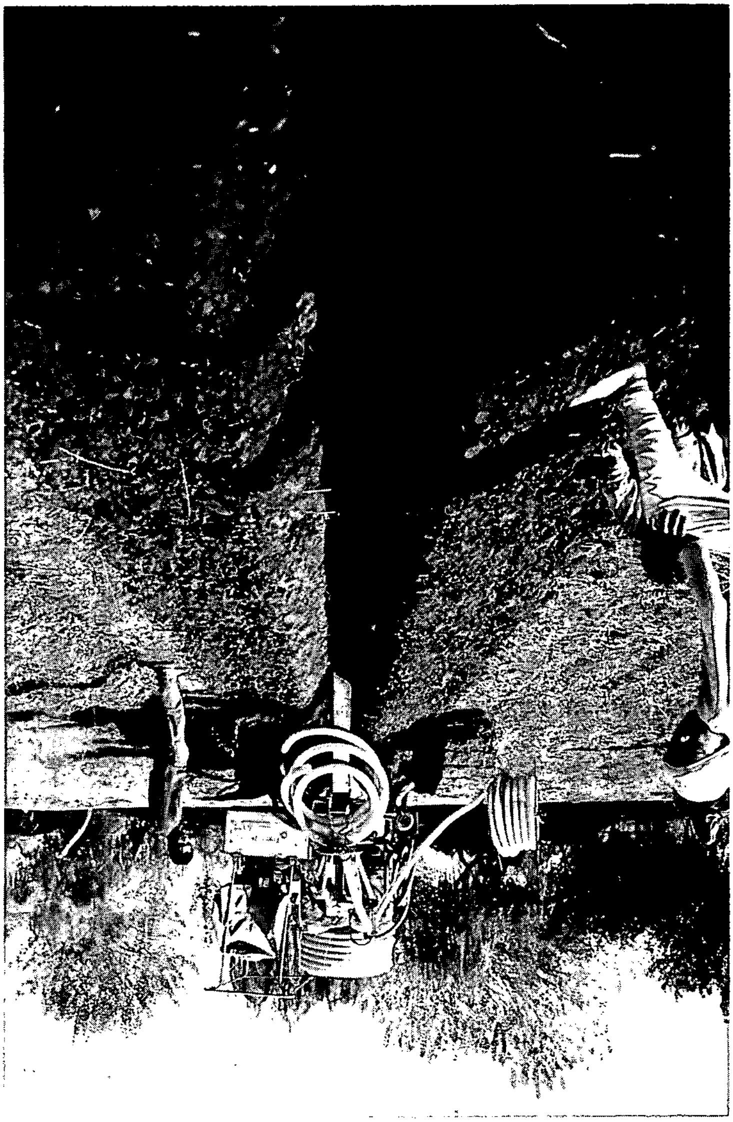
Proceedings, Symposium 25th International Course on Land Drainage

Twenty-Five Years of Drainage Experience



Proceedings, Symposium 25th International Course on Land Drainage

Twenty-Five Years of Drainage Experience

International Institute for Land Reclamation and Improvement/ILRI
and
International Agricultural Centre/IAC

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J. Vos

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Preface

Like most other techniques, land drainage began by trial and error. Landowners and land users, not content with the condition of their fields, tried to improve them – or even entire regions – by digging channels, constructing outlets such as sluices, and installing pumps driven by wind or steam. If the fields were still too wet, they were then drained by open trenches or, beginning in the eighteenth century, by subsurface conducts.

Over time, land drainage also became an indispensable part of the cultivation and settlement of low-lying coastal areas and of the irrigation of lands in arid zones. In the coastal areas, it reduces salinization from seawater and, in the irrigated fields, it reduces the even greater salinization that occurs because of accumulation. In less extreme cases, land drainage can secure better yields and lead to more economical crop production.

Land drainage techniques evolved through experience and were being practised successfully long before the underlying principles were well understood. In fact, it was some one hundred years after the first widespread application of subsurface drainage that the processes occurring in the soil were finally adequately analysed and formulated. Now, however, these theories are well established and are being applied on a large scale.

More recently, new developments in land drainage have mostly been concerned with the transfer of techniques to areas where they have never before been used, like the humid tropics. A striking example of such a transfer is the subsurface drainage of irrigated fields in arid regions, where, only a few decades ago, this technique was virtually unknown. Now these regions are the main centre of drainage activity.

Today, new materials and improved installation methods can offer solutions to problems still unsolved – while sometimes giving rise to new ones. In this respect, theory is much less developed, and the old ways of trial and error are still the only appropriate ones. But it is just this mixture of art and science, practice and theory, experiment and experience that makes land drainage so attractive.

In this book, we have compiled the results of the Silver Jubilee Symposium, which was held jointly by the International Institute for Land Reclamation and Improvement and the International Agricultural Centre to mark the occasion of the twenty-fifth anniversary of the annual International Post-Graduate Course on Land Drainage. On the basis of these results, we have tried to summarize the state of the art worldwide.

W.H. van der Molen
Chairman of the Board,
International Post-Graduate Course on Land Drainage

Editor's Introduction

The Silver Jubilee Symposium was held in Wageningen (The Netherlands) from 24 to 28 November 1986 to mark the twenty-fifth anniversary of the annual International Post-Graduate Course on Land Drainage. Under the theme 'Twenty-Five Years of Drainage Experience', the Symposium attracted 108 professionals from 37 countries, including 24 participants of the 1986 Land Drainage Course and 24 participants from previous years.

Preparations for the Symposium had been initiated early in 1985 by the International Institute for Land Reclamation and Improvement (ILRI) and the International Agricultural Centre (IAC). At that time, these two institutes, who co-operate to give the Course on Land Drainage, appointed a committee to organize a symposium on the development of land drainage during the past twenty-five years, in which emphasis would be placed on the practical aspects of drainage (e.g. design criteria, construction, operation and maintenance) and attention be given to problems, solutions, and future developments. The members of the Organizing Committee were J.W. van Hoorn (Chairman), C. de Jong (Co-Chairman), J.A.H. Hendriks, J.T.A. Groenevelt, G.A. Ven, and E.J.L. Hotke-Staal.

Five major topics were discussed in separate sessions during the Symposium:
1. Drainage in the humid temperate regions;
2. Drainage in the (semi-) arid regions;
3. Drainage in the humid tropical regions;
4. Drainage machines and materials;
5. Organization of the maintenance of drainage projects.

The topics were introduced by one or two keynote lectures, whereafter a number of country papers were presented and discussed. The sessions were chaired by W.H. van der Molen, I.A. Risseeuw, W.C. Hulsbos, and C.L. van Someren. A visit to an exhibition of drainage machines and materials was also arranged.

Because most of the country papers contained elements of more than one of the major topics, the Editorial Committee of the Symposium decided to order the Proceedings as follows:
- Conclusions and recommendations of the Symposium;
- Keynote lectures;
- Country papers grouped by climatic region;
- Discussion of the sessions.

The keynote lectures appear in their original form. Most of the country papers were edited to improve their readability, which made it necessary at times to shorten the text, eliminate tables, and combine figures. These changes, however, do not in any way affect the authors' ultimate responsibility for the contents of their contribution.

The members of the Editorial Committee, R. van Aart, J.W. van Hoorn, L.K. Smedema, and J. Vos, would like to express their gratitude to the authors of the keynote lectures and of the country papers, and to all the other participants for their active involvement in the Symposium. A list of the participants can be found in Appendix 1.

We sincerely hope that these Proceedings will find a place in the literature and prove to be helpful to the many people around the world who are interested in the drainage of agricultural lands.

For the Editorial Committee,

J. Vos
Editor

Contents

Conclusions and Recommendations

1. For drainage of fine textured soils of low permeability requiring very close spacing mole drains in combination with pipe drains laid in trenches filled with highly permeable backfill can be applied.
   In unstable soils moles filled with gravel can be a good technical solution.
2. Clogging of drains by ochre formation appears to be mainly a problem encountered in humid temperate regions. No serious cases are reported until now from drainage projects in arid regions.
3. The computer can be used for:
   - drainage design, calculation of spacing, pipe diameter, length, etc.;
   - investigating the effect of drainage on crop growth and yield, and on soil and water salinity by simulation models;
   - assessment of spatial variations in drainable surplus by groundwater models;
   - cost optimization studies.
4. Drainage should be considered as a part of watershed management that also includes soil and water conservation, irrigation, and crop management.
5. Drainage projects should be designed in such a way as to maximize the positive impacts on society, and be evaluated in that respect.
6. Subsurface drainage in arid regions differs from that in humid temperate regions with respect to objectives, criteria, field investigations, design options, construction practices, equipment and materials.
7. Monitoring for engineering and/or socio-economic purposes should be incorporated in the design and operation of large drainage projects.
   The design should clearly describe the aim of the monitoring, and the ways and means to achieve it.
8. In humid tropical regions surface flow and interflow predominate over groundwater flow.
   Subsurface drainage can find its application for deep rooting crops.
   Notwithstanding the rainfall being higher than in the temperate regions, the discharge criteria for subsurface drainage do not seem to be higher since the soil profile is a limiting factor for groundwater flow.
   Since little experience with subsurface drainage of dry foot crops exists, more research is recommended.
9. Improvement of drainage for rice can be obtained by development or management strategies or a combination of both, in which irrigation management plays a major part.
   A special case is rice cultivation in rotation with other crops on tile drained land in arid regions.
   Special precautions are needed in that case.

10. Most failures in drainage projects are due to faulty construction or lack of maintenance.
    The application of corrugated plastic pipes and recently developed trenchers for plastic collector drains with in-built installation for quality control will contribute to better construction.
    Composite drainage systems with a minimum length of deep open drains will contribute to minimize the burden of maintenance.
11. Gravel remains for the time being the most reliable filter material.
    In view of the cost of gravel the development of design criteria for synthetic materials merits the highest priority.
12. The application of trenchless machines is currently limited to a depth of two metres.
13. Organization of maintenance is a bottleneck for the success of drainage projects.
    At the design stage due attention should be given to minimize future maintenance as well as its organization, including training and financing.
    Research programmes should pay more attention to maintenance aspects.

Keynote Lectures

The development of drainage in humid temperate regions

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Introduction

In humid temperate regions mankind settled first in those locations with natural drainage systems in the form of rivers and brooks. Agriculture started on the higher and dryer soil types.

With the increase in population more land was needed for food production and soon people learned that the best soils for agriculture were situated in the river valleys and coastal plains, provided that they were protected from flooding. From the early middle ages onwards dike building and river regulation allowed the reclamation of vast areas of agricultural land by digging canals and ditches for the removal of excess rainfall and seepage water. This system itself, often called the main drainage system, was not sufficient to obtain reasonable drainage conditions and additional farm drainage in the form of ditches and furrows had to be applied.

The Greeks already knew that they could improve the quality of their vineyards by digging trenches and filling them with stones. The Romans seem to have applied clayware pipes for drainage purposes. However, it was not until the middle of the 19th century before subsurface drainage was introduced to Europe after the system had been demonstrated at the Great Exhibition in London in 1851. This relatively expensive system was then applied to better agricultural soils that could compensate for the high costs. The world of agriculture realized that certain drainage was necessary to protect the crops from flooding and to achieve a certain trafficability of the soil, but it took a long time before it was convinced of the need for good drainage, despite the fact that the first German Dränanweisung that appeared in 1857 (Schirmer 1959) already published figures for discharge capacities of drainage systems that differ only slightly from those used today.

The Dutch Ministry of Agriculture made a survey of the drainage conditions around 1915. The report showed that drainage conditions were very poor. Flooding, even in summer occurred regularly and the capacity of many pumping plants and main canals was too low. At that time winter flooding was still considered necessary to maintain soil fertility.

In the period between the two World Wars drainage conditions were improved considerably in many countries by enlarging the capacity of the main drainage systems and pumping plants. In literature the first publications advocating drainage as a measure to increase production then appeared.

After World War II the demand for more food, and especially the acceleration in agricultural mechanization brought about a new interest in drainage, and many governments tried to stimulate drainage by allowing grants for installation. Although trench diggers and mole ploughs had already been available for a long time in the USA and England, they only replaced manual labour in the 1950's. With the introduction of more powerful machinery it soon became clear that speed of installation was limited by the use of conventional burned clay and concrete pipes. New techniques such as the in situ formation of a concrete pipe (Ede 1957) were surpassed by the introduction of plastic tubing. The use of this material gave rise to all kinds of new techniques. In The Netherlands for instance, the first polyethylene pipes were pulled into the soil by means of a mole plough. In other countries methods were developed to form tubes from plastic strips, like the Janert system (Janert, 1955) in the DDR, and the American system described by Fouss and Dennon (1962). This technique, also known as mole lining, disappeared with the introduction of the corrugated pipe, although the present Big-O system in the USA actually belongs to that type.

Despite the efforts of conventional pipe producers to reduce transport and handling costs by paletting, the corrugated pipe gained the upper hand and nowadays is used in the majority of cases.

With the introduction of this type of pipe, the competition between mole-lining and trenching changed into that between trenchless and trench drainage.

The above developments and the favourable economic conditions in agriculture caused an acceleration of the drainage of agricultural land. With the worsening of economic conditions since the 70's and the surplusses in agricultural production, agriculture in many countries now faces the growing objections of environmentalists who fear that improvement of drainage damages wildlife habitat, and intensive agriculture causes damage to the environment.

Drainage as a tool to increase production has changed into a means to lower production costs by allowing better trafficability of the soil, the possibility of an early crop growth, and prevent damage caused by animals and machinery.

Drainage design

At the time of introduction of pipe drainage the system was applied by individual farmers. Depth and spacing were chosen on the basis of guesses and practical experience. Around 1920 flow theories, nowadays known as drainage equations, started to appear in literature, but it was not until about 1945 before they were applied to design purposes. This was especially the case where groundwater drainage took place, and the government was involved in design or financing. In Germany the previously mentioned Dränanweisung is used, while in the UK and the USA the governments issued a special guide (MAFF, 1983, Soil Conservation Service, 1971). In The Netherlands the Government Service for Land and Water Use designed systems for private farmers on which grants were based.

With the withdrawal or reduction of grants design is often left to private contractors who generally work on the basis of experience. In countries with special drainage problems (heavy soils, peat soils) such as UK, France, Ireland, standards and methods are still being formulated.

Drainage theory

As indicated in the announcement of this symposium, emphasis will be placed on practice rather than on theory. Theories themselves will be therefore left out, but they will still need to be reviewed as and when it is important to understand what is happening.

Around 1962 a large number of analytical drainage theories were available for the flow of water towards drains. These theories were for both steady and non-steady states, and can be used for design purposes and for the analysis of field experiments. Since that time not much has been changed and it might be stated that solutions are available for the most practical problems, and even for rather complicated conditions like multi-layered situations.

Problems for which no analytical solutions are available, can nowadays be solved by means of numerical methods, thanks to developments in the world of computers. This implies that enough solutions are available to design a system for groundwater drainage. There is, however, one exception and this concerns fine textured soils with low permeability. Despite a considerable amount of research, there is no common opinion about the drainage of these soils. Both in England and Ireland (Galvin 1978) the use of mole drains is advocated as a remedy. A combination of conventional drainage with trenches filled with permeable backfill and moles perpendicular to this system, with a very narrow spacing of 2 to 4 m also seems to be a solution in certain cases (Bailey 1978). Groot (1973), who analysed a series of field experiments in the Sava valley in Yugoslavia, supports the conclusion of Van Hoorn (1960) that subsurface drainage is preferable in the event that there are layers with a higher permeability within the range of the drain depth.

In other cases a subsurface drainage system with highly permeable backfill may offer a solution, provided that this backfill remains permeable during the lifetime of the system. Further details are given in the reports of Spoor and Galvin (this Symposium).

In any case the flow towards drains in these situations is complicated and difficult to analyse (Lesaffre 1985) and rather expensive field experiments have to be carried out for the design of a system.

One has to conclude that our knowledge about the flow of water in this type of soils is still very scarce. New methods to determine soil properties and to detect flow patterns in heavy soil are now being tried out (Bouma 1977, 1981, 1985).

A second restriction to the use of drainage theories for design is the fact that design criteria have to be set for both the steady and non-steady theories. In the former case one has to assume a given discharge at a certain watertable depth. In the second case a rate of fall in the watertable is used. The drainage criterion is a problem in itself, and this will be discussed under the heading 'Effects of drainage on agriculture'.

Apart from the hydrological design, there is still the problem of hydraulic design, i.e. what diameter of drains should be used. Here one is concerned with the transport of water in the drainlines themselves. Apart from a variety of flow resistance equations to be used (Manning, Colebrook, Chezy-Bazin), there is a fundamental difference in design. In most countries the so-called transport principle is applied, i.e. it is assumed that the design discharge has to be transported in full over the total length of the pipe (cf. Soil Conservation 1971). In The Netherlands the drainage principle is used, i.e. the flow in a drain-line is zero at its upper end and increase to the design discharge at its outlet. (Wesseling 1964, Van Someren 1972).

This controversy may be explained by the fact that under Dutch conditions large slopes hardly exist, so that surcharge of drain-lines does not occur, while in most other countries, steeper slopes are applied.

Performance of drainage system

The second type of use of drainage theories is in analysing field data, in other words the performance of drainage systems. Until about 1960 drainage experimental fields were mainly used to study the effect of drainage on groundwater behaviour and on agricultural production. They were meant to obtain information about the required drain spacing where no practical experience was available in similar types of soils.

With the introduction of new pipe and envelope material, a large number of field experiments were carried out to investigate the behaviour of these materials. Perhaps the most important development for analysing data of these fields was the drainage theory developed by Ernst (1962). By splitting up the flow into a number of components, he introduced the concept of resistances.

With the aid of this concept the behaviour of pipes and materials could be characterized by the so-called entrance resistance. Wesseling and Van Someren (1972) gave various values for this parameter for drainpipes and envelopes applied in The Netherlands. Wesseling (1978) gave a discussion of the extent to which the material properties have to be taken into account in the design.

The concept of resistances offers the possibility not only to compare the behaviour of various materials, but it also enables a comparison of the results from field and laboratory tests (cf Knops 1978, Wesseling and Van Someren 1972). The reason why this concept has not been accepted outside The Netherlands may be due to the fact that the Ernst theory never has been published in English and the resulting drainage equations seem to be rather more complicated than the well-known equations of, for example Kirkham, Hooghoudt, Kirkham and Toksöz.

Despite a careful choice of pipes and filters, and the necessary precautions during installation, drain pipes might eventually become clogged. Maintenance of the system in the form of jetting for instance, necessary in order to keep the system working.

This method is exclusively applied in flat countries (cf. Busser and Scholten 1978). A lot of attention is paid to flushing of drain pipes particularly in Europe. The reason for this may be that in Europe drain pipes with a diameter of about 60 mm are used generally while in the USA for instance, diameters of 100 mm and more are common. Moreover the slopes under which drain pipes are laid may also play a role. The problems in jetting or flushing of drain pipes are as yet unsolved. There are several aspects to be considered such as type of jetting equipment, water pressure to be applied, type of soil and filter material, length of lines, etc. During the sessions on drainage materials this problem is certainly to appear once more.

Another still unsolved problem is the clogging of drain-lines by ochre formation. Research on this problem especially has been done in de FRG (Kuntze 1978), in the USA (Ford 1978) and in The Netherlands (Ven 1985). In certain areas iron may render a drainage system inactive within one or two years. Sometimes jetting may be a temporary solution, and at other times it may not. Envelope material also seems to play an important role here, and this problem will also be discussed under that subject.

The performance of a drainage system will highly depend on the care with which it is executed. Problems like depth control by means of laser equipment, soil conditions during execution and several other aspects will be discussed during the course of this symposium.

Effects of drainage on agriculture

Subsurface drainage is an important tool used to increase agricultural yields. In humid areas one has, however, to take in consideration that a soil can be overdrained with the consequence that drought damage occurs.

There is a tremendous amount of literature concerning the effect of drainage conditions on crop growth. A short review may be found in Wesseling (1974).

In a review on drainage problems, Van Schilfgaarde (1978) states that adequate analytical tools are available to describe the behaviour of the watertable, or even the time course of the water content in the rootzone. However, what is missing is an adequate data base to interprete such calculations for the economic return from a drainage system. In other words, given a certain drain depth, spacing and meteorological conditions, those watertables and soil water contents to be expected can be derived, but their effect on crop growth and yield is not yet known.

A considerable amount of field experiments are necessary to solve this problem. Fortunately, especially during the last decade, new possibilities arose in the form of so-called computer experiments. These experiments are based on the simulation of actual processes. Typical examples of models are given by Feddes and Van Wijk (1976), Skaggs (1978), and De Jong and Zentner (1985). Feddes and Van Wijk (1976) applied their model to Dutch conditions, while Hardjoamidjojo and Skaggs (1982) gave an example of determining the effect of drainage on maize yields in the USA.

Time is lacking to discuss these models in full. Therefore only the principles of the model of Feddes and Van Wijk are given here. For given soil and drainage parameters, the model computes watertables, discharges and soil water contents during the winter period. On the basis of the latter data, the time of sowing and planting is determined in terms of workability conditions. A crop growing model is then used to determine the crop growth during the growing season under prevailing meteorological and soil conditions. At the end of the growing season, workability demands can again be taken into account to determine the harvesting time.

A period of 30 sequential years is used to compute crop yields. By changing the drainage parameters in the model, different drainage conditions can be investigated in a very short time. Based on a statistical analysis the most effective depth and drain spacing can then be chosen. Moreover, the model results offer the possibility to translate drainage into additional crop yield, and hence offer the possibility of an economic evaluation.

It should be noted here that realization of such models calls for a number of data on e.g. workability of the soil, crop growth parameters, such as rooting pattern, Leaf Area Index, etc.

Under humid conditions, like those in Western Europe, there are two aspects to be considered, namely damage to the crops because of waterlogging/flooding of the soil and the workability of the land.

Soon as drainage reaches a certain level, the first aspect will be of little importance. In The Netherlands for instance, the advantages of drainage are thought to be found in an early workability (trafficability) of the land, rather than in preventing waterlogging. This is especially true for arable land. For permanent grassland the problem of poaching by grazing cattle forms an as yet unsolved problem. This aspect has not been considered in the model of Feddes and Van Wijk, although in principle the problem can be approached in the same way. A lot of research, however, has to be carried out before sufficient data are available to derive boundaries for poaching.

The above-mentioned models offer good possibilities to derive drainage criteria for design purposes. The most efficient combination of depth and spacing expressed in terms of crop yields adapted from the models leads directly to the required criterion.

Drainage and environment

In irrigated regions there is the problem of salinity of drainage water that may influence water quality in downstream areas.
In humid regions there is the problem of eutrophication of surface waters as a result of drainage activities. Moreover, drainage of agricultural land may lower the groundwater in adjoining natural areas, thus affecting wildlife habitat. In the third place drainage may influence stream flow from catchment areas (Ryder and Ward 1985).

Leaching of nutrients by drainage is a well-known phenomenon itself. Increase of this leaching has primarily to be sought in a more intensive use of fertilizers caused by an intensification of agriculture due to better drainage conditions. In certain cases this leaching has lead to pollution of groundwater aquifers, especially with nitrate, but pollution of surface water can also occur. In the intensive agriculture of Western Europe another problem is arising, namely the spreading of cow slurry. Due to lack of storage capacity, farmers want to spread slurry throughout the winter period. For this purpose they need a good trafficability of their parcels and hence good drainage conditions. Spreading in winter, however, increases the danger of run-off of slurry, especially when it is applied in large quantities under poor soil conditions, where soil structure is damaged. Agriculture is therefore faced by governmental regulation prescribing the terms and amounts of application of slurry, but also of the maximum amount of fertilizers to be applied. This in turn could reduce the economic benefits of drainage.

On the other hand, not much is known yet about the demands wildlife habitat imposes on drainage conditions. With the improvement of drainage conditions in many countries, maintaining poorly drained wet areas for preserving wildlife habitat seems to become a more important issue in this respect.

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Drainage in arid regions

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1 Introduction

The need for drainage to control the watertable and soil salinity in irrigated arid land is now generally accepted. 30 years ago this was not the case. In 1955 for instance people in Iraq still doubted whether drainage was the right answer to combat salinization and to reclaim saline land. It was for that reason among others, that in 1955 the Dujailah Drainage Experiments in Iraq were started (ILRI 1963).

When discussing drainage, distinction has to be made between drainage of groundwater and drainage of surface water. Drainage of irrigated arid land refers primarily to groundwater drainage (needed for salt control) but surface drainage may also be required to remove excess rain or excess irrigation water, especially for soils with low infiltration rates. Surface drainage is further needed if rice is grown. Shallow surface drains can also serve to leach out salts by surface as well as subsurface flow. For instance, with ditches of only 0.4 m depth the farmers in Egypt succeed in leaching their new salty land. If rice is grown in rotation with dry foot crops, such as on the old land of the Egyptian Nile Delta, subsurface drainage, required for groundwater control of the non-rice crops, implies the risk of excessive percolation losses in periods that rice is grown. The solution worked out in Egypt is to grow rice in drainage units in which the watertable can be backed up by means of a closing device at the drainage outlet.

Groundwater drainage can, apart from with horizontal drains, be achieved with pumped vertical wells. Vertical drainage requires the presence of a permeable aquifer. Vertical drainage may be an attractive solution, especially if the pumped drainage water is of good quality, so it may be re-used for irrigation. In that case the required pumping for drainage should be integrated into a regional programme for optimal management of surface waters for both irrigation and drainage purposes.

In arid lowland areas groundwater is often saline and as a rule salinity increases with depth. Deep vertical drainage wells will produce highly saline water unfit for re-use and difficult to dispose of. In that situation a solution called 'skimming drainage' may be considered. Skimming drainage intends to drain the least salty upper water only, and can be achieved with shallow low capacity wells but much better with horizontal drains.

There are three successive phases involved in implementing a drainage scheme:

1. Surveys and studies;
2. Design;
3. Construction.

Construction, which in fact is very important and is probably the most critical phase for the success of the drainage operation, will be discussed in a separate paper.

This paper deals mainly with survey and design aspects of horizontal pipe drainage of irrigated, non-rice cropped arid land. After a comparison of the drainage in arid and humid climates and a brief review of the past and present drainage activities in arid regions, some selected items regarding technological developments, lay-out options, design criteria and monitoring are discussed.

2 Drainage for salinity control

Groundwater drainage in irrigated arid and semi-arid regions is in many aspects different from drainage in humid areas. The aim of drainage in humid temperate areas is to control soil water conditions for better aeration, workability, and temperature regime. The primary objective of draining irrigated arid land is to control soil salinity. This may be a subject of debate, but is easily understood if we consider the hypothetical situation of irrigation in an arid region, where neither the irrigation water nor the groundwater contains any salt. In that case drainage is not needed to leach and evacuate salts. Nor it is needed to avoid waterlogging as groundwater depth and soil water conditions can be adequately controlled by proper irrigation. A watertable too near to the surface can be corrected by reducing the irrigation amount or frequency, after which, in a dry hot climate the watertable will drop rapidly due to evapotranspiration. This hypothetical situation corresponds with the dry season irrigation in regions with a tropical monsoon climate. Because of excess rain in the wet season, neither soil nor groundwater are saline. In those areas, groundwater drainage is practically not existent. There is apparently no need for it.

Apart from this fundamental difference in the drainage objective between irrigated arid and rainfed humid areas, there are many other aspects in which drainage of arid land differs from that of humid land. Arid regions are by definition characterized by the absence of an active natural drainage system. For irrigation projects situated in river valleys the river represents the main water supply for irrigation and domestic uses, and should not be contaminated with salty drainage water. Therefore, drainage of irrigated land involves not only the installation of field and collector drains, but also the construction of a drainage infrastructure.

This may eventually imply the need for constructing an extensive and costly main outfall system to carry the drainage water from the irrigated area to the sea. Examples of such man-made main drain networks are found in Egypt, Iraq and Pakistan. In Egypt an enormous network of main and secondary drains has been constructed throughout the delta to transport drainage water. In Iraq the main outfall system from north of Baghdad to the Arabian Gulf has been designed and its lower section is under construction. In Pakistan the construction of the Left Bank Outfall Drain in the Indus Valley has been started. In Haryana State (India) where, as a result of increased irrigation water supplies, waterlogging and soil salinization are becoming a threat for agricultural production, the disposal of the saline drainage water is a not yet solved problem. A main outfall would require 450 km of drain and 17 pumping stations with a total lift of 100 m, and is not considered feasible. As long as there is no major drainage outfall system, temporary solutions are often applied, such as disposal into evaporation ponds or, if drainage water is not too saline, into the river or other irrigation systems.

Field drainage conditions in arid regions are also different from those in humid regions. Drains have to be situated at a greater depth for salinity control and are usually spaced much wider apart (30 to 150 m) than in humid areas (8 to 30 m). Deeper drains and wider spacing imply that soil investigations to determine the hydrological parameters needed for design have to be carried out to a considerably greater depth in arid regions than in humid regions. This requires application of more complicated and costly investigation techniques and equipment.

Finally, the construction of a drainage infrastructure in arid and humid regions is also different. The construction of a deep, widely spaced drainage network in arid land requires larger pipes and heavier installation equipment and is more difficult than that of a shallow, narrow spaced drainage system in humid areas. Trenchers used in arid regions are in the power range of 200-300 kW compared to 100-200 kW in humid regions.

Although the drainage objectives, approach, and construction in arid and humid regions are different, the flow of groundwater to the drains is identical in both cases. The same drainage formulae are used for the design of drainage schemes and the drainage requirements are formulated in similar terms as for drainage in humid temperate regions.

3 Drainage activities in arid regions

The need for drainage in arid and semi-arid regions is directly linked to irrigation. Archeological studies in Iraq (NN 1958) have shown that as early as 2400 B.C. waterlogging and salinization were causing yield reduction and were reasons to abandon irrigated land in the Mesopotamian Plain. Drainage of excess surface water to depressions and marshes was already applied at that time, but no indications have been found of drainage with a view to lower the groundwater table and to leach out salts. Still farmers succeeded at that time to keep salts low and to cultivate the land for many centuries in succession. This was probably achieved by means of an adapted farming system which, as described by Russel (NN 1958) consisted of long fallow periods (summer-winter-summer) between two winter crops. During such fallow periods the watertable dropped to 2 m and deeper by transpiration of deep rooting weeds such as shok (Proposis Stephaniana) and camel thorn (Alhagi Maurorum). This made it possible to leach the salts accumulating in the surface layers to the subsoil at the start of the next irrigated winter crop season. This practice resembles in some way the farming method known as Niren system, applied in Iraq until recently.

The modern history of land drainage for irrigated land started in the USA around the end of the last century. In 1886 Hilgard (Luthin 1957) had already noted the need for drainage in the San Joaquin Valley of California. One of the first drainage schemes for the control of watertable and soil salinity was probably constructed in the Pecos Valley Irrigation Scheme (New Mexico), where in 1918, 1800 m of deep open drains and 150 m of covered drains were completed (Euroconsult 1985). In 1950 large areas of irrigated land in California and other states had already been pipe drained. Also in sugar estates in Central and South America drainage, including pipe drainage to control the watertable was applied long before 1950. Undoubtedly drainage for watertable control was also applied before 1950 in the irrigated arid regions of Australia and South Africa.

In Egypt drainage problems developed after the introduction of perennial irrigation at the beginning of this century. As early as in 1892 the British engineer Scott Mongrieff (Wilcocks 1913) stressed the need for drainage which should receive priority above extension of water supply to new areas. In 1952 a reported 50 000 feddan were pipe drained in Lower Egypt.

A general feature of the drainage before, say, 1945 was its empirical approach. Drains were designed and constructed according to local experience, and later on intensified, deepened or in another way adjusted whenever this appeared necessary. After 1945 drainage and land reclamation received a scientific base. In 1940 Hooghoudt published his well-known analytical approach to the flow of groundwater to drains, following which many other researchers turned their attention to this field. They confirmed, improved and extended Hooghoudt's work, and drainage formulae for steady and non-steady flow and for complicated multi-layered aquifer systems were developed. In 1957 the well-known handbook 'Drainage of Agricultural Lands' (Luthin 1957) was published and contained many contributions to drainage theory. In the same period in different parts of the world research on the drainage and reclamation of saline land was conducted. In 1948 Reeve et al. published a bulletin on reclamation of saline alkali soils by leaching and in 1954 the US Salinity Laboratory Handbook 60 (USDA 1954) was published on the diagnosis and improvement of saline and alkali soils. Basic and operational research on the reclamation and drainage of saline and alkaline land was carried out in The Netherlands in connection with the reclamation of the Zuiderzee, and the floods of 1945 and 1953 which inundated large parts of the low-lying land with sea water. In 1955 operational research started in Dujailah and other parts of Iraq to study the drainage and reclamation of extremely saline and alkaline land (ILRI 1963).

After 1950 the application of pipe drainage in the arid regions rapidly expanded in North Africa and the Middle East. In Egypt, as a result of the law of 1965, the Government made itself responsible for the implementation of field drainage. A long-term implementation programme, the largest in the world, was started and is still in operation. In Tunisia the first pipe drains were installed about 1958 in the Medjerda Valley. In Iraq all new or reconstructed irrigation schemes since 1950 have been provided with pipe drainage. The total area drained, still zero in 1950, now covers several hundred thousands of hectares. The first pipe drainage in Morocco dates from about 1970, when the Gharb Valley Irrigation Project was implemented in the Sebou Basin. In other Middle Eastern countries like Syria, Israel, Lebanon, Jordan and Iran, drainage of irrigated land was mainly introduced after 1965.

A different kind of development took place in Pakistan. Because of increased water supplies for irrigation, waterlogging and salinization affected in creasingly more agricultural land and after 1950 became a major danger to agriculture in the Indus Basin.

In the early sixties with the assistance of United Nations and World Bank, large-scale studies were undertaken and a number of SCARP's (Salinity Control and Reclamation Projects) identified. Tubewell drainage appeared to be the best solution in most areas due to a highly permeable aquifer and groundwater of good quality. The extent and degree of the problem and the remedial measures in the Indus Basin were further investigated during 1964 – 1966. The first SCARP with tubewell drainage was implemented in this period, followed by many other tubewell SCARP's. The first pipe drainage scheme – the East Khairpur Tile Drainage Project – started in 1978 in an area unsuitable for tubewell drainage. A second pipe scheme is now under construction and a third is in the preparation phase.

During the last decennia the drainage activities in the Middle East were concentrated in the Nile Delta of Egypt, the Mesopotamian Plain of Iraq and the Indus Valley in Pakistan, all areas with comparable climate, land slope and irrigation water quality. The method of drainage, however, varies greatly in the three countries due to differences in soil conditions and cropping systems.

In the Nile Delta of Egypt the soils are heavy and poorly permeable and the aquifer conditions are not suitable for vertical drainage. The land is practically permanently irrigated without fallow periods, and rice is part of the crop rotation, with the result that there is no serious salinization problem. The pipe drains in Egypt are therefore installed at a relatively shallow depth (1.2 to 1.5 m) and, as compared to other regions, narrowly spaced (30 to 60 m).

The Iraqi soils of medium to heavy texture offer better permeability, but aquifer conditions are not suitable for well drainage, this is because the groundwater is saline. Winter is the main cropping season and summer irrigation is limited which results in a great part of the land being fallow in summer, and subject to salinization by the capillary rise of saline groundwater. The pipe drains in Iraq are therefore installed much deeper (1.7 to 2.2 m) and with wider spacings (60 to 150 m) than in Egypt.

In Pakistan soils are medium textured, well-permeable and underlain by a highly permeable aquifer with often good-quality water. Cropping is semi-intensive (60 to 70% cultivation in summer and winter). Conditions in many areas are favourable for tubewell drainage, and this is largely applied. As in Iraq the pipe drains are installed deep with even larger spacings. Owing to the highly permeable aquifer, the natural drainage conditions as a result of different topographies determine the need and degree of (additional) drainage, more so than in Iraq and Egypt.

To end this review it may be concluded that since 1950 when, except for USA, drainage of irrigated land was practically unknown, much has changed. The need for drainage of irrigated land is generally accepted these days and large areas have been provided with drainage facilities. Future prospects include the continuation of activities such as those in Egypt, Iraq and Pakistan and the expected start of new large scale drainage programmes in countries like Turkey, Iran, India and China and in South America.

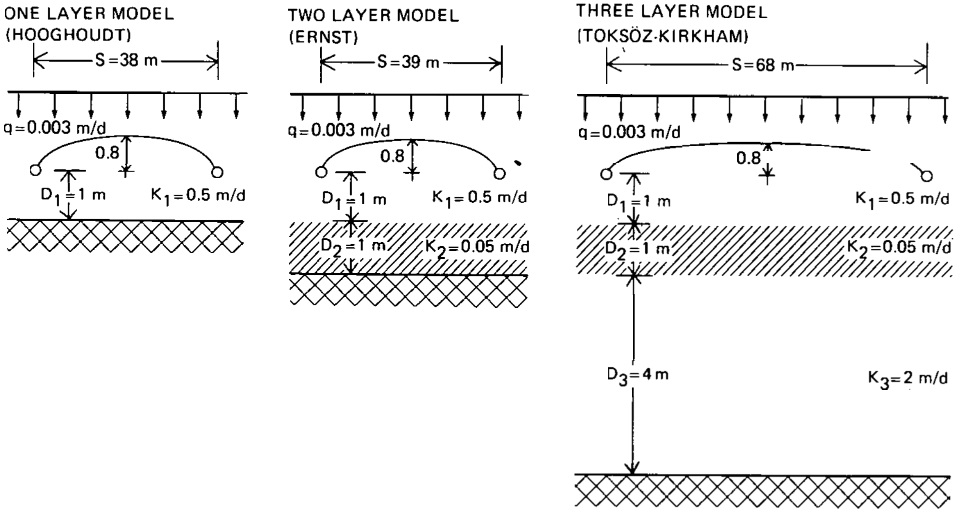
4 Developments in design and construction technologies

Present principles and concepts for draining irrigated land are the same as 25 years ago, but design methods and construction techniques have developed as a result of the advanced techniques which were made available to the design and the construction engineer. In this respect particular mention should be made of the use of the computer for design work and the introduction of the flexible corrugated drainage pipe.

4.1 Computer Aided Design

In 1960 computers were scarce and mainly used for administrative purposes or scientific research. At that time computers were permanently installed in a central office and only operated by specialized staff. Use of computers for drainage design had no priority and moreover was impractical as data had to be processed far away from the project area. This lead to delays and made it impossible for the engineer to intervene during the data processing stage. Although in the 70's computers increased in number and availability, there was still too great a distance both literally and figuratively, between the engineer in the field and the computer in the main office. After 1980 the situation rapidly changed. Programmable pocket calculators had been introduced, and portable microcomputers became available as well as user-friendly software which opened the way for every drainage technician to make use of these powerful instruments in a direct interactive way. The use of computers for design rapidly grew. Computers were used for field surveys, data processing, groundwater modelling, drain spacing calculations, and for detailed design of drainage networks including the preparation of maps, drawings and cost estimates. The computer made it possible to improve the speed and quality of the drainage studies and designs. Groundwater flow analyses and calculations of the salt-water balance, which had previously been considered too complicated and too costly for manual execution, now became possible. Two examples of computer applications in drainage follow:

1. The aquifer of alluvial plains generally consists of stratified sediments of different hydraulic conductivity. For drain spacing calculations the layered aquifer is usually simplified, as shown in Figure 1, to one homogeneous layer (Hooghoudt model) or sometimes to two layers (Ernst model), despite the fact that in 1971 Toksöz and Kirkham (T-K) had already presented a correct solution for multi-layered soils. The T-K solution, however, has found little application. It was unsuitable for manual calculations and even the proposed graphic solution was too difficult. With a computer, however, application of the T-K formula is very easy and there is no reason at present not to apply the T-K approach for spacing calculations in stratified soils. This is particularly true for drainage of irrigated land, where because of large spacings, the groundwater flow to the drain penetrates deeply into the stratified aquifer. The error which can result by using the one-layer model for a three-layer aquifer is presented in Figures 1 and 2. In the one-layer approach the second stratum with a permeability of only 1/10 of the layer above is taken as the impervious barrier, and a drain spacing of 38 m is calculated for the hydraulic



Figures 1 and 2 One, two and three layer steady flow drainage models

head and discharge rate assumed. If calculated for a three-layer profile with the T-K formula the result would be 68 m, almost twice as much as the one-layer model;

2. The second example refers to the question whether and to what extent the designed system is able to reduce and control soil salinity. It is possible to calculate the leaching requirement with one of the available formulae and to check whether this requirement is met during the irrigation period. This, however, is a rather arbitrary method which does not take into account that the salt regime in the soil is a dynamic process and that a lack of leaching in one period may be compensated by an excess in other periods. A better approach is to analyse the salt balance in the soil throughout the entire cropping cycle, which may be one or more years. The computer is an excellent tool for these salt simulation studies. It analyses and processes rapidly the complex water and salt movements in the soil. An example of a salt balance analysis for a two-year crop rotation is presented in Figure 3.

