NRAP analysed, together with IIMI-Pakistan the possibilities to introduce irrigation based cropping. The availability of water in Pakistan, however, is not sufficient for crop-demand based supply of canal irrigation water, with the capacity of the existing reservoirs fully utilized. Hence, a shift to crop-based supply in one scheme cannot be done without affecting the water share of other schemes. Moreover, the capacity of the canal system in Pakistan is not sufficient for crop-demand based supply of irrigation water. Matching crop requirements would also result in demands that vary considerably over time. This would require another system, with much more regulation flexibility, and a more intensive operation throughout the seasons. Moreover, the sediment load of the water prevents canals to run at less than 70-75 per cent of their design capacity. It appears that efforts towards crop-demand based supply end up in recommendations towards irrigation based cropping. In a water deficient situation, moving towards demand-based operations is beset with problems. It will be better to improve the performance of the present water allocation than to respond to field-generated demand that cannot be satisfied. The possibility to achieve a better match between crop water requirement and delivery of water through introducing structural, operational and management improvements is very limited. In many canal systems it seems better to just keep the supply constant and let the farmers pump from tubewells to complement the shortage of canal water.

Lessons learned:
1. One should forget about on-demand based supply of canal irrigation water in Pakistan.
2. Improvement of irrigation practices reduces the need for subsurface drainage

References: Wolters et al (1997)

Title: Benefits of shallow drainage		**Case Study**: Pa-07
Country: Pakistan	**Location/Project**: nation-wide	**Years**: 1997

Indicator(s) used in this case study: drainage method, implantation process, soil and hydrological conditions

Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical	○	●	○	
Socio-economical				
Environmental				

Background: In Pakistan the design depth of the subsurface drainage systems is rather deep, varying between 1.8 and 2.4 m:

project	designed	drain depth (m)
East Khaipur Tile Drainage project	1976	1.95
MARDAN SCARP	1983	2.25
Fourth Drainage Project	1983	2.40
Chashma Command Area Development Project	1984	2.30
Fordwah Eastern Sadiqia (South) project	1994	2.10
Khushab SCARP	1990	2.10
Swabi SCARP	1994	1.80
Mirpurkhas project	1994	1.80 – 2.40

Problem description: In drained areas where a deep water table is maintained, farmers sometimes complain about the increased need for irrigation water. A shallow water table, especially in the fine soils of the Indus plains, is capable of water delivery to the crops through capillary rise. In areas with an 'acceptable' ground water quality, there is no need to maintain a deep water table (See also Pa-13).

Action/intervention: IWASRI conducted a research programme to investigate the possibilities to reduce the drain depth. The research results show that maintaining a shallow water table can be beneficial. It is, however, suggested to study the following aspects in more detail:

- Long-term study on salinity/sodicity build-up in soil profile for various soil types and under different groundwater table depths
- Further groundwater contribution to meet the crop water requirement under different soil moisture stresses and water table depth

Lessons learned:

1. In areas with acceptable groundwater quality, shallow drainage will reduce the volume of drainage effluent, reduce the need for irrigation water supply, and will also reduce the cost of installation.

References: Qureshi et al (1997), Bhutta et al. (1995b)

Title: Benefits of research		**Case Study**: Pa-08
Country: Pakistan	**Location/Project**: nation-wide	**Years**: 1988-2000

Indicator(s) used in this case study: cost and benefits, implementation process, capacity building

Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical				
Socio-economical	●	○	○	○
Environmental				

Background: Pakistan has set billions of Rupees aside for investment in improved land and water management in the National Drainage Programme. A small, but still significant, part of these resources is used for research, for example through the Netherlands Research Assistance Project (NRAP).

Problem description: Past experiences at IWASRI has made it very clear that a modest investment in research could yield large benefits. It will, however, always be difficult to quantify the direct benefit of research in monetary terms. IWASRI has address this issue and attempted to calculate the benefits of research.

Action/intervention: The potential and realised benefits or savings of the research have been summarized in the following table:

Subject of study	(Potential) Benefits and Savings
Use of Synthetic Drain Envelopes	FDP: potential savings US$ 1.4 M
Measuring Soil Salinity with the EM38 Instrument	Not yet estimated financial benefits, but greatly improved quality of monitoring
Improved Drainage Design	FDP: potential benefits approximately Rs 100 M (US$ 3.5 M)
Interceptor Drainage and related Water Management Research	FESS: Savings of more than US$ 20 M
Lower field drainage design discharge	Pakistan: Hundreds of Millions of Rupees (Millions of US$)

For Drainage IV, potential savings of about US$ 1.8 M were estimated for the use of synthetic drain envelopes (see also Case Pa—03). The measurement of soil salinity with the EM38 Instrument greatly improves quality of monitoring, and saves time, labour, as well as cost (Case Pa-25). The estimation of potential benefits of improved drainage design amounts to approximately Rs 100 M (US$ 3.5 M) for Drainage IV. The first-ever inclusion of a research phase in FESS has already led to saving: for the interceptor drainage part of the project (including related water management work) the savings are currently estimated at about US$ 20 M. The gradual decrease in field drainage design discharge has already saved enormous expenditure for Pakistan, in the order of hundreds of millions of Rupees (millions of US$).

Lessons learned:

1. Research in ongoing projects can have a far-reaching impact on the implementation of those projects, but also on the planning and design of other drainage projects.
2. Realizing that potential savings, in hindsight, as well as actually saved expenditure by a better design, is not cash in hand, but IWASRI research shows that it is *value for money*. The cost of having an IWASRI is more than justified.
3. A lot of site-specific, practical research on engineering, social, socio-economic, and environmental issues is still needed to find practical and economically feasible solutions for the pressing problems in land and water development.
4. The joint research effort has been very worthwhile and the results are tangible, in terms of recommendations towards control of waterlogging and salinity, as well as in terms of human resources development.

References: Mohtadullah et al (1997), Wolters (2000)

Title: Impacts of subsurface drainage		**Case Study**: Pa-09
Country: Pakistan	**Location/Project**: nation-wide	**Years**:
Indicator(s) used in this case study: benefits, drainage method, stakeholder participation		

Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical	●			○
Socio-economical	●			○
Environmental	●			○

Background: The cost of pipe drainage is high, and any not all impacts are understood and well-documented.

Problem description: IWASRI started to evaluate the subsurface drainage projects in Pakistan to get a better understanding of the impacts of SSD-system.