These examples concern relatively simple computer applications. There are many other possibilities with various degrees of complexity. Much basic research has already been done in this field and is or soon will be available for practical application. At the International Seminar on Land Drainage held in Helsinki in 1986, 11 of the total 36 presented papers dealt with computer applications for drainage research and design. Promising simulation models of the saturated soil water conditions throughout the cropping cycle and depending on rainfall, evapotranspiration and drainage conditions, are already available.

Developments in computer application in drainage will continue and proceed rapidly. After a number of years the approach, the techniques, and the procedures of drainage design may be quite different to those of today. But common sense and good field experience will remain essential tools for the new computerized designer as much as they were for the drainage engineer in the past.

4.2 Corrugated pipe

The 6 m long rigid plastic drain pipe introduced in the late fifties was a great improvement as compared to the heavy clay or concrete pipes used to date. But the introduction in 1962 of the flexible corrugated drainage pipe was an event of more significance. The corrugated pipe made trenchless drainage techniques possible. The trenchless drainage concept has been known for a long time, and around 1935 M.F. Visser performed trenchless drainage experiments with square pipes made of wooden boards. Following Visser many others tried to develop this technique, but it was only possible to develop to the attractive installation techniques so often used today after the introduction of the flexible corrugated pipe.

The trenchless technique is not frequently applied in irrigated areas because of the still limited installation depth.Another spin-off from the invention of the flexible corrugated drainage pipe is of great interest for drainage of irrigated land, because the corrugated pipe facilitated the development of trenchers and construction methods with which installation of laterals and collector pipes at depth of up to 3 m and more has become much easier, much better, and cheaper than before. This is important for the drainage of irrigated arid land and particularly in view of the feasibility of constructing large composite underground drainage networks, a concept discussed below.

crop	fallow		wheat					fallow grazing				
irr. (mm)		100	70	70	70	100						
EC (mS/cm)		1	1	1	1.5	2						
rain (mm)		10	46	30	35	10						
cap. rise (mm)	10						20	20	30	30	30	20
drain. (mm)	0	50	88	37	28	22						

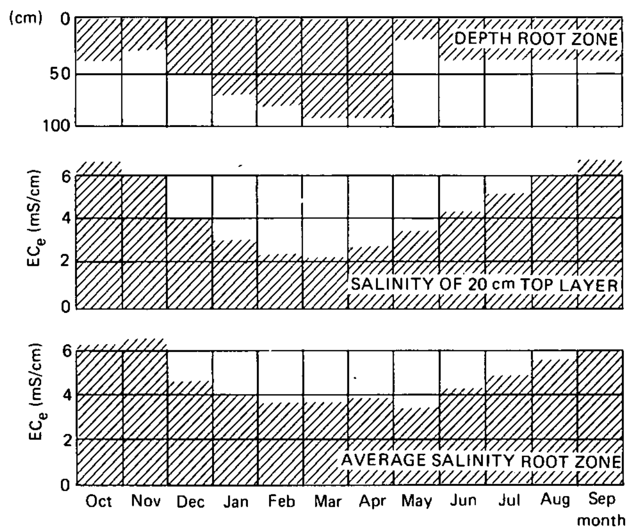


Figure 3 Salt balance analyse for wheat-fallow rotation

5 Complete underground systems

The singular system (Figure 4-A) is the traditional method of draining flat land in humid areas. The system consists of pipe drains which discharge directly into an open collector ditch. The length of the pipe drain is usually not more than 200-300 m, as it can then conveniently be cleaned with flushing apparatus. The main advantages of this system are its simple lay-out and construction, the visibility of its performance at outflow pipes, and its easy maintenance. However, the great length of open collector drains implies fragmentation and loss of valuable land for agriculture. This also leads to high excavation and especially maintenance costs and additional construction costs for crossings with irrigation canals and roads.

The singular lay-out also initially served as a model for the drainage in irrigated arid and semi-arid regions. But in view of the risk of salinization under these conditions, the drains have to be installed at a much greater depth, and disadvantages count much more than for shallow drainage in humid areas. This is shown in Table 1 for the excavation costs and loss of land of required collector ditches. It holds even more for the maintenance costs which also increase disproportionately with depth. Moreover, instability and collapse of the side slopes of deep ditches makes proper maintenance a permanent and often almost unsolvable problem.

As open drains may need crossings with roads and irrigation canals, there is a strong argument to design the drainage system in arid areas in such a way as to minimize the length of open collector drains. This can be achieved in two ways: by using the composite lay-out (Figure 4-B), in which the collector ditch is replaced by a buried collector pipe, or by using the extended lateral lay-out (Figure 4-C), in which there are very long laterals discharging directly into the main system.

Table 1 Excavation costs for and land loss due to drain ditches *

Depth of ditch (m)	Relative excavation cost	Land loss (%)
1.6	100	2.7
2.1	161	3.5
2.6	235	4.3
3.1	324	5.2

* Drains with bed width 1.0 m, side slopes of gradient 3h:2v, a 2 m berm, a maximum spoil height of 2 m, and spaced at 500 m intervals.

A possible next step is the pumped composite lay-out shown in Figure 4-D. In this system which has been applied in Khairpur (Pakistan), for example, the collector pipes discharge into a sump equipped with a pump to lift the drainage water into a shallow disposal drain. In this concept not even a deep main or outfall drain are required, but the price of installation and operation of the pumping stations will have to be paid.

In the past developments towards large, composite drainage networks have been slowed down by the fact that construction of deep composite pipe networks with clay

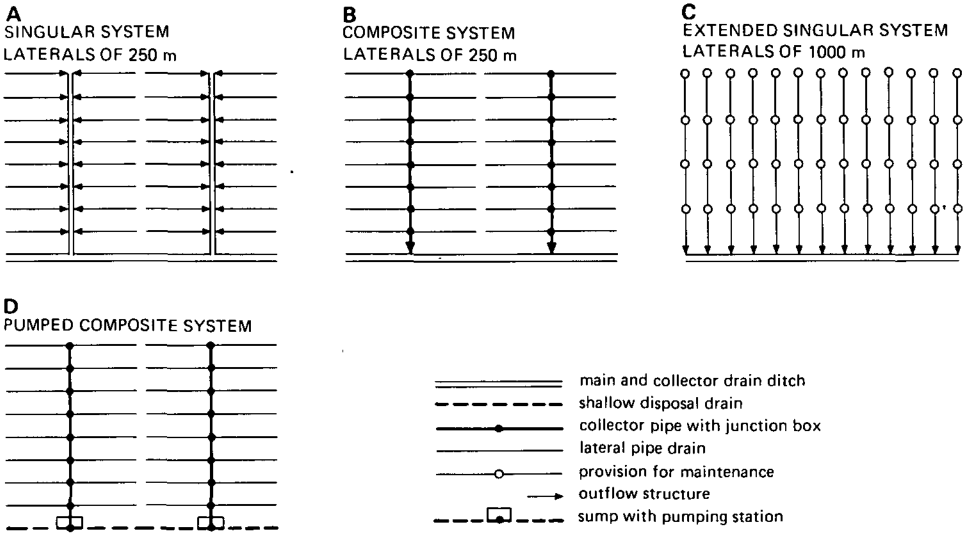


Figure 4 Lay-out alternatives

or concrete pipes was difficult and hence costly. However, as mentioned above, construction problems could be solved to a great extent due to the introduction of corrugated drainage pipe, which also reduces the risk of silting up and need for maintenance. We therefore expect that in irrigated arid regions the construction of extended underground pipe drainage networks to minimize the need for deep, impractical, open drains will find more and more support and application in coming years. The final target, and one which is believed attainable in the future, is an almost fully underground pipe drainage network. With the aid of reliable and payable mineral or synthetic filters this network should be practically maintenance free.

6 Discussion of criteria

6.1 Formulation of requirements

The required performance of a groundwater drainage system can be defined by the combination of the minimum groundwater depth to be maintained in the critical periods, and the amount of excess groundwater to be drained during those periods.
This requirement formulation is very appropriate and commonly applied to drainage in relation to irrigation and salt control. The quantity to be drained is predictable and to a certain extent controllable, and is related to irrigation losses, seepage supplies and leaching requirements. The minimum groundwater depth to be maintained is related to avoiding damage by waterlogging and by capillary salinization. Waterlogging and capillary salinization, however, refer to different critical periods of the cropping cycle, namely the irrigation and the fallow periods. This implies that there are two

independent depth criteria, one related to waterlogging in the irrigation periods, and one related to capillary salinization in fallow periods. The situation is demonstrated in Figure 5 with the annual movement of the watertable in an irrigated field with winter cropping and summer fallow.

The watertable reaches its maximum level during the irrigation period. It is in that period that waterlogging has to be avoided. No capillary salinization then occurs; on the contrary, salts are leached owing to the net downward groundwater flux of percolation losses from irrigation. The watertable is at its lowest level in the non-irrigated period, thus no risk for waterlogging but upward capillary transport of groundwater causes salinization of the upper soil layers. The capillary transport, initially fast, rapidly slows down and finally stops due to the accompanying drop in the watertable by drainage and evapotranspiration, unless the watertable in the fallow land is recharged by lateral inflow of seepage water from neighbouring higher areas or adjoining irrigated land, both common phenomena. In that case the role of drainage in the fallow period is to intercept the lateral seepage inflow, and to keep the watertable at such a depth that the capillary rise is considered negligible or acceptable. This depth is called 'critical depth'.

As a result the drainage criterion for irrigated land is indicated by two requirements which need to be satisfied. The drainage should be able:

1. To discharge the peak drainable surplus during the irrigation season,maintaining the watertable at the minimum required depth to avoid waterlogging;
2. To discharge the drainable surplus during the fallow season, the seepage supply, maintaining with the watertable at the depth needed to avoid capillary salinization.

It should be noted that in fallow periods and even during each interval between irrigations, salinization of surface layers by a redistribution of the salts in the soil profile cannot be avoided, whatever the depth and intensity of the drainage system might be. These salts are leached prior to sowing at the start of the irrigation season and further with each following irrigation.

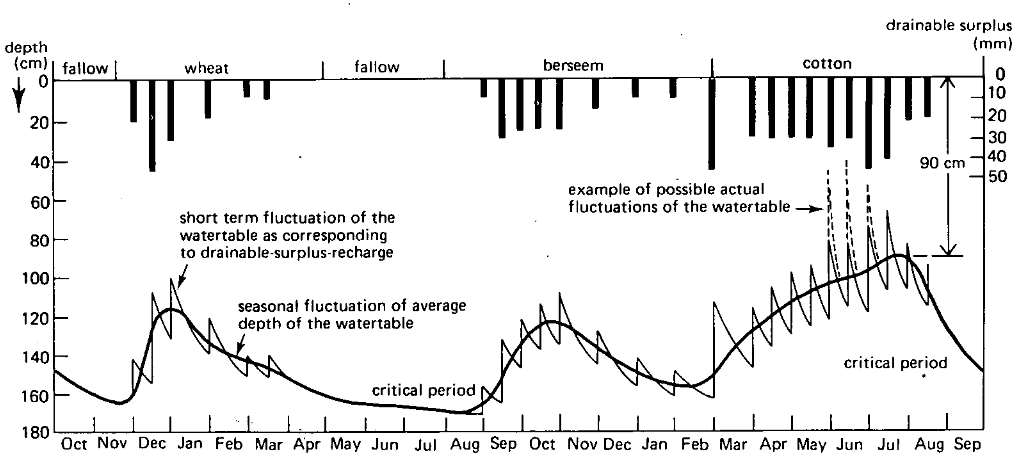


Figure 5 Groundwater fluctuations in a drained field

6.2 Depth to watertable requirements

Waterlogging should be avoided in the irrigation season which is usually specified as the watertable being kept below the root zone of the crop. In steady state drainage calculations the depth requirement for field crops is usually applied in the range of 0.8 to 1.2 m. The FAO publication, 1980, on drainage design factors recommends values of 1.0 to 1.2 m for steady state and 0.9 m for non-steady state drainage calculations depending on the soil. The non-steady state requirement of 0.9 m refers to the so-called minimum depth of the watertable after irrigation. So-called, because in non-steady state calculations the rise of the watertable after irrigation is based on recharge equal to the net drainable surplus, whereas the actual recharge and thus the rise may be much more, due to the fact that the actual groundwater recharge mostly includes water which is later consumed by the crop.

As for the depth requirement, it is noted that the relation between depth of the watertable and crop development is much more complicated than can be expressed by a simple rule, as the watertable should be kept below the root zone. Furthermore, the rooting depth is a purely relative notion, as crops may adapt their root system to the prevailing soil and water conditions. It might therefore be more practical to consider the depth criteria as empirically established values which, although not scientifically proven, have shown to be satisfactory for practical design purposes. It is doubtful whether better depth criteria can be established with field experiments. The empirical criteria could be tested with computerized models (growth simulation models).

With the choice of the waterlogging-depth criterion, the choice between the steady or non-steady state approach also arises. The following remarks result from this choice:

1. As mentioned the actual watertable fluctuations will differ from the calculated ones, which do not take into account the fact that after irrigation the watertable rises more than that due to the recharge, equal to the drainable surplus (irrigation minus evapotranspiration), and that the following drop of the watertable is not only due to drainage, but also to evapotranspiration. The actual minimum depth of the watertable will thus be less than the one calculated;
2. There is no evidence that the minimum depth in the irrigation interval is a better yardstick for evaluating the relation between watertable and crop development than the average interval depth, independent of the manner by which the minimum is to be calculated. Analyses of the watertable variation within the irrigation interval are thus not required, and there is thus no reason for applying the non-steady state approach for that purpose;
3. The non-steady state or dynamic equilibrium analyses, however, are useful for simulating the seasonal, annual or multi-annual variations of the depth of the watertable. This is particularly true for crop rotations which include fallow periods (see Figure 5). This Figure shows watertable conditions and the critical periods for waterlogging and salinization throughout the year;
4. Further, the non-steady state analyses take account of the possible reducing effect of water storage on the peak discharge requirements;

5. The non-steady state approach is thus preferable in situations with significant seasonal watertable fluctuations.

The watertable should be kept below the 'critical depth' in the fallow season which in general terms is defined as the depth at which the upward capillary flow becomes negligibly small, although there is no precise definition of what rate is to be considered negligible. The critical depth is related to the type of soil and is usually taken in the range 1.4 m (for soils with fine and coarse textures) to 1.7 m (for soil with a medium texture) (FAO 1980). The critical depth is an essential design parameter which determines the minimum depth at which drains are to be installed in irrigated land. Some additional remarks on proper application of this design parameter are relevant here:

1. The critical depth is only relevant as a drainage criterion in situations with seepage. Without seepage the watertable will automatically drop in the fallow period to below the critical depth (even without drains) as a result of any evapotranspiration and natural drainage. Seepage to fallow land is, however, a common phenomenon, as discussed before.
2. In the case of intensive cropping and more or less continuous irrigated land, the critical depth also has no practical meaning. This explains that in the Egyptian Nile delta, with a more than 200% cropping intensity, drains are installed at relatively shallow depths of 1.2 to 1.5 m, compared to depths of 1.7 to 2.2 m applied in Iraq and Pakistan;
3. The critical depth has been related to type, or better, the capillary properties of the soil. It should, however, also be related to the length of the fallow period and the evapotranspiration in that period. If the given values of 1.4 to 1.7 m refer to long summer fallows in extreme hot climates (Iraq and parts of India and Pakistan), then smaller values could be applied for winter fallows, short summer fallows and summer fallows in less extreme climates (Tunisia, Morocco, Algeria). It is therefore suggested that the critical depth design parameter must be redefined in terms of the depth of the watertable where the capillary soil water transport to the surface, totalized over the entire fallow period, should not exceed a certain established limit. Apart from soil type, the totalized capillary water transport is also related to the length of the fallow period and its climate, for which the totalized potential evaporation of the fallow period might serve as a yardstick.

6.3 The required discharge rate

The required discharge rate, also called the drainage coefficient, is the rate required to discharge the drainable surplus in the critical periods. The drainable surplus in the irrigation season is composed of leaching water, irrigation losses, excess rainwater, canal seepage, and seepage from neighbouring areas. In the fallow season the drainable surplus consists of seepage water only. The drainable surplus is usually determined by means of soil water balance studies. The different components of the drainable surplus will be examined.

The irrigation component of the surplus consists of percolation losses which are related to the irrigation method and to the efficiency of the field water management.

With localized irrigation methods such as drip irrigation and for sprinkling systems such as central pivot and linear move, practically no irrigation water need to be lost to the subsoil. In those cases the irrigation component of the drainable surplus may be small and the drainage coefficient not determined. With gravity irrigation, however, percolation losses generally constitute the major part of the drainable surplus. The percolation losses are usually assumed to be a constant percentage of the irrigation supply throughout the entire growing season. It is doubted whether a constant percentage is realistic, whether the percentage of losses is higher in the initial growing stage when water requirements are low (crops are shallow rooted and cover only part of the soil surface) than in the full development stage with maximum water demands, full crop coverage, and deep rooting system. In fact no evidence could be found which justifies the constant percentage assumption. On the contrary, the available information points to a decreasing percentage of losses during the growing season.

Figure 6 shows the field water balance of a cropped field in Iraq taken from data of the Dujailah Drainage Experiments. The area was underlain at a depth of 4 m by an impervious barrier, so the drain discharge could be taken equal to the percolation losses. Figure 6 also shows that the percentage of losses for winter crops are higher than for summer crops and that, as expected, this percentage decreases during the growing period. In the peak summer period the losses are 8% only.

Other indications to support our theory can be observed in many irrigation schemes in arid and semi-arid countries. With constant proportional losses, the drains in those schemes should have an increasing discharge during the growing season, and a maximum flow in periods of peak irrigation demand. In reality, however, it is observed

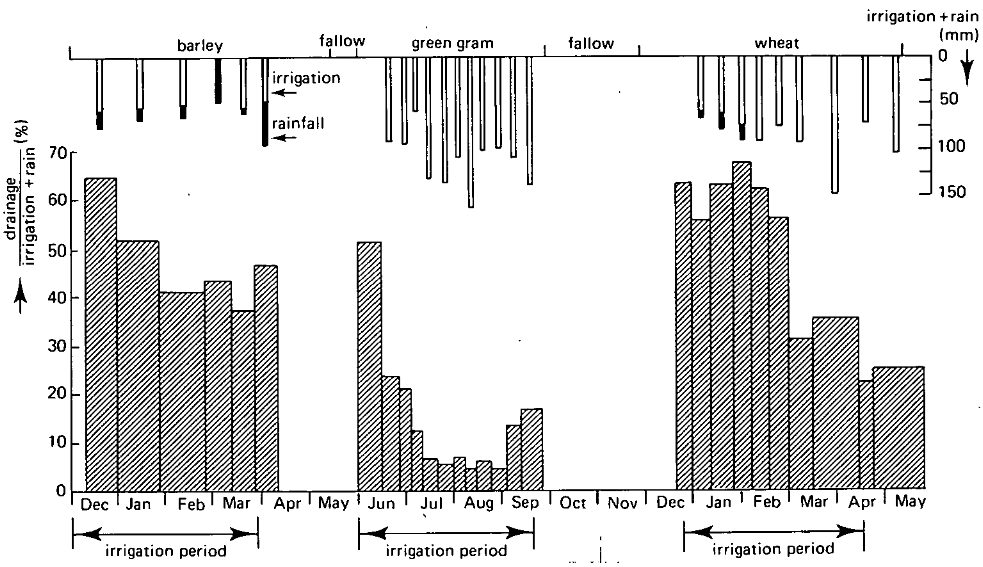


Figure 6 Drainage in percentage of irrigation and rain in relation to cropping season and growing stage. Dujailah Drainage Experiments (ILRI 1963)

that drain discharges do not increase. On the contrary, drains often have minimum flow in periods of peak irrigation demand.

Application of a constant percentage for field percolation losses overestimates the drainable surplus as well as the irrigation requirement. It is therefore, suggested to apply a variable decreasing percentage for field losses during the irrigation period. A rather conservative example of variable field efficiencies is given in Table 2. The effect of decreasing losses on the calculated drainage requirement in Table 2 is evident; the peak (July) drainable surplus, which would be 71 mm/month if constant losses are assumed, decreases to 29 mm/month for variable losses.

Table 2 Drainable surplus in relation to application efficiency

	Feb*	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Net irrigation requirements	80	13	46	108	138	165	126	20	696
Variant I: Constant applic. efficiency		0.7	0.7	0.7	0.7	0.7	0.7	0.7	
Field requirements	80	19	66	154	197	236	180	29	961
Drainage		6	20	46	59	71	51	9	265
Variant II: Variable applic. efficiency		0.5	0.7	0.8	0.8	0.85	0.85	0.7	
Field requirements	80	26	66	135	173	194	148	29	851
Drainage		13	20	27	35	29	22	9	155

* pre-irrigation

The leaching component or the leaching requirement (LR) is usually defined as the leaching needed to control the salinity of the soil at a specified tolerated maximum level, expressed as a percentage of the irrigation supply. Several formulae for calculating the LR have been developed and used since the LR concept was introduced in Handbook 60 (USDA 1954 No 60), (FAO 1976 No 29), (ILRI 1963 No 11).

Leaching occurs by rain or irrigation water percolating through the soil to the watertable. If the percolation from losses is not sufficient to control the salt, additional irrigation is needed for leaching. Only in that case does the leaching requirement affect the required discharge rate. This might occur in case of drip and sprinkler irrigation.

The relation between irrigation, drainage and soil salinity is more complicated than expressed by the LR formula. It is not necessary that the LR be satisfied for each irrigation interval individually, because excess leaching in one period may compensate for shortages in other periods. Leaching operations may therefore be scheduled outside the irrigation season when water is available and the drains are not heavily charged. As stated previously, a study of the salt and water regime in the soil in relation to irrigation and drainage by means of computer simulation models provides the best method of evaluating the drainage requirements for leaching. Simple models are already available. Development of more precise complicated models is only a question of time and priority.

The seepage component is the most difficult one of the series of drainable surplus. It includes canal seepage, seepage from irrigated to fallow land, and groundwater movement at greater depth and over larger distances from high land to areas of depression. The latter is responsible for the differences in natural drainage and seepage conditions.

Canal seepage is a local problem. It may be accounted for by designing seepage interceptor drains, and it may also be accounted for in the drainage coefficient by assuming an uniform seepage rate over a strip of land on both sides of the canal. Both approaches are not very accurate but considered satisfactory, in view of the low accuracy with which the canal seepage losses are usually known. To estimate canal losses and their distribution, flow analyses with two-dimensional numerical computer models are nowadays applied.

Seepage from irrigated to fallow land is very common and is the main cause of salinization in fallow land. As is the case with canal seepage, quantification of this seepage is difficult. It is usually taken as an estimated uniform rate for the area concerned.

In areas underlain by a highly transmissible aquifer, the natural drainage and seepage conditions resulting from lateral groundwater movements may have a great effect on the drainable surplus and on the discharge criterion for design. Areas with natural drainage have a small drainage coefficient or require no drainage at all. Areas with seepage have an increased surplus and are moreover subject to salinization if not properly drained. For a quantitative analysis of the natural drainage and seepage conditions in areas where these are considered of importance, groundwater modelling is the only proper solution, especially as drainage/seepage conditions will vary throughout the year. Groundwater modelling, however, is still quite a complicated and costly exercise, and is preferably done as a part of an integrated regional groundwater management study.

An example of groundwater modelling for assessment of drainage coefficients is the 250 000 ha SCARP VI project (Figure 7), in the central part of the Indus Basin in Pakistan. This project area is underlain with a highly permeable aquifer. The lateral groundwater movement provides for natural drainage in some parts of the project area, and causes serious drainage needs in other parts. A computer model study, aimed at optimal integrated ground and surface water management, and the determination of the areas in need of drainage and the regional variation in drainable surplus, was developed and calibrated with historical watertable records. Some results of the model study are given in Figure 7 (WAPDA 1981).

6.4 The drain depth

The drain depth refers to the installation depth of underground drains or to the depth to the watertable in open drainage ditches. The drain depth is directly related to the drainage criterion. The drains should at least be installed below the required level of the groundwater table during the irrigation season or below the critical depth if the criterion of the fallow season is to be met. Drains are usually installed deeper than the required minimum. The optimum drain depth is to be found as a compromise

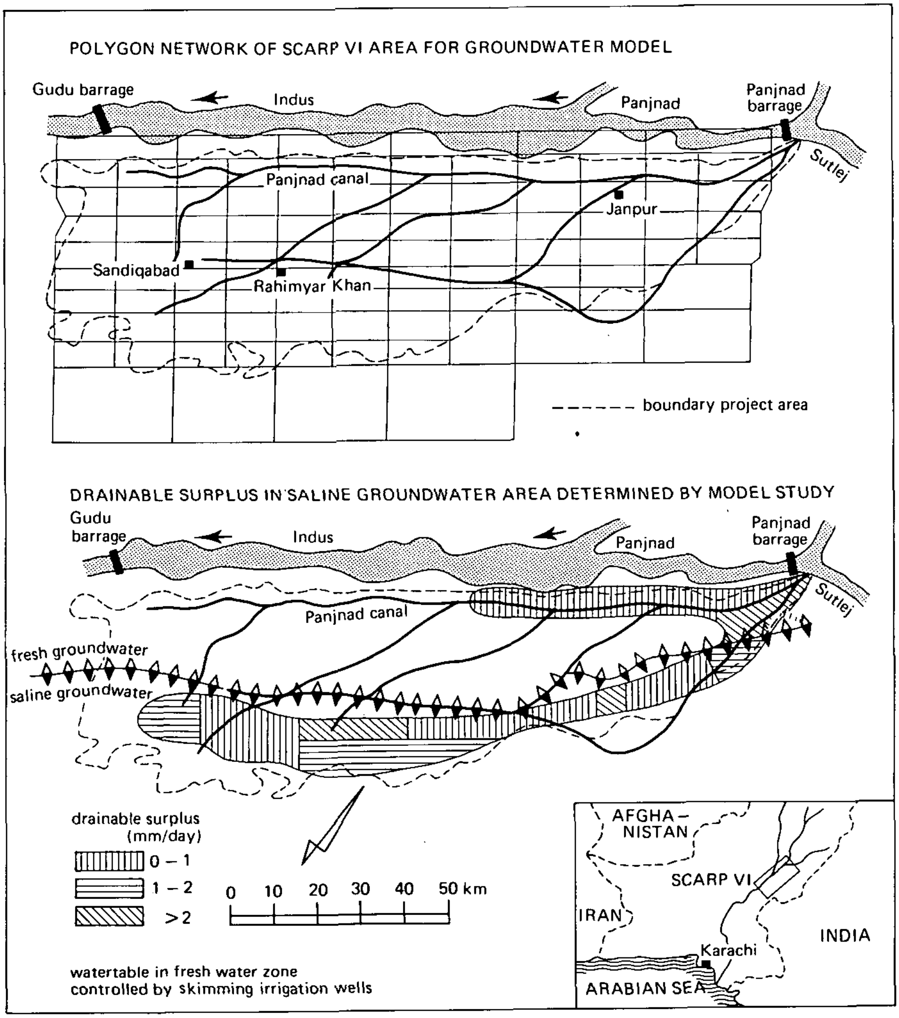


Figure 7 Groundwater modelling for determining drainable surplus

between the advantages and disadvantages of a greater depth.

Advantages of deep drains are greater hydraulic head and more storage capacity in the soil, both resulting in larger spacings and thus less length of drain per unit area. Another advantage is that deep drains will discharge continuously, and thus may have less risk of silting up.

Disadvantages of deep drainage are increased technical problems in proper installation, increased costs of installation and materials per unit length of lateral, and possible costs for deepening the main outfall system and pumping. The installation depth of lateral drains has been steadily increasing since 1960, and installation of deep drainage has become better and cheaper. There is an economic optimum drain depth, corresponding to minimal costs per unit area. This depth has recently been analysed (Boumans and Smedema 1986), and corresponds rather well with the depth ranges actually applied in humid as well as arid regions. We expect that the existing trend towards deeper drainage will continue, because further improvements in the construction technology will reduce the disadvantages of deeper installation.

7 Importance of monitoring

It will have become clear that there are still incomplete answers and thus further research is required into fundamental questions such as relation of drainage with crop yield, choice of design criteria, salt regime and drainage. Research is still necessary for testing and improvement of current survey and design techniques, drainage materials, construction equipment and installation methods. Research is carried out in the laboratory, on experimental fields and with simulation computer models. Another very valuable research instrument is monitoring the performances of the drainage scheme in operation. Monitoring is a direct way of measuring the effect of the implemented works on crops, salinity and groundwater: pre and post-project conditions as well as actual and forecasted performances can be compared; operation and maintenance aspects studied; costs and benefits evaluated; and design and construction shortcomings identified.

Unfortunately monitoring has not generally been applied to date. Reliable monitoring of drainage schemes is almost non-existent. Monitoring should therefore be promoted in the interest of operational and fundamental drainage research, and also for proper operation and maintenance of the drainage works. The drainage and project authorities responsible, have to be convinced of the importance of monitoring. Monitoring should already receive proper attention in the study and design phase of a drainage project. A detailed monitoring programme, and the requirements of staff, equipment and funds, should be part of the project planning documents. The drainage design should take monitoring into account by providing adequate facilities for data collection.

Monitoring is considered costly because of the staff required for field work and data processing. However, monitoring nowadays can make use of modern technology and this is very advantageous. Not only the staff requirements for data collection can be greatly reduced but also better data-processing techniques can be applied with less staff. Of the many possible applications of modern technology for monitoring of drainage schemes the following are mentioned:

- The use of remote-sensing images for recording changes in soil water and salt conditions and developments in land use and crop growth;
- The use of automatic electronic recorders for all kinds of data collection. These recorders are preferably fitted with facilities to transmit recorded data directly to the computer processors and eliminate the need for manual input. A good example of such equipment is the 'Preslog', a small battery powered instrument which is very easy to install and can register and store in a memory block (Eprom) hourly

records of waterlevels or rainfall for one year. The Eprom can be read by a computer which also is used for data processing and filing;
- The use of computers for data filing, data processing and reporting. The great advantage of computers compared to traditional data processing by hand is obvious.

Monitoring as well as processing and evaluation of data requires highly qualified staff. It may therefore be practical to carry out monitoring in collaboration with a specialized drainage research institute which can advise on the kind and method of data collection and on the equipment required, and can participate in data processing. The different objectives of monitoring may then be served in the best way. A good example of such a specialized institute is the 'Drainage Research Institute (DRI)' in Egypt which is an agency of the Ministry of Irrigation.

8 Final remarks and conclusions

In this paper we have discussed the horizontal drainage of irrigated arid lands which is different from the drainage in humid temperate areas in many ways. Developments with respect to design, construction, and research have been discussed. Present design practices, criteria and standards have been critically examined.

The major conclusions are summarized below in the form of statements presented for further discussion.

1. Drainage or better subsurface drainage for irrigated arid land is very different from subsurface drainage in humid areas, with respect to the objectives, requirements and criteria, field investigations, design options, construction practices, equipment and materials. It is questionable whether the difference between drainage in humid and arid regions is sufficiently reflected in the structure and programme of the International Post-Graduate Course on Land Drainage;
2. Computer drainage applications have been started and are expected to increasingly contribute to drainage research and to the introduction of improved and automated design procedures for the drainage of irrigated land. Particularly simulation models for studying the salt and water regimes as related to soil, irrigation and drainage will be important in these respects. Simulation models have the advantage that they can be adjusted to local conditions, since they can be calibrated with actual field data;
3. Monitoring is a valuable tool for fundamental and operational drainage research, and for controlling the proper functioning of the system. Monitoring should be included in the design and operation of any drainage scheme. Monitoring can make use of modern electronic equipment. Monitoring should, if possible, be coordinated by a national drainage research organization;
4. With respect to lay-out and construction of drainage systems, the projected development is an ongoing trend towards extended underground piped drainage networks in order to minimize length of deep open drains. The final target being an almost fully underground system and practically maintenance free;
5. The drainage requirements for the irrigation and fallow seasons should be clearly distinguished. The irrigation season requirements must be related to waterlogging

and leaching, and the fallow season requirements related to intercepting seepage and maintaining the watertable at the critical depth. The critical depth must be defined in terms of the depth for which the totalized upward capillary soil water flux during the fallow period does not exceed a certain norm value;

6. The common practice by which field percolation losses and, consequently the drainable surplus are taken as proportional to the irrigation supply may lead to an overestimation of the drainage discharge requirement. The percentage of losses is generally higher in the initial growing stage than in the period that crops reach their full development. Application of decreasing losses (or increased field efficiencies) during the growing season is therefore recommended in water balance studies for assessing drainable surplusses;
7. The relation between leaching requirement and drainage can best be analysed by means of salt regime simulation models;
8. In schemes with a highly permeable aquifer, groundwater modelling may be needed for a proper assessment of both the natural drainage conditions and the spatial variations in drainage requirements and drainable surplusses;
9. Drain installation depth has the tendency to increase as a result of improved construction technology.

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Field drainage for dry foot crops in the (semi-)humid tropics

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1 Introduction

The knowledge and application of field drainage is still very much limited to the developed countries in the temperate zones. In contrast, field drainage in the tropics is a neglected subject, both in terms of attention and research devoted to the subject, and in terms of tracts of land provided with proper field drainage systems (drainage for salinity control in the semi-arid tropics being the sole exception). This situation cannot be accounted for by a lack of need for drainage, as under the prevailing heavy rainfall conditions much land in the (semi-)humid tropics experiences serious waterlogging.

In addition to technical constraints (to be discussed below), the present state of field drainage in the tropics is of course also related to the overall state of development of the countries concerned, with as particular aspects:

- Low input/output type of agriculture limiting the economic scope for improved field drainage;
- Agricultural production often limited by a number of factors, field drainage not always being the minimum factor;
- Lack of institutions, trained personnel and funds for research, development and extension.

In this respect it is significant that the few cases of proper field drainage in the (semi-) humid tropics almost all relate to either a developed country (e.g. the southern part of the USA) or to estate-type agriculture in the developing countries (sugar estates in the Guyana's, banana estates in Central America, oil palm estates in Malaysia, etc.). Other high input/output types of agriculture in the (semi-)humid tropics are generally undertaken on the naturally better drained upland soils where intensive field drainage is not required. The local farmers will often also have adapted their land use to the prevailing conditions (rice and other tolerant crops on the bottom lands, other crops higher on the slopes) or have adopted 'ad hoc' measures to reduce waterlogging damage to crops (planting on mounds or raised beds, Figure 1). Regular field drainage systems are, however, almost non-existent.

This review paper is restricted to the field drainage of dry foot crops: drainage of wet rice has been dealt with in a separate paper (Bhuiyan and Undan 1986). A further restriction is that only waterlogging problems due to excess rainfall have been considered. Other drainage problems like flooding and erosion are of course also highly relevant to the tropics, but generally require other solutions.

Drawing attention to the neglected state of field drainage in the (semi-)humid tropics, would actually appear to come at an appropriate time. The agricultural develop-

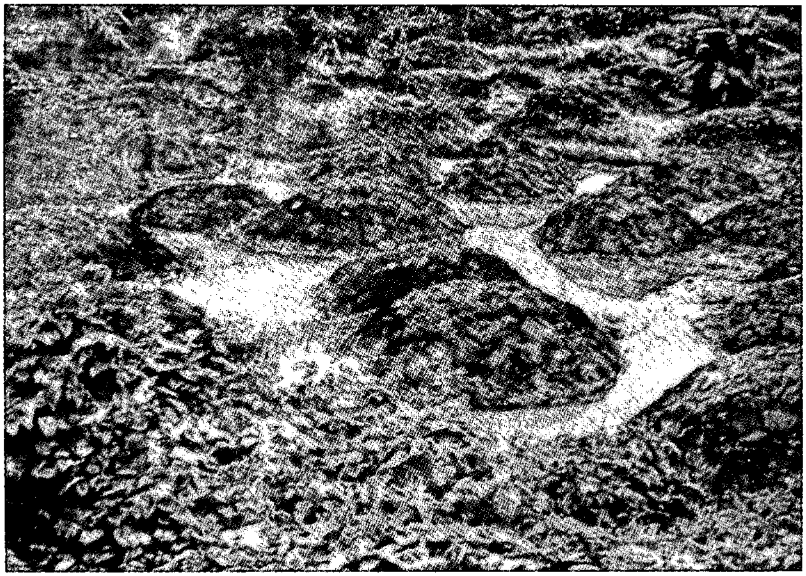

Figure 1 Growing of upland crops on mounds during the rainy season in Eastern Nigeria (Lal 1983)

ment in some countries in this region has reached a point where large-scale drainage improvement may have become viable and necessary, while other countries will sooner or later reach this stage. Some countries in the monsoon region of S.E. Asia have also reached self-sufficiency in rice production and are actively exploring possibilities for crop diversification. Improved drainage undoubtedly has an important role to play to create suitable conditions for the introduction of non-rice (dry foot) crops in the traditional low land rice growing areas.

2 The waterlogging problem

Waterlogging refers to a situation where (part of) the main rootzone receives excess water to the extent that it hinders the farming of the land. The adverse effects on farming may be grouped in two categories:

a. Impaired crop growth: the water and nutrient uptake functions of root systems are impaired by the poor aeration conditions in waterlogged soils. Especially the harmful effect of oxygen shortage in the rootzone is generally much more severe in warm than in cold climates (Figure 2), since in warm climates the soil oxygen is consumed more rapidly and the water uptake demands generally are higher (Williamson and Kriz 1970).

   In addition there are other harmful effects of waterlogging on crop growth (denitrification of the soil, formation of toxic substances, deterioration of soil structure, etc.). Some of which might also be strongly influenced by the soil temperature.

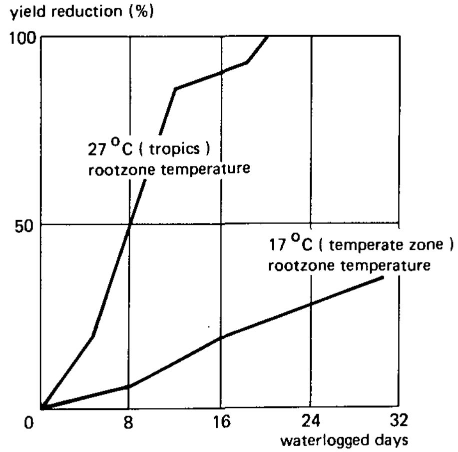

Figure 2 The defect of soil temperature on yield reduction of plums due to waterlogging (Row and Catlin 1971)

The damage varies greatly depending on such things as the type of crop, duration and frequency of waterlogging, and on its timing in relation to crop development. Even for the temperate zones where so much more research on drainage requirements has been done, very little 'hard' information is available on tolerances and damage due to waterlogging and on response due to improved waterlogging control. For tropical crops under field conditions, such information is virtually non-existent.

Waterlogging will not generally lead to harmful soil salinity levels in the humid tropics. In the semi-humid tropics, however, crop growth may be affected by poor aeration during the wet season and also by excess soil salinity during the dry season (Figure 3).

Such salinity problems may be expected when leaching conditions during the rainy season are unfavourable (e.g. due to poor percolation and drainage conditions of the soil), while on the other hand, conditions are favourable for a strong capillary salinization during the dry season (e.g. due to the occurrence of saline groundwater at shallow depth). Few such cases have been identified, while the identified cases generally seem to relate to situations with fossil salinity sources, either in the soil but more often in the groundwater. Introduction of irrigation during the dry season could in some cases upset the natural favourable salt balance in the semi-humid tropics when no drainage measures are taken, as has generally been the case with irrigation development in the semi-arid tropics.

b. Impaired farming operations: the reduced workability of the soils and the reduced accessibility of the land under waterlogged conditions will result in either delays, higher costs or poorer quality of work. The incurred damage is of course highly dependent on the prevailing farm system, especially on the degree of mechanization. In modern farming in the temperate zone, waterlogging often causes more damage due to its adverse effects on farming operations than due to its direct impact on crop growth. Under subsistence farming, the effects on farm operations would, however, be minimal, while climatic conditions in the tropics generally allow more flexibility in the timing of planting than in the temperate zone where especially spring planting is very critical. Future developments rather than present problems should be considered in this respect.

Adapting crop calendars to the prevailing climatic conditions, notably to avoid coincidence of critical crop growth or farm operation periods with high rainfall periods, may help to solve waterlogging problems. This approach, however, also has its limitations as temperature and sunshine may favour the growing of certain crops during certain seasons, while with rainfed agriculture the main crop season will naturally largely coincide with the main rainy season.

The role of the evapotranspiration should also be mentioned in this respect: the year-round high evaporative demand of the atmosphere makes evapotranspiration a major water-depleting mechanism of tropical land. The concept of self-drainage ('crops drinking their way out of a waterlogged situation') is appealing but also deceptive as growth conditions are obviously not optimal during such a self-drainage period. Moreover, the strongly drying atmospheric conditions which enhance self-drainage also inflict the most crop damage as under waterlogged conditions the root system will be unable to meet the high evapotranspirative demand. However, in combination

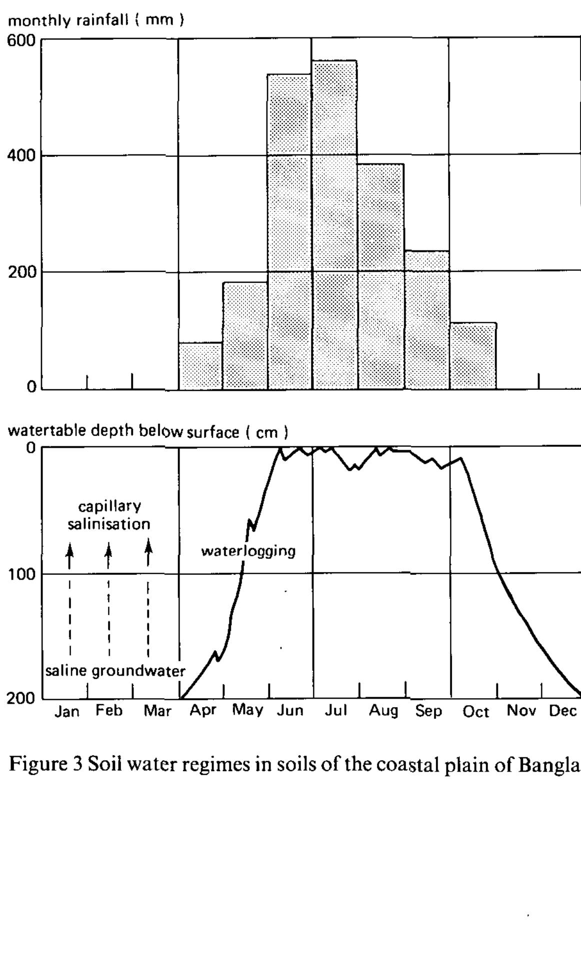

Figure 3 Soil water regimes in soils of the coastal plain of Bangladesh

with improved drainage, evapotranspiration can be a powerful aid to shorten excess water periods and also to create a reserve storage in the soil during intervening dry periods which can accommodate (part of) subsequent storms. This especially applies to soils with poor internal drainage characteristics (e.g. the so-called 'heavy lands'), where the high tropical evapotranspiration rates (easily 5-7 mm/day) are in fact often of the same order as the 'through the soil' drainage rates.

3 Types of drainage flow

Excess water on the land or in the soil may be drained from the land/soil by movement of the water to a nearby drain by one of the following three flow types (Figure 4):
- Overland flow (surface run-off): flow of non-infiltrated surface water over the surface of the land;
- Interflow: lateral flow of perched/impeded soil water through the soil over an impeding layer;
- Groundwater flow: flow through the soil below the true watertable.

Overland flow and interflow are difficult to identify separately, and often occur simultaneously. Drainage systems functioning on the basis of these two types of flow remove excess water mostly from the surface of the land and from the permeable topsoil, and are therefore termed shallow drainage systems (Smedema and Rycroft 1983). Groundwater drainage systems function on the basis of groundwater flow. The aim of groundwater drainage systems is to maintain a deep watertable enabling/promoting excess water to percolate down through the soil profile to the subsoil/substratum where it is picked up by the drains. Groundwater systems can only be used effectively and economically when the percolation flow is not impeded, and when there are good conditions in the subsoil/substratum for groundwater flow to the drains.

The prevailing type of drainage flow depends especially on the rainfall intensity in relation to the rate at which water can move downward through the soil profile. Under sustained excess rainfall, this downward water movement proceeds under approximately unit gradient (gravity flow), and the maximum steady percolation rate may therefore just equal the (vertical) hydraulic conductivity (K) of the relevant profile layer(s). When the rainfall rate P > K of the subsoil, a perched watertable builds

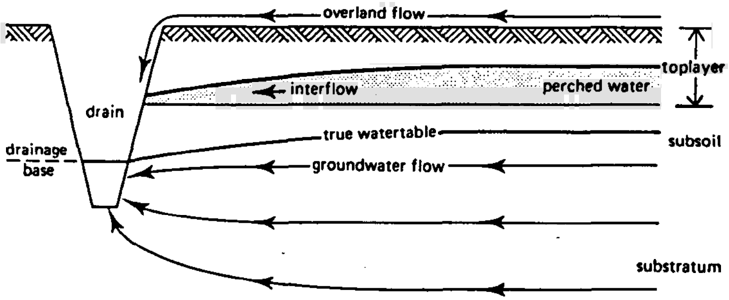

Figure 4 Types of field drainage flow

up in the topsoil, leading to interflow when a lateral gradient is imposed on this water. When $P > K$ of the topsoil, water will pond on the land surface and overland flow may occur.

During prolonged heavy rainfall, the entire soil profile may become saturated, raising the watertable to the soil surface. In view of the higher rainfall depths and intensities, situations conditional to the occurrence of interflow and overland flow may be expected to be much more prevalent in the tropics than in temperate zones. Soils which may have adequate infiltration/percolation capacity to be suitably drained 'through the soil' with groundwater drainage systems under temperate zone conditions, may be more suitably drained by shallow drainage systems under tropical conditions. In this connection, the role of interflow should especially be stressed. This type of flow is now widely accepted by hydrologists as a major drainage flow mechanism in soils (Ward 1984), but drainage engineers do not seem to have yet fully grasped the significance of this type of flow for field drainage, especially in the tropics.

4 Field drainage methods/systems

Figure 5 presents the main characteristics of the more widely-used field-drainage methods of the (semi-)humid tropics. It is notable that all these methods are essentially based on combinations of induced overland flow and interflow, rather than on induced groundwater flow. In upland situations, natural groundwater drainage flow may be adequate to maintain low groundwater tables, but this is not the reason for the absence of groundwater drainage systems in lowland situations. A further analysis of the role of groundwater drainage systems in the (semi-)humid tropics has been presented in section 5 of this paper.

The most common field-drainage method of the (semi-)humid tropics is the bedding system. This method is of course also known in the temperate zone, although mostly restricted to flat heavy land. The method essentially involves the provision of closely-spaced shallow drains to induce overland flow and interflow. The drain depth is often not more than 30 cm. The spacing may be only a few metres as in some indigeneous systems ('raised mounds' in West Africa, the 'sorjan' system of S.E. Asia), and in the modernized versions suitable for mechanized farming (the 'Louisiana bank' system developed for sugar cane in the Mississippi delta and the 'broad bed' system developed by ICRISAT). Close spacings provide steeper gradients for drainage flow from the beds to the drains and more in-field storage of excess water. Crowning of the beds also enhances the drainage flow from the beds by providing steeper gradients, allowing wider spacing than with flat beds for the same drainage rates.

The parallel shallow ditch system of field drainage is generally applied where conditions for discharge somewhat deeper through the soil are more favourable (e.g. less rainfall, deeper and more permeable soils). The drains are deeper than with the bedding system and induce some (shallow) groundwater drainage in addition to inducing overland flow and interflow.

As an additional drainage measure, crops in the (semi-)humid tropics are often grown on ridges which provide 'dry feet' to the crops while the furrows between these ridges provide means of conveyance for overland flow (row drainage), as well as means for in-field storage of excess rainwater. When the ridges are aligned in parallel with the field drains (as in Figure 5), the direct lateral overland flow to the drains is blocked, and cross drains (variously termed ridge cuts or quarter drains) should be installed to intercept the row drainage at suitable intervals and lead it to the field drains. The alternative alignment with ridges/furrows perpendicular to the field drains, is detrimental to farm operations when the field drains are closely spaced and are well incised, while the field drains are made more shallow and passable, or the spaces between the drains are widened. These will generally be at the expense of the quality of the drainage achieved.

Land grading has been applied on a large scale, especially in the USA, as a measure to promote overland drainage while reducing the intensity of the in-field drain systems, thus facilitating mechanized farming. As such it has also been introduced on some tropical sugar estates (Smith 1976). However, it is doubtful whether this is a generally recommendable practice for the (semi-)humid tropics, even when the consideration is not included that the present state of mechanization does not generally pose a high enough demand on sizes and shapes of field plots. Elimination of field drains results in more prolonged saturation of topsoils after rain, as the interflow drainage of the topsoil is reduced and not fully compensated by improved overland drainage. Furthermore, the combination of enhanced overland flow and reduced in-field storage due to filling-in of field drains, may lead to serious downstream flooding problems or

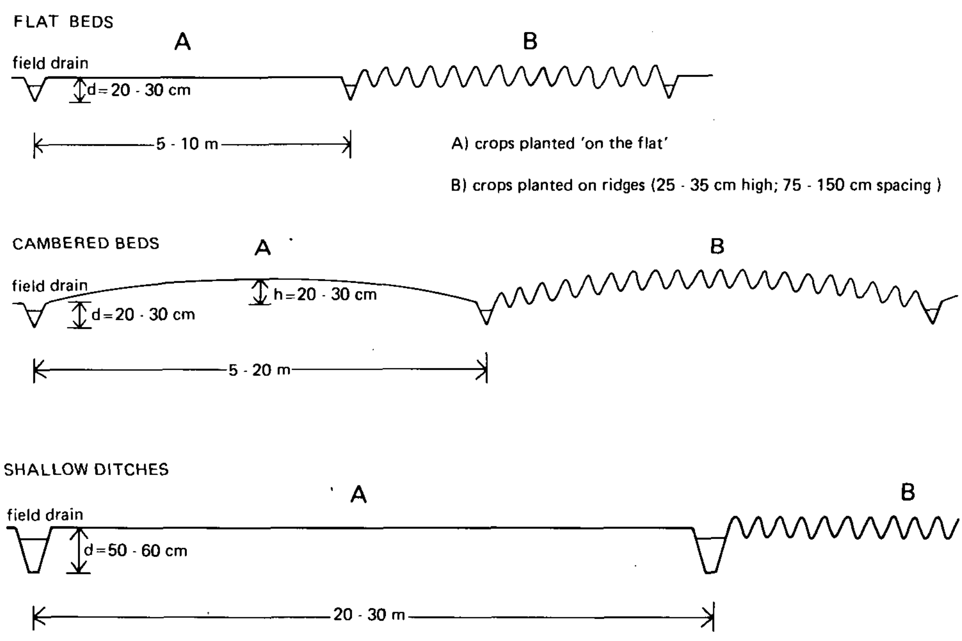

Figure 5 Field drainage systems of the (semi-)humid tropics

require large main-system capacities. The topsoil drainage function by interflow inducement of the field drains and the in-field storage function of these drains, should be duly recognized and for as yet large-scale land grading would seem to find limited application in (semi-)humid tropics. Small-scale grading and smoothing of the land is, however, useful, as it helps to spread the infiltration load equally over the surface of the land, and prevents excessive and prolonged ponding.

Table 1 Calculation of common* drainage loads for the temperate zone and for the (semi-)humid tropics

Duration (days)	Rainfall (mm)	Deductions		Drainage load	
		Storage (mm)**	Evapotranspiration (mm)***	Total depth (mm)	Rate (mm/day)
Temperate zone (The Netherlands)					
1 (24 hrs)	15– 25	15	–	0– 10	0–10
2	25– 35	15	–	10– 20	5–10
3	35– 50	15	2	18– 33	6–11
5	45– 60	15	5	25– 40	5– 8
10	70– 90	15	10	45– 65	4– 7
30	80–110	15	30	35– 65	1– 2
(Semi-) humid tropics					
1 (24 hrs)	60– 90	20	–	40– 70	40–70
2	80–120	20	–	60–100	30–50
3	100–150	20	5	75–125	25–40
5	120–200	20	10	90–170	20–35
10	170–300	20	25	125–255	12–25
30	300–400	20	75	205–305	7–10

* 1 to 2 times occurrence per season/annum

** 5-10 mm storage in the soil profile; 5-10 mm storage on the soil surface } giving a total storage between 15-20 mm

*** temperate zone : 1 mm/day; (semi-)humid tropics: 2-3 mm day } both values for periods > 2 days

5 Drainage rates versus discharge capacities

In Table 1 common drainage loads i.e. excess water quantities occurring one to two times per season/annum have been calculated by deducting expected rainfall depths by storage and evapotranspiration. These calculations apply to an assumed critical situation during the wet season in which antecedent rain has replenished all exhausted storage, and only a small deduction can be made for the dynamic storage (water temporarily stored to build up the necessary head and gradients for drainage discharge). Deduction for evapotranspiration losses have been applied only for rainfall periods longer than 2 days (for shorter periods these losses are insignificant in relation to the rainfall depths, while these have already been largely accounted for in the measured rainfall depths).

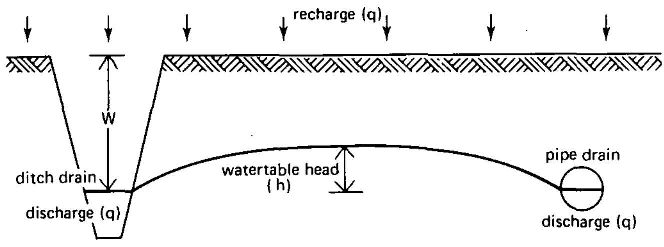

Figure 6 Illustration of the q and h parameters of groundwater drainage systems

In Table 2 the calculated drainage loads have been compared with what is considered to be the economically feasible maximum groundwater drainage capacity. This capacity was deduced from applied drainage intensity values (q/h ratio, Figure 6). Systems with a high q/h ratio give better watertable control, but are also more costly as spacings must be narrower. For North West Europe, applied q/h ratio's vary from $q/h = 0.010$ day^{-1} for tolerant/low value crops, to $q/h = 0.015$ day^{-1} for sensitive/high value crops. These values apply to systems with a drain depth $W = 1.0$-1.2 m. The maximum discharge capacity of these systems, applying when the watertable is near the soil surface (say $h = 1.0$ m), amounts to:

$$q_{max} = (q/h) * h_{max} = 0.010-0.015 \text{ m/day} = 10-15 \text{ mm/day}$$

Very little information is available on economically feasible drainage intensity limits of groundwater drainage systems in the (semi-)humid tropics, but values proposed by Carter (1976) for sugar cane in the Mississippi area are of the same order as those used in North West Europe. The economic limit to groundwater drainage capacity, both for the temperate zone and for the (semi-)humid tropical conditions, would therefore appear to be in the order of 10-15 mm/day.

Comparing this capacity with the discharge requirements (Table 2) calculated earlier, the limitations of groundwater drainage under (semi-)humid tropical conditions are clearly demonstrated. Such systems cannot prevent waterlogging of the entire soil profile for periods of up to 10 days, while watertables remain near the topsoil for periods as long as 30 days. The temperate zone situation has also been presented in Table 2 for comparison, showing that waterlogging can generally be suitably controlled by means of groundwater drainage systems. This analysis is supported by available watertable regime studies.

6 Research and development

Research and development of drainage in the (semi-)humid tropics has thus far been very incidental and focused on cash crops grown on estates. The latter primarily applies to the sugar cane industry, much of which is located in (semi-)humid tropical lowlands. Long-term research on the drainage of sugar cane has been conducted at the agricultur-

Table 2 Comparison of prevailing types of drainage discharge in the temperate zone and in the (semi-)humid tropics

Drainage loads (1 to 2 events/season)		Types of drainage discharge		
Period (days)	Rate (mm/day)	Groundwater drainage	Interflow drainage	Overland drainage
Temperate zone (The Netherlands)				
1	0–10	++	−(+)	−
2	5–10	++	−(+)	−
3	6–11	++	−(+)	−
5	5– 8	++	−(+)	−
10	4– 7	++	−(+)	−
30	1– 2	++	−(+)	−
(Semi-) humid tropics				
1	40–70	+	+	++
2	30–50	+	+	++
3	25–40	+	+(++)	+
5	20–35	+	+(++)	+
10	12–25	++	+(++)	+
30	7-10	++	−(+)	−

++ sole or major type of drainage discharge
\+ additional type of drainage discharge
− not normally occurring/required
( ) applies to drainage of heavy land

al experimental station at Baton Rouge (Louisiana, USA). The past research concentrated on the improvement of shallow drainage systems (improved bedding systems, land grading) but recently some experiments with groundwater drainage by means of pipe systems have also been initiated (Carter 1976 and Carter et al. 1982). Although good results were obtained, the economics of pipe drainage for sugar cane appears to be highly unpredictable due to the instability of the world sugar market. Moreover, rainfall conditions in the Mississippi area are moderate (reasonably distributed annual rainfall of some 1300 mm) compared to other (semi-)humid tropical locations, and the scope for groundwater control might be rather favourable. Good response to improved groundwater drainage was, however, also obtained with sugar cane in North Queensland (Australia) where the annual rainfall is as high as 2000-4000 mm, mostly concentrated in the summer (November-April).

Banana yields have also been found to respond rather well to improved groundwater drainage under (semi-)humid conditions (reports by Kamerling 1974 from Surinam, and by Murillo 1986 from Costa Rica). Both countries are located in the humid tropical zone of the Caribbean, characterized by pronounced and prolonged wet seasons. In Surinam (annual rainfall some 2000 mm), ditches are still exclusively used, but in Costa Rica (annual rainfall 2000-3000 mm) pipe drainage has recently been introduced in some banana estates.

Oil palm estates in the coastal zone of Malaysia (monsoon rainfall of 1550-2500 mm) still seem to rely entirely on shallow drainage systems; up until now no work on deep groundwater drainage systems has been undertaken (Hubbard 1975).

The lack of systematic drainage research and development is even more apparent for food crops grown by peasant farmers. The recommended drainage solutions must obviously be compatible with the farming systems practised, which are quite different from farming systems of the modern agriculture of the temperate zone and of the estate-type agriculture of the tropics. Instead of the familiar modern technological solutions as land grading, pipe drainage etc., intermediate technology solutions may be more appropriate (see the approach to the development of land and water management technologies outlined by Kortenhorst 1985). Some work on the plant physiological drainage requirements of tropical food crops has been done at the IITA (Ibadan, Nigeria), but the technological, socio-economical and institutional aspects of improved drainage for peasant farming in the (semi-)humid tropics, have as yet hardly been touched upon by the relevant national and international agricultural research stations.

7 Discussion and conclusion

Modern land drainage has its roots in the agriculture of the temperate climates of North West Europe and the USA. Here it has reached a firm scientific basis as a field of applied soil physics and applied hydrology. Significant changes have taken place in the past two decades, notably:

- A shift in objectives from increased crop production to improve conditions for (mechanized) farm operations and conservation of the environmental quality;
- The introduction of new technology (different types of drainage machinery and drainage materials).

Around 1960-1970, land drainage extended from the temperate zones to the semi-arid tropical zones, where basically the same land drainage methods were applied to control soil salinity. In tandem with this development, land drainage also extended from the developed world to the developing world. While the first extension introduced new technical concepts, the second extension was even more significant in placing land drainage in an entirely different socio-economical and institutional situation.

It would appear that a new challenge has since arisen on the horizon, i.e. the extension of land drainage to the (semi-)humid tropics to support general agricultural development in this region, and in particular crop diversification in traditional rice -growing areas. This may require the development of new drainage methods and technologies adapted to the prevailing soil and water conditions and to the farming systems of the subsistence farmer.

In the discussion of the drainage conditions and drainage requirements of the (semi-) humid tropics presented in this review paper, some significant differences from the temperate zone drainage situation emerged. These are mostly the result of the much higher rainfall load to be coped with in the (semi-)humid tropics, which is often so enormous that waterlogging of the entire rootzone must be accepted. Under these conditions, shallow drainage systems which promote interflow and overland flow drainage can play an important role. Groundwater drainage induced by deeper drains,

however, also appears to be effective, and the ideal field drainage systems for the (semi-) humid tropics may in fact have to provide three functions:
- Overland drainage to serve as a main discharge process during short periods (< 2 days) of very high and very intensive rainfall when the 'through the soil' discharge capacity (combined interflow and groundwater flow) or the infiltration capacity of the soil is inadequate, resulting in ponding of excess rainwater on the soil surface;
- Interflow drainage to serve as the main discharge process during rather prolonged (2-5 days) periods of heavy rainfall when either watertables have risen to near the soil surface or when perched watertables have built up in the toplayers of the soil profile due to the high recharges;
- Groundwater drainage to achieve a rapid watertable drawdown during intermittent rainless periods during the rainy season, to restore aeration of the upper rootzone. To lower the watertable during prolonged dry periods even deeper, after the end of the rainy season, the self-drainage (evaporative soil water depletion) of the soil can be relied upon.

To achieve the groundwater drainage objectives, a reasonably deep and narrowly-spaced system of drains is required. The interflow drainage also requires a rather narrow drain spacing, but here the drainage base can be quite shallow (30 cm depth just below the permeable topsoil will suffice). A shallow drainage base will also suffice for overland drainage but depending on the lay-out of the land and the secondary drainage measures taken (row drainage, grading, smoothing), the spacing of the field drains may be rather wide. Separate field drainage systems could of course be used for the three types of drainage flow, but this would seldom be a viable solution. When the drain functions are combined, the demands imposed by groundwater drainage on drain depth and drain spacing will usually prevail, while the type of field drain must meet the shallow drainage flow requirements (should be an open drain, e.g. a ditch, although a highly permeable, e.g. gravel-filled trench, could be considered when there is only interflow). Up to now no field drainage systems have been developed which fulfil all these requirements and functions whilst remaining economically feasible and compatible with such other requirements as rational plot lay-out, easy field accessibility, efficient field operations, low land loss and low maintenance requirements.

Other differences from temperate zone drainage and special features of drainage in the (semi-)humid tropics may be noted:
- Responses to improved drainage: whereas in the temperate zone and in the semi-arid tropical zone these responses mainly relate to farm operations and salinity control respectively, responses to improved drainage in the (semi-)humid tropics primarily relate to crop growth. Considerable yield responses may in fact be expected due to the prevailing high soil temperatures;
- Adapted farming: given the technical difficulties of adequate waterlogging control, some form of adapted farming is often a sensible contribution to a drainage solution. The classical example is of course the use of the lowlands for wet rice land (the tropical parallel of grassland use in the temperate zone). Other examples are the use of tolerant crops/varieties and scheduling of crop calendars to circumvent criti-

cal situations. While adapted farming may offer the best available solution in some cases (e.g. for poorly drainable land), it may impose undesirable and unnecessary constraints which could be more suitably solved by improved drainage in other cases;

- Secondary drainage measures: special farming and cultivation practices as an aid to improved drainage, will always play an important role in the (semi-)humid tropics. Several of these measures have already been mentioned: ridge cropping, smoothing and grading of the land surface. For interflow drainage, good soil management to maintain a permeable topsoil is important, while this is also true for soil conservation measures with respect to overland flow;
- Storage function of field drains: field drains in the (semi-)humid tropics have to fulfil several functions. Firstly the classical 'sink' function (point/line of low hydraulic potential, attracting a flow of excess water from the surrounding soil/land). In addition, however, it is often desirable that the field drains also fulfil a combination of significant storage functions. This combination of functions poses requirements as to the type of field drain, the spacing/intensity and the lay-out;
- Attention and maintenance: field drainage systems involving interflow and overland flow will always require much care to ensure their proper functioning throughout the drainage season. This is inherent to the 'open/surface' nature of these systems which makes them more prone to flow blockage than e.g. underground pipe drainage systems which can function, once properly installed, with a minimum of care and maintenance. It is also true that much of this care has to be done in a standing crop and can only suitably be realized by hand labour.

Finally attention is drawn to the fact that at present in many of the countries concerned, main drain systems are in a deplorable state due to both lack of funds and lack of proper institutional arrangements. Under these conditions improved field drainage must obviously go hand in hand with improvement of the main drain systems.

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Drainage in rice culture in the Asian humid tropics

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1 Introduction

The humid tropical region of Asia, with its abundant sunshine, extensive rainfall and high temperatures, offers excellent opportunities for year-round crop production. A high population pressure has historically forced this area to intensively cultivate its agricultural lands. Wetland rice cultivation is a logical choice for most parts of the region, but in the wet season it is risky in many areas due to frequent tropical cyclones and consequent flooding problems. Over 25% of the 126 million ha of Asian ricelands suffer excess water problems during rice cultivation (IRRI 1982, IRCN 1974).

Asian ricelands have seen a rapid development of irrigation facilities during the past two decades. Many of these developments have been in the fertile river flood plains and deltas where the topography of the land is relatively flat and natural drainage facilities are inadequate to remove excess water during monsoon months with high rainfall. Artificial drainage systems are most often needed to remove the excess water timely. However, despite the development of irrigation facilities, in some cases as a result of over-irrigation and canal seepage, excess water problems hamper crop production within the command areas of irrigation systems. In many cases the extent and severity of the problem are increasing.

Flood-prone rice areas, whether irrigated or rainfed, are usually confronted with the twin problems of too much water during the wet months and insufficient water during the dry season. The productivity of these areas could be greatly increased if their drainage problems were solved.

The above concerns mostly land drainage, i.e. the removal of excess water from the soil surface. The internal drainage of the soil profile adds another dimension to the problem. While the importance of internal soil drainage for upland crops is well established, the relative importance of land drainage and soil profile drainage for rice culture requires further study.

2 Riceland classification and drainage

Rice is grown on a wide range of landtypes affected by an equally wide range of hydrological conditions (Greenland and Bhuiyan 1982). Several approaches have been used to classify ricelands, emphasizing their hydrological conditions.

Sys (1985) used the taxonomic approach to classify the excess water conditions in flood-prone rice areas in terms of flood classes, considering both drainage depth and duration of flooding. The classification relates the maximum capability of land class for wetland rice cultivation to depth and duration of flooding under naturally flooded and irrigated environments.

Based mainly on the water regime conditions dominating rice culture, Kush (1984) classified rice-growing environments as: (1) irrigated, (2) rainfed lowland, (3) deep water, (4) upland, and (5) tidal wetlands. The first two categories comprise about 70% of the total rice area in humid tropical Asia. Wetland cultivation is generally practised in these two environments. In wetland (also termed as lowland) cultivation, rice fields are kept well-bunded for holding water. Field operations such as land soaking, ploughing, repeated harrowing, levelling and soil puddling, transplanting seedlings (or broadcasting seeds), and maintenance of a shallow water depth throughout most of the crop growing period are all common practices. The field is usually drained of water (terminal drainage) before harvesting to reduce soil wetness.

For a better understanding of both the drainage problems in ricelands and their potential productivity, Moorman and Van Breemen (1978) adopted a system of riceland classification based on (1) topographic position and related hydrological conditions, and (2) the natural sources of water supply. Their classification recognized three types of ricelands, i.e., pluvial, phreatic and fluxial (Figure 1). Most areas under the rainfed wetland culture defined above, fall within the fluxial and phreatic types. Irrigated rice could be in any one of the three land types, including fluxial, wherein flood control measures through provision of dikes or polders and water control gates may be required.

From a drainage point of view, the fluxial ricelands are of utmost significance. These lands are in valleys and closed depressions, and on river flood plains with slight slopes often less than 1%. Inundation due to periodic excess of water from rainfall or river overflow is common because natural drainage is constrained by limited head at outflow or by low internal percolation. Flooding in these areas may damage the crop by prolonged submergence, plant uprooting or lodging. A wide range of flooding conditions can exist in this type of ricelands depending on the depth, duration and frequency

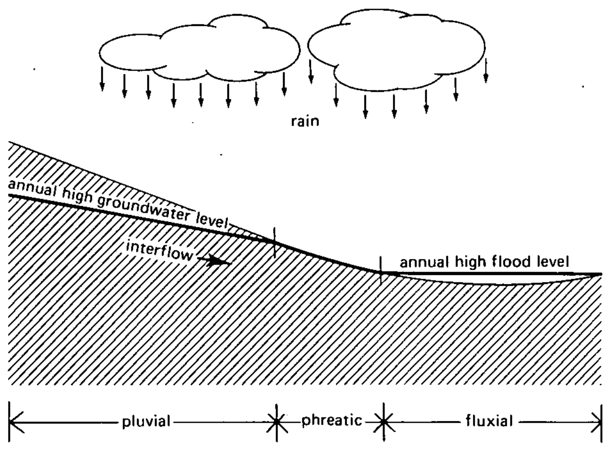

Figure 1 Classes of riceland according to topography and water supply (Moorman and Van Breemen 1978)

of inundation. Based on these factors, Moorman and Van Breemen (1978) described eight different types of fluxial ricelands found in Asia.

Irrigated fluxial lands are often protected from river overflow or coastal seawater intrusion, but many of these areas are still prone to flooding from heavy rainfall. An attempt was made to classify irrigated lands for the Canaman Irrigation Project in the Bicol River Basin, Philippines, based on soil, topography and drainage deficiencies identified from seasonal flooding records (PCARR 1980). The four classes of drainage deficiencies recognized are:

F_1 class- Slight flooding up to depths of 30 to 40 cm during heavy rainfall, receding to less than 20 cm within 1 to 3 days;

F_2 class- Moderate flooding up to depths of 40 to 90 cm during heavy rainfall, receding to 20 to 30 cm or less within about 1 week;

F_3 class- Severe flooding up to a depth of about 150 cm during heavy rainfall, receding to 20 to 30 cm within 1 to 5 weeks;

F_4 class- Flooding by river overflow or local runoff to depths exceeding 100 cm, whereby the lands remain under water for most or all of the wet season.

Such a classification is helpful in zoning areas with different degrees of flooding, and in identifying specific measures which may alleviate the problem. However, for practical use, the classification should incorporate a factor of probability of flooding.

3 Role of drainage in wetland rice culture

As they can adapt to wetland conditions, rice plants exhibit a greater tolerance to high soil water level or flooding than most other crops. While soil rootzone aeration is a requirement for good upland crop production, rice plants also thrive in shallow ponded water since they are able to transport oxygen from the shoot to the root system efficiently (Yoshida 1981). However, the frequent interpretation of this unique characteristic that drainage is not important for rice culture is wrong. Many irrigation systems, developed without proper recognition of the role of drainage in rice cultivation, are suffering the ill consequences of inadequate drainage.

Wetland rice culture requires water control for which adequate drainage provisions are essential to remove excess water from rainfall or the irrigation source. The following cultural operations or practices particularly require good drainage facilities:

- Land preparation
  Saturating the land is convenient for tillage with the commonly used low draft animal-drawn or mechanized tillers (Lucero 1984). Between ploughing and harrowing the paddy field is generally flooded with 2-4 cm water to prevent the soil from drying and hardening (APO 1977). Extra water must be drained to bring the land to a final puddled condition;
- Crop establishment
  After transplanting the seedlings, the puddled field is maintained for about 3 days in saturated conditions, or with a thin layer of (2 to 3 cm) water over the soil (Tsutsui 1984). For wet seeded (broadcast) rice, seeding is carried out in the saturated soil, and the removal of excess water is critically important to keep the young plants

free from waterlogging during the early seedling establishment stage;

- Crop maintenance
  From about 3 days after transplanting until 10-15 days before harvest, modern varieties of rice in heavy soils would normally require for optimum yields a standing water layer of about 5 cm deep, and a layer 5-10 cm deep for traditional tall varieties (Van de Goor 1979). If fertilizer is applied as topdress, water should be kept impounded with no irrigation or drainage allowed for at least 5 days (Singh 1978). Lack of standing water allows weed growth and can cause water stress on the crop plant if the soil water is below the saturation level. In the dry season water depths of 15 cm or more can reduce yields of certain rice varieties (De Datta 1981).;
- Pre-harvest (terminal) drainage
  Surface water is drained about 10-15 days before harvest (Lucero 1984) for uniform and timely ripening of grains and to facilitate harvesting. Water requirement of the crop after the terminal drainage is to be met from residual water in the soil. Grain quality is sacrificed if rice fields are not drained in time prior to harvest.

Mid-season drainage of rice fields

Several investigators in Japan (Fukuda and Tsutsui 1968; Samato et al. 1964; Yamada 1965; Kung 1971; Tsutsui 1971; and Sakai 1976) have reported beneficial effects on yields from draining the ponded water of the rice field at the end of productive tillering, and keeping the field unwatered for 7-10 days. Their reported benefits are attributed to the removal of toxic substances produced in the plant rootzone due to the prolonged reduced condition of the soil, the higher soil potassium absorption by the plant, and the increased strength in plant culm and lodging resistance, etc. Farmers in Japan, China and Korea are reported to practice mid-season drainage in their summer rice crop.

In the humid tropics of Asia, research mostly showed no significant rice yield benefits from mid-season drainage (De Datta et al. 1973; Nagajarah et al. 1973; Upadhya et al. 1973; Sugimoto 1971). However, exceptions have been reported in the work of Habibullah et al. (1975) in Bangladesh, and Mukherjee (1970) in Thailand, who have found some increase in yield from this practice.

Information on mid-season drainage effects on rice yields under both the tropical and temperate climatic conditions are mostly empirical. Most past research on this topic lacks the adequate soil and plant analyses required to interpret the results completely. The issue therefore deserves more systematic research. However, it must be recognized that in the humid tropical region the rice soils are generally low in organic matter, and the rice is grown in higher temperature regimes and with much less use of fertilizers than in Japan, China or Korea. Therefore, the biochemical processes involved in the rice soils in the humid tropics could be significantly different from those in the temperate climatic areas.

4 Rice plant performance under varying conditions of submergence

Rice plants are not able to perform their normal physiological functions when the water depth in the field exceeds a certain level. It is recommendable not to allow the depth of water in the field to exceed about 15% of the crop height. The degree of damage to the rice yield is positively correlated to the degree of excessive water depth. However, in certain growth stages the plant is more susceptible to excess water than in others. Although there are varietal differences in the response of the rice plant to excess water conditions, a general understanding of the plant behaviour under varying conditions of excess water is useful in formulating strategies and designing drainage systems. The following summarizes most of the recent findings from pertinent literature:

1. The panicle initation and flowering stages of the rice crop are most sensitive to full submergence i.e., when the entire crop canopy is under water. During inundation treatments in the Philippines, Undan (1978) found that a one-day submergence at the panicle initation stage can reduce IR-30 rice yield up to about 75% (Table 1). During this stage the young stalks of rice plants appeared to be easily weakened by flooding;

Table 1 Percentage reduction in yield of IR-30 rice variety as affected by inundation treatments in the Philippines (Undan 1978)

Crop growth stage	Ave.crop ht. (cm)	Type of submergence	Period of submergence (days)			
			1	3	4	5
2 weeks after transplanting (early tillering)	30	Fully submerged	24.6	61.2	63.7	84.2
		Partially* submerged	6.9	3.9	10.3	12.2
4 weeks after transplanting (max. tillering)	48	Fully submerged	24.5	37.6	81.5	94.6
		Partially* submerged	0.1	7.6	8.7	4.8
6 weeks after transplanting (panicle initation)	68	Fully submerged	74.2	94.0	96.4	100
		Partially* submerged	10.2	8.0	9.5	11.3

* *Partially submerged means crop was submerged at half its height.*

2. Minor submergence injuries at the early stage of crop could be overcome, at least partly, during the remaining period of the crop's life cycle. Full submergence with

clear water for one day at the early tillering stage can reduce the yield by about 25%. A 3-day full submergence reduced IR-30 rice yield by about 60% (Undan 1978);

3. Partial submergence of 'Jaya' variety at 25% of plant height during any of the three major stages of rice growth, i.e., seedling establishment to maximum tillering, maximum tillering to flowering, and flowering to maturity, can result in a 20 to 30% yield reduction in the Aman (Jul-Nov) or Boro (Jan-Apr) season in India (Table 2) (Pande 1976).

Table 2 Yield of variety 'Jaya' under three levels of submergence (25, 50, 75% of crop height) at each of the 3 growth stages during Aman (Jul-Nov) and Boro (Jan-Apr) seasons in India, 1973-74 (Pande 1976)

Plant growth stage	% Submergence of crop height	Relative grain yield(%) 1973 (Aman)	1974 (Boro)
Control (Continuous) submergence (5 2 cm)		100	100
Seedling establishment to maximum tillering	25%	82	75
	50%	75	62
	75%	68	58
Maximum tillering to flowering	25%	81	74
	50%	71	64
	75%	72	56
Flowering to maturity	25%	79	71
	50%	76	66
	75%	70	50

4. Only slight yield reduction (up to about 12%) resulted when IR-30 rice plants were partially submerged at 50% of the plant height for 5 days or less during the tillering to panicle initiation stage in the Philippines (Undan 1978);
5. Muddy or turbid flood water inflicts greater damage to the plants than clear water (Fukuda and Tsutsui 1968; Pande et al. 1978), because sediments in turbid water block the pores in the plant body and hamper the respiration and photosynthetical processes;
6. Tall varieties are more advantageous than short varieties under partial submergence conditions (Vinaya Rai and Murty 1976);
7. Certain cultural practices such as the use of older seedlings, a greater number of seedlings per hill at transplanting, and nitrogen fertilization after flood water recession, may contribute to better performance of semi-dwarf varieties (Pande et al. 1979).