Action/intervention: The impacts of eight ssd-projects were evaluated, i.e.:

	Designed	Constructed	Field Drainage Design Discharge (mm/d)
East Khairpur	1976	1986	3.5
Mardan SCARP	1983	1992	2.0
Drainage IV	1983	1994	2.44
Chashma CADP	1984	1994	1.2 – 4.6
Khushab SCARP	1990	199???	1.8
FESS	1994	199???	1.5
Mirpurkhas LBOD	1994	199???	0.95
Swabi SCARP	1994	199???	2.0
DG Khan SCARP	1995		1.88

Lessons learned:

1. Subsurface pipe drainage systems, although more expensive, are better for the environment than tubewell drainage systems. Generally, the shallow groundwater quality in pipe drainage systems improves (or at least remains constant) whereas the deep groundwater quality does not change. In areas drained by tubewells the trend is that effluent quality decreases, except near canals.
2. Pipe drainage systems have been evaluated to show both ‘technical’ and ‘socio-economic’ benefits, including:

- Technical: (1) Controlled the water table; (2) Decreased soil salinity; (3) Increased crop yield (wheat and sugarcane); (4) Decreased area abandoned land; (5) Increased cropping intensity
- Socio-economic: (1) Increased income, with households in non-saline areas better off in terms of assets (refrigerator, sewing machine, etc.); (2) Improved situation for women, landless and tenants (livestock conditions also improved); (3) Decreased workload for women; (4) Enrolment of children (aged 5-15 years) is significantly higher in non-saline area than in saline area, with boys better educated than girls; (5) Improved drinking water quality in the villages where the drainage system is working continuously; (6) Re-immigration towards the farms after reduction of waterlogging and salinity

3. There is a limited awareness about the benefits of drainage among farmers. Moreover, there is an urgent need for better maintenance as well as farmers’ participation and co-operation. In the non-saline areas, 80% of the farmers perceive the existing drainage system as not adequate. In saline areas, the perception of the farmers is slightly better: only 60% of the farmers perceive the existing drainage system as not adequate.

References: Bhutta et al (1995a,b), IWASRI (2000), Mann et al (1997), Niazi et al (1997), Kishwar and Donaldson (1997), Saeed (1999), Wolters et al (1996)

Title: Improving ssd-design practices through groundwater modelling		**Case Study**: Pa-10
Country: Pakistan	**Location/Project**: Fordwah Eastern Sadiqia	**Years**: 1994 -1998

Indicator(s) used in this case study: drainage design, drainage method

Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical	○	●		
Socio-economical	○	●		
Environmental				

Background: Traditionally, subsurface drainage systems are installed in the total project area. An analysis of watertable data (collected twice per year) and inverse modelling with the groundwater model SGMP show that not the total area needed ssd-systems and that the design discharge rate varies quite a bit because of the variation in the natural conditions and the location and capacity of the existing water courses (both irrigation, drainage and natural streams & rivers).

Problem description: For the Fordwah Eastern Sadiqia (South) project (FESS), groundwater model simulations, based on actual field data, were conducted to estimate which part of the area is in need of drainage and to calculate the corresponding drain discharge.

Action/intervention: For the study, 125 observation wells were installed in a triangular pattern, some 4 to 5 km apart and the model was used to predict the effect of (i) interceptor drains along the main branch canals; (ii) lining distributaries and minors, (iii) improved main drainage systems, and (iv) area in need of subsurface drainage and the corresponding discharge rate. The simulations showed that: (i) the effectiveness of interceptor drains can be improved by an optimum design, in terms of distance to the irrigation canal, drain depth and diameter. The depth and distance to the canal are the most critical design parameters. The costs to achieve increased effectiveness are, however, often elevated. For FESS, more tan 10 m^3 of induced seepage need to be pumped for each m^3 of net intercepted seepage. (see also Case Pa-04); (ii) lining the distributaries and minors will reduce canal-seepage with 75%, but it does not eliminate the need of a field SSD-system; (iii) a proper functioning surface drainage system can significantly reduce the need of subsurface drainage (see also Case Pa-05), and (iv) only about 60% of the area is in need for subsurface drainage and the corresponding design discharge rate can be reduced to 1 mm/d (Table).

	Design Report	Expert assessment	Simulations
Drainage area (ha)	73.500		42.845
Drainage coefficient (mm/d)	2.74	1.5	1.00
Design watertable depth (m)	1.5	1.5	1.5

Lessons learned:

1. Interceptor drainage and canal lining do not significantly reduce the subsurface drainage requirements, but:
2. Only about 60% of the project area in the FESS project is in need of subsurface drainage and
3. The corresponding design discharge rate for the subsurface drainage system can be reduced to 1 mm/d.

References: Javed (1999), Boonstra and Bhutta (1996), Bhutta et al. (1996c), NESPAK (1991), and Smedema van Aart (1992)

Title: Modelling approach in field drainage design		**Case Study**: Pa-11
Country: Pakistan	**Location/Project**:	**Years**: 1991-2000

Indicator(s) used in this case study: drainage design, soil and hydrological conditions, drainage method

Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical	○	●		
Socio-economical				
Environmental	○	●		

Background: The standard drainage design procedure used by WAPDA is to add-up all separate groundwater recharge components, which will then give a certain quantity of water to be removed. This procedure works well if the answer obtained is used for determination of the quantity of water to be removed in a certain time period (e.g. a year) as a 'drainable surplus'.

Problem description: One of the problems associated with the standard procedure is that the recharges of the separate components are all estimates by rule-of-thumb, and there is no easy way to check those estimates. By using a computer model simulating the soil water fluxes in the profile with a link to crop growth model, factors as a varying water table and a link with crop growth are inherently investigated. By simulation of a whole range of conditions, the parameters for an 'optimal' drainage design could be found for the various conditions prevailing in the field.

Action/intervention: Research on the use of models at IWASRI-NRAP focussed on two pipe drainage projects; the Fourth Drainage Project (FDP) near Faisalabad, and the Fordwah Eastern Sadiqia South Project (FESS) near Bahawalnagar. In both the FDP area and the FESS area, selected drainage units have been monitored to provide field data for the following studies:

- Assessment of the best depth of the water table to maintain favourable crop growth conditions by application of the numerical vertical one-dimensional SWATRE model.
- Calculation of the water and salt balance of the complete aquifer-soil system with the SALTMOD/RSM model.
- Development of a water and salt balance spreadsheet model (WASB).