Drainage system design implications

The research findings mentioned above have important implications for drainage system design. Since full protection of the rice field from flooding may be too expensive to set up a target area, the design of the drainage system may be based on the concept of providing full protection from flooding events with a certain expected return period and only partial protection from events expected to be less frequent. Furthermore, the design discharge rates for drainage canals and outlets are chosen in such way that the design flooding event will not allow ponding of water in the rice fields beyond a selected depth and duration. An optimal choice of such design parameters is essential from the point of view of both protection from flood damage and economics. For example, Undan (1978) showed that the required discharge rate for tertiary drainage canals for a 5-year return period flooding event in a rice area in Central Luzon, Philippines, is 13.5 liters/second per hectare (l/s.ha), if no rain water storage on the field is desired. However, if 15 cm of additional ponding beyond the assumed 10 cm field water depth is allowed for 5 days, the required design discharge rate is lowered to 6.7 l/s.ha.

Different values of drainage discharge rates are used in different countries for designing drainage systems for flood protection, depending on the choice of the design flooding event and also on the extent (depth and duration) of submergence considered tolerable. For example:

- In Thailand, the design criterion used for the Chao Phya delta was 5.32 l/s.ha for tertiary drainage canals based on a 3-day rainfall total, expected at least once in 10 years (Van de Goor 1974);
- In irrigation projects in Indonesia and Malaysia, the average drainage canal capacity was 7.3 and 6.5 l/s.ha respectively, based on a rainfall of 5-year recurrence interval (Van de Goor 1974). For a 10-year return period, the value was 9.6 ls/ha in Kelantan, Malaysia;
- In the Philippines, the recently built terminal drainage facilities in the national irrigation systems were based on capacities of 5-8 l/s.ha designed for protection against rainfall at 10-year recurrence intervals (Mercado 1978). This was an improvement over the 2.56 l/s.ha rate used for farm-level drainage in the Upper Pampanga River Integrated Irrigation System design (Lucero undated).

A major problem in many irrigation systems is that there is a significant gap between the design and what is constructed in the field. For example, the Libmanan-Cabusao Pump Irrigation System in the Philippines used a design discharge capacity of 11.4 l/s.ha for its drainage system, which is expected to protect the area from a 3-day rainfall total of 194 mm, expected to occur once every five years. But within two years after the system became operational in 1981, a 2-day rainfall total of 160 mm caused a major inundation within the project area, and about 850 ha, or 30% of the total protected area, remained under water for one week or more (Agua et al. 1984).

5 Natural and man-made factors contributing to drainage problems

Of the natural causes of major drainage problems in the low-lying (fluxial) lands, high intensity rainfall is the most dominant. Such a rainfall produces very high run-off which accumulates in the lower areas; consequently rivers overflow and inundate their flood plains. On top of this natural problem, a man-made problem of deforestation in the river catchment causes excessive soil erosion, which results in high rates of sedimentation in the river bed along the lower stretches of the river basin, where the gradients are very low. Consequently, the river discharge capacities are reduced. Furthermore, as the water detention and infiltration capacities in the upper catchment are reduced due to deforestation, flash floods are more frequent and severe in their effect on the lower parts of the basin. As the erosion-sedimentation process goes unabated, the problem of flooding continues to worsen. Many river basins in the humid tropics of Asia are major victims of this process.

Waterlogging from intensive rainfall in the monsoon and tropical cyclones affects both rainfed and irrigated lands, the latter mainly due to inadequate provision of drainage capacity for handling such amounts of water. In the Philippines, an average of about 20 tropical cyclones hit the country each year. These are most frequent during the months of July-October when wet season rice is mostly in the field (Figure 2). Records of the past 38 years indicate that there were 90 rainfall occurrences which produced rainfall of more than 300 mm/day. The high ratios of run-off to rainfall in many river basins indicate that large proportions of rain-water end up as run-off (Table 3) which eventually builds up ponding water in the ill-drained lower areas.

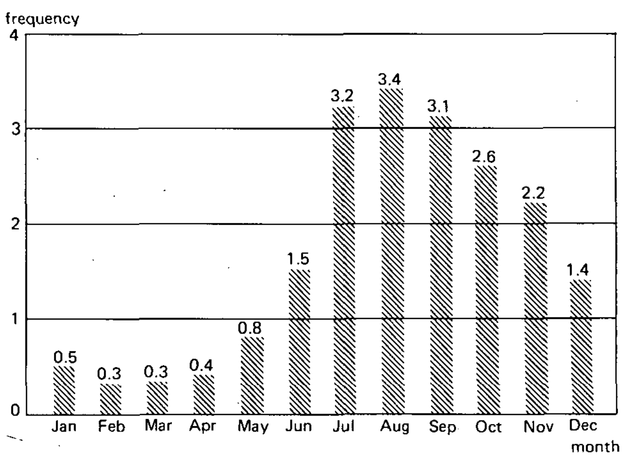

Figure 2 Mean monthly frequency distribution of tropical cyclones in the Philippines, 1948-85

Table 3 Annual rainfall and run-off on selected river basins

River basin*	Country coverage	Drainage area (km^2)	Mean annual rainfall (mm)	Estimated Mean annual run-off (mm)	Run-off/ rainfall ratio
Brahmaputra	China, India Bangladesh	580000	2125	1177	0.55
Ganges	India, Bangladesh	977500	1250	367	0.29
Meghna	India, Bangladesh	80200	3500	1715**	0.49
Kosi	Nepal,India	86900	1790	643	0.36
Red	China, Vietnam	120000	1500	1090	0.73
Bicol	Philippines	3771	2347	1353	0.58
Pampanga	Philippines	9759	2067	1505	0.73
Chico	Philippines	5247	2390	1379	0.58
Ilog-Hilabangan	Philippines	1945	2640	1293	0.49
South Cotabato	Philippines	6945	2317	1114	0.48

* Source of data: NWRC (1979-83) for the river basins in the Philippines; ECAFE (1966) for the others.

** Run-off estimated for Bhairab Bazar, Bangladesh, up to where the effective drainage area is 64700 km^2

In the irrigated lands, serious drainage problems have been caused by some weaknesses in the design and management of many irrigation systems. The designs of the majority of rice irrigation systems have not received sufficient attention to remove the excess water from the fields, and out of the systems. Inadequate number and size of structures such as drain crossings and culverts provided across irrigation canals and roads are also a common problem restricting water flow and prolonging the submerged conditions upstream of those structures (Agua et al. 1984; Undan et al. 1984). In addition, drainage systems often suffer from inadequate maintenance. Dense vegetation growth and erosion-siltation of drainage canals and ditches reduce their effective capacity.

An equally widespread problem within rice irrigation systems is the excessive use by farmers with easy access to irrigation water, and the low effective use of rainfall, creating waterlogging in the lower areas. Excessive seepage and percolation occurring from unlined canals and irrigated areas with lighter soils also contribute to waterlogging and eventually decrease the productivity of the land.

The above-mentioned problems have been emphasized in assessments made in several countries:

- India

  High seepage loss, over-irrigation and use of vast areas for growing crops with high water requirements with connected high percolation losses, resulted in a steady rise of watertables in the command areas of many irrigation systems (Swaminathan 1980). In the large Sarda River irrigation system alone, at least 50 000 ha of land in the Uttar Pradesh State are judged to have been rendered unproductive by waterlogging caused by excessive seepage of highly alkaline irrigation water (Chaturvedi 1983). The introduction of canal irrigation in the Hirakud Dam Project increased the waterlogged area from 12-15% in the total area in 1965 to 28% in 1971; the total conveyance loss was estimated to be 45% of the water supply at canal head; net loss by percolation and seepage was about 50% of the supply entering the canal head (Lenka et al. 1974);

- Philippines
  Ill-drained areas were estimated to be 19% of the total 197 800 ha of irrigated area surveyed (Table 4). In the national and communal irrigation systems, about 9% of the 1.2 million ha did not have adequate drainage facilities (National Water Resources Council 1980).

Table 4 Ill-drained areas in selected National Irrigation Administration projects, Philippines (Uwagawa 1980)

Project	Service area (ha)	Ill-drained area (ha)	Per cent of service area affected
UPRIIS			
District 1	24100	2200	9
District 2	25800	1700	7
District 3	32600	9900	30
District 4	25000	4100	16
AMIADP-APO	30200	6000	20
TISIP			
CamRIS	9000	4000	44
Taris	9700	3000	31
SmoRis	6300	400	6
AGUSAN DEL SUR IP			
Andanan RIS	5500	300	5
Simulao RIS	3200	2000	62
DAVAO DEL NORTE IP			
Batutu RIS	5100	500	10
Saug RIS	6300	1000	16
DAVAO II IP			
Libuganon RIS	10500	1000	10
Lasang RIS	4500	700	16
TOTAL	197800	36800	19

6 Percolation rates and rice yields

Most rice lands, especially those under wetland cultivation, have soils of medium to heavy texture, and water percolation rates are low during the rice-growing period. Kawaguchi and Kyuma (1977) reported that about 40% of paddy soils in South and South-east Asia contain at least 45% clay. The presence of the plough pan, created in most rice soils by the puddling process, further inhibits downward movement of water. The presence of a shallow watertable, which in many cases is caused by the use of irrigation water, limits the internal drainage of areas in lower parts of irrigation schemes (Greenland 1985).

Are rice yields in these lands inhibited by low levels of aeration in the rootzone, or is a high percolation rate needed to sustain high rice yields allowing more oxygen supply to the roots?

Studies in Japan indicate that, given the high fertilizer use, a relatively high percolation rate is needed to achieve yields of more than 7.5 t/ha. Tsutsui and Fukuda (1968) concluded that the average percolation rates in fields where high yields are obtained range from 10 to 15 mm/day. They observed that the optimum percolation rate would vary according to the amount of toxic substances to be leached, soil characteristics, crop growth stages and related farming practices, especially fertilizer application. They further concluded that where percolation rates are less than 5 mm/day or more than 40 mm/day, heavy application of fertilizer does not result in high rice yields.

Greenland (1985) cited Chinese literature which suggests that higher percolation rates in paddy soils are associated with higher fertility. The percolation rates considered necessary for high yields are 9-15 mm/day for Jiangsu Province (Yang and Chen 1961) and Shanghai Province (Institute of Soil Science 1978), and 7-20 mm/day in the Zhujiang river delta (Institute of Soil Science, Nanjing 1978; Institute of Soils and Fertilizers, Guangdong 1975). These soils may produce 15-20 t/ha of rice grain from two to three crops per year. Such a cropping intensity maintained for several years has been recognized as likely to lead to increased gleying and lowering of yields, unless the soil is allowed to dry between rice crops (Li and Li 1981).

There is little reported and convincing evidence which shows that high percolation rates, as suggested in the above-mentioned literature for China and Japan, are needed for high rice yields in tropical areas. At IRRI, Manila, three crops of rice per year have been grown for over 22 years on a soil where the percolation rate is less than 1 mm/day. Although annual yields have declined slowly over that period (Figure 3), the total annual yield still exceeds 14 t/ha (Greenland 1985). The production situation at the IRRI farm is complex, however, as the varieties grown during these years have not been the same and the prevailing pest and disease pressure as well as the soil boron content originating from the use of groundwater for irrigation have increased.

Whether increased percolation rates in heavy rice soils will boost low rice yields is unclear, but this is an issue that deserves further investigation. The existing information based on rice yield relationships with drainage regimes and other soil characteristics is limited and systematic, long-term research is needed in this area.

Figure 3 Rice yields of continuous cropped plots at IRRI farm, 1968-82 (Greenland 1985)

7 Riceland drainage for upland crops

Upland crops following wet-season rice can be an alternative choice to growing a second rice crop. In irrigation systems, low-lying tail-end farms inadequately supplied with irrigation water in the dry season are encouraged to shift to low water-demanding upland crops. Furthermore, many low-lying rainfed lands with adequate residual soil water and relatively high watertable can grow an upland crop after rice without supplementary irrigation. Where water is costly, upland crop production can be more profitable than rice if it has an attractive market at harvest time (which is often absent). There are other reasons for advocating a rice-upland crop pattern instead of a rice-rice or rice-fallow cropping pattern:

a. Upland crops after rice allow time for the soil to 'breathe' and exude any toxic substances, that may have accumulated during the months of wetland rice cultivation;
b. Productivity of the soil is enhanced through incorporation of left-over rice straws and other farm wastes, and planting of legumes;
c. Weed and pest problems are reduced;
d. Alternate wet and dryland farming improves the bearing capacity of the soil.

There are, however, identified drainage-related problems which confront the rice-upland crop farming, especially in low-lying lands:

1. Difficulty in tillage
   Rice soils with high clay content, special montmorillonitic clay, have slow internal

drainage but when dry, a few mm at the top of the soil becomes hard (underneath it may remain wet) which makes it difficult for animal-driven or small mechanized tillage implements to prepare land for upland crops (IRRI Ann. Rep. 1985);

2. Poor crop establishment
   Seed germination is often hampered either by poor soil-seed contact due to the presence of large clods in poorly prepared soils as a result of difficulty in tillage or a high water content in the soil (IRRI Ann. Rep. 1985);
3. Excess seepage from rice fields
   Most farmers prefer to grow rice if enough water is available and fields cultivated with upland crops often suffer from excess seepage water from adjacent ditches or flooded rice fields. This problem is aggravated by lack of coordination among farmers and absence of group planning for upland crop production;
4. Uncontrolled irrigation water
   In some irrigation systems, low areas planted with upland crops suffer from flooding by the flow of uncontrolled irrigation water further upstream. Such areas may also suffer from unexpected heavy showers and flooding at critical stages of the crop.

The use of heavy tillage equipment for dryland preparation at low soil water content can effectively solve the tillage and crop establishment problems, but their use not only requires higher land preparation costs, it also destroys paddy bunds within the fields, which in turn require additional costs to rebuild them for wetland rice cultivation. The prospects of using suitable oxygenating compounds should be investigated to solve the seed emergence problem caused by anaerobic conditions. Ogunremi et al. (1981) concluded that application of calcium peroxide improved crop emergence, leaf area, dry matter, and the grain yield of cowpeas grown in a poorly drained soil.

To protect the upland crops from seepage from adjacent flooded fields, interceptor ditches can be used between the fields to remove the water through existing drains. Such drains will also remove excess rain-water. But additional investments will be required for many rice areas in both irrigated and rainfed environments, because they lack adequate drainage facilities for rapid removal of excess water to protect upland crops.

Can the excess water problems for upland crops be resolved economically by the provision of surface drainage systems? The installation of subsurface drainage systems is costly, and they cannot be economically justified for the small rice farmers' holdings for growing agricultural crops. Less expensive surface drainage systems are required to remove excess overland water for growing rice and upland crops. Most ricelands have some surface drainage facilities, and these are usually in the form of shallow ditches along the boundary of the plot or farm, connected to a larger natural or artificial drain. However, the use of deeper internal surface drains to lower the watertable in the field for better upland crop production might be counter-productive in the case of rice culture. Such drains would hamper water retention during rice cultivation, and fertilizer losses would increase. Furthermore, the generally heavy rice soils with poor hydraulic conductivity will require close spacing of such drains, which require taking significant portions of small farmers' holdings out of production.

In soils with certain nutritional problems, such as those with a zinc or sulphur deficiency, the provision of a good internal surface drainage system should be helpful in increasing the productivity of the soil for rice or upland crops. Moorman and Van Breemen (1978) cited the beneficial use of such a drainage system in the Philippines, where the severe zinc deficiency was removed, and soil productivity improved considerably after the land was drained through narrow ditches.

8 Strategies to improve productivity

In considering possible strategies or approaches to improve the productivity of ricelands with drainage problems, we must first analyse extensively the type of problem and its causes. In Table 5, we have listed four major types of drainage problems found in ricelands of the humid tropics of Asia, the possible reasons for the problems and the relevant alternative strategies to be considered for their allevition. The strategies are of two kinds: development-related and management-related.

The development-related strategies would resort to using physical structures to protect the target area from accumulating an excess of water and/or to remove the excess water. They can also be termed as 'engineering solutions' to the problems. This approach is usually aimed at providing a permanent solution. The decisions concerning the choice of technology and the type of specific structural measures to be applied are governed largely by economic and financial considerations.

The management-related strategies often require no physical infrastructure to make the desired change. They would not usually aim at providing a solution to the problem itself, but may indicate how to live with it for higher benefits.

For the type 1 problem, i.e. the problem of intermittent or seasonal flooding, three possible management-related strategies are indicated. The choice of one or the other as a strategy will depend on the specific hydrological and agroclimatical environment of the area under consideration, but all three are usually relevant. Use of short-duration varieties allows flexibility in adjusting the cropping schedule, in order that the crop can be grown and harvested during the relatively safer or less risky period of the season. In our analysis of the Bicol River Basin in the Philippines, a highly flood prone area, it was estimated that by advancing the cropping schedule for the wet season, and using early-maturing rice varieties to allow harvesting by early October in place of late November, the probability of damage to the crop from an average flood would be reduced from 82% to 45% (IRRI Ann. Rep. 1985).

Early-maturing but high-yielding rice varieties are now being developed at IRRI and national rice research centres in many rice-growing countries in Asia, and these have opened up new opportunities for areas that had remained unproductive or had low productions before.

Varieties with tolerance to submergence would provide additional security for the rice farmers of flood prone areas. Research on the development of such varieties is in progress. It is desirable that rice varieties with tolerance to both submergence and salinity be developed for flood prone areas in coastal regions, where the soil has salinity problems.

9 Concluding remarks

Unlike some temperate regions, drainage problems of the humid tropical region of Asia have not been adequately studied in the past. The scope of direct transfer of drainage technology from the temperate region to the Asian tropics is limited by the wide differences in their climatological and socio-economic backgrounds.

Solution of the excess water problems is often a prerequisite to the improvement in productivity of the ricelands affected by these problems. In this respect, the development-related strategy has the advantage in that it aims at providing a permanent solution of the problems, which in turn allows other technological innovations to function in the area to improving its productivity. On the other hand, it is also generally true that these solutions are very costly, and if not done properly, they may provide only a partial solution and may create new problems which could be even more difficult and expensive to solve. Therefore, appropriate precautionary measures must be applied to ensure that such developments are founded on sound scientific principles and adequate technical information.

Table 5 Major types of drainage problems in rice-lands, possible reasons and alternative strategies to consider for improving productivity

Type of problem	Possible reasons	Possible alternative strategies
1 Intermittent or seasonal flooding	– Lowland elevation; – Limited drainage capacity; – High rainfall and run-off.	Management-related: – Use of short-duration rice varieties; – Adjusting cropping calendar to harvest before flood prone periods of season; – Use of submergence-tolerant rice varieties Development-related: – Provision of flood protection measures and adequate drainage capacity.
2 Waterlogging within irrigation systems during major part of season or year	– Low elevation; – Excessive seepage from irrigation canals or higher over-irrigated areas; – Shallow watertable; – High rainfall; – Low internal drainage of soil.	Management-related: – Control of excess water at source(s) (e.g canal lining, more efficient management of irrigation water upstream); – Use of land for alternative crop or aquaculture purposes, which may better suit the given water regime conditions. Development-related: – Provisions of surface and/or subsurface drainage facilities; – Improvement of natural drainage outlets.

3 Prolonged waterlogging in soils with nutrient deficiency (or toxicity)	– Low elevation; – Low internal drainage; – Upwelling or interflow form adjacent high areas in soils with nutrient deficiency (e.g. Zn and P) and toxicity (e.g. Fe and Mn).	Development-related: – Provision of adequate surface or subsurface drainage facilities to remove excess overland water, if any, and lower watertable,
4 Excessive water on soil or high soil water content for upland crop culture	– Lowland elevation; – High watertable; – Low internal drainage in soil; – Seepage from higher or wetter lands; – Uncontrolled flow from irrigation source.	Management-related: – Use of appropriate cultural practices for better seed germination and crop growth (e.g. bedding, ridging, etc.); – Control of seepage from wet areas and excess irrigation flow by improving crop production planning and water management; – Choice of crops which are more tolerant to excess water conditions. Development-related: – Provision of drainage network for removing excess water from surface; – Provision of internal drainage facilities to lower watertable.

Where development-related strategies are to be of limited capacity or not feasible at all, management-related strategies are more relevant. In many cases, however, the two can be complementary.

It should be mentioned here that a long-term, sustainable solution to the flooding problem in river flood plains could hardly be achieved without proper management of the river's upper catchment which is the source of the soil erosion and sedimentation processes responsible for many of the common ills in the flood plains. Very little attention is being given to this problem in the humid tropics of Asia.

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Drainage Machines

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Introduction

Until the early fifties the installation of tile drains in The Netherlands was carried out entirely by hand. A narrow trench was dug accurate to the required depth and grade, the last few centimeters of soil being removed with a gutter-shaped scoop to form a proper bedding for the pipes. To avoid soil disturbance around the pipes, a man would stand beside the trench and lay the pipes using a hook with a long handle. Clayware pipes, 0.3 m in length were used, and the drain depth was around 1 m.
Drain installation by hand required 230 to 300 manhours per 1000 m drain, and was thus very labour intensive. Therefore, it is not surprising that efforts were made to mechanize the installation of subsurface drains, since a large expansion of new agricultural areas and existing areas, where the rationalization of agriculture required larger field sizes and better trafficability, were to be tile drained, wages were steadily increasing and there was a growing scarcity of experienced labour for this work.

Trencher drainage machines

Drain installation was first mechanized in the USA around the 1920's, but it was not until the 1950's that it was introduced to Europe.

The first drainage machine to be used successfully in The Netherlands was a Buckeye imported from the USA in 1954. It had an open digging wheel with scoops, and a trench box with a shoe to shape the trench bottom. The pipes slid down a chute and were laid in position by a man standing on the machine or walking alongside. The trench was thus excavated entirely by the machine, but pipe laying was still largely manual.

The application of cover material, if used, was a separate operation. An average capacity of 140 m drain per hour could be obtained with the machine.

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

Several Dutch machine constructors recognized the wide scope for drain laying machines and started their own manufacture. The introduction of drain-laying machines also led to the appearance of specialized drainage contractors, working on a price per meter basis, and therefore keen to further improve the technique. This interplay led to a rapid development.

The first drainage machines manufactured in The Netherlands were built onto a farm tractor. As experience was gained with these machines, it was found that they could excavate the trench and lay the pipe with as much accuracy as pipes laid by hand. Within a few years various improvements were incorporated:

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

In 1958 some 80 drainage machines were already in use in The Netherlands. When clay tiles were laid by these machines at the usual depth of 1.2 m and the trench width of 20 to 25 cm, capacities of 250 to 300 m per hour were normal. A crew of 7 was required for this operation, with a labour input of 25 to 30 manhours per 1000 m drain. These machines can be characterized as 'flat' digging chain type; they have a digging boom and trench box connected to the machine frame by a parallelogram construction (Figure 1a). With this system the angle of the digging boom varies according to the working depth. These machines are most efficient at working depths of up to 1.4 m in soft soils, which are predominant conditions in The Netherlands.

The success of the drainage machines in The Netherlands led manufacturers to build machines for export as well. This greatly stimulated the adaptation of the machines for a wide range of working conditions: hard and stony soils, larger working depths of up to 2.5 m for arid irrigated lands, and the application of a gravel pack around the pipe. This led to the development of 'steep' or 'semi-vertical' digging chain type machines, in which the digging boom and trench box are connected to the machine chassis by an intermediate frame (Figure 1b). While trenching, the digging boom is at an approximately constant angle of 60° from horizontal, irrespective of working depth.

Other notable improvements in the machines were adjustable width between the tracks (narrow for transport, wide for digging to make room for the excavated soil), and the flexible connection of the track frames to the machine chassis for movement over uneven ground.

Apart from the technical development of the machines, two other developments must be mentioned that have also greatly contributed to simplify and streamline the pipe drainage operations. These are the introduction of flexible corrugated plastic drainpipes after 1968, and the laser system for depth and grade control in the early 70's.

The corrugated plastic drainpipe is light-weight, comes in coils of long lengths and with factory-made perforations for water entry. Their use has simplified and reduced the cost of transport to and on the work site, and virtually eliminated the possibility of open joints and pipe misalignment. Their installation by machine is very straightforward. Coils of the smaller diameter pipe are usually carried on a reel on the machine and wound off as installation proceeds. The larger diameters are mostly laid out on

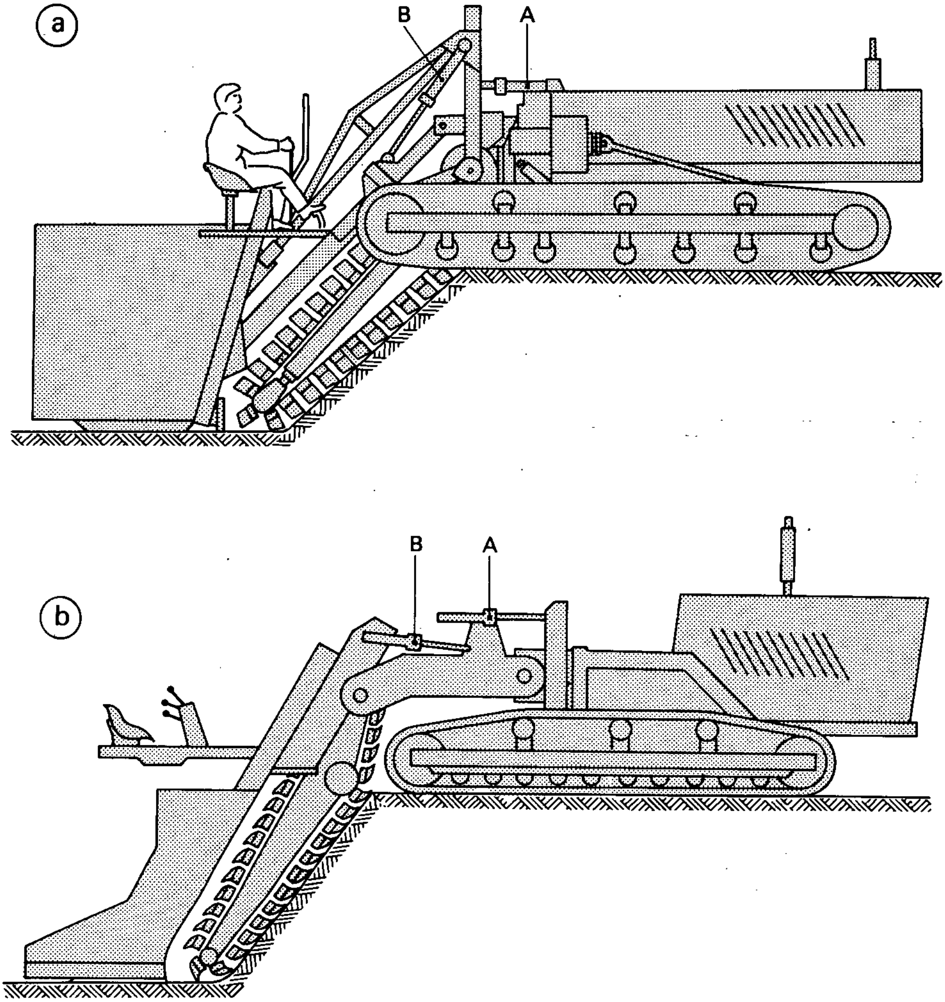

Figure 1 Two main types of trencher drainage machines. Principle of depth regulation: while trenching, the shoe rests on trench bottom and the lifting cylinders A are in float position; depth is regulated by expanding on retracting cylinders B

the field beforehand and then guided through the machine.
The depth and grade of the drains was initially controlled by means of sighting targets installed on each drain line at a constant height above the drain alignment. The machine driver's position was attached to the digging mechanism, and he would keep a sighting bar on the machine in line with the targets, by actuating the switch for the hydraulic valve of the depth control cylinder as required. The accuracy depended very much on the constant attention of the driver and on good visibility conditions, and the system limited the speed of the whole operation (Figure 2).

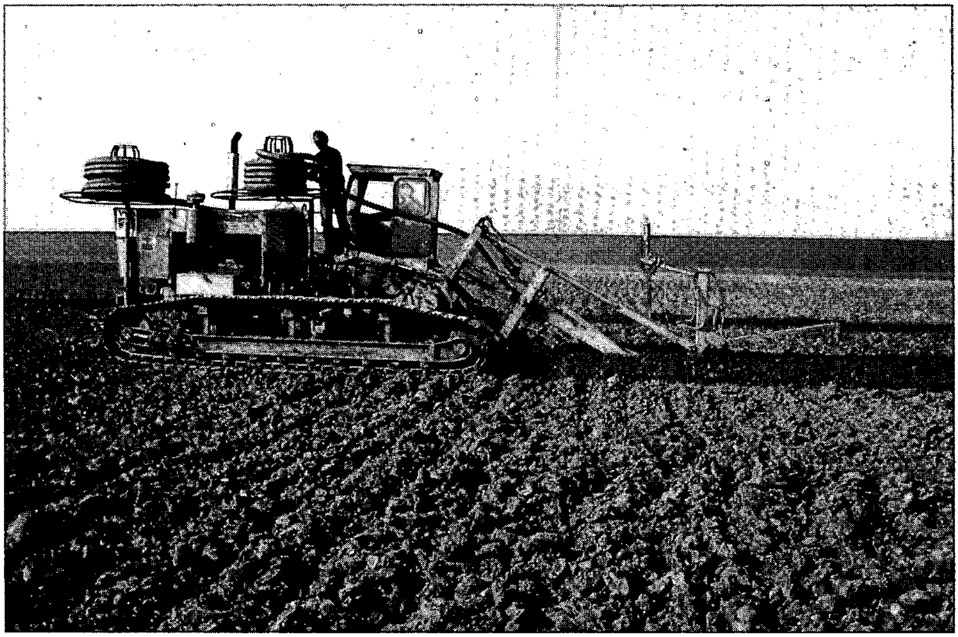

Figure 2 Trencher drainage machine, flat chain type, laying prewrapped corrugated pvc pipe in The Netherlands

Nowadays the grade control by sighting targets has largely been replaced by an automatic control system. The laser system, developed in USA, consists of a command post mounted on a tripod in the field, and a receiver and control box mounted on the machine. The command post contains a small laser emitter sending out a narrow laser light beam. The laser beam falls on a rotating prism, so that it is deflected to describe a horizontal plane. The prism rotates at a frequency of 5 to 10 times per second. The plane of rotation can be tilted at the command post according to the required drain gradient. A reference plane is thus established above and parallel to the drain alignment. The receiver, mounted on the machine's digging mechanism, contains a vertical series of five photoelectric cells. Its height is adjusted before digging commences, so that the laser beam hits the middle cell when the trencher is at the correct depth. When the laser beam hits the receiver at a higher or a lower cell during digging the machine is digging too low or too high, and the signal from the receiver is processed in the control box to actuate the hydraulic valve of the depth control cylinder which will automatically adjust the digging depth. A set of lights on the control box indicates the position of the digging mechanism continuously. The digging depth is constantly checked in this way, small deviations are immediately detected and automatically corrected. The system is effective in a radius of 300 metres, so that several drains can be installed without having to move the command post. Using the laser control system, the process of staking out the drains is very much simplified, and the setting and resetting of sighting targets for each drainline is completely eliminated.

Of course, good results will only be obtained when the laser is correctly set up, solidly mounted, and not disturbed during operation.

In The Netherlands, the installation of corrugated pipe with a trencher machine with laser grade control and a crew of 3 or 4, rates of about 600 m pipe per hour have become normal, resulting in a labour input of 4 to 7 manhours per 1000 m drain.

In a trencher drainage machine the major part of the engine power is used in excavating the trench while the machine moves forward. The machine is a carrier rather than a puller. Because of the long and wide tracks, the ground pressure is low, so that the trencher drainage machines – as opposed to the trenchless machines – can still generally work under rather adverse conditions on wet and soft land. The technical development of trencher drainage machines, together with the invention of the corrugated plastic pipe, has not only increased the productivity in drain laying tremendously, but also made pipe drainage a practical possibility in situations where it was previously considered unpractical, as e.g. in irrigated lands where large drain depths are required and in soils with little cohesion where a trench will not stay open. Pipe drainage is then only feasible when the trench is excavated, the pipe installed, and the filter applied in one single operation before the trench caves in after the machine has passed.

Trencher drainage machines of the steep digging-chain type are nowadays built in a range of sizes, from 100 kW (140 hp) engine power – 150 cm trench depth and 12 tons weight, to 200 kW (270 hp) – 300 cm trench depth – 20 tons weight for lateral drain installation, and the very large machine with 300 kW (400 hp) – 350 cm trench depth – 60 cm trench width – 40 tons weight for large diameter collector drain installation. They are successfully used in the temperate climatic regions of Europe and North America, and in irrigation areas in semi-arid countries (Figures 3 and 4).

Trenchless drainage machines

A parallel development has been that of the trenchless drainage machine, also called drain plough. As the name implies no trench is excavated to lay the pipe, but a blade – something like a large ripper tine – is pulled through the ground to break and lift up the soil to make room for the pipe which is guided into position through a hollow part of the blade or through a pipe guide, trailed behind the blade. This method only became practical after the availibility of flexible corrugated drainpipe increased and the laser grade control was perfected. Several makes of drain ploughs are used in Europe, North-eastern USA and Canada, mostly for the smaller diameter pipes in lateral drains. The drain plough is manufactured either as an attachment to a standard heavy crawler tractor (e.g. Caterpillar D8 or Komatsu), or as an integral unit.

The shape of the vertical blade has been much improved. It is generally curved forward with a flat front to lift up the soil rather than push it aside, to create the space needed for the drain pipe and to reduce the force required to pull the blade through the soil. Because of the large amount of pull required for the trenchless system, the machines are heavily built and need a relatively dry topsoil for the crawler tracks to find enough grip to develop the high traction power needed.

The main advantage of the trenchless technique lies in its greater working speed

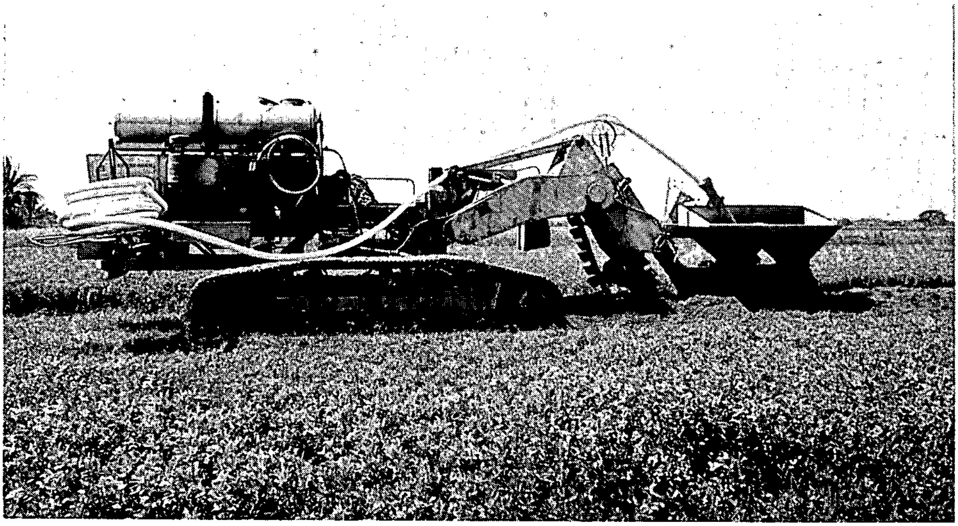

Figure 3 Trencher drainage machine, steep chain type, installing corrugated pvc pipe with gravel surround in Egypt. Note water tank for wetting chain and trench box sides to avoid sticking of clay.

Figure 4 Self unloading gravel trailer for supplying into hopper of drainage machine, Pakistan

and less wear on the machine (fewer moving parts in the ground), providing the contractor with a higher productivity. There is also no trench backfilling necessary. The trenchless machine is more suited to stony soils than a trencher.

The functioning of drains installed via the trenchless technique depends very much on the changes in soil structure brought about by the passing of the blade. Above a certain critical depth, heaving and fissuring of the soil takes place, but below that depth, the soil will be displaced sideways along the blade and deformation will occur. This may reduce the hydraulic conductivity of the soil in the vicinity of the drainpipe and hamper the entry of water, especially in clayey soils where the water flow depends on the continuity of large pores like rootholes and cracks.

In recent years a drain plough with V-shaped blade, known as V-plough or delta-plough, has found increasing application in The Netherlands. A triangular soil wedge is cut loose and lifted up with the V-shaped blade. The corrugated pipe is guided into position at the lower tip of the V through one of the sides of the blade. Deterioration of soil structure around the pipe is largely avoided with this system, and there is very little disturbance of the land surface, which is especially an advantage for grassland. The working depth of the trenchless machine does not exceed 1.8 – 2 metres; larger models have around 225 kW (300 hp) engine power and weigh up to 35 tons (Figure 5).

Up to the present trenchless drainage machines have not found much application in the semi-arid irrigation areas, because of their limited depth range and because the method is not well suited to the application of a gravel filter around the drain pipe.

Figure 5 Trenchless drainage machine 'delta plough' installing prewrapped corrugated pvc pipe in The Netherlands. Maximum installation depth 1.8 m

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Developments in land drainage envelope materials

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1 Developments in installation techniques and materials

1.1 Introduction

Watertable control is often realised by means of subsurface drainage: a technique consisting of systems of perforated or open-jointed pipes, by wells or by 'mole' drains. The technique of subsurface drainage was developed mainly in the temperate climatic zones: Europe, North America and the Soviet Union. Nowadays it is also used in semi-arid and arid zones as an integral part of irrigated agriculture.

In The Netherlands, internal pollution of drain pipes, clogging by mineral particles or ochre, root penetration and effects of internal jetting have long been the subject of discussions, but it is difficult to acquire reliable data on these matters.

In the past three decades, rapid developments have taken place, both in installation techniques and materials. These developments have been interdependent in that new materials prompted the development of new installation techniques, and vice versa.

In The Netherlands, drains were installed manually until the late 1950's. Clay tiles or concrete pipes were often covered with a layer of organic material. After the introduction of mechanized installation, cover materials were installed in strip form, saving labour expense and providing a homogeneous top cover to the pipe.

The introduction of corrugated pipe in 1962 was followed by the development of drain envelopes: cover materials which are wrapped around the pipe to form a pre-wrapped subsurface drain.

In The Netherlands about 80% of all drainage systems are exclusively equipped with pre-wrapped pipes, in an attempt to overcome the above-mentioned problems. Drain envelope research in this country is prompted by the fact that new drains are installed in Dutch soils for the equivalent of US$ 20 million annually.

1.2 Research

Field investigations have been going on nearly as long as drainage itself. Laboratory research started in the 1960's (Cavelaars 1970). Current envelope research is still mainly empirical.

In 1985, the Dutch Foundation 'KOMO' (=Quality Declarations Organization for Building Materials and Components) initiated and sponsored a laboratory research project at the Institute for Land and Water Management Research. In this project, mineral clogging is monitored on 33 soil/envelope combinations (Stuyt 1986a).

To study the functioning of sheet envelopes under field conditions on the long term, the Dutch Governmental Service for Land and Water Use recently set up three new pilot areas where mineral as well as chemical clogging is monitored.

In The Netherlands, low-cost coconut fibre envelopes are frequently used despite their rapid decomposition and inadequate sand-tightness. Therefore, a field survey was made comprising 1200 drains wrapped with coconut fibres and several other envelopes, 3 to 15 years old and situated in 280 different parcels in 9 of the 12 Dutch Provinces. Recommendations, updated as a result of research as outlined above, are published regularly (Van Zeijts 1986).

1.3 Drainage machines

Mechanized drain installation was introduced to The Netherlands in 1954. The then drainage machine, an American 'Buckeye', had an open digging wheel, comparable to a contemporary Finnish machine. The first Dutch drainage machines were built onto farm tractors. These machines were rapidly improved and at the end of the 1950's, Dutch drainage machines were built as integral units. As these machines were successful, they were exported in versions which were adapted to various conditions such as larger working depths, different soil types and stony soils.

A comparatively new development is the trenchless installation technique. With a trenchless machine, a hollow blade (e.g. the 'Delta' plough), is pulled through the ground, lifting the soil rather than pushing it aside, and the (pre-wrapped) drain pipe is guided into position through the blade.

Sometimes drain installation must be done by hand, even today. In Costa Rica, drain pipes in banana plantations must be installed manually in order to avoid damage to the plantation (Murillo; this Symposium).

1.4 Drain pipes

The introduction of new drainage materials has contributed to the simplification of drainage operations, the increase of installation capacities, and the reduction of installation costs. Some 30 years ago only clayware and concrete pipes were used. Nowadays, these materials have been practically superseded by corrugated PVC (polyvinyl chloride) pipes. In some countries, clayware is still used in substantial quantities, e.g. in Finland (40%), and in Scotland (24%) (Morris; this Symposium).

Smooth plastic pipes were introduced in 1959. They were made of rigid PVC and were perforated by longitudinal slits. Wall thickness, perforated area, water flow entrance resistance, and hydraulic capacity were investigated. The main advantage over clay tiles and concrete pipes was the low weight per unit length, greatly reducing transportation costs. An additional cost-saving factor was the reduced need for labour during installation.

Corrugated pipes were introduced in 1962. Corrugated pipes have gradually rep-sandy, silty and dispersive soils, and in unstable subsoils, especially when the watertable is shallow.

The thickness of granular envelopes varies from 5 cm for drains, installed at 60 m spacing or wider (Egypt); 8 cm (Pakistan) and 8-10 cm (Turkey) (Abdel-Dayem, Jokhio, Sener; this Symposium).

The watertable often remains shallow throughout the year in irrigated areas. In such cases it is difficult to select a favourable period for drain installation. A gravel pack around the drain pipe is a good way to prevent soil particles from being washed into the pipe immediately after installation.

Maintenance of drainage systems is indispensable for good long-term functioning. Currently, however, in many countries concerned, main drainage systems are not well maintained due to lack of funds and the lack of proper institutional arrangements (Smedema; this Symposium). In India, where drain silting and weed growth are serious problems, weed removal and desilting is done by hand (Singh; this Symposium).

2 Dutch research into drainage envelopes

2.1 Nationwide field 'dig-up' programme

2.1.1 Procedure

This programme was aimed at the investigation of the sand-tightness of envelopes without considering the hydraulic properties. Light sea clays, eolic sands and riverine deposits were included. The following envelope types were examined: coconut fibres, a mixture of peat fibres and coconut fibres, peat fibres, polystyrene granules in perforated plastic sheet, nylon sock, and 'Cerex'. The following data were collected: soil type (description of profile and structure), type of envelope, trench backfill characteristics, watertable depth, year of installation of drainage system, and whether internal pipe jetting had been applied or not.

Five drains were then selected at random and examined internally. Starting at the outlet in the collector ditches, a glass-fibre rod, with a cylindrical-shaped device on top, was pushed into the drain pipes over a maximum length of 100 m. Places where the rod got stuck were excavated. Additional excavations were carried out in the case of low pushing resistance to inspect the pipe internally. At each excavation, the textural composition and the weight of the pipe deposits were determined.

2.1.2 Results and discussion

The data presented in Tables 1 and 2 lead to the following conclusions:
1. The service life of organic envelope materials is variable and regionally bound;
2. In several soil types with comparable textures, mineral clogging rates vary considerably; traditional filter rules are therefore not applicable;
3. Most synthetic envelopes have a better sand-tightness than organic ones, mainly due to structural differences between the two;

4. In marine silts, the rate of mineral clogging was independent of the rate of envelope decomposition. Therefore, this clogging must have taken place immediately after installation;
5. If the mean clay content of the soil (particles $<2\ \mu m$) exceeds 17.5% from soil surface to drain depth, unwrapped pipes may be installed;
6. The obvious relationship which was found between i) the service life of organic envelopes and ii) the type of eolic sand in which these envelopes are installed cannot be stated as yet;
7. Based on the textural composition of eolic sands, a substantial rate of mineral clogging was expected but did not occur. This leads to the question whether envelopes should be applied at all on these soils for reasons of sand-tightness.

Table 1 Percentages of the number of investigated drain lines where a sediment layer thickness exceeding 15 mm was found.*

Type of envelope	Thickness of sedimented layer > 15 mm (%)		
	marine silt	alluvial deposit	eolic sandy deposit
Coconut fibres	27 (540)	18 (45)	0 (185)
Mixture of peat- and coconut fibres	14 (175)		0 (13)
Peat fibres	19 (60)		0 (15)
Polystyrene granules in perforated plastic sheet	0 (28)		
Nylon sock	0 (23)		
'Cerex'	0 (21)		
plain	60 (68)		

* The total number of drains investigated in each case is given between brackets.

Table 2 Sensitivity of organic envelope materials due to microbiological activity in the soil.*

Type of envelope	Rate of decomposition (years)			
	marine silt	alluvial deposit	eolic sandy deposit north-eastern Netherlands	eolic sandy deposit southern Netherlands
Coconut fibres	< 5 (540)	< 5 (45)	> 10 (75)	< 5 (110)
Mixture of peat- and coconut fibres	< 5 (175)		> 10 (3)	< 5 (10)
Peat fibres	< 5 (60)		> 10 (5)	> 10 (10)

* Two classes are distinguished:
< 5: fully decomposed in less than 5 years;
> 10: in more than 10 years.
The total number of drains investigated in each case is given between brackets.

As for the sedimentation rate, the maximum permitted sediment layer thickness in The Netherlands in a 60 mm corrugated pipe is set at 15 mm. This criterion was chosen because the flow capacity of the pipe is adversely affected if this value is exceeded (Dekker and Ven 1982).
This threshold level is indicated in Figure 2. The curve indicates that a sediment weight of 100 grams in a permeameter coincides with the criterion of 15 mm.

With respect to the hydraulic gradient, the head loss at steady-state design discharge (7 mm/day) for arable land is 50 cm when drains are installed at a depth of 1 m (Dutch standard). In exceptional cases, 60% of the total head loss is lost to the trench. Therefore, any soil/envelope failure which occurs at a head loss below 30 cm is unacceptable. In the permeameters a head loss of 30 cm is equivalent to a hydraulic gradient of 3. The lowest acceptable hydraulic failure gradient is therefore set to 3. It is noted that the radial flow which exists around drains in the field is different from the flow in our permeameters, where the flow pattern is theoretically one-dimensional. Close to a field drain, hydraulic gradients are usually larger than those in laboratory permeameters if the head losses are the same in both cases. The lowest acceptable failure gradient should therefore be set at a higher level, e.g. 4.

The impact of the hydraulic conductivity of a soil/envelope sample on the mid-drain watertable depth in the field, recorded during a permeameter flow test is evaluated as follows.

In a field drainage system, the total head loss is roughly caused by a horizontal and a radial flow component. The area of radial flow is theoretically confined to 0.7 times the distance from the drainage base to the impermeable layer (Hooghoudt 1940).

The hydraulic conductivities as recorded in the laboratory are converted into corresponding hydraulic conductivities in the area of radial flow in the field, assuming that the hydraulic conductivity of the undisturbed soil in this area is known (Gustaffson 1946). The head loss as recorded in a permeameter is equal to the head loss in a drain

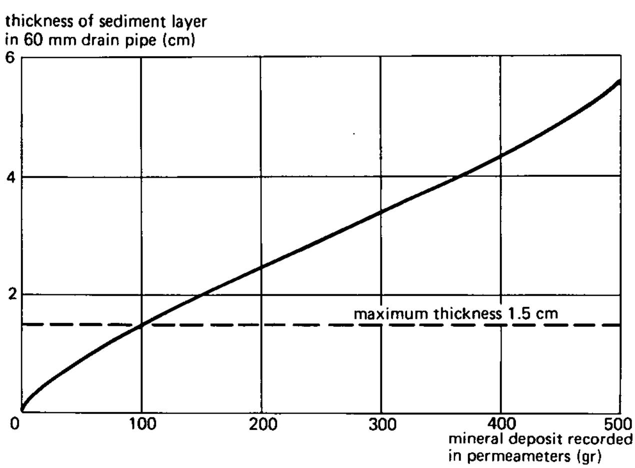

Figure 2 Relation between the weight of mineral deposit in a permeameter and the corresponding tickness of a sediment layer in a 60 mm drain pipe.

trench; the sample height in the permeameters is 0.1 m and the trench width in The Netherlands is 0.2 m. After computation of the mean hydraulic conductivity in the area of radial flow, the drain spacing formula of Ernst (1962) is used to compute the horizontal and radial head loss components.

For a typical land drainage system in a one-layered Dutch soil profile (drainage coefficient 0.007 m/day; drain spacing 15 m; drain depth 1 m; depth of impermeable layer 2 m; diameter of drain envelope 0.07 m; saturated hydraulic conductivity of the soil, Ks, 0.5 m/d; saturated hydraulic conductivity of the trench, Kt, 0.5 m/d), we find

$$h_{total} = h_{hor} + h_{rad} = 0.33 + 0.10 = 0.43 \text{ m} \tag{4}$$

If the hydraulic conductivity of the trench, Kt, is decreased due to structural deterioration of the trench backfill, the mean hydraulic conductivity in the area of radial flow, Kr, is related to Kt as follows (Wesseling and Homma 1967):

$$Kr = 1.0 / (1.30 + 0.35/Kt) \text{ [m/d]} \tag{5}$$

Equation (5) is valid only for the specific drainage case as outlined above.

The radial head loss, hr, as caused by Kr, is given by

$$hr = h_{rad} (Ks / Kr) \text{ [m]} \tag{6}$$

The impact of the hydraulic conductivity of a soil/envelope sample on the mid-drain watertable depth in the field, recorded during a permeameter flow test, can now be computed from:

$$h_{total} = h_{hor} + hr \text{ [m]} \tag{7}$$

2.3.2 Results and discussion

Some preliminary results of the permeameter flow tests are given regarding mineral clogging rates, hydraulic failure gradients and hydraulic conductivities.

The sand-tightness of sheet envelopes was significantly better than that of voluminous envelopes (thickness > 2 mm), regardless the status of the adjacent soil (disturbed or 'undisturbed') (Wilcoxon test; Wilcoxon 1945).

Mineral clogging seems to coincide with the development of a macropore network near envelopes, because a hydraulic conductivity increase was often found near the drain, while the results of dye-tracing experiments indicated that the water flow pattern through the envelope was irregular in almost all cases.

Mineral clogging generally appears to be coupled with an increase of hydraulic conductivity of a combination soil envelope pipe. This trend is very clear in the case of voluminous envelopes (Figure 3), but is less obvious in the case of sheet envelopes (Figure 4). In both Figures, the hydraulic conductivity of the above-mentioned combinations at the end of a permeameter flow test is plotted against the thickness of a sediment layer in a 60 mm pipe. Simultaneously, pipe sedimentation will adversely affect water inflow through the bottom of a pipe as well as the pipe flow capacity.

In most cases, the hydraulic conductivity is favourably affected by a disturbance of the structure of the soil: the hydraulic conductivity is generally higher when disturbed soil samples are used as compared to 'non-disturbed' samples.

No obvious trend in hydraulic conductivity related to time was found. The variance of the hydraulic conductivity figures, reached at the end of the permeameter flow tests, was larger for disturbed soil samples than for 'undisturbed' samples. In case of 'undisturbed' samples, many macropores may have been present, but these were not generally completely involved in the water-flow pattern. It appears that in the case of disturbed soil samples, a more regular network of mutually interconnected macropores exists.

In none of the tests executed to date, the hydraulic conductivity figures give rise to watertable elevations shallower than 20 cm below the soil surface. The worst case was found with a plain, disturbed soil. Generally, however, the watertable increase was several centimeters only. It is concluded that long-term, severe clogging of envelopes and drains, leading to shallow groundwater levels, cannot be simulated by laboratory testing.

A significant difference exists between the final hydraulic conductivity figures in

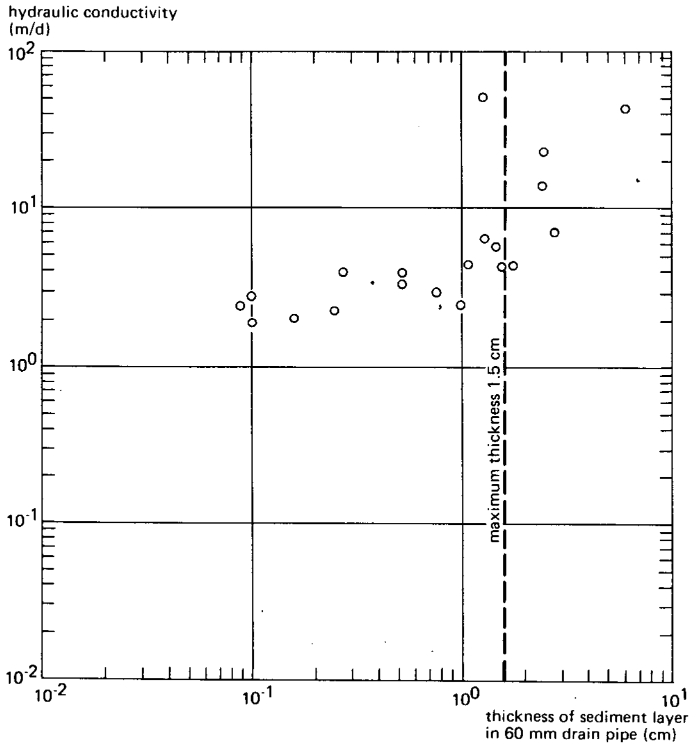

Figure 3 Hydraulic conductivity of a soil/envelope combination plotted against the equivalent thickness of a sediment layer in a 60 mm pipe; type of envelope: voluminous

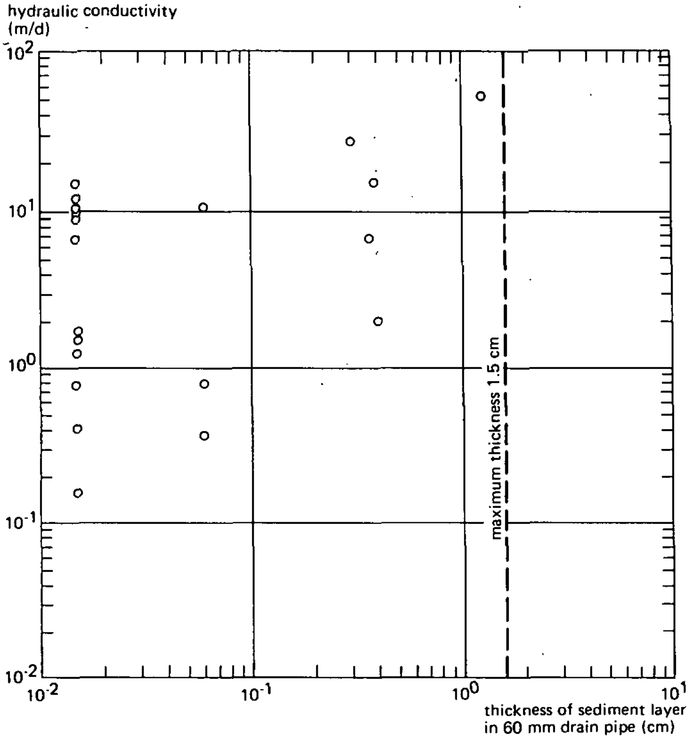

Figure 4 Hydraulic conductivity of a soil/envelope combination plotted against the equivalent thickness of a sediment layer in 60 mm pipe; type of envelope: sheet

case of disturbed soil samples on the one hand, and 'undisturbed' samples on the other, both in combination with thin envelopes (Wilcoxon test). In combination with voluminous envelopes, there was no significant difference. This would indicate that voluminous envelopes are a better means to level out the effects of widely different hydraulic conductivities of adjacent soils than do thin envelopes, as is confirmed by theory (Nieuwenhuis and Wesseling 1979, Widmoser 1968).

One third of all envelope materials scheduled to be examined have been tested so far. Preliminary conclusions are the following:

1. Soil texture is an important parameter when it comes to prediction of the risk of mineral clogging. The structure of the soil is at least as important, however;
2. A permeameter flow test is an adequate tool for examining and comparing proposed soil/envelope combinations. However, it cannot be used for simulation of long-term clogging;
3. An obvious spatial heterogeneity of the soil- and envelope samples was detected. As a consequence, theoretical parameters which have been defined for homogeneous media such as entrance resistance and effective drain radius are unsuitable to account for the head losses around drains;
4. The macropore network which develops around a drain is of vital importance for

the development of the hydraulic conductivity;
5. Thin envelopes may be more prone to long-term clogging than voluminous ones because of the smaller surface area involved in the flow;
6. The use of voluminous envelopes does not necessarily safeguard higher hydraulic conductivities than does the use of sheet envelopes. However, by using voluminous envelopes, there is a greater chance of favourable hydraulic flow conditions near drains;
7. Even accurate permeameter flow tests do not allow for monitoring of relevant phenomena which occur near the interface of envelope and soil. The tests give an indication on the functioning of soil/envelope combinations, but they cannot reveal which physical processes lead to the phenomena which are monitored on the outside.

3 Dutch recommendations for envelope applications

Relevant factors for selecting an envelope material are the following: soil structural stability, clay content, ochre clogging risk, rate of ripening of a soil, organic matter content, and pH.

Generally, Dutch fine-textured soils with more than 17.5% clay particles are stable and do not need an envelope. Any soil material entering the pipe will be easily washed out again.

In loamy soils, sheet envelopes are not recommended because of the risk of envelope blocking. Coarse-textured soils without a substantial loam fraction may be drained with sheet envelopes.

If the ochre clogging risk is high, voluminous envelopes are recommended exclusively. However, if ochre accumulates continually and to a significant extent, it is difficult to maintain drainage systems. Provided that internal drain jetting is performed frequently, a pipe wrapped with a coarse envelope may have an acceptable expected lifetime. A synthetic envelope material is required, if the ochre clogging risk is permanent.

It is still difficult to forecast ochre accumulation. The method developed by Ford (1983) is reliable though laborious, and is therefore not used as regular practise. Visual inspection is done more often following guidelines from Kuntze and Eggelsmann (1974).

Non-ripened soils have low hydraulic conductivities and require a voluminous envelope.

The higher the organic content, the more rapidly voluminous envelopes will decompose, especially if the pH of the soil is high. However, decomposition of envelopes appears not to have a significant impact on the long-term functioning of drains, provided that the drains are not jetted too often.

In peat soils, sheet envelopes may be blocked by suspensed, decomposed organic matter.

From the results presented in Table 3 it is seen that voluminous synthetic envelopes have the widest range of applicability.

The scattergrams of hydraulic conductivities of voluminous and sheet envelopes (see Figures 3 and 4) recorded in a laboratory test, indicate that the data spread of

Table 3 Applicability of envelopes in Dutch soils if no ochre clogging is expected

Soil type	Voluminous* (organic)	Voluminous** (synthetic)	Sheet*** (synthetic)
Ripened clay soil	–	–	–
Unripened clay soil	+	+	O
Ripened loamy soil	O	+	+
Unripened loamy soil	O	+	O
(Clayey) peat soil	+	+	O
Silty sand	+	+	O
Very fine sand	O	+	+
Moderately fine sand	+	+	+

– = envelope is not needed;
+ = envelope is applicable;
O = better envelope is available.

* Coconut fibres, peat fibres, mixture of coconut fibres and peat fibres;
** Polypropylene fibres, polystyrene granules in perforated plastic sheet or in plastic screen;
*** 'Cerex' 25g, 'Typar' 68g, nylon sock, others.

hydraulic conductivities of sheet envelopes largely exceeds the spread which is found when voluminous envelopes are used. Under field conditions, this dissimilarity is likely to be even more pronounced. Consequently the use of sheet envelopes is not encouraged.

It is important that envelopes are of a constant quality. Manufacturers can subject their products to a regular, obligatory quality control. In The Netherlands the requirements as mentioned in the Dutch Standards, 'NEN', serve as a basis for this control. Manufacturers, whose products satisfy the demands, are authorized to supply these products under certificate (so-called 'KOMO-certificates). Many Dutch contractors require materials with such a certificate.

4 Prospects of current research

Despite past and current research efforts, fundamental problems still remain unsolved. Apparently current research is inadequate and progress is therefore liable to stagnation.

Various analytical solutions are available for flow to subsurface drain pipes, with or without envelopes. Significant contributions in this respect were made by Dierickx (1980), Nieuwenhuis and Wesseling (1979), and Widmoser (1968). Field experiments as well as laboratory tests lead to superficial knowledge with only regional validity.

Results of laboratory research reveal that analytical solutions do not adequately describe the flow of water and particles due to unevitable theoretical simplifications. Additionally, long-term phenomena occurring in the vicinity of installed drains, are not studied at all. Substantial progress can only be made if a non-destructive technique is available which yields micromorphological data concerning the media around subsurface drains. Current soil morphological techniques aiming at the determination of this data are all disruptive, time consuming and qualitative. As a result, little is known as yet about three-dimensional changes in soil structure, and the macropore network which develops near the interface between drain pipes and envelopes. Details concerning the spatial distribution of detrimental ochre accumulation around drains are also largely unknown.

Non-destructive, three-dimensional internal images of the human body have become available with the development of the x-ray transmission computed tomographic (CT) scanner (Hounsfield 1972). Precision, linearity, spatial resolution and limitations of the CT-scanner for determination of soil morphological characteristics like distribution of aggregates and bulk density was evaluated with a Siemens Somatom-DR scanner.

It was established that the CT-scanner can be used to quantitatively determine soil morphological data with good spatial resolution, see Figures 5 and 6 (Crestana et al. 1986). The application of CT to soil/envelope studies has many prospects, not only for the study of mineral, but also of chemical and microbiological clogging. The processing of parallel tomographic sequences may enable accurate construction of three-dimensional representations of structural configurations and clogging patterns.
Unlike analytical solutions, finite element models can take account of irregular flow patterns in the vicinity of drains, as caused by the spatial heterogeneity of the hydraulic

Figure 5 CT-image of a 60 mm pipe drain wrapped in spunbonded polypropylene ('Typar'), installed by a trencher in 1985 and sampled in an acrylic cilinder on 13 October 1987. Internal erosion has developed a macropore through the trench into the drain

Figure 6 CT-image of another cross-section through the same media as described in Figure 5. Note that external pipe corrugations underneath the drain are partly clogged (courtesy Dr. B. Verbeeten jr. and Dr. H. Venema, Medical School, AMC Hospital, University of Amsterdam)

conductivity which in turn is linked to the micromorphological variability, inflicted by the drag force of the flowing water, mineral clogging, (bio)chemical clogging, etc. A research project based on the above considerations is in a preparatory stage at the Institute for Land and Water Management Research/ICW.

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Organizing the maintenance of drainage systems

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1 Introduction

Agriculture can exist without drainage, but only under certain conditions such as rainfed shifting cultivation, still practised in many parts of the world. Irrigated agriculture can hardly exist without drainage, but still occurs, as seen in drip and trickle irrigation, or in sprinkle irrigation (Saudi Arabia). In many cases drainage is practised without irrigation, such as in the Dutch polders or in several countries elsewhere, in order to drain excess rainwater. In such cases specific drainage organizations have been established for the operation and maintenance of the systems. We mention the Dutch polder authorities, the organizations for tidal drainage of polder plantations in Surinam and Guiana, and the polder systems in Indonesia and other parts of the world (Polders of the World 1983). Drainage systems have to evacuate an excess of rainwater, irrigation water, or groundwater, usually a combination of these. Cases of drainage of irrigation water without rainwater do occur, as in the coastal areas of Peru, where there is virtually no rain at all (a shower of 1.5 mm in Lima, Peru, drew a front-page story in a large daily newspaper in November 1984).

Drainage is one of the most important activities to enable sustained agriculture, either irrigated or rainfed. Insufficient drainage has led to the decline of crop yields, even to the abandonment of lands, and to the decline of rich cultures, as in ancient Mesopotamia. Salinization of lands will occur wherever drainage is neglected, caused by insufficient or inadequate maintenance of drainage systems. In the early 1960's it was estimated that Pakistan was losing some 40 000 ha of cultivated land annually – about the size of the Dutch North-East Polder – due to waterlogging and salinization (Bhatti 1986), and mention was also made of the far from satisfactory state of maintenance of surface drains. In Peru some 30% of cultivated lands are in varying states of salinization (De la Torre 1986). Morris (1986) reported that in Scotland disappointing results in drainage were often caused by lack of design guidance and by untrained and inexperienced contractors. Dierickx and Feijen (1986) stated that the maintenance of subsurface systems was often neglected in Belgium, whereas Sener (1986) reported the irregular maintenance in Turkey.

It was estimated that some 50% of the world's irrigated land is salinized to the extent that productivity is affected (Carruthers 1985). The result is that rehabilitation of existing irrigation projects and their drainage systems is becoming more important these days than construction of new systems (Wade 1984, Jurriëns and M.G. Bos 1980).

2 The Dutch polder organizations, water-boards

The first Dutch polder organizations had already been established by the inhabitants in the 12th century. These were organizations for both flood protection and drainage. Such water-boards gradually gained a fixed place in the country's system of public authorities (Nienhuis 1983), which also had judicial powers in relation to water management in the polders since the 15th century. The responsibilities of the polder water-boards were to maintain the dikes which were to protect the low-lying areas from flooding, to maintain the drainage system inside the polders, and to evacuate excess rainwater. In the past the farmers' contributions were mainly in kind, i.e. their own labour, materials such as faggots, and partly in cash when, for example other materials or larger equipment than their handtools, such as windmills, had to be purchased or constructed.

The water-board checked the maintenance of the ditches of the farmer's land each year, which they had to clean each autumn, in order to enable proper drainage of excess rainwater. Farmers could be fined in the event that their drains were not up to the standards prescribed by the board. The members of the board were elected by the farmers from the farmers in the polder. That fact that often the bigger farmers and thus the most powerful were elected, was not a problem, since the rules laid out by the boards were subject to public laws, and suppression could thus be prevented by the independent and incorruptible judiciary (Bos 1985). However, once corruption does penetrate the project management system, and even the police force and the courts (Wade 1984) then anarchy will be the only result, and this is also true for the maintenance of drainage systems.

In the past the Dutch government delegated several tasks and powers to the water-boards. They are responsible for dike protection, drainage of excess water, maintenance of some roads, and nowadays also for the prevention of water pollution. The water-boards levy water-charges on the polder inhabitants, both farmers and non-farmers, and industries, and others who use the polderland in any manner. They also have to promulgate regulations relevant to water management, and can fine trespassers.

Levies from farmers are proportional to the acreage of their lands. Tasks beyond farmer's control, like the evacuation of polder water by windmills or modern electric pump stations, are carried out by technicians of the polder organization. Water-boards budgets are financed by the levies from the farmers, domestic users non-farmers, industries, and other users. For more extensive activities the government can subsidize the water-boards.

3 Organization of drainage system maintenance

Maintenance of a drainage system is often organized together with the organization of an irrigation system and its maintenance, except of course in cases where irrigation is not practised, as in the Dutch polders.

The most simple organization of drainage system maintenance is the case of a single farmer, who drains his parcel of land by a small ditch, maintained by himself and the members of his family. They often also organize the irrigation themselves, tapping a small stream from the hills, as still observed in many parts of the world. In The Netherlands one can often see several small iron windmills on plots where a farmer drains his land into the larger polder drainage system. A farmer on the hills of Java, irrigating his rice terrace with water from above, also drains his own fields by letting out surplus water either to a small stream or to the field below.

Such examples serve to illustrate that farmers were and are aware of the importance of drainage, and the maintenance of the system. However, the maintenance of the drainage system becomes a matter of larger organizations in all cases where farmers live in large projects, and have to organize themselves, and in many cases are required to co-operate with other groups of farmers, with technicians, engineers and civil servants of governmental organizations. Such larger project organizations will have to establish rules, define rights and obligations, set fines for trespassers, organize the distribution of tasks among farmers and technicians, organize the financing of the organization and its operation, arrange for equipment, machinery, tools, transport, and everything else required to operate such an organization. It should be stressed that such organizations are actually service organizations. They render various services to the farmers in order to secure optimum and sustained agricultural production.

Good co-operation with farmers' organizations is therefore a prerequisite for its functioning properly and this requires strong and efficient management of the organization, and good discipline both among the officials of the organization and among the farmers. Irrigation and/or drainage organizations can therefore not do without legislation.

The structures of organizations, for either both irrigation and drainage, or for drainage only, may vary. It might be an organization in itself, or a part of a larger organization, like a production organization, such as a plantation. In the latter case the drainage division of a plantation is part of the whole production system belonging to a private or government-owned estate. It can be an organization within itself when serving the drainage system for a number of independent farmers, as in the Dutch polders and in many other drainage projects throughout the world.

Bhatti (1986) described the Pakistan structure in which, under the federal government WAPDA (Water and Power Development Authority) is the agency for the identification, planning, design and construction of drainage systems, which, after completion, are handed over to the respective provincial governments for operation and maintenance, and the collection of water-rates. In Hungary the National Water Authority provides the main structures, whereas the polder societies are responsible for the inter-farm facilities, and the farmers for the on-farm works (Csontos 1986). A similar structure is reported for Turkey (Sener 1986) where at government level the management and maintenance of major installations is carried out by a directorate, and at village and farm-levels this is achieved by farmers' co-operatives, unions, or village authorities.

As indicated above, the maintenance tasks of the system are often partly carried out by the farmers themselves, like the field drains and tertiary drains, and the Dutch polder ditches. The larger drains, and particularly subsurface drains, are often maintained by the organization with specialized staff and machinery, or by contractors, either manual or mechanical. In the Ganges-Kobadak Project in Bangladesh even very large drains, with capacities of over 100 m^3/s, were cleared by hand in order to provide employment to many thousands of men and women, who were contracted under a Food for Work Programme.

An important aspect in the maintenance of the system is the organization of farmers' groups. Such groups are often already well-organized as Water Users Associations for irrigation purposes, which usually includes drain maintenance activities. The distribution of tasks among the members of such farmers' organizations should always be proportional to the area of land they cultivate, and thus have to drain. In the case of tenants, the tenancy arrangements should clearly indicate who is to bear the burden of maintenance, either the tenant/cultivator, or the owner, in the event that, besides own labour, financial contributions are levied. Good co-operation between the farmers' organizations and the officials of the drainage organization is a prerequisite for timely and adequate maintenance.

In Pakistan it was recommended that farmers' associations be more actively involved in the planning and implementation stages of drainage projects (Bhatti 1986), and in Spain it was advocated to improve the link between drainage engineers and water management organizations (Martínez Beltrân 1986). It is clear that this will apply for all countries wherever drainage systems are in operation or planned.

In many countries farmers are obliged by law to participate in such farmers' organizations, and to contribute in cash and kind, often by providing labour. In several cases the functioning of such farmers' organizations or water users' associations has been ruined by conflicts between head and tail-end farmers. Often tail-end farmers are harmed in two ways. Firstly by receiving less irrigation water, or at too late a stage, and secondly by more serious drainage problems in their lower lands. Problems in co-operation and coordination of activities may also arise at high levels, as reported for India (Singh 1986), where the construction of drainage works in upstream riparian States caused difficulties in the discharging capacities of downstream States. Conflicts of power between big and small farmers, landowners and tenants, and the misuse of funds and corruption will often also result in the malfunction of such organizations.

Whatever the organizational structure, or who is doing what, the most important thing is that it gets done, regularly and up to standard. This always requires an efficient system of regulations on functions, tasks, budgetting, and the management of these. Without a well-managed organization for regular maintenance the whole system will rapidly decline, and crop yields will thus decrease, and likewise farmers' incomes, thus jeopardize the financing of the organization, and fields will finally have to be abandoned, as has happened in so many projects throughout the world.

4 Financing operation and maintenance

It can in general be stated that, in cases where they have invested in the establishment of irrigation and/or drainage systems, governments will seek ways and means to recover (a part of) the costs from the farmers who benefit from the system. This can be achieved either by water charges, or indirectly via higher taxes on lands being improved by the system. Farmers will often additionally have to pay for the major part of the costs of the operation and maintenance of the system. These will include costs for pumping, maintenance of the surface or subsurface drains, labour, equipment, materials, and the cost of the organization's technical, supervising and administrative personnel. A government can either charge all costs for the operation and maintenance to the farmers, or it can partly subsidize the project from public funds. The latter is the case in The Netherlands, where the major part of the costs are borne by the farmers and other inhabitants of the polders, and some larger works are subsidized from State revenues.

A more or less similar system was reported for Hungary (Csontos 1986). In Scotland grants for drainage works once amounted to up to 70%, but today vary between 15 and 30% (Morris 1986). Spoor (1986) reported even lower percentages for the United Kingdom.

Various systems of payment for irrigation and/or drainage can be distinguished, such as:
- Payment for used or drained quantities of water;
- Payment for irrigated or drained acreage;
- Payment for a part of the increased yields and values of crops;
- Payment for (a part of) operation and/or maintenance costs, proportional to acreage;
- Combinations of these.

Payment for used or drained quantities is the most just and accurate way, but it is also the most labour, equipment and cost-intensive method. It requires the measurements of quantities at each farm outlet, and this can be very intensive in the case of numerous scattered small plots. Moreover, it may cause differences if various crops are grown, requiring different water quantities for irrigation, and thus resulting in varying quantities to be evacuated. In several parts of the world this has led to compulsory cropping patterns and calendars. In order to avoid costly measuring activities in several countries, charges are levied proportional to acreage, irrelevant of the quantities used and drained.

A combined system is in use in The Netherlands. Farmers in a polder have to pay polder charges proportional to the acreage in use. Industries have to pay charges in relation to the quantities of used and polluted water discharged. In principal this also applies to houses where water is used for domestic purposes, but in such a case measuring quantities would again result in too high costs. Therefore, a uniform rate is levied for each housing unit for drainage and purification. Such water charges also cover the costs of technical and administrative staff of the water-boards.

In several countries costs of operation and maintenance are often partially borne by the government. Personnel of large irrigation and/or drainage organizations are often part of the civil service.

Charges for irrigation and drainage should always be in proportion to the actual costs of the operation and maintenance of the system. In the Ganges-Kobadak project of Bangladesh, water fees were collected from the farmers. However, because of a very inadequate collecting system – via the Land Tax Revenue Collectors, who were quite unwilling to carry out the extra task of collecting water fees – only some 1.5% of the assessed water fees were in fact collected. Moreover, the costs of the staff of the project organization required to assess the fees for about 100 000 farms, were about 20 times higher than the amount that was actually collected. This means that the farmers did not in fact contribute to the maintenance of the system, other than cleaning their own field drains (Bos 1983).

In Peru the charges for operation and maintenance systems were collected to a reasonable extent, up to 80% in the early 1980's. However, the charges did not keep pace with the very high local inflation rate, and therefore the collected funds were far from sufficient to maintain the system adequately within a couple of years, and rapid deterioration was the inevitable consequence. De la Torre (1986) stated that the basic problem in the operation and maintenance of Peruvian drainage systems was the recovery of the 'tarifas de agua' (water rates), resulting in a gradual deterioration of the works, and finally, the production capacity of the lands. Abdel-Dayem (1986) noted that in Egypt the law provides for a direct and full recovery of the costs of field drainage over a period of 20 years, and for an indirect recovery of maintenance costs through the annual land tax.

In planning for financing the costs of regular operation and maintenance, an organization should also create sufficient reserve funds in order to meet possible calamities, and to finance reinvestments. Whatever the system of financing maintenance, either by the farmers, or the tax payers, or both, it always should aim at having adequate funds in order to carry out regular and effective maintenance. In Bangladesh, because of government's budget limitations, about a quarter of the operation and maintenance staff of the Ganges-Kobadak project was laid off in the early 1980's, with the immediate effect of substandard maintenance and related consequences for thousands of farmers. Singh (1986) reported that the maintenance problems in India are usually due to the insufficient allocation of funds. Bhatti (1986) made a similar statement for Pakistan, where inadequate funding resulted in delayed completion of drainage works.

In general it is often a better policy to maintain that what exists and operates successfully, than to divert part of the funds for creating new projects (Boschmann 1983). In Madagascar funds were used to increase the irrigation and drainage area of a large project in the north, resulting in an insufficient budget remaining for several hundreds of smaller projects all over the country.

5 Drainage legislation

Irrigation and drainage cannot do without strong management and good discipline among farmers and organization officials, and thus irrigation and/or drainage cannot exist without rules, regulations and laws. The law of Hammurabi of about 1780 BC in Mesopotamia is one of the oldest known in this respect. Such rules existed in other ancient civilizations, and were already established at an early stage for the Dutch polders. Today legislation on irrigation and/or drainage may take only a few pages, like the Kenyan Irrigation Act, 1966, where large-scale irrigation was only introduced after the Second World War, and an earlier Ordinance which governed the duties and responsibilities of the licensees on such irrigation projects. Very detailed laws exist in other countries, especially in those countries with centuries' old irrigation and drainage, such as the Ley General de Aguas in Peru. As in the regulations based on the Ley General de Aguas, such legislation can occupy hundreds of pages.

Important chapters in laws on irrigation and drainage are those dealing with the legal basis for the establishment of special organizations for irrigation and/or drainage, such as ministries, departments, national or regional boards and the like, the powers vested in such organizations and their functions and the provision and operation of their funds.

Legislation on drainage may read only that the farmer 'shall maintain at all times his holding and all field, feeder and drainage channels to the satisfaction of the manager' (Art. 8 (1), The Trust Land Ordinance, Kenya, 1963). It can also stipulate, as in Madagascar, how much a farmer has to pay for the maintenance of the system, laid down in a formula, (Décret 82-353 aux résaux hydro-agricoles, Madagascar), or it can further add that grazing of animals is not allowed, and that watering and washing of cattle inside a canal or drain is an offence, and that operating a boat or any type of raft in a canal or drain, pollution of water, bathing of people and washing of clothes is not allowed without proper authorization (Art. 49, The Irrigation Ordinance, 1983, Bangladesh). Bhatti (1986) considered that in Pakistan legislation would be necessary in order to check the disposal of untreated city sewage and industrial waste in surface drains. The regulations in Chapter IX of the Ley General de Aguas in Peru state in quite a number of articles, those acts which are punishable by law, in regard of the use, or inappropriate use of water, drainage, protection of riverbanks, roads, construction works, passing of cattle, submission of forged data in relation to these, changing or obstruction of watercourses, both canals and drains, etc. It also defines the minimum and maximum fines of trespassers, and the cases for which water users can be banned from using water. Moreover, the law states explicitly that the water districts can call on the help of the police force in order to enforce water users to comply with the rules and regulations, as in any country where irrigation and drainage is regulated by law. Most of these laws also indicate the maximum fines, and the maximum periods of imprisonment for trespassers.

In several countries the functions, tasks and powers of water users organizations are also regulated by law, as in Peru. The law also establishes the relationship between the water authorities and such organizations. The farmers' organizations in the Dutch polders and the legislation on water-boards is another example of this, as is the Peasant Water Users' Organization (P3A) in Indonesia (Duewel 1984).

Especially legislation on delegating powers and responsibilities to farmers' organizations is an important factor for the proper functioning of irrigation and drainage, and of the operation and maintenance system. However, it requires internal solidarity and cohesion among such groups of farmers and mechanisms to protect small farmers and tenants against big landlords.