All three models were used to study the effects of different drainage designs and irrigation water management practices on crop growth conditions in the agricultural fields.

Lessons learned:

1. Planners and designers of drainage systems will not be keen to use computer studies for field drainage design for various reasons including: (i) data requirement and related time duration of the study and (ii) discrepancy between field situation and model schematisation.
2. The model approach to field drainage design can, however, be useful to:
   - Evaluate drainage systems to possibly improve on issues as: (1) choice of drain depth; (2) finding improvements to scheduling of irrigation water supply (e.g. in times of water shortage); (3) finding the effect of different depths of the water table on cropping conditions in the field. Such type of work is usually done post-construction but the results are available for future incorporation in designs of course.
   - Prediction of long-term effects by simulating management alternatives over periods of, say, 10 years or more.

References: Abid (1991), Akbar (1995), Beekma,(1993), Beekma et al (1993 a&b, 1995), Heijnen (1995), Kelleners (1997 & 1995), Khan (1993), Kielen (1999), Mahmood et al (1997) and Oosterbaan (1998)

Title: Groundwater approach to drainage design		**Case Study**: Pa-12
Country: Pakistan	**Location/Project**: Fourth Drainage Project	**Years**: 1994-1996

Indicator(s) used in this case study: drainage design, drainage method

Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical		●		
Socio-economical				
Environmental		●		

Background: It appeared to be impossible to make a water balance of a sump in Fourth Drainage Project (FDP). The area of influence of a sump turned out to be beyond its physical limits. The reason for this was the highly permeable, phreatic, aquifer. Upon this observation the joint IWASRI-NRAP groundwater study started. The developed approach is a combination of 'inverse' modelling (finding recharge from known water table elevations) and the 'decomposition' approach (finding recharge from deduction of losses from rainfall and head deliveries. The seasonal net recharge values based on the decomposition approach were 'tuned' with the inverse modelling results. This has as advantage that all recharge and discharge components are looked at in an integrated way.

Problem description: Application of the groundwater approach, as an addendum to drainage design, enables the detection of spatially varying drainage needs. For FDP it was found that only eleven of the earlier identified twenty-one sub-areas were in urgent need of drainage.

Action/intervention: Application of the groundwater model approach as an addendum to drainage design enables the detection of spatially varying drainage needs, which was previously impossible. For FDP, such a study was carried out. The model operates on basis of 32 nodal areas, selected on basis of groundwater level observations. The size of these nodal areas varies from 0.3 to 3.0 km^2, with an average size of 1.6 km^2. The total model area (Schedule-I-B) extended over some 66 km^2. In the actually implemented drainage system for FDP, drainage is installed in 21 nodal areas. The IWASRI results show that only 11 of those areas are in urgent need of drainage. Such results indicate that the application of this approach has enormous savings potential.

It was by no means the intention to criticize the original design. That was an excellent design on basis of the data and resources available at the time. Only after the installation of the drainage system, the extent of the mutual influence of sump units was found. Moreover, important reductions in cost, compared to the first plans, were already realized during the design and construction of the FDP. In the approved PC-1 there were 1600 miles of subsurface drains and 250 sumps. After time, this evolved in 500 miles and 79 sumps. The project cost was first budgeted at Rs. 700 million, and in 1994 the cost, despite inflation etc, equalled Rs. 300 million

Lessons learned:
1. Application of the groundwater approach, as an addendum to drainage design, enables the detection of spatially varying drainage needs.
2. The 'tuning' procedure that is part of the developed approach gives the advantage to check on the rules-of-thumb used for estimation recharge from rainfall and the irrigation water supply system.

References: Boonstra and Bhutta (1996), Bhutta et al. (1996c), Boonstra et al. (1994), Rizvi et al. (1996), Javed et al. (1999), Moghal (1994)

Title: Optimizing the drainage design discharge | **Case Study**: Pa-13

Country: Pakistan | **Location/Project**: nation-wide | **Years**: 1996-1999

Indicator(s) used in this case study: drainage design, soil and hydrological conditions

Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical	○	●		
Socio-economical				
Environmental	○	●		

Background: The cost of pipe drainage is high, and any possible savings should be realised. Two decades ago, the initial field drainage design discharge in Pakistan was chosen as 3.5 mm/d (Khairpur-East), as there was no experience at all with pipe drainage. It was half of the 7 mm/d as applied in Europe/The Netherlands, mainly to counteract waterlogging in a temperate climate).

Problem description: To get a better assessment of the drainage design discharge, IWASRI started to evaluate the subsurface drainage projects in Pakistan.

Action/intervention: The evaluations of pipe drainage systems conducted by IWASRI shows that the field drainage design discharge can be reduced from its initial value. Now, research experience has advanced to the stage where 1.5 mm/d is acceptable as a starting point for design. In the prevalent semi-arid conditions, drainage is mainly necessary to control root-zone salinity. Nevertheless, the FESS project was initially (early 1990s) designed for 2.7 mm/d, but IWASRI and NRAP could reduce it to 1.5 mm/d (IWASRI, 92/6). The Khushab SCARP drainage system, the last one before FESS, was designed at 1.8 mm/d, mentioning IWASRI work in its design report (EC-NESPAK, 1990). Similarly, Mardan SCARP was designed for a field drainage design discharge of 3 mm/d, but neighbouring Swabi SCARP, subject to equal climatic and other conditions, was designed at 2 mm/d, also mentioning IWASRI. Table 4.1 in Chapter 4.2.2 summarized the drainage design criteria of the major subsurface drainage projects in Pakistan.

Lessons learned:

1. The design discharge for field drains could be lowered from an initial 3.5 mm/d to the value of 1.5 mm/d as a starting point.
2. It is extremely difficult to calculate a field drainage design discharge: drainage remains an art and science. It is, however, possible to calculate a 'drainable surplus', which is the amount of water that has to be evacuated to prevent waterlogging by excess water.
3. The evaluation of the FDP yielded lessons about the spatial variability of drainage needs in the conditions prevailing in the Indus plains: a highly permeable phreatic aquifer (KD values > 5000 m^2/d) (this is dealt with under the lessons learned through the IWASRI-NRAP groundwater studies; see e.g. Case Pa-10).