Many more examples from various countries on legal aspects of irrigation and drainage could be given. Legislation of course varies from country to country, but whatever the differences are, or the rate of detailing of tasks, responsibilities, powers, the delegation to farmers' organizations, and the procedures for appeal to higher judicial authorities, the most important factor always will be the just and timely enforcement of the law, equitable for all concerned. Whenever non-adherence to the rules, and non-enforcement of these becomes practice, and corruption in whatever form enters into the administration, the water users' organizations and water-boards, and even into the courts, then the operation and maintenance of a system will deteriorate rapidly.

6 Concluding remarks

In the above sections some cases of inadequate organization of maintenance of drainage systems were discussed. This does not of course exclude the fact that there are many well-functioning drainage systems in various parts of the world, as stated in numerous reports, a fact which has been observed in a number of countries by this author.

The general conclusion can be that the organization of the maintenance of drainage systems, its financing, the enforcement of relevant laws and regulations, and the promotion of better co-operation between farmers and between farmers' organizations and officials, is often a more difficult task than designing and constructing a system. This will therefore require much more attention, both from engineers, extension officers, staff of users' organizations, projectmanagers, and policy makers, than is the present case for several countries and projects. The programme of the 25th International Post-Graduate Course on Land Drainage, more or less, reflects this situation. According to the programme only some 3% of the total 525 lecture units were devoted to organizational aspects. Of the 25 papers (as it stood on 6 November 1986) presented to the Silver Jubilee Symposium, 12 reported on some aspects of organization and financing, but expressed in pages this was only 10 of a total of 365.

It is obvious that the importance of a subject cannot be measured by the number of lectures or pages devoted to it, but it is an indication. That for this Symposium, however, one of the five keynote lectures is dealing with these aspects is probably a hopeful indication for the future planning of course programmes.

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Future trends in drainage projects

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Introduction

Any discussion on future trends is a little risky, and there is no exception when talking about trends related to drainage. The primary trends that we feel will have an impact on future drainage projects are centred around five items. The first of these involves the growing awareness of environmental-related problems. Secondly, maintenance measures must be strengthened to correct the early degradation of many new drainage channels that we observe. The third item relates to the use of computer models for design and operation of drainage systems. The fourth item needs to be an extension of computer modelling which has led to the installation of numerous watertable control systems that allow subsurface irrigation via the drainage network. Last of all, new types of installation equipment, materials and techniques are revolutionizing the drainage industry and will contribute to improvements in future drainage system durability. We believe these trends will have a great influence on future irrigation and drainage projects and would like to discuss these items in more detail.

Environment

Environmental concern is very real throughout the world, and pressures to treat this concern in project planning and implementation will increase.

Drainage projects or projects with drainage components often have serious potential for environmental degradation if careful evaluations and plans to minimize degradation or preferably to enhance environmental values are not included in respective projects. We feel that this challenge can and will be met by drainage engineers co-operating with other specialists. Many techniques are already being used in some countries and must be considered for use in projects now being planned in order to have early positive impacts.

Some of the techniques now being used in projects to help control environmental values are not that difficult to plan and implement. For example, in-channel sediment traps are often used to collect the coarse fraction sediments moving in a channel. They can be constructed by simply widening and deepening the reaches of the channel. This technique reduces water velocities to permit deposition in the sediment trap where

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a periodic clean-out can be provided. The technique helps protect other reaches of the channel from sediment accumulation, thus reducing the overall maintenance costs. The reduction in sediment transport also helps protect estuaries, lakes and streams from excessive sediment accumulation, and therefore provides environmental benefits. Other items to consider in projects helping to protect the environment are:

- Filter strips using close-growing grasses in areas where run-off water from crop fields enters the drain directly, thus minimizing sediment transport and the movement of agricultural chemicals that move with soil;
- Conservation of wetlands of an environmental value;
- Control of water-entry points along channels to minimize erosion contributing to sediment deposition in the stream system;
- Avoid barriers to fish migration where applicable;
- Provide sound land-treatment programmes to reduce sediments reaching the stream system;
- Minimize shallow standing water to help control water-related diseases such as malaria;
- Provide water-level control structures in channels, where appropriate, to enhance environmental values;
- Consider the visual quality of the area with the channel by using smooth natural alignments, protect existing or establish new trees in appropriate areas (however, consider future channel maintenance with equipment), grass side slopes or other disturbed areas, and shape spoil materials to fit the landscape.

The environmental inputs will grow as experience is gained and should be planned during the early stages of project development. Environmental evaluation is normally one of the first actions to be undertaken at the planning stage. It should be made part of the normal project investigation and data collection. The evaluation provides the basis for developing environmental protection measures that can be included in the project plan.

Maintenance

Drainage channels are often the forgotten infrastructural measure when it comes to maintenance. This is becoming a very serious problem in many projects around the world. The authors feel that the lack of maintenance will have to be combatted with a major campaign to create the relevant awareness on the part of the public officials responsible. Economic benefits anticipated for projects cannot be achieved if channels are allowed to deteriorate prematurely. Future trends will place more emphasis on maintenance to protect investments. Some of the elements that should be considered are:

- As-built plans or record drawings should be prepared for all projects as construction is completed. These should be submitted to the responsible maintenance organization to update, as system modifications are made during maintenance and to assist in maintenance inspections as well as evaluations;

- Responsibility must be designated to an appropriate organization which must have the necessary authority, funds and equipment to perform the necessary work;
- Training must often be provided for people who will be performing the monitoring, evaluations, inspections and actually do the maintenance work;
- Inspecting, monitoring and evaluations must be routine and must entail that critical work is performed quickly and that normal maintenance is completed before costly emergency work is required;
- Techniques must be clearly explained where needed. It is necessary to use operation and maintenance plans and checklists that are specific to the project.

The authors feel that the above factors are the critical elements to be addressed to achieve proper and timely maintenance on project drains. The techniques and measures involved in actually performing maintenance work are fairly well known and will not be discussed in our presentation. It should be noted, however, that many items can be considered in the initial project plans to reduce future maintenance costs. The trend we see in drainage project planning is to include more items of this nature, and we are encouraged by these actions.

Computer models

Computer models for drainage design are becoming more common and more accurate. The trend to use these models for design has provided the opportunity to try many more alternatives and provide recommendations that are often less costly. Another area that models seem to be leading to involves the operation of water management systems. This is particularly true in the area of controlled watertable levels via subsurface irrigation. The improvement in computer models for drainage design is encouraging. We expect to have drainage design models in the near future that will also estimate erosion potentials, water quality of effluents, salinity changes in the rootzone, and crop yield from each alternative design. When models with these capabilities are available, our system designs should improve .

Watertable control

Watertable control systems have been used for many years in peat and other organic soils. We now note an increase in the use of these types of systems for sandy soils and even finer-textured soils. Many of the more recent systems go beyond the traditional concepts of controlled drainage, and involve the addition of water to facilitate subsurface irrigation during dry periods. Computer design concepts have facilitated significant improvements in the design of these systems. Computer models also are expected to eventually help in providing guidelines for operation of the systems to maximize production, control run-off, minimize water quality problems and facilitate harvest.

Installation improvement

The major improvements in drainage installation equipment, materials and techniques cause changes in installation quality in many parts of the world. Some of these high-speed operations must be monitored carefully to ensure quality work, but the new equipment has been proven to perform well. Trenchless installation equipment for subsurface drains, when coupled with laser grade-control equipment and corrugated plastic drainage tubing, has already made a major impact on drainage projects in many parts of the world. We are learning much about tubing quality, geotextile fabric envelope materials, equipment handling techniques, and equipment design. All of these new items are helping us build better drainage systems. We see this trend continuing and rapidly spreading to the majority of new project areas.

Country Papers

I Drainage in humid temperate regions

II Drainage in the (semi)-arid regions

III Drainage in the humid tropical regions

Drainage developments in the United Kingdom between 1961-1986

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1 Nature of drainage problems

Due to the combination of soils and climate in the U.K., most areas require some form of artificial drainage for successful agriculture. Rainfall, which is uniformly distributed throughout the year, varies from approximately 600 mm to 1600 mm/year from east to west. This rainfall exceeds evapotranspiration during winter and early spring in the east and for most of the year except for summer in the west.

The majority of soils are medium to fine in texture with the largest proportion being clayey in nature. The predominant drainage problem is one of perched watertables (60-70% approx.) followed by groundwater control (30%), with seepage and spring problems constituting the remainder.

Although drainage practice started in Roman times, the major draining period in history was during the 18th and 19th Centuries. During this period almost the whole of the country, except for the mountainous areas, was drained with subsurface pipe systems and the mole drainage system developed. Drainage practice is therefore very much a case of replacing or intensifying old systems.

A survey by the Ministry of Agriculture in England and Wales in 1968-69, identified an area of approximately 3 million hectares which could repay investment in further drainage works. Drainage activity since then has done little in many areas to correct this need, in most cases, it has simply kept pace with the deterioration of old systems.

2 Area of drainage activity

Drainage activity over the past 25 years has followed closely the most profitable areas of agriculture, which have been the arable and intensive dairy sectors. The arable sector in particular has expanded greatly and drainage has played a major part in this. Governments have tried, by offering larger drainage grants, to encourage drainage in the more marginal farming areas. This unfortunately has not been as successful as was hoped, due to the relatively low profitability of the prevailing cattle and sheep enterprises. Drainage work therefore, although being carried out all over the country, has been concentrated in the predominantly arable areas of the Midlands and South East England and of Eastern Scotland.

The area of land drained in England and Wales over the 25 year period is shown in Figure 1. Installation over the last 5 years has been estimated, due to the lack of exact statistics. The figures show a very rapid expansion in the late 1960s to a peak in the mid '70s of 110 000 ha/year. During this period government grant aid for draina-

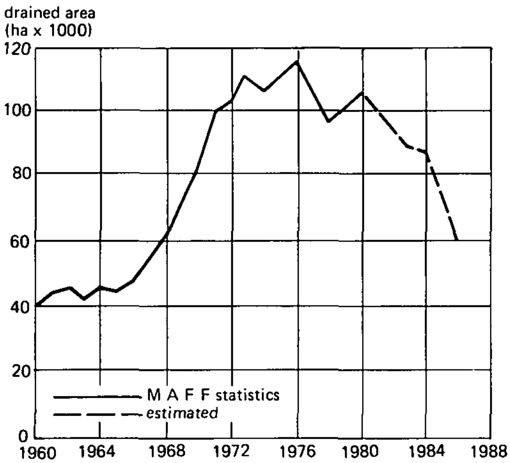

Figure 1 Area drained in England and Wales

age was between 50-60% of total costs. Installations continued at between 90-96000 ha per year in the '80s until 2 years ago after which there has been a rapid downturn. The peaks in the 1970s followed very wet years and the latest downturn is due to greater uncertainty in agriculture as well as to the removal of almost all government support for drainage.

It is not anticipated that there will be any major change in the distribution of drainage schemes around the country in the foreseeable future, but the area to be drained and the nature of future schemes could change markedly. Environmental considerations are now being given much more emphasis and as a result, it is unlikely that any of the remaining marsh and wetland areas will be drained for arable farming purposes. As the profitability of agriculture falls and with moves in some areas to low input/low output systems, the need for cheaper, less intensive drainage systems will increase. Where farmers aim to maintain profitability through greater intensification, drainage as practiced over the last 25 years is likely to continue.

In most environmental circles at the present time, drainage is considered an activity which destroys wildlife habitat. Wildlife habitats, however, require specific water regimes like any agricultural crop. Once this is fully recognized, it is anticipated that drainage will play an important role in the maintenance and creation of specific habitats and in allowing wildlife habitats to coexist alongside profitable agricultural enterprises.

3 Drainage criteria

Drainage scheme design is based largely on past experience, with no use being made of drainage equations. Whilst the equations would be applicable in the groundwater control areas, they are not appropriate for the major problem, namely perched watertables or for mole drainage installations. Nevertheless, estimates of discharge require ments and the water flow characteristics of the soil influencing spacing are still required, together with desired water levels in groundwater areas.

3.1 Discharge

The main requirement for discharge data is for pipe sizing calculations and a standard procedure has been developed by the Ministry of Agriculture over the past 10-15 years, which has proved very successful. The estimates are made on the basis of the climatic data for the critical winter/spring period and the considered acceptable risk for the particular farming system.

Where subsurface pipes only are to be installed, the daily discharge is estimated from the 5-day rainfall input figure for the appropriate return period. In the case of pipe collectors in mole drainage schemes, the 1-day rainfall input value is used, to allow for the higher discharge rates from mole systems.

The return periods considered acceptable are as follows:

1 year	grassland
2 years	cereals
10 years	horticulture

Pipe selection charts derived from laboratory tests and theory have been devised by the Ministry of Agriculture for the different types of pipe on the market.

3.2 Soil permeability/drain spacing

In the 1960s/70s R.H. Miers of the Ministry of Agriculture, devised a method for estimating the drain spacing requirement from a soil profile pit analysis. Soil structure plays a critical role in controlling soil permeability in the medium and fine textured British soils and so this parameter is central in the Miers system. Soil texture, structure and the degree of crack development in winter were assessed in the profile pit and combined using empirical charts to indicate the required drain spacing. The drain spacing estimates represented the recommended subjective values of experienced drainage officers for that particular set of conditions.

This technique proved valuable in the rapid training of new drainage officers over some 15 years. Although the technique is not used directly now, it has increased considerably the awareness of those designing schemes to the importance of structure and macro-porosity of soils in the swollen state, when selecting spacings.

3.3 Heavy soils

Numerous major field experiments executed by the Field Drainage Experimental Unit of the Ministry of Agriculture over the past 25 years, proved conclusively the need for close drain spacings for satisfactory water control on British heavy soils. Spacing requirements are frequently 2-3 m when structure and crack development is poor.

These spacings can only be achieved at an economic cost through the use of mole drains. The mole drains themselves discharge into permanent pipe collector systems through a gravel or stone backfill, placed above the pipe.

The design criteria used in these situations is not related to the spacing of the mole drains themselves, but rather to the spacing of the pipe collectors. Mole drains are very cheap and hence are usually installed at spacings of 1.5-2 m which will allow for some failures. The chosen collector spacing is a function of the moling qualities of the site and the topography of the field. The moling quality of a soil is currently assessed in terms of its texture, structural stability and the presence or absence of silt or sand lenses. Collector spacings vary from 20 m on the poorer moling soils to 80 m on the better soils.

On heavy soils unsuitable for moling, decisions are required as to whether a permeable stone backfill is required above the pipe, to connect the more permeable surface layers to the drain. This decision is taken subjectively on a basis of soil structure macropore development and the likely benefit from subsoiling operations.

Subsoiling as a treatment following pipe installation has increased considerably over the past 25 years, not only to shatter compaction pans, but also to increase the depth of more permeable soil in the surface layers in perched water situations. Permeable backfill over the pipe drains helps connect the subsoiler created fissures directly to the drains. The increase in secondary treatments which includes both moling and subsoiling is shown in Figure 2.

3.4 Future requirements

Before water management practices in wildlife habitat situations can be improved or matched to agricultural requirements there is a need to determine steady and nonsteady state watertable requirements, as well as allowable water deficits, for the different plant communities.

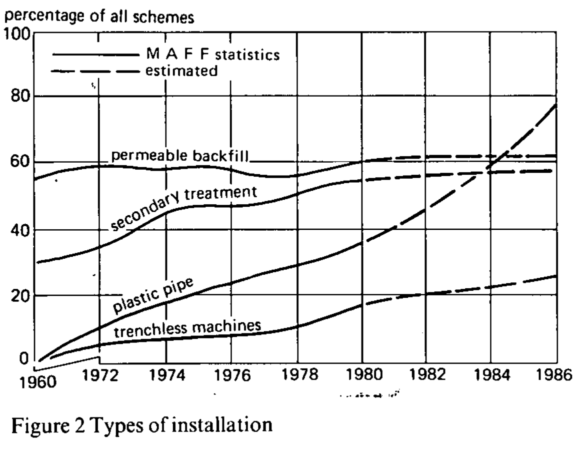

Figure 2 Types of installation

Possible criteria for the use of mole drains as a replacement for the stone backfilled pipe collector in moling systems need further investigation. This system was used on good moling soils prior to the 1950s and offers a way of very significantly reducing drainage costs on heavy soils.

4 Machines and materials

4.1 Machines

Major changes have occurred in both drainage machinery and materials during the 25 year period. The commonest method of pipe installation in the early 60s was to use the wheel trencher. These machines, however, were fairly quickly superseded by the chain type trenchers, which still dominate today. The main changes in the chain trencher have been the increased availability of power and speed, with reductions in the width of trench excavated. A complete range of trenchers from 45-225 kW power is currently available to suit the different sizes of drainage scheme. Trench width is particularly important in the U.K., through its influence on drainage costs in the large number of schemes (60-65%) where permeable backfill is used above the pipe. The wider the trench the greater the amount of expensive backfill consumed. Minimum trench widths of 100 mm are required for moling schemes.

In 1960 the trenchless drainage machine was in the early stages of its development, and was found in two forms, the low output winched and higher output self propelled machines. A major attraction was the narrow trench width and hence backfill saving, to be followed later by higher output and less running and maintenance costs than the equivalent trenching machines. The problems encountered in some other countries, of poorer drain performance after trenchless installation, were not common in the U.K. This was because the machines were mostly used in perched watertable, permeable backfill situations. Research in the U.K. identified the causes of the poorer performance problems and developed techniques for avoiding them.

The smaller winched trenchless machines tend to be used on schemes of up to approximately 8 ha in size, with the larger self propelled machines working on sites usually greater than 15 ha. Problems do arise with trenchless installations in some situations, where old drainage systems have been cut on sloping land and blow-outs occur. Figure 2 shows the rate of increase in the usage of trenchless machines, levelling out at about 20% of all schemes.

V-ploughs were first used in the U.K. in 1983 and there are currently a few operating in the groundwater control problem areas of Eastern England. As yet they have not been modified to place stone above the pipe.

In stony and rocky areas, backacters tend to be used on the smaller schemes up to about 2 ha. They are also used for springline problems and for laying main drains on some of the larger sites of between 2-8 ha.

In areas where gradients are low, laser grade control has displaced boning rods almost completely during the last 10 years. An intermediate stage, developed alongside the trenchless machines, based on interfering light beams or on remote control from a static level, disappeared quickly following the introduction of the laser. Boning rods are still used in other situations, although on steeper regular grades, grade is estimated from the soil surface. Limitations to accurate grade are still controlled by the operator. Wrongly adjusted lasers and excessive installation speeds on undulating ground, particularly with trenchless are the main causes of grade error.

Gravel carts for handling permeable backfill have advanced from what were effectively farm trailers in the 1960s to special purpose power driven or self-propelled vehicles in the 1980s. Most are now effectively tyred or tracked to minimize soil compaction problems and capacities vary from 6 to 15 tonnes.

Changes in mole plough design have taken place over the last 25 years with the introduction of double beam and floating beam ploughs. The floating beam plough has a considerably lower draught (up to 50% less) than the traditional single beam plough. In addition, it is less susceptible to trash blockage with less grade variation when operating on undulating surfaces. A further feature is its ability to install graded mole channels on level surfaces.

4.2 Materials

The major change has been in pipe materials. In 1960, almost all pipes were clayware whereas plastics now completely dominate. The rate of uptake of plastics pipe on a scheme basis is shown in Figure 2. Plastics gained entry initially because the 50 mm pipe had adequate carrying capacity for many schemes and was priced similar to the minimum sized clay tile (75 mm). Lower handling costs and convenience, together with further developments such as the large coil, then took over to displace the tile.

Many materials have been tested as alternatives to stone and gravel as permeable backfill materials, these include products made from power station waste, cement, clinker and plastics. Although some are in use, crushed stone and gravel still dominate despite their weight and cost. Figure 2 shows that the use of permeable backfill has remained fairly constant over the period.

The area of unstable soils in the U.K. is limited and hence the use of envelope materials is not particularly widespread. Thicker envelopes such as coco-fibre have been used where necessary over the whole period, together with thin synthetic envelopes during the last few years.

5 Drainage costs

The gross cost of drainage has risen steadily over the 25 year period as detailed in Figure 3, which presents average costs. Real costs to the farmer have been less than these, due to government drainage grants, and to tax savings on reinvested profits within profitable enterprises. Drainage grants varied between 50-60% of the total cost in the '60s and '70s, falling rapidly after 1980 to approximately 15% or less in 1985. Drainage in the less favoured marginal farming areas has received even more encouragement, with grants remaining at 70% until 1983, thereafter falling to 60% and again to 30% in 1985. Unfortunately profit margins were so low in many of these marginal areas that relatively little drainage was done.

Over the whole 25 year period, there has never been any particular difficulty in justifying drainage economically, in situations where poor drainage was limiting output. This remains the case today even without drainage grants. The greatest returns on drainage investment were achieved, when coupled with good farm management, in the following situations: where it gave a very significant improvement in agricultural potential (almost a reclamation situation), where it allowed a change from poor grass to arable and where it allowed greater intensification of either arable or grass.

The major factor influencing drainage cost is permeable backfill which can constitute up to 60% of the total cost. The clear identification of sites where permeable backfill is unnecessary will, therefore, contribute very significantly in reducing drainage costs. Possible future restrictions on production would necessitate a review of the potential benefits of drainage in some areas.

6 Project organization and management

Resulting from the substantial government aid which has gone into drainage works, the Ministry of Agriculture has played a very important and useful role during the past 25 years in the design, organization and setting of standards of projects. Until 1980, all drainage designs and installations had to be approved by Ministry officials before grants could be paid. After this date standards became the farmers responsibility.

In the 1960s almost all designs were made by the Ministry officers, this input decreased and was passed to contractors and consultants in the 1970s and after 1981 the officers role was mainly an advisory one.

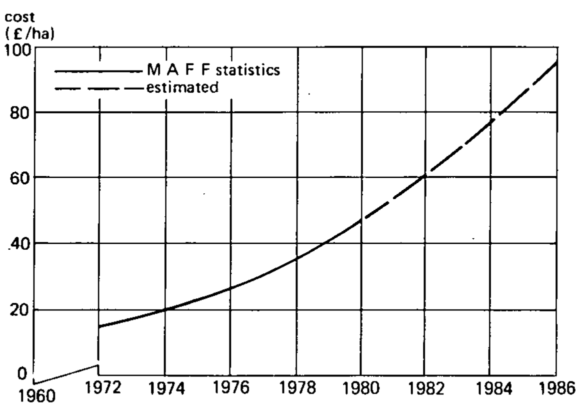

Figure 3 Drainage cost

Ministry drainage officers now offer a commercial consultancy service for farmers requiring drainage. In an attempt to maintain standards of workmanship and to promote drainage, the land drainage contractors have recently formed their own association.

The major drainage season in the 1960s was during autumn and winter. Winter work is now minimal, with much more 'through-crop' drainage being practiced under drier soil moisture conditions.

7 Maintenance of systems

British farmers prefer complete subsurface pipe systems with a minimum of open ditches. Most like to feel that they will never have to maintain any of the pipe systems they install. Evidence collected recently, on silting within pipes installed in the 1970s, suggests that this is a fair assumption on most soils. Except on the few unstable fine sand/silty soils, siltation was minimal where the pipes had been laid satisfactorily. More siltation was found in clay tile than plastic pipe systems, due to soil entering at the joints, and in systems installed using backacters. Flushing machines have been used over the past 5-8 years on some of the unstable soils.

Despite numerous investigations over the past 20 years, no solution has been found for the ochre problem. Cleaning is carried out with either flushing machines or by emptying a tanker of water down the upper end of the pipe system. Poor water entry into plastic pipes in peats has been partly resolved by enlarging the hole area.

Maintenance of farm level open ditches is almost wholly by mechanical means.

8 Acknowledgements

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Field drainage in Scotland

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1 Introduction

Scotland is one of the four countries which make up the United Kingdom. It is a small country with a population of five million and a total land area of 7 715 000 ha occupying the Northern part of the British Isles. Of the total land area approximately 84% or some 6 500 000 ha is classified as agricultural land; the remainder largely being classified as forest, ungrazed uplands and urban areas. Most of the agricultural land is used only for extensive hill or rough grazing with only approximately 25% or 1 650 000 ha being classified as arable or improved grassland. The relative proportion of land in these categories is shown in Table 1.

Table 1 Agricultural land classification

Year	Total improved grass and arable land (1000 ha)	Improved grassland (1000 ha)	(%)	Arable land (1000 ha)	(%)
1963	1722.2	1118.6	65	603.6	35
1973	1645.3	1073.6	65	571.2	35
1983	1686.4	1051.6	62	634.8	38

Table 1 shows that grassland production and associated livestock enterprises form the mainstay of Scottish agriculture. Traditionally most farms were mixed enterprises with a combination of grass and crops. Over the last decade, however, there has been a shift away from traditional rotations in the drier Eastern areas with more emphasis being placed upon arable cropping. This is a reflection of the more favourable economics of arable farming over this period and is a trend that has accelerated since 1983.

In its topography, climate and land use Scotland is a country of marked contrasts. The mountainous nature and high rainfall of much of the Northern and Western parts of the country precludes all but the most extensive forms of agriculture. The arable cropping is concentrated along the drier Eastern coastal fringe where the annual rainfall is less than 900 mm. The main crops grown are barley, wheat, potatoes and oilseed rape. Livestock enterprises predominate in the wetter Western and Northern areas and principally involve dairying, beef cattle and sheep. Because of the adverse winter climate feed must be conserved for overwintered livestock which in the case of diary and beef animals are usually housed during this period. Pigs and poultry products are another important facet of the Scottish agricultural economy with their production mainly being concentrated in intensive housed units.

2 Drainage requirement

Approximately half of the area devoted to improved grassland and arable crops is upon soils that are naturally freely drained. On the remaining area of some 825 000 ha some form of underdrainage is required for the full agricultural potential of the land to be realized. Scottish farmers have long realized the benefits that good drainage confers and there has been a long tradition of drainage improvements on these soils stretching back over the last few centuries. Most of the land in this category has therefore been drained at some time in the past. Unfortunately nothing lasts forever and no matter how well drainage schemes were designed and installed in the first instance, they eventually cease to function and have to be replaced. With an average life expectancy of 50 years, just to maintain the status quo or to ensure that drainage schemes are being replaced at the same rate as they are passing out of commission, the annual Scottish drainage requirement will be somewhere in the order of 16 500 ha. As indicated in Figure 1a, however, the statistics show that since 1955 this annual maintenance target has never been achieved. If the figure of 50 years is an accurate estimate of the life expectancy of drainage schemes it can only be concluded that at best, there

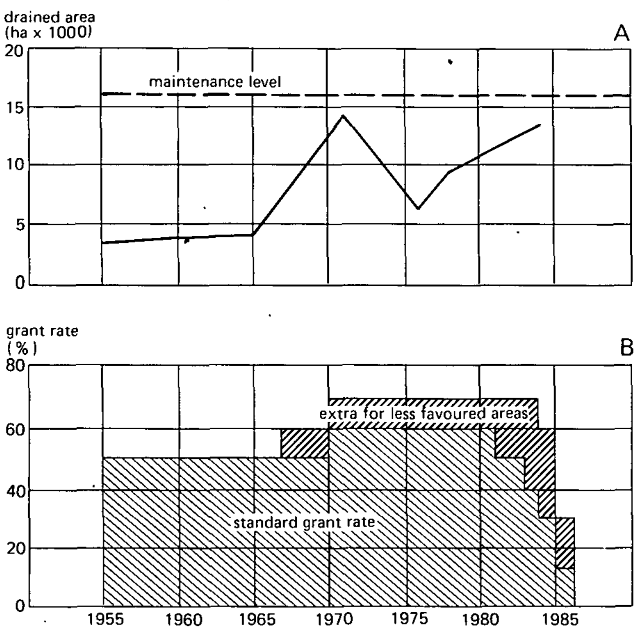

Figure 1 Area drained and grant rate in Scotland

is a substantial area of land where the drains are working at sub-optimum efficiency or at worst, the drains are completely defunct and are making no significant contribution to the drying out of the land.

3 Drainage problems

Most of the drainage effort is on mineral soils with less than 10% of the annual area drained being classified as peat. There are basically three types of drainage problems encountered under Scottish conditions namely surface water, high watertable and springs or seepage lines. Table 2 shows the classification of drainage problems into these categories for 1984.

Table 2 Dominant drainage problems (1984)

Drainage problem	% Area drained
Surface water	65
High watertable	20
Spring/seepage line	15

Although there are regional variations where the relative proportion of these problems differ in response to variations in dominant soil types, the above figures are typical of the overall annual distribution of drainage problems in Scotland.

Accounting as they do for two-third of the area drained, surface water problems are by far the dominant drainage problems under Scottish conditions. This is due to the fact that most of the soils are developed upon dense and slowly permeable glacial tills. The above problems are by no means mutually exclusive and are frequently found in combination.

4 Drainage systems

In all but the most extensive forms of land use in the hill farming and crofting areas field drainage is achieved by pipes. The geological and more recently the glacial and post glacial processes which have formed the Scottish landscape have ensured that there is an adequate network of rivers and streams throughout the country which form the arterial or main drainage outlets. These have been supplemented since the earliest land improvements by a network of man made canals and field ditches to transmit water to the main drainage channels. Another legacy of the natural land forming processes is that the landscape in the main agricultural areas is an undulating one. In most cases therefore drainage can be achieved by a gravity outlet and only in a few cases has recourse to be made to pumping.

5 Drainage criteria

In common with the rest of Britain the most widely used method for the design of piped drainage systems is that advocated by the Ministry of Agriculture, Fisheries and Food (MAFF 1983). In determining daily design rates this system takes account of the incident rainfall, proposed land use and the type of drainage system to be installed. The daily design rate is then used in conjunction with the slope on the land surface, the area served by the pipe and an assessment of soil permeability to calculate the design discharge. From this and the pipe gradient the appropriate size of pipe can be selected.

Because of the large variation in rainfall it would be unwise to adopt a single daily design rate for the whole country. For this and for other agricultural reasons the main agricultural areas have been subdivided into 17 agroclimatic areas (Meteorological Office 1981) for which appropriate meteorological data are available. This includes long-term rainfall data which are used in the determination of the daily design rates for drainage purposes.

6 Drainage materials

Since its introduction in the early 1960's corrugated plastic pipe has had a major impact upon the Scottish drainage scene and currently accounts for 75% of the drainage materials used. Traditional clayware tiles make up most of the remaining 25% with less than 1% being classified as other pipes (mainly concrete).

As indicated earlier the dominant drainage problem encountered in Scotland is the removal of surface water on dense glacial tills which have a slowly permeable subsoil. In response to an increasing number of drain failures and an intensified extension effort the use of permeable infill as a trenchline connection has become increasingly popular on such soils since 1970 and is at present used in 55% of the area drained. In the same context subsoiling and moling are presently practised as permeability aids on 12% and 1% respectively of the area drained.

7 Drainage machinery

Drainage work in Scotland is for the greater part undertaken on a large number of relatively small schemes. The 1984 statistics show that the average project size was 5 ha with the most frequently occurring size falling in the 1-1.9 ha range. This scale of operations limits the use of large capacity drainage machines. Consequently on just over half of the area drained in Scotland the drains are installed by backacting machinery. The remaining area is equally divided between trenchless and continuous trenching machines.

8 Drainage grants

Grants towards field and arterial drainage works were first introduced in the United Kingdom in 1921. Since then the rate of grant has varied between 15% and 70% but has mostly stood at the 50% level. Today, in an era of surplusses in most of the agricultural commodities within the European Economic Community (EEC) and less emphasis being placed upon home grown food production the rate of grant currently stands at 15% for low ground farms and 30% for farms in areas classified as less favoured (LFA) (Figure 1b). From Figure 1 it can be seen that the rate of grant has a bearing upon the amount of drainage done. There are other factors, however, principally the state of confidence of farming and climate. The records show that periods of high drainage activity have coincided with periods of relative prosperity within the agricultural community when the industry was in a confident mood, or have occurred in response to wet years.

9 Drainage costs

In 1984, without taking account of arterial works or ditch improvements and before grants, Scottish farmers spent £15.2 million on field drainage. In so doing 13 312 ha were drained at an average cost of £1.145 per ha. There were wide variations about this average with the lowest regional cost being £485 per ha and the highest just over 2 000 per ha. This variation is due to the variations in soil type and their associated drainage problems throughout the country and the different types of solutions adopted to combat them.

The development of average drainage costs over the last 25 years together with the corresponding values of the different types of agricultural land is shown in Figure 2. The sharp rise in both land values and drainage costs is in part due to the high inflation rate in the United Kingdom at this time. The continuing steep increase in land values during the 1970's and early 1980's was also due to a confident agricultural industry during this period and the fact that the acquisition of land was perceived by farmers and institutional investors as a good long-term investment and a hedge against inflation. In addition to the inflationary aspects the rise in drainage costs from 1970 is also due to the increasing use of permeable infill in drainage schemes which at current costs can account for more than half the total cost of a scheme.

Until 1984 the graphs show that even before grant if a project was based upon a sound financial footing, drainage and land improvements were an attractive economic proposition especially for arable land. Since then, however, there has been a sharp fall in agricultural land values especially in the more marginal LFA areas while drainage costs have remained constant. As a result the economics of drainage have to be much more carefully assessed before embarking upon major projects.

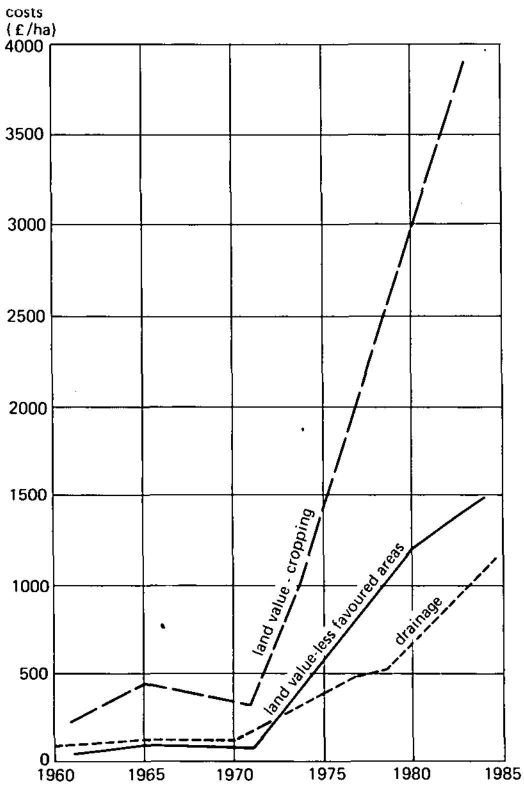

Figure 2 Drainage cost and land value in Scotland

10 Problem areas

In the preceding sections a brief description of the Scottish physical and agricultural background has been given together with an outline of the recent development and current state of the drainage industry. In the following sections attention will be focussed upon the main problem areas confronting the drainage industry in Scotland.

10.1 Standards of design and installation

At least as far as Scotland and indeed the rest of the U.K. is concerned field drainage is an area in which, in the majority of cases, the theory and science of the subject is far in advance of the practice. This is largely due to the structure of the industry and the nature of a large proportion of the servicing contracting industry. Because of the large number of relatively small schemes it is impractical and uneconomic for most of the projects to have a major design input. Consequently in most cases the farmer and his chosen contractor are left to their own judgement and a large proportion of drainage schemes are installed without design guidance and often by untrained and inexperienced contractors. It is not surprising therefore that the final results are often disappointing. This was exemplified in a recent survey into the efficiency of recently installed drainage schemes in S.W. Scotland, carried out by Merrilees & Keer. The results of this survey are shown in Table 3.

Table 3 Farmer and surveyors assessment of drainage efficiency (% of schemes)

	Good	Sub-optimal	Poor	Total
Farmer	58	18	24	100
Surveyor	47	27	26	100

Further detailed investigations of the schemes showed that all the reasons for poor or sub-optimal drainage could and should have been avoided through good design and installation practices.

In an ideal world all drainage contractors should have undergone formal training and be licensed by the administrative authorities. Such a state of affairs is unlikely to occur at least in the forseeable future in Scotland. Under these circumstances the only method of combatting this problem is therefore through a continuing extension and education programme to the wider agricultural community.

10.2 Iron ochre

Almost one third of Scottish drainage schemes have a potential problem due to the presence of iron ochre. In most cases its presence only reduces the efficiency of the drains. In the worst cases, however, it can cause complete drain failure within a few months of installation. Two types of ochre formation have been identified by Kuntze (Kuntze 1982) namely Allochthonous (permanent) and Autochthonous (temporary). Both types are found in Scottish soils with the Allochthonous type presenting the most serious problems.

As yet no satisfactory and environmentally acceptable cure has been found for this problem. Promising work is currently in progress with the use of coniferous bark to absorb the iron from solution. At present, however, the only method of combatting the problem is through design factors to facilitate drain maintenance by rodding or jetting.

10.3 Drainage economics

In a reclamation situation where drainage is a prerequisite to any meaningful agriculture, or where there has been a complete breakdown of an existing system, the benefits of drainage can be easily quantified and justified by economic analysis. For the reasons indicated, however, much of the drainage work undertaken in Scotland does not take place under these categories but is the replacement of sub-optimum drains which are unable to cope with the needs of modern agriculture. Under these conditions drainage economics is much more open to question. This is especially the case under Scottish circumstances where most of the drains are installed to deal with surface water and the drainage need and therefore responses can vary markedly from year to year in accordance with the vagaries of the climate. For U.K. conditions therefore it is a matter of urgency that work is undertaken in this area to allow any drainage improvements to be made on a sound basis.

11 The future

The outlook for the drainage industry in Scotland and the rest of the U.K. will mirror the fortunes of agriculture in general and the emphasis that will be placed upon home grown food production. This in turn will be determined by the priorities of the government of the day and the political sway that the agricultural lobby has with that government. As a member of the EEC any such policies will of course have to comply with the wider interest of the community.

At present both public and political opinion has been coloured by the increasing importance of the environmentalist lobby and the bad publicity targetted at agriculture and fuelled by the high cost of storing the agricultural surplusses produced within the EEC. In this climate it seems unlikely that on a national scale major emphasis will be placed upon increasing or even maintaining current production levels. On the contrary policies being advocated at present would suggest that a decrease in production levels is to be sought. In the future therefore it seems likely that drainage improvements will be concentrated in areas where the interests of the individual farmer are at variance with the national interest of lower production levels.

Against this background it is inevitable that there will be a reduction in the amount of drainage carried out and a corresponding reduction in the capacity of the ancillary industries. In response to this there will be a shift away from single purpose drainage machinery requiring large capital investment and an increasing reliance on the more versatile backacting equipment.

To maintain efficient agricultural production greater emphasis will be placed upon reducing drainage costs without a lowering of standards. The most likely ways of achieving this end for Scottish and U.K. conditions is through alternatives for gravel as permeable infill and the extension of mole drainage to a wider range of soil types. One method of reducing costs which is already gaining in popularity with farmers is 'do-it-yourself' drainage. This trend is likely to increase in importance in the future.

Finally it can only be concluded that within the U.K., agriculture in general and the drainage industry in particular is heading for uncertain times. Many changes will be required while the industry adjusts to the policies of the day and the consequent market pressures. These changes in themselves will produce interesting and stimulating challenges across the whole spectrum of field drainage activities.

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Aspects of land drainage development in Ireland over the last twenty-five years

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1 Introduction

The total land area of the Republic of Ireland is 6.89 million ha. Of this 1.18 million ha are occupied by woods, bogland, rocks, water, urban areas etc. The remaining 5.71 million ha are utilized for agriculture. In Table 1 the land use and drainage status of the utilized agricultural land are outlined. These data indicate that over 90% of this land is under grass: dairying and beef production are the major enterprises.

Table 1 Land use and drainage status of agricultural land in the Republic of Ireland (million ha)

Arable crops	0.50		
Hay and silage	1.25	Dry mineral soil	3.35
Pasture	2.96	Wet mineral soil	2.00
Rough grazing	1.00	Peat land	0.36
Total	5.71		5.71

Table 1 also shows that 2.36 million ha (over 40% of the utilized agricultural land) is in need of drainage. Some of this has been drained over the last 38 years but as outlined in Table 2, approx. 65% of the wet land still needs drainage.

Table 2 Estimated area and drainage status of wet land (million ha)

	Wet soil (permeable)	Impervious soil	Peat land	Total
Total wet land	1.20	0.80	0.36	2.36
Drained (1948-'85)	0.70	0.35	0.07	1.12
Not yet drained	0.50	0.45	0.29	1.24
Needs re-draining (estimate)	0.14	0.14	0.02	0.30
Total area in need of drainage	0.64	0.59	0.31	1.54

1.1 Rainfall

Excess rainfall is a major factor in Irish agriculture and leads to many problems, especially in the wetter regions of the west. As outlined in Table 3, the annual rainfall in the west ranges from 1 000 to 1 600 mm. Potential evapotranspiration (PE) is 360-390 mm (annual) and 310-340 mm (April-September). The normal April-September rainfall is 400-650 mm but in a wet summer (1985) the April-September rainfall ranged from 600 to 850 mm which is considerably in excess of the PE.

Table 3 Rainfall and PE data for the Republic of Ireland (mm)

		East	West
Rainfall	Annual	700–1 200	1 000–1 600
	April-September	350– 500	400– 650
	April-September(1985)	450– 550	600– 850
PE	Annual	420– 470	360– 390
	April-September	370– 410	310– 340

1.2 Drainage

In a survey of land drainage problems and installations in Ireland (Galvin 1969), it was found that seepage and springs (38%), impermeable soil (31%) and high watertable (24%) were the major drainage problems in the country.

The wet permeable soils, affected by a high watertable are usually drained in the conventional manner using a drainage coefficient of 10-12 mm/day. For soils affected by artesian seepage or springs detailed investigations are required to greater than normal depths to determine the position of the various soil layers especially the more permeable ones. Considerable progress has been made in the development of investigative techniques and in the design of drainage systems for seepage problems (Mulqueen and Gleeson 1981). The solution usually requires deep drains to maximize the drainage potential of the free-draining layers. These soils respond well to drainage and the installations generally have high benefit/cost ratios.

The impermeable soils, especially those of a plastic nature, give rise to major problems. Under conditions of high summer rainfall and relatively low evaporation (Table 3), substantial moisture deficits rarely occur and trafficability problems can arise for both animals and machinery. Because of this, these soils are totally unsuitable for tillage and need intensive drainage for grass production and utilization. In many cases the primary objective in draining these soils is for the survival of the farmers concerned rather than a boost to production.

Peat land has as wide a range of permeabilities as mineral soil and is affected by similar drainage problems. Although the total area drained is relatively small, the design of suitable drainage systems is somewhat complicated especially where the depth of peat varies.

2 Drainage of peat land

2.1 Peat types

Irish peat lands can broadly be divided into two major categories, blanket bogs and raised bogs (Hammond 1979). The blanket bogs cover extensive areas along the western seaboard and the higher hill and mountain regions where the annual rainfall averages 1 250-1 600 mm.

The raised bogs are mainly located in basin-type hollows in the central plain of Ireland, where the rainfall is approx. 850 mm. In contrast to the blanket bogs which are relatively uniform in composition, the raised bogs generally display a distinct sequence of peat types through the profile. The physical properties of the various peat types vary considerably (Galvin 1976).

2.2 Drainage systems

The total area of peat that has been drained is relatively small (Table 2). The main drainage emphasis has been on the more permeable cut-over basin peats and on the shallow to medium-depth (300-600 mm deep) peats overlying permeable subsoils. Some drainage has also been carried out on deep and shallow blanket peats.

2.2.1 Deep peat (> 1 m)

Where the peat is permeable (often the case with cut-over raised bogs), conventional drainage systems are installed. It has also been found very beneficial to grade the bog surface to provide uniform surface slopes (Galvin 1972).

For draining deep blanket peat, closely-spaced shallow drains are required (Galvin and Hanrahan 1967). Grubb and Burke (1979) developed an improved tunnel plough for this purpose which excavates and extrudes a band of peat (380 mm high x 280 mm wide) at a depth of 800 mm. Although developed for agriculture the machine is now used extensively for forestry drainage. The aeration provided in the large tunnel encourages prolific root development resulting in far greater tree stability and improved growth.

2.2.2 Peat (< 1 m deep) over a permeable subsoil

Where the peat is permeable, conventional drainage is used. Impermeable peat is usually separated from the permeable subsoil by an iron pan. In such situations, the peat is reclaimed by ploughing to a depth of 70-150 mm below the iron pan. This has the dual effect of breaking the pan to allow free drainage through the permeable subsoil and of providing a peat/subsoil mix at the surface to improve trafficability.

2.2.3 Peat (< 300 mm deep) over an impervious subsoil

This material is usually reclaimed by ploughing to a depth of 50-70 mm below the bottom of the peat and installing mole drains at a depth of 500 mm. The moles provide drainage channels and the deep crack system while the ploughing develops the upper crack structure for increased infiltration. The ploughing also provides subsoil at the surface for trafficability improvement.

2.2.4 Peat (300-1 000 mm deep) over an impervious subsoil

Where the peat is greater than 300 mm deep, the drainage potential is lessened mainly because moles cannot be installed in combination with deep ploughing. In those situations, collector drains are provided and the area is ploughed to a depth of 80-150 mm below the base of the peat. The soil is generally left for one year to dry and ripen after which it is back-bladed and cultivated. This system uses the plough furrows as drainage channels and it is therefore essential to provide continuous well-formed furrows. However, as the drainage effectiveness of the furrows may disimprove with time, this type of reclamation is questionable.

3 Drainage of impermeable soil

For the drainage of impermeable soils, a combination of soil disruption and closely-spaced (1.3-2 m) drainage channels is required. The effectiveness of the system depends on the size and type of cracks formed during disruption and on the permanency of these cracks and of the drainage channels. Irish glacial tills are usually overconsolidated and crack well if disrupted under dry conditions. Mole drains, gravel moles and ripping (or subsoiling) are used as soil disruption cum drainage techniques (Galvin 1982).

Mole drains are quite effective where the soils are stable. However, in many Irish soils, the moles deteriorate completely after a relatively short period (1-3 years). Similar deterioration problems arise in relation to the stability of the disruption channels formed during ripping and subsoiling.

In the early stages of channel deterioration the overall drainage effectiveness is not reduced to any great extent because the channel capacity at close spacing, exceeds the discharge requirements. However, progressive channel and crack deterioration coupled with occasional channel blockages can give rise to reduced channel flow and higher watertable levels. If land is intensively grazed during wet periods under those conditions, poaching damage occurs and the cycle of deterioration escalates rapidly. In those situations, the gravel mole system (Mulqueen 1985) has proved very successful. Apart from the fact that a stable channel is provided, the improved crack system provided by the wider leg of the gravel mole plough is also most beneficial (Galvin 1983).

4 Pilot drainage schemes

During the 1975-78 period agricultural advisors operating the farm modernisation scheme requested assistance in the development of effective drainage systems for a variety of heavy impermeable soils in the west of Ireland. At that stage because of financial constraints it was not possible to install instrumented drainage trials. However, pilot trials were installed on a number of typical farms in particular localities (and soil types), beginning in East Clare (Galvin and McGrath 1977) and extending to the other areas later. Invariably 0.5-1 ha plots of mole drains, gravel moles, ripping and an undrained control were installed and farmed commercially. The condition of the moles and ripping was monitored by excavation and examination and by taking polyurethane casts over a period of 1-4 years. By that time the moles and ripping had deteriorated substantially on all but one site (the moles lasted for 8 years on this site). The extent and serious nature of the deterioration is typified by the situation that developed on the Cree site.

The Cree pilot scheme which included moles, gravel moles, ripping, piped drains spaced at approx. 15 m and a control was installed in 1977. The initial results on all the disruption plots were very good. The moles, gravel moles and ripping maintained good watertable control over the first year while the piped drainage plot and control were quite wet. However, during 1978 and 1979 the monitoring showed that the moles and the ripping channels were deteriorating rapidly. This was borne out by increasing surface wetness and trafficability problems. The early summer of 1980 was dry and there was no difficulty in harvesting the first silage cut. However, the breakdown in drainage coupled with the wet weather in June, July and August of 1980 forced the farmer to postpone the second silage cut until September. At that stage he harvested the gravel moled plot without difficulty but failed completely to travel on any of the other plots. He was compelled to cut these plots with a rotary mower and use a buck-rake to remove the grass. During this process extensive surface damage occurred on all but the gravel moled plot. The farmer subsequently gravel moled the whole area.

The major advantage of these pilot schemes was that they were operated by farmers with whom other farmers in the neighbourhood and on similar type soils in other areas could relate. The Cree site which was visited by many groups of farmers and members of the advisory services demonstrated, in a very clear cut manner, the disastrous results of a drainage breakdown during a wet summer and the contrast between effective drainage and poor drainage. Some farmers and advisers who had visited the site in 1978 and 1979 were amazed at the deterioration that occurred during 1980 and realized after explanation that it was the culmination of a cycle of deterioration that began very early in the life of the moled and ripped plots. These farmers examined the condition of moles installed on their own land and became far more discerning in their selection of drainage systems for future farm developments.

5 Experimental trials

5.1 Field trials 1980-1984

In 1980/81 under a project, partly funded by the EEC, a number of instrumented drainage trials were installed (Galvin 1983). The drainage techniques under test combined soil disruption with channel formation and included:
- Mole drains spaced at 1.3 m;
- Gravel moles spaced at 1.3 m;
- Gravel moles + ripping. The gravel moles are spaced at 2.6 m with intermediate ripping (also spaced at 2.6 m);
- Ripping spaced at 1.3 m;
- Control (undrained).

Summary of results

The following is a summary of the results which are discussed in more detail (Galvin 1983; Galvin 1986a; Galvin 1986b). Data from the Kanturk site which are typical of the type of breakdown that occurred generally, are shown in Figures 1 and 2.
- Mole drains
  On many sites the moles failed after relatively short periods (1 to 3 years). On those sites the watertable control was quite effective during the early part of mole collapse but became less effective as the deterioration increased;
- Gravel moles
  The gravel moles have generally given good results where they have been installed

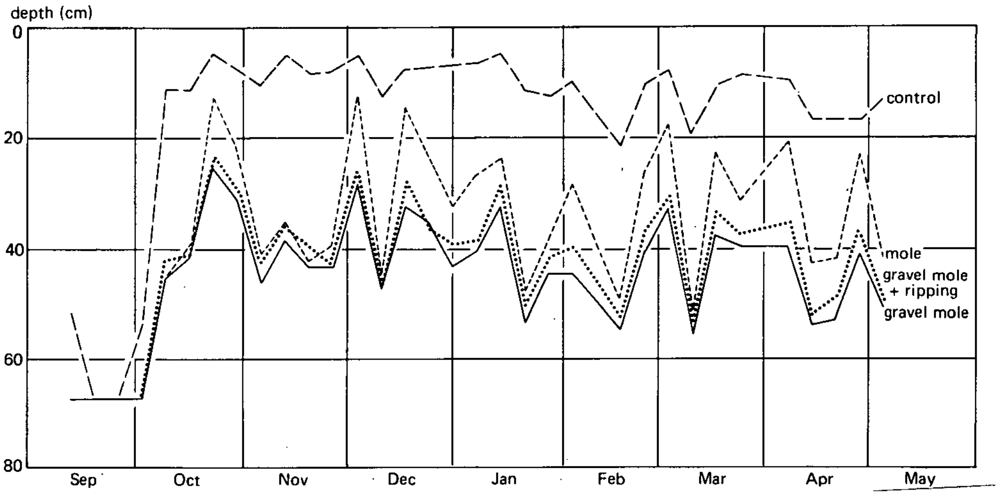

Figure 1 Waterlevel fluctuations at Kanturk 1982-83

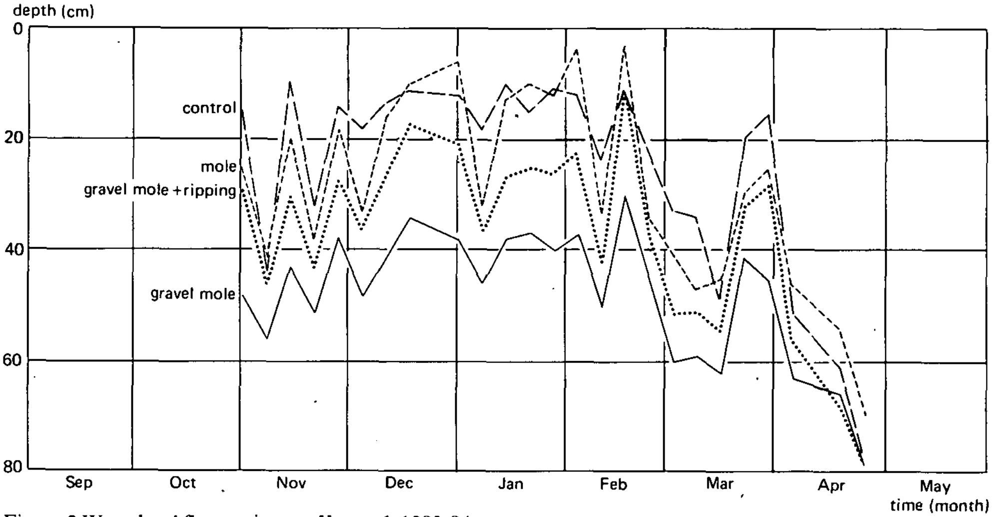

Figure 2 Waterlevel fluctuations at Kanturk 1983-84

under suitable conditions so that adequate soil cracking was attained. No problems have been encountered in relation to the clogging of the gravel channel. The effectiveness of the system is therefore directly related to the cracking developed during installation and to the preservation of that crack structure;

- Ripping
  Ripping has generally performed in a manner somewhat similar to mole drains. The cracking developed during ripping (using the gravel mole machine) is generally better than that developed by the mole plough but the channel formed is less stable;
- Gravel mole + ripping
  This system was installed in an effort to reduce expenditure and was based on the premise that if the soil profile to the depth of installation were completely cracked, the water could discharge through the gravel moles at 2.6 m centres. In practice it was found that the soil was not completely cracked between adjacent gravel moles but that each gravel mole and rip channel controlled the watertable within its own sphere of influence. As the rip channels deteriorated the watertable control also deteriorated. This system is more effective than moles or ripping in unstable soils but is not as effective as gravel moles installed at 1.3 m centres.

5.2 Shallow moles

Shallow moles (at a depth of approx. 300 mm) were installed at the Kilmaley site in an attempt to improve the upper crack structure over moles, gravel moles and ripping which had been installed under unsuitable soil water conditions (Galvin 1986b). It was envisaged that the shallow moles would collapse very quickly due to the shallow depth of installation and that the effect of shallow moling would be limited to a general loosening and improvement in crack structure over the existing disruption channels (moles, gravel moles etc.). However, the shallow moles did not collapse quickly and were still operating very efficiently 14 months after installation. At that stage they were disrupted by subsoiling because the efficiency of the shallow moles in removing rainfall was masking the relative effectiveness of the other drainage systems. This experience and some further experimental work have shown that shallow moles have a reasonable life-span even in unstable soils and that they are very efficient in removing rainfall quickly. They are unlikely to be as effective as moles installed at the standard 450-500 mm depth in controlling watertable at sufficient depth to prevent poaching. However, they should prove very effective as an ancillary system to moles or gravel moles installed at the standard depth. Furthermore the system is relatively inexpensive and can be installed with a light tractor. It can therefore be repeated at regular 2-3 year intervals by farmers without much difficulty.

5.3 Field trials 1984-1986

The 1984-86 field trials which are expected to continue beyond 1989 are designed to simulate normal farming practice as realistically as possible. Three major systems are being tested: moles, gravel moles and an undrained control. Each system is installed on two plots one of which will be shallow moled at 2-3 year intervals to relieve compaction and improve hydrological efficiency. The project is being installed at two sites (Kilmaley and Laragh) and there are two replications on each site: twelve 0.25 ha plots per site.

The plots will be grazed continuously and grass production, grazing days and ground conditions will be monitored. Hydrological measurements include continuous water flow recording (Talman 1979) and watertable measurements on a number of maximum-reading piezometers (Davies 1969). These piezometers are read at 2-3 days intervals and the ground scoring is recorded at the same time. The collector drains and disruption treatments were installed at the Kilmaley site in August 1984. It was re-seeded in August 1986 and will be grazed in 1987.

The collector drains were installed at Laragh in July 1985 but the disruption treatments have not yet been installed due to unfavourable weather and soil conditions. However, sacrificial moles were installed at the full 450 mm depth on the mole and gravel mole plots in September 1986 at a time when the soil conditions were too wet for adequate shatter. It is hoped that the moles will speed up the drying process on these plots during the early part of 1987 and thereby improve the effectiveness of the shatter achieved during the installation of the moles and gravel moles.

5.3.1 Kilmaley measurements

Piezometric measurements at Kilmaley during 1984-85 and 1985-86 indicate that all the drained plots are giving effective watertable control throughout the year, whereas the watertable on the undrained control is at or near the ground surface for extended periods. There has been no major fall-off in the effectiveness of any of the drainage treatments over the two-year period. This is borne out by the SEW(30) figures in Table 4 which show no major increase in SEW values on any of the drainage treatments. The flow hydrographs confirm that no major breakdown has occurred as yet even though site excavations and surface observations indicate that moles have deteriorated substantially in places.

Table 4 SEW(30) figures for Kilmaley 1984-85 and 1985-86

	1984-85	1985-86
Control	3,188	4,802
Shallow moles	1,005	1,093
Gravel moles	160	177
Moles	467	477

This was evident during re-seeding (August 1986): small areas randomly distributed through the mole drained plots were wetter and softer than the general drained area. Observations carried out by excavation and examining the moles and shallow moles have shown that the deep moles contain substantial quantities of slurried soil and appear to be failing by unconfined swelling. Occasional total blockages were encountered but in the majority of moles examined, the channels were still capable of transporting water. The shallow moles are in a better condition and contain comparatively little slurry. There was evidence in some of the shallow moles that the complete roof had dropped down without collapsing leaving an elliptically-shaped channel (width greater than height). This is typical of the disturbance that occurs when moles are installed slightly above the critical depth. Continued hydrological observations and production data from Kilmaley and Laragh should provide basic information on the cost effectiveness of the various disruption systems.

6 Acknowledgements

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Drainage development in Belgium

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1 Introduction

Subsurface drainage is widely applied in Belgium in the low lying, flat agricultural lands and the valley bottoms for better crop production, trafficability and workability. The scientific design for drain spacing is mainly based on Dutch knowledge and experience, and due to the geographical and climatological similarity the same drainage criteria as proposed in the Netherlands are accepted.

Not only from the design point of view, but also the materials and equipment used to install subsurface drains are strongly controlled by the changes in drainage technology in the Netherlands. Most of the pipes installed in Belgium are imported either from the Netherlands or West Germany. Some 25 years ago Belgium started to produce clay pipes to compete with the bulk volume imported. Since the introduction of corrugated plastic tubing those small plants disappeared soon, and only since 1984 Belgium is producing small diameter corrugated pipes, used as field laterals. Recently this industry has the capacity to wrap the pipes with envelope materials. Up to now, the larger diameter pipes are still imported. Most of the Belgian contractors use drainage machinery manufactured in the Netherlands. In addition it can be stated that, due to the proximity of the Netherlands, being Belgiums northern neighbour, quite a volume of drainage work is being done by Dutch contractors.

Summarizing it is a fact that drainage development in Belgium has been strongly influenced by the changes in drainage technology in the Netherlands, primarily due to the geographical situation of both countries and in the second place due to the world leading role Dutch scientists have played in field drainage.

2 Analysis of the area drained and prospects for the future

Most of the drainage activity in Belgium is directly or indirectly supervised by the Nationale Landmaatschappij, which main task is the re-allocation of farm land. Within the re-allotment projects executed by the Nationale Landmaatschappij subsurface drainage is installed where the low productivity of the soils is due to high watertable conditions or poor drainability of the profile. According to their information the total area drained in re-allotment schemes amounts to 23 000 ha by the end of 1984. In 1985 about 1500 ha was drained and it is estimated that the area drained in future will be in between 1 500 and 2000 ha per year. The rather low intensity with which the area potentially suited for drainage is drained, is due to the current economic recession and the introduction of production quota's by the EC policy. The distribution of the areas drained through the Nationale Landmaatschappij are given in Table 1.

Table 1 Areal distribution of the drained land in Belgium

Province	Drained area (ha)
West-Flanders	9,801
East-Flanders	6,966
Brabant	2,809
Antwerp	572
Limburg	97
Luxembourg	793
Liège	58
Namûr	1,751
Hainaut	145
Total	22,992

(Source: Nationale Landmaatschappij)

Information about privately installed subsurface drainage is very scarce. Some sources estimate the total drained area installed between 1960 and 1977, including the land area drained by the Nationale Landmaatschappij, at 49 000 ha. Assuming a yearly growth since then of about 1500 ha some 60 000 ha should have been drained by 1984. According to previous hypothesis the land drained by the Nationale Landmaatschappij should only represent about 1/3 of the total land area drained. This seems to be rather small, because the already drained zones in the re-allotment areas are generally negligeable.

The size of the provinces are not that different to explain the differences per province in area drained in Table 1. The main reason for the relative large area drained in both West- and East-Flanders is the specific land use, which is mostly arable land. In the province of Antwerp and Limburg to the contrary, most of the sandy soils with shallow watertable are used as pasture, now gradually being converted for the production of fodder maize. Notwithstanding the current slow trend in drainage activity in Flanders, where only about 10% of the drainable land is drained, it is expected that interest in subsurface drainage will increase due to an increased interest in the growth of field vegetable crops used for fresh consumption and canning industry. The expansion in the sandy region will depend mainly on the long term effect of the milk quota measure on farm activity.

The area drained in the southern part of Belgium, so-called Wallonia, is small in comparison with the area drained in the northern part of the country. This can be explained by the difference in geology, topography and land use. The arable soils, where mainly the field crops winter wheat, sugar-beets and barley are grown in rotation, are composed of deep permeable loam with the watertable beyond the influence of the root zone. The plateau soils in the far south are used as pasture land or covered by pine forest. The drained soils are mainly meadows in the valley bottoms eroded by the numerous meandering rivers. Here the lay-out of the drainage network is strongly influenced by local topography, and consists primarily of single lines of pipe draining wet patches in the field.

Generally it can be stated that with a yearly growth in drained area of about 1500 ha and an expected life-time of 25 to 50 years, the effectively drained area in Belgium will never exceed 20 to 35% of the 300 000 ha, being the total area in Belgium which needs drainage.

3 Drainage criteria

An important aspect concerning drainage systems is the ability for the designer to determine the appropriate dimensions because it is those which count for the quality of the installation as well as the economic acceptability of the investment. Notwithstanding theoretical insights and practical relationships concerning models for unsaturated and saturated flow, that describe the infiltration and drainage processes, and models for the approximation of the discharge process of simple and more complex drainage units, have become available, drainage design in practice is mainly based on the application of Hooghoudt's equation. The reasons for the wide use of this equation are probably its simplicity and effectiveness. The equation involves the selection of two parameters only, rainfall intensity (q) and watertable depth (H) at mid-drain spacing. Last parameter determines together with the drain level (d) the steady height (h) of the watertable above drain level. Commonly applied values for these parameters are represented in Table 2. They originate from field experiences and research work performed in the Netherlands.

Table 2 Design criteria for rainfall intensity and watertable depth at mid-drain spacing

Land use	Discharge rate $q(mm.d^{-1})$	Watertable depth H(m)	Watertable head h(m) for d = 1 m*	Ratio h/q(d)
Pasture	7	0.3–0.4	0.7–0.6	100–85
Field crops	7	0.4–0.5	0.6–0.5	85–70
Vegetables	7	0.6–0.7	0.4–0.3	70–60

* d = drain level of 1 m below surface

The h/q ratio is considered as the drainage criterion for steady state drainage equations; the lower its value, the closer the drain spacing. In the case of a non-steady state approach the drainage criterion is specified by the required recession rate of the watertable at mid-drain spacing within a given period. The design criteria as specified in Table 2 are typical for the wet conditions in winter which approach nearly steady state. Evapotranspiration is negligeable and the rainfall is fairly uniform distributed in time. In addition it can be assumed that by the end of November soil water has been replenished, so that storage variations are minimal. To solve under those conditions Hooghoudt's equation the following soil information is required: the saturated hydraulic conductivity of the soil profile below the watertable and the level of the impervious layer. Last information is either derived from the soil map on scale 1/20 000, which is almost entirely published for Belgian territory, or from local field investigations. Traditionally the hydraulic conductivity is determined in situ with the auger hole method. Distinction is thereby made in the determination of the saturated hydraulic conductivity above and below drain level. The number of observation holes for the determination of the hydraulic conductivity varies according to the project size and the heterogeneity of the soil pattern. For small projects, from 10 to 15 ha, 3 to 5 auger holes are made.

Subsurface drainage originally was planned to control the watertable depth during the winter period. Nowadays more and more attention is paid to keep the water content of the plough layer below a critical threshold value for satisfying workability and trafficability of the soil during late harvest period and early spring, when sowing and pre-emergence treatments are carried out. Drainage systems designed for those periods are often called off-season drainage systems and the criteria specified in Table 2, typical for winter conditions, do not hold. For off-season drainage preference is given more and more to criteria for the non-steady state approach. The criteria are a depth criterion for the watertable at mid-drain spacing and a frequency of exceedance during harvest or seeding time. The watertable depth is defined in relation to the threshold value of the water content of the top layer. Those relations which are soil dependent, are found empirically. If the non-steady state approach is used in the design phase, the designer calculates the watertable elevation during the critical period for different drain levels and drain spacings. The drainage intensity which meets the specified criterion is normally installed.

Other problems encountered in drainage design are the likelihood of change in land use when the economical conditions are favourable, and the parcelling of the land. The fields of a farmer seldom are united in one block. The only way to test various geometric variants is with the aid of an interactive computerized design approach. In that way it becomes feasible to make a design tailored to the exploitation and at the same time optimally integrated in the main drainage system. Under the conditions that the land use is likely to change it is preferable to use the most stringent design criteria.

4 Drainage materials and machinery

The formerly used clay pipes are, in Belgium at least, completely replaced by corrugated plastic tubes. Smooth, rigid plastic pipes have not been used to a great extent at all. The corrugated plastic tubes used as field laterals have an outside diameter of 50 mm, equal to the inside diameter of the clay pipes. In spite of their smaller dimension it has been experimentally proven that corrugated tubes are more effective than clay pipes due to the more uniform pattern of perforations. In flat areas the laterals are normally oriented to use the available field slope and the main or collector lines are oriented parallel to the natural water ways. As a consequence of field size, field slope and nominal diameter of the laterals, their length is restricted to 150 and 200 m. Collector drains have diameters up to 200 mm and their length is in principle unrestricted. In practice too long collectors are avoided by junction boxes.

The main envelope material used in the past was coconut fibre, but flax straw was also successfully applied. Glass fibre sheet and glass wool were also used but their susceptibility to blocking and clogging, especially in soils with a high clay and/or silt content or rich in organic dust or where iron deposits occur, has cancelled their use as a drainage envelope. Other materials have been experimented, but for one or another reason they have never been accepted by designers or contractors. Under certain profile conditions coconut fibre and other organic envelopes can decay very rapidly. For those conditions, loose synthetic fibre envelopes are recommended. A newly applied envelope material is a mat of polypropylene fibre, a waste product of the carpet industry. The mat should meet following specifications: a mean thickness of 6 mm and a minimum thickness of 5 mm; a mean weight of at least 450 $g.m^{-2}$ and a minimum weight of 400 $g.m^{-2}$; the 90% pore size diameter as a mean of 5 replications should be in between 600 and 1000 micron, whereby each individual pore diameter should not deviate more than 25% from the mean. The only disadvantage of this synthetic envelope is its price, which is far higher than the price of coconut envelopes.

In spite of the availability of a wide range of envelopes, the problems of silting up of drains and clogging due to iron deposits still exist. The mechanism of envelope materials is not fully understood. Particularly with regard to the interaction between soil conditions, clogging and decay of the envelope further research needs to be done. It is still very risky to predict the structural stability of the soil in the trench, the need for envelopes and hence the type of envelope.

Nowadays drainage in Belgium is installed by modern trenching machines with digging chain, and trenchless machines with ripper or V-plough originating from the Netherlands and West-Germany. Where depth regulation in the past was done manually by the machine operator, keeping a reference mark on the digging part of the machine fixed on a sightline visualized by stakes, now only laser equipment is used for depth regulation.

5 Cost evolution of drainage

Information on the cost evolution of subsurface drainage with a regular parallel layout, the laterals discharging into an open collector, was supplied by the Nationale Landmaatschappij from their archives of tenders. The total cost price, expressed in Belgian franc per meter, includes the cost of drain pipe, the envelope and the installation costs. Each of those items represents about 1/3 of the total cost. The prices given in Figure 1 hold for simple drainage systems with coconut fibre or flax straw as envelope and for a minimum project size of several hundred hectares. Drainage investments on request of individual farmers can be expected to be about 50 to 100% more expen-

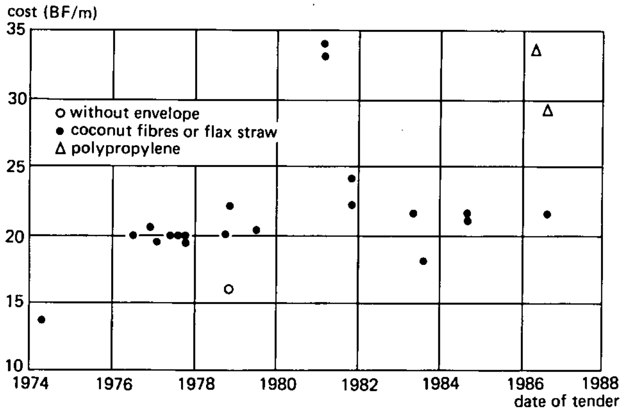

Figure 1 Cost price of parallel drain systems Source: the tender archives of the Nationale Landmaatschappij, Brussels, Belgium

sive. Figure 1 reveals that the unit cost price of parallel drain systems with either coconut fibre or flax straw as envelope did not vary much during the past decade, with the exception of the steep price increase around 1981. Figure 1 illustrates also the effect of envelope material on the total unit price.

During the period covered by Figure 1 the subsidy on drainage works executed within the context of re-allotment schemes decreased from 60 to 45%. Drainage works supervised by the administration of municipalities, polders or 'wateringues' receive a subsidy of 30% if the design is made by an authorized consulting office. Unfortunately it takes 2 years on the average from the start of the project before the drains are installed. Due to the administrative delay and the expense of the consulting office the benefits of the subsidy are often gone before the first drain tubes are installed. As a consequence more and more farmers prefer to drain their land by private enterprise, thereby loosing the grant of the local authorities. In practice most farmers ask a contractor to drain their land without any investigation of the site. Drain spacing and drain depth are based on soil type, land use and local experience. Although the cost per meter pipe almost doubles when installed by private enterprise, the farmer immediately profits from the advantage of drainage.

6 Drainage maintenance

Although maintaining properly designed and installed subsurface drains not difficult, maintenance is frequently neglected in Belgium. Only when severe siltation problems occur, drain pipes will be cleaned by flushing. Broken outlets are seldom repaired, unless waterlogging is hindering normal farming operations. Generally Belgian farmers consider drain pipes as free of maintenance.

7 Conclusions

Drainage development in Belgium has been and will be strongly influenced in future by the evolution of drainage technology in the Netherlands. The obvious reason is the nearby location of the Netherlands and the similarity, in particular for Flanders, of climate, soils, agrohydrological conditions and farming practice. In addition the public funds allocated for drainage research will never allow the development of a typical Belgium drainage profile. The only research being done and receiving international recognition, is the study of envelopes, their short and long term performance. To a lesser extent research has been done with regard to the development of a computer aided design package for use on personal computers. So far a software package for drain design on a main frame computer has been established. It is not expected that in the immediate future new areas in drainage research will be explored.

Drainage in Denmark
Developments and prospects for the future

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1 Introduction

Denmark covers an area of 43 032 km², of which approximately 29 000 km² is agricultural land. Subsurface drainage in Denmark was initiated in the middle of the past century, and since then about 15 000 km² or nearly half the agricultural area has been drained. A State Act authorising subsidies for drainage and soil improvement and the general economical situation for agriculture have been of great importance for drainage activities. In the past 25 years the drainage activity has been relatively low, and only 5 to 10 000 ha has been drained annually. In order to meet the demand for new drainage, re-drainage and spot drainage some 20 to 30 000 ha ought to be drained annually. A surplus in agricultural production, a public demand for nature resources and for extensive use of low lying wetlands and marginal agricultural land, point towards and even more reduced drainage activity in the future. Still a great effort has to be made to increase drainage activities in order to maintain well-drained agricultural land with a good potential for cropping and farm production in the future.

2 Climate

The climate is temperate and influenced by the close coastal position. Annual rainfall varies from 550 to 760 mm with an average of 660 mm. The actual evapotranspiration is on an average higher than the amount of precipitation during the summer months, and in this period there is a rain deficit. From August to April there is a precipitation surplus for replenishing soil water, for groundwater recharge and run-off. The annual precipitation surplus varies from province to province between approximately 310 and 400 mm. The groundwater recharge and run-off amount to about 280 mm annually on an average.

3 Landforms and soils

The country can be divided into 9 different landforms (Holst & Madsen 1986):
1. Old morainic areas from the Saale glaciation period;
2. Young morainic areas from the Weichsel glaciation period;
3. Outwash plains from the Weichsel period;
4. Dune sand areas;
5. Old marine deposits (yoldia) from just after the Weichsel period;

6. Marsh areas;
7. Younger marine deposits (littorina) and recent marine forelands;
8. Rocky areas;
9. Areas below sea level.

Figure 1 shows the distribution of landforms in Denmark.

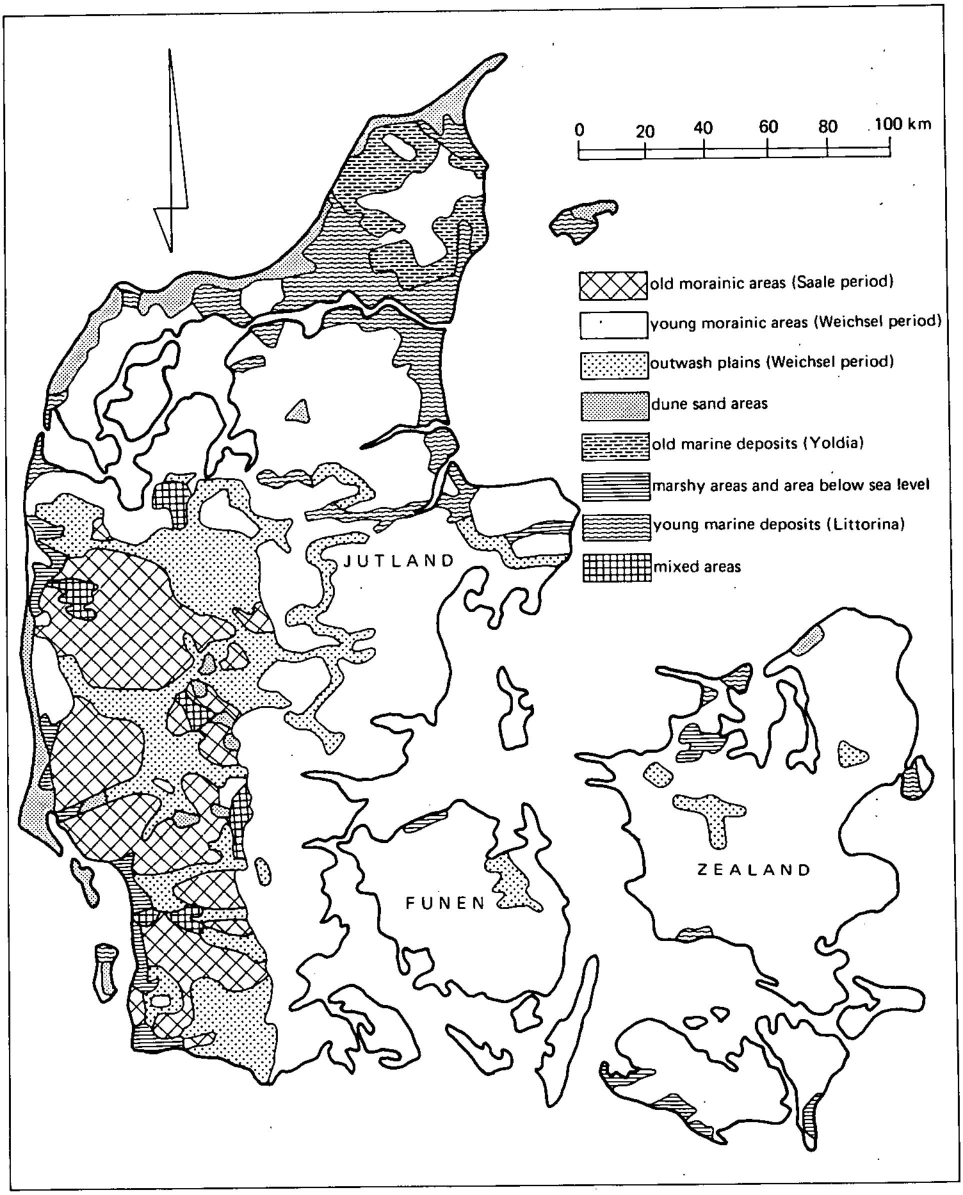

Figure 1 Landforms in Denmark (Holst & Madsen 1986]

An outline of clayey and sandy subsoils in non-marine deposits from the geological map shows that areas with clayey subsoil are mainly situated in eastern Denmark in young morainic areas. Areas with clayey subsoils cover roughly 40% of the country. The main part of Jutland has a sandy subsoil (Holst & Madsen 1986).

In 1975 a nation-wide soil classification of Denmark was initiated and was completed in 1980. The definition of soil types is shown in Table 1.

Table 1 Soil classification of Denmark: Definition of soil types (Anon 1982)

Map colour code	Soil type	JB-nr.	Percentage by weight				
			Clay $<2\ \mu m$	Silt 2-20 μm	Fine sand 20-200 μm	Total sand 20-2000 μm	Humus 58,7% C
1	Coarse sand	1	0- 5	0- 20	0- 50	75-100	
2	Fine sand	2	0- 5	0- 20	50-100	75-100	
3	Clayey	3	5- 10	0- 25	0- 40	65- 95	
	sand	4	5- 10	0- 25	40- 95	65- 95	
4	Sandy	5	10- 15	0- 30	0- 40	55- 90	$\leqq 10$
	clay	6	10- 15	0- 30	40- 90	55- 90	$\leqq 10$
5	Clay	7	15- 25	0- 35		40- 85	
6	Heavy	8	25- 45	0- 45		10- 75	
	clay or	9	45-100	0- 50		0- 55	
	silt	10	0- 50	20-100		0- 80	
7	Organic soils	11					>10
8	Atypic soils	12					

The classification was primarily based on samples of the ploughlayer and samples from 35 to 55 cm depth in the subsoil. Sandy soils dominate in the western and northern part of Jutland. Clayey soils dominate on the islands and in the eastern part of Jutland (Anon 1985). Table 2 shows the distribution of the soil types represented by Map Colour Codes 1-8 in Table 1.