References: Bhutta et al (1995a,b), IWASRI (2000), Mann et al (1997), Niazi et al (1997), Saeed (1999), Smedema and Van Aart, 1992

Title: Use of poor quality water for crop production and reclamation		**Case Study**: Pa-14
Country: Pakistan	**Location/Project**:	**Years**: 1997

Indicator(s) used in this case study: drainage method, soil and hydrological conditions, operation

Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical		●		○
Socio-economical				
Environmental		●		○

Background: The salinity of the effluent from subsurface drainage varies between 4.7 to 15 dS/m and that from tubewells can be twice as high (see also Case Pa-22).

Problem description: Disposal of this drainage discharge in the Punjab in the upper reached of the Indus basin is restricted as too high salinity levels in the river will make the water unsuitable for downstream (agricultural) use. The option to use this poor quality water for crop production and or reclamation has been investigated by IWASRI.

Action/intervention: There is not always the need for good quality water when reclaiming salt-affected soils. A wealth of data is available as to which waters can be used for which circumstances. The recommendations from these studies need specific application; they cannot be used as 'blanket' recommendations. Use of certain poor quality waters can be acceptable in one location whereas it could be detrimental in other locations

Lessons learned:

1. Saline and saline-sodic water can be used to supplement canal water deficiencies without the use of any amendment, provided that sufficient leaching water is guaranteed.
2. Saline sodic alkaline waters can be casually applied to augment the canal water deficiencies if sufficient amendments are added and leaching of excessive salts is guaranteed.
3. Marginal and hazardous water can be used on salt-affected soils for reclamation if gypsum or organic matter and leaching are applied.
4. Use of sulphuric acid as water amendment appears un-economic and hazardous to farmer's health

References: Kielen et al (1997).

Title: Testing gravel and synthetic envelope materials		**Case Study**: Pa-15
Country: Pakistan	**Location/Project**: Fordwah Eastern Sadiqia	**Years**: 1994 -1988

Indicator(s) used in this case study: drainage materials, installation method, cost and benefits

Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical		○	●	
Socio-economical			●	
Environmental				

Background: For a number of subsurface pipe drainage projects, field tests were conducted to verify their design parameters for envelopes. In these projects a range of design concepts and technologies were applied, but little effort was made to test the suitability of design in a particular area.

Problem description: As the gravel drain envelope used in the Drainage Fourth Project caused many problems (Case Pa-16), it was decided to test synthetic envelops at three representative pilot sites of the Fordwah Eastern Sadiqia (South) (FESS) project, named as SSDTS-I, SSDTS-II, and SSDTS-III.

Action/intervention: Two synthetic envelopes (N-30 and N-60) were selected based on soil laboratory testing and different envelope treatments (see Table) were tested in the laboratory and in the field. The total head loss midway the drains and the entrance head loss were collected on a weekly basis. Using this data, the head loss fraction, which is the ratio of the entrance head loss and the total head loss and the entrance resistance, was calculated. The synthetic drain envelopes performed equally well or even better than gravel envelope for the prevailing soil conditions (Table).

The use of synthetic envelopes is expected to result in savings. A rough estimation of the potential savings for FDP has been made. In the project, about 800 km (500 miles) of drains have actually been laid, with 15% collectors and 85% laterals.

Collector	Material	Performance
SSDTS-I-B	Gravel	Moderate to good
	N-30 + Sand	Good
	N-30	Moderate to good
SSDTS-I-C	Gravel	Poor to good
	N-30 + Sand	Moderate to good
	N-30	Poor to moderate
SSDTS-II-B1	Gravel	Good
	N-30 + Sand	Good
	N-30	Poor
	N-60 + Sand	Good
	N-60	V. poor
SSDTS-II-B2	Gravel	Poor to moderate
	N-30 + Sand	Good
	N-30	Good
	N-60 + Sand	Good
	N-60	Poor to moderate

The applied envelope material was gravel, with an assumed 0.15 m thickness around the laterals, and a thickness of 0.20 m around the collectors, in a 0.45 m and 0.6 m wide trench, respectively. This worked out, with a unit cost of gravel of US$ 19.7 per m^3 (FDP Design Memorandum) to US$ 3.25 M. The estimated cost for the synthetic is US$ 1.8 M. The savings to be obtained when using synthetics would be about US$ 1.4 M.

Lessons learned:

1. The previously standard design rules for granular (gravel) envelopes did not apply for the very fine soils of the Indo-gangetic plain.
2. The subsequent IWASRI-NRAP research led to refinement of the design standards for envelopes for the prevailing soils in large parts of Pakistan.
3. Field experiments showed that geo-synthetic envelope materials could safely replace the usual gravel envelope materials for the prevailing soil conditions when properly designed and installed.
4. Use of synthetic envelopes results in: (1) Less material cost in comparison to gravel envelopes; (2) Reduced construction cost because installation is faster; (3) Less logistic problems; (4) Easier quality control of pipe-laying.

References: Rafiq (1998), Shafiq et al (1996), Smedema and van Aart (1992), Vlotman et al (1993) and WAPDA (1994)

Title: Adapting envelope materials requirements to local conditions		**Case Study**: Pa-16
Country: Pakistan	**Location/Project**:	**Years**: 1980-2001

Indicator(s) used in this case study: drainage material, installation method, costs and benefits

Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical	○	○	●	
Socio-economical				
Environmental				

Background: Most soils in Pakistan are fine-textured (silty loam, sandy loam, silty clay etc) and require an envelope material.

Problem description: Gravel envelopes were installed generally based on design criteria developed in the USA (USBR, SCS and others) because no well-established criteria to determine the need and type of envelope existed. To adjust the envelope requirements to local conditions several modifications, both for the used envelope material and installation methods, had to be introduced.

Action/intervention: In several projects, problems with the use of gravel envelopes were encountered and improvements were successfully introduced:

- As the field drains have a comparatively large diameter (100 – 200mm) it was observed that gravel was not laid uniformly around the pipe. A modification was made in the trencher box with an addition of auger which was moving around the pipe below the gravel box feeder. The speed of the gravel auger is automatically adjusted to the speed of the trencher during drain installation. This modification was first introduced in Fourth Drainage Project and subsequently improved in the Chashma Command Area Development (CCAD) and the Fordwah Eastern Sadiqia South (FESS) projects. The results are encouraging and gravel is laid comparatively uniformly.
- In the East Khaipur Tile Drainage project, the cost of the gravel envelope material, including transport, (€ 205/ha) was 17% of the total cost of installing the SSD-system (€ 1,183/ha), about the same as the cost of the pipe material (€236/ha) and double the cost of the installation of pipe & envelope (€ 100/ha).
- In the CCAD project, 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.
- Serious problems occurred with the crushed rock envelope at the Fourth Drainage Project although it was designed according to the specifications. 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. 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 chocked 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. 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.

Lessons learned:

1. Specifications based on knowledge that was developed elsewhere should be locally verified during the project's preparation phase.
2. 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.
3. Under wet conditions, the option to use a light synthetic envelope instead of gravel should be considered.

References: Alterra-ILRI (2001), Nijland et al (2004), Mardan SCARP (1984)

Title: Construction under wet conditions		**Case Study**: Pa-17
Country: Pakistan	**Location/Project**:	**Years**: 1985-1995

Indicator(s) used in this case study: drainage equipment, soil and hydrological conditions, implementation process

Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical	○		●	
Socio-economical				
Environmental				

Background: 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) (See also case Pa-24 about the ineffectiveness of those interceptors):
- 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).

The executing agency was the Water and Power Development Authority, a international consultant consortium served as consultants and the contract was awarded to a pre-qualified contractor.

Problem description: Because of the emergency from flooding and the resulting local pressure on the Government to initiate the works, execution took place under extremely wet conditions. 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.

Action/intervention: 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:

1. 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.
2. These specifications should be developed in close cooperation between the consultant, the contractor and the manufacturer.
3. The implementation schedule should take into account time required to import equipment, the assembly and adjustment to local soil conditions.
4. Modifications to adjust the installation equipment to the extreme wet conditions were required, i.e. wider tracks on the trencher, float tyres on the trailers, track-mounted feeders and a power auger for the gravel placement.
5. 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;

References: Nijland et al (2004)

Title: Trench backfill and the occurrence of sink holes		**Case Study**: Pa-18
Country: Pakistan	**Location/Project**: nation-wide	**Years**: 1980-1995

Indicator(s) used in this case study: installation method, soil and hydrological conditions, implementation process

Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical	○		●	○
Socio-economical				
Environmental				

Background: In Pakistan, the soils in the areas in need for subsurface drainage have relatively fine-textured soils (silty loam, sandy loam, silty clay, etc.). Consequently, drain spacing are wide and thus field drains and collectors are deep, sometimes up to 4 m near the sumps.

Problem description: 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.

Action/intervention: 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, puddling, extra soil, blinding, slow water table draw down and deep tillage were used to overcome this problem.

Lessons learned:

1. Deep drains require special attention during backfill to reduce the risk of sink holes.
2. Pumping should be reduced during backfill to avoid excessive hydraulic gradients.
3. Pumping can be resumed after the backfill has been exposed to one cropping season of irrigation and/or a heavy rainfall event.

References: Nijland et al (2004)

Title: Comparison of costs of SSD-systems in Pakistan and Egypt		**Case Study**: Pa-19
Country: Pakistan & Egypt	**Location/Project**: Nation-wide	**Years**: 1980-2002

Indicator(s) used in this case study: installation method, drainage equipment, costs and benefits

Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical	○		○	
Socio-economical	○		●	
Environmental				

Background: The construction costs of subsurface drainage systems are substantial. They vary from country to country and from situation to situation. For the planning of this type of systems, unit rates and unit prices a needed.

Problem description: Installation capacities, machine cost and total cost of large-scale subsurface drainage projects vary considerable due to exchange rates, local conditions, condition of the equipment etc.

Action/intervention: For a number of drainage projects in both Pakistan and Egypt the installation capacities, machine cost and total cost per hectare have been analyses and converted to 2002 prices. Capacity has been expressed in effective time, thus the time that the machine is actually operational, i.e. laying pipes and excluding the time the machine is available but unable to operate due to daily maintenance, organisational losses (e.g. non-availability of pipes) and daily breaks.

Installation method	Country	Capacity (m/hr)	Machine Cost (€./m)	Total Cost (€/ha)
Field drains by trencher	Egypt	190-380	840	400
Field drains by trencher	Pakistan		950	1183
Field drains by V-plough	Egypt	625	257	321
Collectors by trencher	Egypt	55-100		
Collector by excavator	Pakistan		7050	1183

Lessons learned:
1. Unit rates and unit prices of the construction of subsurface drainage systems vary from country to country and from situation to situation.
2. They depend on factors like the exchange rates, local conditions, condition of the equipment etc.

References: DRP (2001), Hussein and Hoogenboom (1999), Nijland (2000), Nijland et al (2004), Ochs and Bishay (1992)

Title: Cost of subsurface drainage		**Case Study**: Pa-20
Country: Pakistan	**Location/Project**: East Khaipur, Sindh	**Years**: 1981 - 1986

Indicator(s) used in this case study: drainage materials, installation method, costs and benefits

Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical	○		○	
Socio-economical	○		●	
Environmental				

Background: 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.

Problem description: The EKTDP project was the first project in Pakistan to install a SSD-system on a large scale. Numerous practical problems had to be solve to adapt the existing installation practices to local conditions.

Action/intervention: The corrugated PVC field drains (Ø 100 mm) were manufactured in Pakistan and were installed at a 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 m^3/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).

	Cost (€/ha)
Field drains	603 (54%)
Collector drains	412 (37%)
Manholes, sumps and open drains	106 (9%)

Of the total costs, 49% was spent on materials, 28% on preparatory activities (including dewatering of the collector drains) and 23% on installation/construction. 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%)

Lessons learned:

1. The installation of the concrete collector drain pipes was a cumbersome and costly job.
2. 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.
3. 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.
4. So, it was decided to install large diameter perforated PE pipes with a gravel envelope in the remaining collector units. The PE pipes had to be imported, as large diameter PE or PVC pipes were not yet locally made.
5. 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.

References: Nijland et al (2004) and Ochs and Bishay (1992)

Title: Farmers' participation in operation and maintenance		**Case Study**: Pa-21
Country: Pakistan	**Location/Project**: nation-wide	**Years**: 1997-1998

Indicator(s) used in this case study: operation and maintenance, farmer's participation

Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical	○			●
Socio-economical	○			●
Environmental	○			●

Background: Formally, operation and maintenance of drainage systems is to be taken care of by the Provincial Irrigation Departments, a few years after completion of the systems. However, these Departments do not receive additional funds when they are presented with the additional charge of O&M of the drainage systems, and therefore, the systems could not be operated and maintained as necessary. Lack of funds for O&M is among the main problems of drainage management in Pakistan where the open main drainage system is not functioning properly due to poor maintenance. Similarly, operation and maintenance of drainage tubewells and pipe drainage systems (where pumping is needed) is not done as per design criteria. The main reasons include lack of sufficient funds; power failure; mechanical problems; lack of farmers' cooperation. Due to this very often the drainage benefits expected at the time of design cannot fully be achieved.

Problem description: To overcome these problems the National Drainage Program proposes to directly involve farmers in the planning, design, construction and O&M of on-farm drainage systems.

Action/intervention: IWASRI has reviewed the performance of drainage systems to assess the problems with O & M and the possibilities to increase farmer's involvement. However, we cannot expect too much of this 'social approach' in a short time, because:

- Farmers might be ready to pump for irrigation, but they will not pump 'continuously' for drainage;
- The resource base of the small farmers is very narrow. Small farmers cultivate about 45% of the land in Pakistan. They typically have a farm size of less than 5 acres and they have virtually no own resources. Moreover, they are even offered lower than market prices of Pakistan for some of their produce, or have to pay water cess when not even receiving canal water. Pakistan market price is much lower than the international market;
- Sincere involvement of farmers takes time. Several current, hurried, attempts to promote 'participative' approaches in on-farm drainage stand little chance of real success quickly. Even with a functioning main drainage system, and a favourable attitude of users and bureaucracy, it would be time-consuming; and
- There seems to be, at decision-taking level, a lack of understanding of what it takes to involve farmers, especially with the objective to involve farmers in the planning, implementation, and O&M of drainage systems.

Lessons learned:

1. Farmers might be ready to pump for irrigation, but they will not pump 'continuously' for drainage;
2. Effluents from drainage systems are usually pumped into the open main drainage system, which is often not functioning properly due to poor maintenance.
3. Due to O&M problems drainage benefits as expected at the time of design cannot be fully achieved.
4. There is no use to implement drainage when the O&M is not secured.
5. The role of the main drainage system in groundwater drainage is neglected in Pakistan.
6. A choked main drainage system leads to waterlogging.
7. The initial cleaning (desilting) of the open drainage system of FDP led to a significant groundwater table drop

References: Alterra-ILRI (2001), Bhutta et al (1995a), Knops et al. (1996), Knops and Siddiq (1997), Knops et al. (1999), Rafiq et al. (2000)

Title: Drain discharge and quality for different drainage options		**Case Study**: Pa-22
Country: Pakistan	**Location/Project**: Punjab	**Years**:1985-1992

Indicator(s) used in this case study: groundwater level, salinity, drain discharge, tubewell and pipe drainage, data handling and analysis

Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical	○	○		●
Socio-economical				
Environmental	○	○		●

Background: To combat the twin problem of waterlogging and salinity, caused by canal seepage and deep percolation from irrigated fields, subsurface drainage is an option. The choice for a subsurface drainage system is between a tubewell and a pipe system.

Problem description: Tubewell drainage is common in Pakistan, is known to effectively lower watertables and cheaper than pipe drains. Tubewell drainage, however, has negative environmental side-effect due to mobilization of salt from the deeper aquifer.

Action/intervention: To investigate the relation between drainage technology and effluent quality a tubewell drainage system (the SCARP-II area in Chaj Doab) and a ssd pipe system (Fourth Drainage Project in the Lower Rechna Project) (FDP) have been compared. Data available from records from the SCARP Monitoring Organisation has been used. The study lead to the following conclusions:

- SCARP II has been successful in lowering the depth to the watertable
- The groundwater quality in SCAP II seems to have deteriorated between 1975 and 1998. In the Saline Zone, the number of tubewell delivering usable quality water decreased from 49 to 41%, the tubewells delivering marginal water quality increased with 1% and the tubewell delivering hazardous water quality increase with 7%. Scientific proof of the deterioration is difficult, because the data are spatially varied in location and time.
- The shallow groundwater quality of FDP seems to have improved. No significant change in water quality of the deeper aquifer was observed. Of the 58 common tubewells, the number that delivers a usable quality, remained constant (17); the number of tubewell delivering a marginal quality increased from 4 to 8 and the number of tubewell delivering a hazardous quality decreased from 37 to 33.
- Valuable data on the relationship between drainage technology and effluent quality, which could lead to recommendations for drainage design, is waiting processing.

These conclusions are concurrent with findings from studies conducted in the East-Khaipur Tile Drainage Project and the Mona Reclamation Experimental Project

Lessons learned:

1. Subsurface drainage by pipe drains is more effective to control shallow groundwater quality compared to tubewell drainage: in areas drained with pipe drains the shallow groundwater quality improved after the installation of the ssd-system. In the tubewell area, the quality remained constant or deteriorated.
2. Much unprocessed data on the effect of waterlogging and salinity project are available in Pakistan. Processing this data will help to formulate strong recommendations on the choice between tubewell and pipe drainage, especially in the light of environmental sustainability.

References: Wolters et al (1996)

Title: Evaporation from freshwater and saline evaporation ponds | **Case Study**: Pa-23

Country: Pakistan | **Location/Project**: Fordwah Eastern Sadiqia | **Years**:

Indicator(s) used in this case study: evaporation, salinity, disposal of drainage effluent

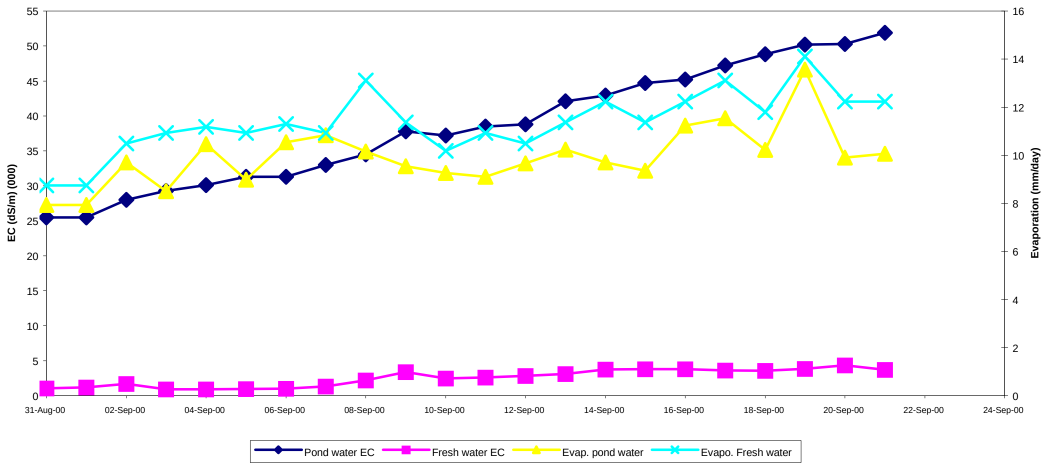
Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical	○	○		●
Socio-economical				
Environmental	○	○		●

Background: Evaporation ponds are considered a feasible alternative for disposal of drainage effluent; drainage water is stored until it evaporates. As the water evaporates chemical constitutes will be progressively concentrated. Numerous chemicals, physical and biological reactions take place in a pond. Surface & sub-surface drainage effluents of Fordwah Eastern Sadiqia (South) Project (FESS) Bahawalnager are being disposed off by gravity via open main drains into evaporation ponds on account of being agriculturally unproductive. The evaporation ponds are a series of inter-dune depressions locally known as `Tobas'.

Problem description: As the drainage effluent evaporated, the salt concentration of the remaining water in the pond will increase and thus evaporation rates will gradually be reduced.

Action/intervention: To investigate the role of salinity in evaporation pond efficiency, two circular Class A evaporation pans were installed in the FESS evaporation pond at Joeya Kama Ka toba. One pan filled with fresh water and the other with pond water. Placing the pans directly in the shallow ponds simulated actual pond conditions as closely as possible. Daily measurements were taken at 9.00 a.m. The temperature, specific gravity, EC in each pan, relative humidity, temperature and wind speed were collected and analysed. A comparison of fresh water and pond water evaporation from class A pan shows that EC of the water affects its evaporation rate. The rate of evaporation decreased as the salinity of water increased. The result reveals that the rate of evaporation of fresh water is about 15 % more as compared with pond water.



Salinity and evaporation from the fresh-water and pond-water ponds.

Lessons learned:

1. Evaporation from an evaporation pond is about 15% lower compare to a fresh-water pond

References: Bhutta et al. (2003) and Javed and Hafeez (2004)

Title: Performance of interceptor drains at CRBC		**Case Study**: Pa-24
Country: Pakistan	**Location/Project**: North Western Frontier Province	**Years**: 1995-1995

Indicator(s) used in this case study: groundwater levels, canal seepage, interceptor drain

Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical	○	○		●
Socio-economical				
Environmental				1

Background: Pakistan has an extensive network of canal irrigation. Part of the irrigation water is lost by seepage from these canals. To alleviate the corresponding problem of waterlogging and salinity, alternative measure like canal lining, drainage by tubewells and surface and subsurface drains are tried. The Chashma Right Bank Canal (CRBC) was commissioned in 1987 and very high rates of seepage were observed in the unlined sections.

Problem description: Eight interceptor drains were installed along both sides of a 12 km long unlined section of the CRB Canal to reduce seepage from the canal and to increase the stability of the canal banks. The interceptor drains discharge into a sump for where the water is pumped. One of these drains (Sump 38) was selected to assess the effectiveness of interceptor drainage.

Action/intervention: Two rows of observation wells were installed perpendicular to the canal at a distance of 660 m. The level in the canal, groundwater levels and discharges from the sump were observed once a week. The data was analysed by using a groundwater model, MODFLOW. The main conclusions of the study are that:

- The groundwater level is below the canal bed. This implies that (i) the interceptor drains do not work as interceptor drain; (ii) there is no induced seepage and (iii) the effect of drain depth and location of the inducement of canal seepage could not be studied.
- The seepage rate from the CRB Canal is about 5.3 mm/d per wetted area
- The discharge from the interceptor drain sump is more than the seepage from the canal
- The interceptor drain is only effective in controlling the groundwater level in its surroundings (with an influence up to 1000 m away from the drain).

Lessons learned:

1. When the surrounding groundwater level is below the bed level of the canal, interceptor drains do not effectively intercept the percolating seepage from unlined irrigation canals.

References: Saleem Bashir at al (1996)

Title: Measuring soil salinity with the EM38 instrument		**Case Study**: Pa-25
Country: Pakistan	**Location/Project**: Fourth Drainage Project and Fordwah Eastern Sadiqia	**Years**: 1995-1999

Indicator(s) used in this case study: soil salinity, investigation

Stage(s) in SSD practices addressed in this case study:

	Planning	Design	Installation	O & M
Technical				
Socio-economical				
Environmental	○	○		●

Background: Soil salinity is one of the major problems hampering agricultural development in Pakistan. Assessment of soil salinity is, therefore, an important activity in planning, design, and monitoring of irrigation and drainage investments in the country.

Problem description: The traditional way of measuring soil salinity is by soil samples that have to be transported to a laboratory for processing. IWASRI and NRAP took the initiative to introduce a modern tool for measuring soil salinity with a device that uses electromagnetic induction. The advantages of using this instrument include: immediate measurement, no need for laboratory analysis; no need for transportation of the samples to the laboratory; many 'samplings' in a short time. IWASRI contributed significantly to the EM38 Workshop that was held parallel to the 8th International Drainage Workshop, Jan/Feb 2000, in New Delhi, India. The sustainability of expertise and the instruments are highly desirable.

Action/intervention: Evaluation of the use of the device showed that the benefits of measuring soil salinity with the EM38 instrument are in improved knowledge of soil salinity, and also in financial terms there are benefits that have not yet been quantified. Earlier scepticism on financial benefits was mainly due to doubts about the calibration. The improved knowledge stems from:

- Quality of the measured salinity data is better compare to sampling as the EM38 measures in a larger soil volume;
- Measurement are direct;
- Measurement can be done quite quickly, so that the frequency and intensity of observations can be increased substantially without extra cost.

The frequency of monitoring, and therefore the understanding of the behaviour of the soil salinity in FDP, FESS, etc., has greatly increased, which aids better management practices.

Lessons learned:

1. Up to now, the calibration of the instrument appears cumbersome and time-consuming. Moreover, it seems that the accuracy of calibration is not to the satisfaction of all scientists. There is opportunity for improvement.
2. The EM38 instrument can be successfully used for determination of EC_e of soils between 0 and 150 cm below soil surface. The instrument measures an EC_a or apparent salinity, that has to be converted into EC_e through the calibration of the instrument
3. The EM38 instrument can be used for pre- and post-project monitoring of soil salinity of reclamation projects in the shortest possible span of time without involving large financial resources
4. Calibration of the instrument, with emphasis on different soil series and correlation between apparent salinity (with EM38) and laboratory measured salinity (from soil samples) is recommended as more confidence on the calibration is needed.

References: Beekma et al. (1994), IWASRI (1999)

Appendix C - Glossary

Agricultural drainage: See **Land drainage**.

Aquifer: A water-bearing soil layer.

Base flow: Water flow appearing in a river or stream as a result of groundwater discharge, with a characteristic delayed reaction to recharge. Most clearly visible after direct runoff has stopped.

Basin irrigation: A system of surface irrigation in which water is ponded on level land parcels surrounded by earthen bunds or banks.

Catchment area: See **Drainage basin**.

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.

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

Criterion: A specified numerical value of one or more (drainage) parameters that allow a design to be calculated with (drainage) equations

Design criterion: a specific value by which an (agricultural) objective can be measured for value.

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

Diversion drain: See **Interceptor drain**.

Drainage: the removal of excess surface and subsurface water from the land to enhance crop growth, including the removal of soluble salts from the soil.

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

Drainable surplus: The amount of water that must be removed from an area within a certain period so as to avoid an unacceptable rise in the levels of groundwater or surface water.

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: see **Criterion**.

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 intensity: (1) An agricultural drainage criterion based on the ratio between the design discharge and the depth of the watertable. (2) The number of drainage provisions (e.g. natural or artificial open drains, pipe drains, or tubewells) per unit area.

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.

Envelope: 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 stabilize the soil material on which the drain is being laid.

Evaporation: (1) The physical process by which a liquid (or solid) is transformed into the gaseous state. (2) The quantity of water per unit area that is lost as water vapour from a water body, a wet crop, or the soil.

Evapotranspiration: The quantity of water used for transpiration by vegetation and lost by evaporation from the soil.

Excess rainfall: That part of the rain of a given storm which falls at intensities exceeding the soil's infiltration capacity and is thus available for direct runoff.

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.

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.

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.

Ideal drain: A drain without entrance resistance.

Indicator: see **Performance indicator**.

Interception: (1) The capture and subsequent evaporation of part of the rainfall by a crop canopy or other structure, so that it does not reach the ground. (2) The capture and removal of surface runoff, so that it does not reach the protected area. (3) The capture and subsequent removal of upward groundwater seepage, so that it does not reach the rootzone of crops.

Interceptor drain: A channel located across the flow of groundwater and installed to collect subsurface flow before it re-surfaces, normally used on long slopes and on shallow permeable surface soils overlying relatively impermeable subsoils.

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.

Land drainage: The removal of excess surface and subsurface water from the land to enhance crop growth, including the removal of soluble salts from the soil.

Land reclamation: Making land capable of more intensive use by changing its general character: by draining excessively wet land, by recovering submerged land from seas, lakes, and rivers; or by changing its saline, sodic, or acid character.

Leaching: Removing soluble salts by the passage of water through soil.

Leaching requirement: The fraction of irrigation water entering the soil that must flow effectively through and beyond the rootzone to prevent a build-up of salinity resulting from the addition of solutes in the water.

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.

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.

Objective: a broad goal that reflects the overall purpose of the irrigation or drainage system or the sector within the irrigation and drainage system falls. Typically, objectives are not precise, exemplified by such phrases as crop diversification, equity, adequacy, or sustainability (Murray-Rust and Snellen, 1993).

Open drain: A channel with an exposed water surface that conveys drainage water.

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.

Parameter: Characteristic or feature that can be measured or quantified.

Peak runoff: The maximum rate of runoff at a given point or from a given area during a specified period, in reaction to rainfall.

Performance assessment: the systematic observation, documentation and interpretation of activities related to agricultural water management with the objective of continuous improvement (after Bos et al 2005).

Performance indicator: A (dimensionless) indicator whose ratio includes both an actual value and an intended (target or critical) value of data on the considered key parameter.

Pipe drain: A buried pipe - regardless of material, size, or shape - which conveys drainage water from a piece of land to a collector or to a main drain.

Precipitation: The total amount of water received from the sky (rain, drizzle, snow, hail, fog, condensation, hoar frost, and rime).

Salinity: The content of totally dissolved solids in irrigation water or the soil solution, expressed either as a concentration or as a corresponding electrical conductivity.

Salinization: The accumulation of soluble salts at the surface or at some point below the surface of the soil profile.

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

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: an man-made system that induces excess water and salts to flow via the soil to wells, mole, pipe and/or open drains, from where it can be evacuated from the land to enhance crop growth.

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.

Surface irrigation: Irrigation whereby the water flows over the soil surface, thereby partially wetting the soil through infiltration, as in basin, border, and furrow irrigation.

Surface runoff: Water that reaches a stream, large or very small, by travelling over the surface of the soil.

Target: a specific value of something, e.g. an objective that can be measured: it provides information on a desired condition that should be met if an objective is to be fulfilled (Murray-Rust and Snellen, 1993).

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

Tidal river: A river whose water level is influenced by tidal water level fluctuations over a considerable distance.

Tide: The periodic fluctuation of the sea-water level that results from the gravitational attraction of the moon and the sun acting upon the rotating earth.

Tile drain: See **Pipe drain**

Tubewell: A circular well, which may be used to dispose of surface water, to control groundwater levels, or to relieve hydraulic pressures, where local physical conditions are appropriate for their use.

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

Tubewell drainage system: A network of tubewells to lower the watertable, including provisions for running the pumps, and drains to dispose of the excess water.

Vegetated waterway: An earthen channel to dispose of excess water safely and therefore lined with vegetation to stabilize the channel and prevent erosion.

Vertical drainage: See **Tubewell drainage**.

Water balance: Equating all inputs and outputs of water, for a volume of soil or for a hydrological area, to the change in storage, over a given period of time.

Waterlogging: The accumulation of excessive water on the soil surface or in the rootzone of the soil.

Water management: The planning, monitoring, and administration of water resources for various purposes.

Watershed: See **Drainage basin**.

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.

Well field: See **Tubewell drainage system**.

Wetlands: Land where the saturation with water is the dominant factor determining the nature of soil development and the types of plant

Appendix D - References

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