Table 2 Area distribution for soil types in Denmark (Anon 1985)

Map colour code	Soil type	Area (ha)	%
1	Coarse sand	808469	23.5
2	Fine sand	338349	9.8
3	Clayey sand	964367	28.0
4	Sandy clay	843780	24.5
5	Clay	211893	6.2
6	Heavy clay or silt	27643	0.8
7	Organic soils	237442	6.9
8	Atypic soils	8285	0.2
		3440228	100.0

Map Colour Codes 1-8 represents 80% of the total Danish area. In the 1980's great interest and effort was given to map the iron sulfide containing soils in Denmark and to examine the effects of drainage of these soils. Madsen et al. (1984) classified the potentially acid sulfate soils in Jutland into 4 classes and described the mapping of the areas. The potentially acid sulfate soils in Jutland cover 1 429 km^2.

4 Areas drained and investigations on drainage classes

The drained area in Denmark was not completely recorded in the past. Aslyng (1980) described on the basis of available data the drainage activity from the middle of the last century up to 1980. Figure 2 shows the results found for the drainage activity and the drained areas in Denmark.

Agricultural land can be divided into drainage classes according to the frequency of areas with a potential need for drainage. Table 3 presents the drainage classes as defined by the Bureau of Land Data, Ministry of Agriculture (Anon 1985).

Table 3 Definition of drainage classes

Drainage class	Potential need for drainage (%)
1	75–100
2	50– 75
3	25– 50
4	0– 25

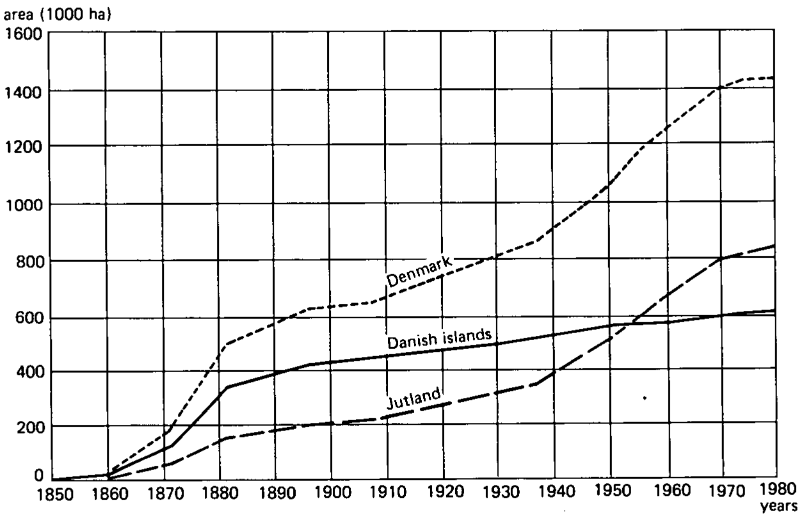

Figure 2 Area drained on the Danish islands, in Jutland, and in Denmark

Table 4 presents some results of the drainage classification (Holst and Madsen 1986). The areas were classified according to their need for drainage that depends on excess of water and soil texture.

Table 4 Drainage class areas for Denmark

Drainage class	Total area (km^2)	Percentage of classified area
1	16,234	47
2	5,047	15
3	8,721	25
4	4,509	13
Not classified	8,495	–

Class 1 areas are mainly situated in the eastern part of Denmark, while Class 2 areas are mainly small areas widely spread over this part of the country. Class 3 areas are mainly found in the northern and western part of Jutland and Class 4 areas are mainly situated in western Jutland.

5 Drainage methods and materials

Most drainage was carried out 'traditionally' in the past 25 years by means of backactors or trencher drainage machines. Trenchless drainage machines were introduced in Denmark in 1971 and since then approximately 10 to 15% of the annual drainage work has been carried out by these machines.

The development from the start of the 1960's until today has brought progress, and the appearance of new materials and machinery has had a great impact on drainage. We have seen the end of the period, when drains were laid exclusively by hand, and the introduction of new and better backactors. Trenching and trenchless machines were introduced, and the laying technique became more mechanized. The use of clay pipes and concrete pipes dominated the drainage market during the 1960's. During the 1970's PVC-drain pipes were introduced. The smooth-walled rigid plastic pipes with saw splits were not much used in drainage projects in Denmark. From the end of the 1970's till now the corrugated PVC-pipes developed from a supplementary to a dominating position on the drain pipe market. Concrete pipes are still widely used in drainage plans for collector drains. For laterals and minor collector drains corrugated PVC-pipes are almost exclusively used. Several materials have been used as drain envelopes e.g. fibrous peat, sawdust (from conifer) and synthetic materials. Nowadays a combination of a thin synthetic sheat beneath and a voluminous material (sawdust or gravel) along and over the pipe, is very often chosen for drain envelope. Prewrapped corrugated PVC-pipes with thin synthetic sheet materials are used too.

In field experiments on different Danish soil types several combinations of pipe envelope material and laying techniques were tested. Experiments with trenching and trenchless machines and drainage materials on moraine loamy soils (Waagepetersen et al. 1983) showed a trend, that pipes laid by the trenchless method had a lower efficiency than pipes laid by the trenching machines, but the difference was not significant. In some experiments drains laid by the trenchless method had a lower efficiency during the first 2 to 3 years and attained later on maximum efficiency.

Drainage experiments on ochreous and sandy soils showed, that the use of suitable pipe and envelope material is of vital importance for drain efficiency. Andersen (1976, 1979) found in some instances clogging of thin synthetic envelope materials, when they were used in ochreous sandy soils. Drain pipes enveloped with a combination of synthetic sheet and sawdust showed a decreasing efficiency too during the experimental period, presumably because of the silt deposits in the envelope materials. From measurements in the zone close to the drain pipe it could be seen, that the entrance resistance of envelope and pipe decreased about 50% by utilizing voluminous envelope materials. Regular flushing was essential for maintaining drain efficiency. Grant (1986) described experiments with drainage materials and submerged drains on ochreous sites. The problems with ochre clogging of perforations were minimized by using drain pipes with large perforations, up to 3.0 mm. Analysis of the soil texture at drain depth showed that it was necessary to protect the drains against siltation by fine sand (Figure 3).

On the experimental site, comprising a fine sandy soil with a low content of clay and organic material and a high hydraulic conductivity, the choice of envelope material was less important. In some cases ochre formation decreased by submerging the drains.

The comprehensive research on drainage and the practical experience gained over the last decades form a valuable base for design and supervision of practical drainage work.

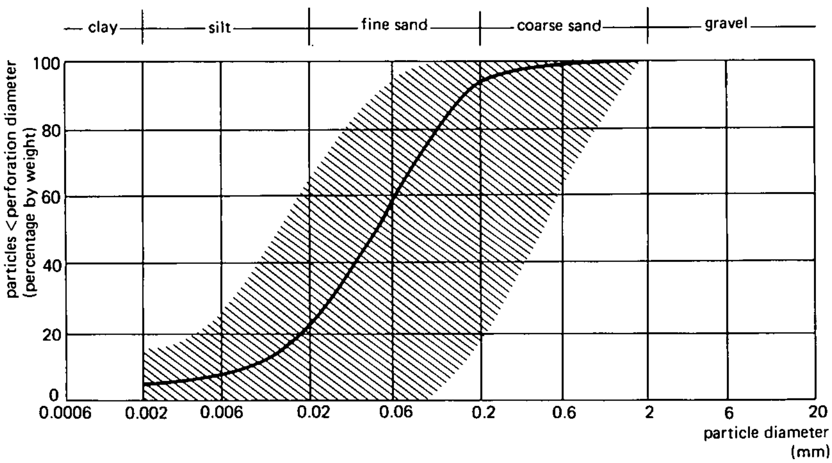

Figure 3 Soil texture at drain depth: within the shaded area there is a risk of silting up drains (Grant 1986

6 Practical drainage

The preliminary investigation, planning, design and supervision are carried out by a private enterprise. The execution of the drainage work is done by private contractors. Each drainage project includes investigations on topography, soil and hydrology. These preliminary investigations form the base for planning and elaboration of the drainage projects.

The drainage systems in Denmark are normally designed for a discharge of approximately 1 l/sec/ha (8.6 mm/day). Locally a higher discharge may be needed. During the discharge period the average drain discharge is often less than 0.1 l/sec/ha and the maximum discharges are often between 0.3 and 0.5 l/sec/ha (Aslyng 1980). Maximum discharges in magnitude of 1-1.5 l/sec/ha may occur.

Drain spacing and depth are chosen according to soil type and hydrological conditions. The choice is normally based on experience and knowledge of drainage on similar soils. In special cases the hydraulic conductivity is measured, and the theoretical equations are used. In mineral soils the drain depth is often 1.0 to 1.2 m and spacing 10 to 40 m varying with soil texture, structure and hydraulic conductivity of the soil. Organic soils are often drained at a depth of 1.3 to 1.5 m and a spacing of 14 to 40 m.

The use of envelope material is estimated from experience and soil texture. An envelope with thin synthetic sheet beneath and sawdust along and over the pipe is very often used.

In some parts of the country artesian water occurs and special interest has to be paid to investigations and drainage design (Stisen & Mortensen 1981). The areas are drained by a combination of horizontal and vertical drainage. Usually 10 to 20 vertical drains per ha are made with a contact to the artesian aquifer and these vertical drains are connected to horizontal outlet pipes. A minimum depth of 1.5 m for horizontal pipes is preferred. The discharge from artesian water drainage varies, but is often between 0.2 and 0.6 l/sec/ha (1.7-5.2 mm/day), although values up to 5.0 l/sec/ha (43.0 mm/day) are recorded.

The drainage technicians base their design and solutions on investigations concerning soil- and hydraulic properties, drainage criteria, depth and distance of drain pipes, materials, methods and cost-benefit analysis. The drainage plan is marked out in the field, and the technicians elaborate working lists for the contractor. The technician supervises the carrying out of the drainage work and inspects the work when completed. Statements of account complete the drainage project.

7 Conclusions

In the past decade great efforts have been made for the survey and mapping of Danish soils, and the investigation on drainage and drainage classes. The results are used in public planning and legislation.

The substantial research on drainage and the practical experience gained over the last decades, together with new material and machinery, holds a promise for the elaboration of future drainage plans. Research on drainage criteria and crop water relations could be extended in the future.

In order to maintain well-drained soils with good potential for cropping and farm production, efforts must be made to increase the drainage activity. Public understanding for the conditions of agricultural production, legislation and planning, will influence considerably the drainage activity in the future.

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The development of drainage in Hungary

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1 Historical evolution

The history of drainage in Hungary goes back to the last century, when it was closely linked to those immense works of river regulation and flood protection which have transformed the Hungarian Plains from wetland to a fertile agricultural area. The proprietors of land that was no longer exposed to flooding, formed polder societies for the construction of drainage systems in order to remove also excess precipitation from local origin. This was necessary since the natural drainage of these areas through dead river branches and channels was cut off by the construction of dykes, so that canal networks had to be dug and their collected water to be lead, or lifted into the rivers. As potential evapotranspiration in these plains largely exceeds precipitation, and the supply of external water from the flooding rivers had been excluded, the groundwater table has generally sunk well below the root zone. The constructed drainage canals did not therefore serve in the long run for groundwater level regulation, but rather for relieving the arable land of logging surface waters originating, mainly in the spring period, from unfavourable infiltration conditions of the upper soil layer. This defined for about a century the objectives of drainage which was exclusively performed by open canals.

With increasing demands from agriculture for reducing, both in extent and in duration, harmful waterlogging, denser networks (expressed in km/km^2 values) of larger canals with greater capacity pumping installation (expressed in l/sec/ha values) have successively been realized.

However, this intensification of the drainage capacity reached its own limitations, when the large scale mechanization and chemicalization of agriculture in the last two to three decades presented qualitatively new demands on drainage. Large scale farming requires that the plots of large size should show uniformly favourable conditions with regard to timely cultivation with heavy machinery, i.e. no waterlogged or soaked soil patches could be tolerated. This means on the one hand that the drainage of heavy soils today has to secure, besides the removal of surface waters, a favourable regime of soil water throughout the root zone. On the other hand, it became evident that since the given sizes of large plots the density of the open canal network was limited, and no further increase of the l/sec/ha drainage capacity would solve this problem.

The requirement of forming big plots with uniformly favourable soil water conditions has drawn attention to the idea of providing subsurface drainage for the logging surface waters. This has lead to the introduction of pipe drainage, primarily for soil water regulation and aeration, and only at very few places for groundwater level lowering as the latter lies generally deep enough. Pipe drainage, as a required supplement in certain areas to the country's generally intensive surface drainage systems, has thus gained space and its further development can be expected.

The development of the country's drainage systems in the last decades is shown by the data of Table 1, and the development of pipe drained areas within the same in Table 2.

Table 1 The development of the country's drainage systems in the period 1960-1980

Year	Total length of drainage canals (km)	Total capacity of drainage pumping stations (m^3/sec)	Specific drainage capacity (l/sec/ha)	Drainage water storage capacity (million m^3)
1960	24 900	443	0,16	150
1965	27 700	503	0,22	180
1970	32 800	618	0,24	232
1975	36 000	645	0,26	260
1980	42 000	690	0,29	300

Table 2 The development of pipe drained areas within the country's drainage systems in the period 1977-84

Year	Area (ha)
1977	4 452
1978	5 427
1979	7 078
1980	6 393
1981	10 635
1982	14 117
1983	19 559
1984	21 184

2 Drainage criteria in relation to various types of land use

As can be seen from the foregoing, the fundamental reason for drainage in Hungary is the harmful saturation of the root zone that occurs temporarily under certain meteorological conditions, and has in general no direct relation with the rather deep groundwater table. This also defines the drainage criteria in relation to land use: in agricultural areas the plant's tolerances to excess waterlogging on the surface and/or saturating the root zone, define the drainage criteria. This recognition has lead to practical research on the matter, performed primarily by VITUKI, the Research Centre for Water Resources Development, in the Mirhó-Gyolcs experimental basin, which resulted in tables giving percentage losses for various crops exposed in different months of the year during different periods to excess water.

Knowledge of the tolerance of crops to excess waterlogging on the surface or saturating the rooting zone, has provided the planners of drainage facilities with sufficient information for their work.

On account of this information, the drainage criteria have been expressed by the number of days within which excess water should be eliminated. Under the prevailing hydrological conditions this has lead to a required drainage capacity around 0.3-0.4 l/sec/ha, a value that has by and large been attained in the country's flat areas. However, to render this drainage capacity effective in all parts of the large plots used in present day farming, supplementary pipe drainage proves useful, as explained above, and a decision for the latter is based on the characteristics of the soil.

3 Machines and materials used in constructing drainage systems

The open canal drainage systems of the country are the results of historical development. The bulk of the canals were dug by manual labour in the past, but their extension in the past decades was realized with various types of hydraulic excavators.

For the pipe drain systems that gain increasing importance, exploratory work helped to find effective and economic solutions. Pipe drainage that serves for soil water control and aeration, requires loose backfill material above the pipes; additional subsoiling and/or mole drains are also required.

After an initial period in which tile drains were used, the use of polyethylene pipes with proper filtering has gained increasing importance. With regard to backfill material, various experiments on mixing sand, ash, perlit, organic remains, etc. with the earth used for backfill have shown good results. Concerning the material for pipe drainage, considerable literature as well as officially established standards are available in the country.

It is evident from the foregoing that properly prepared backfill material plays a crucial role in soil water regulation and aeration. The execution of drainage systems will consist of opening trenches, laying down the filtered pipes and filling back the properly mixed earth above them. This implies that machines which can be practically used in these operations, various types of trench opening and pipe laying-machines, earth mixing and refilling machines, as well as those required for complementary mole drainage and subsoiling are important for pipe drainage in Hungary. Trenchless drain laying machines can effectively be applied in the country only at those relatively rare places where the harmful saturation of the rooting zone is caused by seepage. In areas with waterlogging due to inundations, trencher machines can be used.

The greater part of the used machinery has been imported, and only some of the complementary equipment is manufactured in the country. Imports came from the Soviet Union, the U.S.A., the GDR and, more important, the FRG with Hoes Super Gigant-523, Gigant-585 and Super-Dränpflug 783 and the Netherlands with Draientie D 16 as the main types of imported machines. Connections with the Dutch Steenbergen company gained importance in the past years and widened the range of available drainage machines.

4 Cost development of drainage

When drainage activities in Hungary were started, mainly in the 19th century, it was a necessity to convert marshlands to agricultural areas, and cost was hardly taken into account. Such considerations came up in the 1950's, when the level of drainage had become high enough to raise questions of economy. Then a method was elaborated for determining the 'economic specific drainage value' of drainage systems expressed as q in l/sec/ha. On the one hand all the drainage facilities such as canals, their pertaining structures and pumping station, were dimensioned with q_1, q_2, ... q_n specific values and the involved costs were calculated. On the other hand, detailed investigations were made as to the damages due to waterlogging which would still occur for the same q values. Cost-benefit calculations performed for the q_1, q_2, ... q_n values have finally determined the optimum degree of development. The consulting engineering firm VIZITERV, specialized in hydraulic design, is applying in its practice a method based on the same principles.

In order to lower the cost of pipe drainage, the aim is to utilize the imported machines as much as possible to render their purchase profitable. Owing to the character of drainage problems in the Hungarian Plains, it is important to provide aerating-type pipe drainage to those areas only where significant amelioration of the farming conditions can be expected. The 'benefit' side of the cost-benefit investigations should therefore be studied with great care, in order to avoid misleading results concerning the economy.

5 Project organization and management

In Hungary drainage activities are considered as a part of the complex amelioration measures to secure optimum farming conditions. These measures include, besides drainage, physical planning, soil improvement and soil protection. Drainage itself is interpreted in the broad sense described above, including open canal systems, pipe drainage, mole drainage and subsoiling. These works belong to the competence of OVH, the National Water Authority for the water side and MEM, the Ministry of Agriculture and Food Industry for the farming side, whose close co-operation for the implementation is foreseen.

Effective organization and management of drainage projects is executed on three levels. The state is providing the main drainage systems, the system of main canals with their structures and pumping stations, for which the responsibility belongs to the National Water Authority, and the Regional Water Authorities under it. The second level consists of the polder societies, constituted by the interested parties such as state farms, agricultural co-operatives, etc. of the subregion or polder. They are responsible for inter-farm drainage facilities, secondary canals with their structures and stationary or mobile pumping equipment, and for works requiring greater investment, like the purchase of machines and the execution of pipe drainage. The third level are the land owners such as state farms, agricultural co-operatives, etc., who must secure the drainage of their individual plots by constructing the tertiary canals, subsoiling, etc. in co-operation with the polder society. A higher level in this hierarchy also means supervision of the work done at a lower level. The Ministry of Agriculture and Food Industry is also closely linked to these works, mainly to help in planning farm activities by its specialized agency responsible for plant protection and agrochemistry (MEM-NAK).

The costs of works at each level are borne by the same level, the state, the polder societies, and the land owners. However, state subsidies can also be granted to lower levels, if their own funds are inadequate to complete vital works. Subsidizing is generally planned to stimulate own initiatives and to supplement own investments at lower levels.

6 Maintenance of drainage projects

Since the responsibility for drainage activities is distributed among three levels, the maintenance of the installations also remains their task. The maintenance requires at all levels an annual budget and proper machinery for implementation. As for the state level, the Regional Water Authorities are provided with the required funds to buy dredging machines, ditch cleaning machines, etc. and to secure by regular maintenance the proper functioning of the main drainage systems. The polder societies, which procure in increasing numbers machines of their own and together with the farm level who look after the tertiary installations, provide for the maintenance of the canals, structures, etc. that join the main drainage systems.

The machinery used for maintenance includes special complementary equipment for application with universal tractors such as grading, dredging, mowing, cultivating, etc. and with hydraulic dredging machines. Further, special floating machines are used for mowing the vegetation in canals, others for removing silt from the canal bottom by hydromechanization. Some of these machines are imported from the Netherlands, Poland, etc. but many of them are manufactured in workshops belonging to the National Water Authority.

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Conception and evolution of drainage projects in Romania

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Romania is characterized by a large diversity of geomorphology, hydrography, lithology and soil. The climate also shows a considerable annual and seasonal variation, especially in the alternation of dry and wet periods. Therefore the soils differ much in their yield capacity and present many reclamation problems:
- 2.5 million ha must be protected from inundation;
- 5.35 million ha suffer from excess water and require surface and subsurface drainage works;
- 5.5 to 6.0 million ha are frequently affected by water deficit and may benefit from irrigation;
- 5.5 million ha of sloping lands are threatened by soil erosion;
- 450 000 ha of salty soils and 400 000 ha of sandy soils require soil improvement (Agricultura Socialista).

In the past, due to the historical and socio-economic conditions of Romania at that time, the execution of large reclamation works was not possible. Nevertheless, interesting reclamation vestiges exist in different countries of ancient Dacia and the Romanian principalities. Records show that in the first century B.C. the Dacs in the Cris and Barcau valleys used to build dykes for protection against inundations as well as enemies. Canals in the Hateg country (Tara Hategului) used for drainage as well as irrigation date back to the second and third century and drainage works in the Birsa Depression to the thirteenth century. Since the fifteenth century documents record the existence of many small water accumulations (fish-ponds) in the Moldavian valleys as mentioned in Cantemir's book 'Descripto Moldaviae' (1716).

Big hydrotechnical works for flood protection and reclamation of swamps were carried out; e.g. regulating the Bega river and digging the navigable Bega canal in the Banat, the endikement of the Somes and Crasna rivers from 1751 to 1774 in the Northern Tisa river plain, the digging of drainage canals in Arges of the Dimbovita and Ciorogirla rivers against high water in order to protect Bucharest from flooding. Such works continued during the nineteenth and the beginning of the twentieth century. Until August 1944 the endikement works covered an area of about 622 000 ha. On part of the endiked lands drainage and swamp reclamation were implemented covering 358 000 ha (Agricultura Socialista).

The modernization and the intensive development of the agricultural production asked for a reclamation programme concerning the entire agricultural area. Since the fifties, together with the introduction of the planning that was part of the economic progress strategy, surveys and research were carried out to obtain a better insight of the reclamation problems, a correct territorial location of the reclamation works and the most adequate technical solutions. Projects were made for large natural units and hydrological basins which allowed the implementation of complex territorial projects. The development of the agricultural sector ensured better conditions for a complex approach of the reclamation problems and their solution; the industrialization policy ensured the technical and material basis necessary to implement those projects (Desecari).

In Romania excess water finds its cause in:

- Abundant and often torrential precipitation on soils with little slope and without good run-off and on lowly permeable soils, affecting an area of 2.5 million ha;
- A shallow groundwater table recharged by precipitation and from rivers, terraces or high neighbouring plains, affecting an area of 1.5 million ha;
- River floods affecting an area of 1.3 million ha.

Sometimes owing to local conditions excess water results from a combination of causes mentioned above or from the pedo-geological conditions as in the case of the Romanian plain depressions formed on loess.

Surface and subsurface drainage as well as soil improvement have been carried out step by step. Experience has shown that complete reclamation is a process of long duration. Drainage leads to a gradual modification of both hydrological and pedological conditions and therefore drainage activities were carried out in two stages:

- In the first stage a network of drainage canals was implemented together with soil improvement and, where necessary, tile drainage;
- In the second stage all operations were executed, that aim at a complete improvement of the area, taking into account the modifications resulting from the works achieved during the first stage i.e. tile drainage, reclamation of depressions, land levelling.

By the end of 1986 surface drainage networks, and pumping or repumping stations were implemented over an area of 3.1 million ha, and subsurface drainage on an area of 300 000 ha.

Drainage operations in irrigated and non-irrigated areas comprise improvement of existing drainage systems to obtain maximum efficiency as well as implementation of new drainage systems. For improving the efficiency of the drainage systems, the offices in charge of implementing land reclamation have been equipped for maintenance and repair services and a programme has been established in order to operate the drainage canals and the pumping stations at the designed parameters.

The solutions adopted for drainage can be summarized as follows:

1. For lowly permeable soils suffering from excess water due to precipitation are:
   - ditches at a spacing between 300 and 400 m;
   - land levelling, taking into account local depressions;
2. For soils with a moderate to low permeability suffering from excess water due to a shallow watertable:
   - ditches at a spacing between 300 and 400 m;
   - tile drainage;

3. For soils with a low permeability and excess water from seepage:
   - ditches;
   - wells or drains, discharging with or without pumps into collectors.

These solutions can be adjusted according to the specific conditions of each area.

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Development of drainage in Slovenia and Yugoslavia and its prospects in the future

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1 Introduction

From the beginning of the 20th century up to the present time the world population has more than doubled. It is estimated that this number will rise to 7.0 billion in the year 2000. Meeting at least the basic food requirements for such a number of people will present a most serious problem.

In order to be able to balance food production and demands in the world, the intensification of agricultural production is an obligation of sound economic policy in any part of the world. Intensification of crop production can, according to judgements of world planners, only be achieved in future through:
- Optimizing the soil water regime (irrigation, drainage);
- Developing genetic potentials of crops;
- Improvement of agricultural technologies.

Obviously, there are two ways of increasing the crop production, either by expanding the areas of arable land or by intensifying the production on the existing areas.

In Slovenia, the land and estate structure, the negligible portion of flat land (especially arable land) in the total land area, the hasty and insufficiently planned urban development, the considerable extent of marshy soils, the insufficiently used possibilities of intensifying crop production, as well as the ever increasing importance of agriculture for life and work of the Slovene population, point out the need for acquiring new agricultural land and improving the existing agricultural land. The present post-war process of land use shows a regression in the agricultural surfaces, notably in the arable area.

Slovene, and Yugoslav agriculture will in the near future face a challenging task: how to produce more food with less labour for a growing population on a decreasing agricultural area. The fulfilment of this task depends to a considerable extent on whether we succeed to intensify crop production on the available agricultural area and to stop with the present non-extensive cultivation of land.

One of the main possibilities of intensifying crop production lies in optimizing soil water management and in applying related measures: flood prevention, soil drainage, irrigation, etc.

2 Development of drainage in the past

Drainage is, besides flood control on watersheds, the oldest measure in land consolidation and water management in Yugoslavia, and of vital importance for the development of agricultural production and for the entire Yugoslav economy.

In numerous parts of this country the oldest measures on this field date back to Roman times with a marked upswing in the beginning of the 18th and in the second half of the 19th century when drainage was increasingly implemented in an organized way. The development of agriculture raised urgent demands for hydrotechnical melioration, varying from accumulating excess water in depressions to its evacuation into recipients by means of ditches (either by gravity or pumping), and the present control by pipe drainage, aided by modern cultivation measures. The development of science and technology has provided this field with modern machines, research, planning and construction methods.

Nowadays, a substantial part of the agricultural areas is provided with drainage. The majority of these areas are directly connected with the drainage systems. The rest, either due to their position or to the prevailing conditions, is provided with partial drainage or drains by gravity towards the recipients. Still, much agricultural land remains in need of drainage.

Drainage of heavy clay soils and areas where soil water regimes have been changed due to artificial influences, is at present of vital concern for water management specialists and land users in Yugoslavia. The considerable area of salty land in Yugoslavia, mainly state-owned property, is also gaining importance as the need for their melioration and exploitation increases.

The historical development of drainage works in Yugoslavia varied according to the prevailing situation. The intensity of drainage works in various parts of the country shows much variation. We cannot delve here into the development of drainage in the entire Yugoslavia; suffice it to say that each region has certain distinct qualities.

All measures of land development in the past aimed at improving the soil for intensive crop production. Prior to World-War II, most work on primary drainage was carried out with the aim to protect the land against floods and to promote water evacuation from affected areas by constructing a number of ditches. At that time in Voyvodina alone there were more than 90 water co-operatives actively involved in drainage of agricultural land, and in the post-war period this area increased to 1 500 000 ha. It might be interesting to present some technical data concerning Voyvodina. The density of the ditch network in this region amounted to 5-13 m/ha, in well-drained areas up to 22-30 m/ha. The design capacity of the system was planned for a 20 year recurrence period while in case of pump drainage, pumps with an average design capacity of 0.48 l/s/ha were installed.

Besides by primary drainage the soil water regime is improved in recent times (for the last 18 years) by means of pipe drainage and supplementary agricultural improvements.

3 Drainage in the past 25 years in Slovenia

3.1 General

Slovenia is one of Yugoslavia's six republics. It is comparatively small (2 025 000 ha) and ranges among the most developed regions of Yugoslavia. Some 52% of the region is covered by forests, the rest being agricultural land (41%), urban areas and unfertile soil (7%). Approximately 10% of the total area is in such a condition that it requires amelioration of the soil water regime for intensive crop production. There is a great variety in soil types. Drainage works are carried out mostly on heavy clay soils. Although this area is rather small compared with the surface of Slovenia, yet land development is difficult and involves numerous problems, due to the wide variety of conditions. Although the problems presented in this paper concern only Slovenia, they may be considered representative for the problems in land drainage for the whole of Yugoslavia.

A notable characteristic of Slovenia is the rapid decline of the agricultural area due to rapid urbanization. Whereas in the lowlands industry, traffic infrastructure and urban development occupy an increasing part of the best land, in the uplands a lot of agricultural land is abandoned and taken over by natural reforestation.

Statistics show that in Slovenia, after World War II, some 60 000 ha of high quality agricultural land is lost, i.e. 1500 ha per year. To compensate for this loss and simultaneously to ensure a greater degree of Slovenia's self-sufficiency in food production for the near future up to 2000, a comprehensive land development programme was embarked upon, including hydromelioration works (drainage, irrigation), soil improvement, and land consolidation. Hydromelioration (drainage) in Slovenia only started systematically after 1973 when two important laws were passed: the Law on Agricultural Land and the Law on Water. These two laws are complementary. The Law on Agricultural Land secures means to finance drainage works, soil improvement, land consolidation, small scale water reservoirs, etc. This law also prescribes a special tax for all land-owners who change the use of their agricultural or forest land. The collected funds may exclusively be used for land development with the aim of increasing the soil productivity by hydromelioration, soil improvement, and land consolidation. The Law on Water, also intervenes in the field of agriculture and regards the organization for the implementation as well as the co-financing of main drainage and melioration systems. Thus, these important laws provide both a financing background and a programme for the organization of work on drainage systems in Slovenia.

In the period from 1973 to 1985, some 30 000 ha in systems ranging from 50 to 500 ha have been drained. In Yugoslavia up to 1984 a total of 135 000 ha have been drained: 81 140 ha in Croatia, 30 000 ha in Slovenia, the rest in Serbia, Voyvodina, and Bosnia and Herzegovina.

3.2 Organization of work and financing

The work on land development in Slovenia after enacting the Law on Agricultural Land, is well organized. On the basis of that law levies are collected by the Communes (64 communes in Slovenia) due to the change in the land use (urbanization), and transferred to a central fund of the Republic. Those means are then distributed after approval by the Melioration Board, founded 15 years ago with the Association of Water Districts of Slovenia. The Board takes into account the approved priority list of the

Republic and the basic documents: a master plan of the drainage system, designed on the basis of pedologic and agrohydrologic expertise, appropriate survey maps and an investment programme for the project. The right to apply is given to melioration associations, agricultural production associations (both association forms for individual farmers who wish to apply for financial assistance), agricultural co-ops and state farms. Drainage systems are designed by Water Districts (7 Water Districts in Slovenia). Pedologic and agrohydrologic expertise is provided by professional and scientific institutions (Biotechnical Faculty, etc.) and survey maps by the Surveying Institute of Slovenia.

The applicants get the major part of their financial requirements in form of a subsidy (80% of the needed capital investment), while the rest is covered either by their own resources or bank credits.

Drainage and other land development works are carried out by the Water Districts, Slovenijaceste, a civil-engineering enterprise, as well as private enterprises. Supervision is carried out by civil engineers and agronomists, who have passed a supplementary course in melioration supervision. Later, the supervision of maintenance works during exploitation of the system is performed by commune inspectors.

3.3 Types of field drains

The need to drain agricultural land in Slovenia may arise from one of three phenomena: high groundwater level, impermeable layer in the soil profile and local springs.

In Slovenia the phenomenon of an impermeable layer prevails, impeding natural drainage, and provoking stagnation of water in the field during critical periods of the year (autumn and spring) when the soil must be prepared for sowing or when the main crops (wheat, corn) have to be sown.

In recent years studies were conducted on soils (pseudogley, gley) as to the optimum way of drainage: bedding, mole drainage, pipe drainage and combined drainage. The conclusions were that on this soil type in our climate each of the investigated methods achieved some improvements, while the best and most appropriate results were achieved by combined drainage. This method differs from the standard type of drainage so far that drain pipes (6 cm diameter) are installed at a depth of 0.8-1.1 m with gravel backfill, while perpendicular to or at an oblique angle to these drain pipes mole ploughing (spacing of 2-5 m, depth 0.6-0.7 m) and/or subsoiling (spacing 1 m, depth 0.5-0-6 m) is applied.

The gravel backfill fulfils in this drainage method a multiple function: it enables better evacuation of excess water from the surface into drain pipes, it reduces the entry resistance for water in the pipes, it increases the permeability of the drain trench, and it protects the drain pipe from clogging. During implementation it is important to install drain pipes with gravel backfill at the same time. If gravel backfill is not installed immediately, the soil slides off the trench slopes, reducing the effect of gravel backfill.

Mole ploughing and subsoiling are of paramount importance in this drainage method: not only they secure the drainage, but also the total efficiency of the system.

Mole drainage and subsoiling should not be implemented in a wet soil, and should be executed in summer, following the harvest of the second crop.

For drainage of these soils, it is of great importance to improve the physical properties, especially the soil stability. After the implementation of the drainage system the tillage and selection of suitable crops have to be ascertained. Under wet soil conditions machines must not be employed. In the crop rotation spring crops, especially early ones, have to be avoided in favour of soil preparation and sowing in summer and autumn.

Before 1970 several types of field drains have been practised (e.g. bedding system, open ditch drains, clay or concrete pipe drains, mole drains), while in the past 16 years mainly subsurface drainage with plastic pipe laterals in combination with main open ditches has been applied. Sometimes also pipe laterals in combination with pipe collectors are used, depending on the field situation, but in this case manholes are recommended.

Open ditch drains are not popular due to the loss of land, costly maintenance and the limits they impose on the efficient use of farm machinery on small plots.

Spacing of drain laterals is determined according to calculations using different equations and soil physical data. Certain other points, whether permeable backfill is used or auxiliary measures as moling and subsoiling are practised, are also taken into account.

Plastic (PVC) corrugated pipes with standard diameter are used. They are made in Yugoslavia; the quality, conform to YU standards is continuously controlled in the factory. Openings are distributed according to DIN 1187. Also, ready-made filter pipes are often used. Permeable backfill (gravel, coarse sand, sometimes chopped wood) is commonly used up to 50 cm above the drain pipes. Washed gravel with particle size 4-30 mm proved, according to studies of physical models, to be the most successful and is mostly recommended. In practice, however, muddy gravel of different particle size is often used. In the past also styropore material was used as permeable backfill or filter. It did not prove to be successful as it deteriorated after a certain period of time. Permeable backfill is primarily used to increase the hydraulic performance (reduce the entrance resistance) in combination with moling and/or subsoiling that is applied perpendicular to drain pipes and also to delay ochre clogging in drains, a serious problem in many areas. Good conditions for drainage installation in dry soil exist only for approximately 3 months per year, but it is executed the whole year round (except during the rainy periods), often in too wet conditions. Use of permeable backfill can at least partially help to overcome the resulting problems.

Mole drainage, executed perpendicular to pipe drains (Figure 1) is particularly recommended in dense, poorly pervious clay soils. Very often mole drains filled with sand are applied. The usual depth of moling is 0.5-0.6 m with spacing of 5.0 m (Figures 2, 3, and 4). Mole drainage in combination with pipe drains and permeable trench backfill is supposed to have a fairly good working lifetime. How long will it last? That is not easy to say. Yet studies are being conducted to answer the question of 'How can a drainage system be effective with maximum pipe drain spacing and what is the maximum drain spacing if sanded mole drains are used?'. The answers will

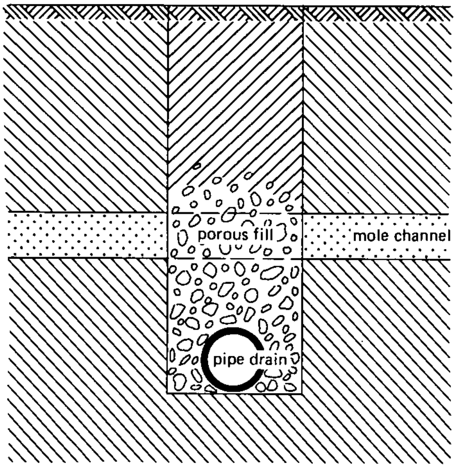

Figure 1 Mole drain installed perpendicular to pipe drain

Figure 2 Mole plough equipped with funnel for applying sand

Figure 3 Installation of sand mole drains

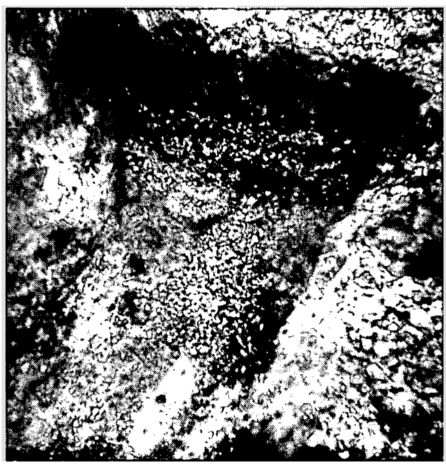

Figure 4 Drain pipe (at 1.0 m depth) with permeable backfill (0.5 m above the drain pipe) and mole drain filled with sand and installed perpendicular to pipe drain

beyond doubt reduce the cost of installation of drainage systems, which have risen to enormous figures lately.

In case mole drains are not filled with sand, then only moling is recommended if the soil contains more than 25% of clay; otherwise subsoiling is preferred.

3.4 Construction of drainage systems

The construction of a pipe drainage system is primarily done by trenching machines, although trenchless drainage machines are also used. At present, some 15 machines are in operation in Slovenia, owned by Water Districts, while 45 machines are employed in other parts of Yugoslavia (33 in Croatia, 2 in Bosnia and Herzegovina, 6 in Voyvodina, and 4 in Serbia) also owned by Water Districts. Moreover, there are also some 30 private owned machines (in Croatia and Slovenia). The machines owned by Water Districts were produced by: Barth & Co, Hoes, Steenbergen, Van den Ende, Interdrain, Mastenbroek. There are no data available on type and make of the private owned machines. Some basic data on performed work with different drainage machines in Yugoslavia are given in Tables 1 and 2.

Table 1 Main indices on performed work of drainage machines in the period 1977-84

Machine type	No. of machines 1984	Observed area (ha)	Performed work		
			Vinyl pipes (m)	hours	m/h
Hoes-Gigant	2	2.97	1 528 754	8 421	181.5
Hoes-Super-Gigant	1	1.80	991 694	4 392	225.3
Subtotal Hoes	3	4.77	2 520 448	12 813	196.7
Barth-K-170	3	10.66	3 652 856	15 675	233.0
Barth-K-171	4	12.62	3 695 293	12 601	293.3
Barth-K-250	3	13.17	4 494 855	13 348	336.7
Subtotal Barth	10	36.45	11 843 004	41 624	284.5
Mastenbroek 25/26	14	1.01	387 154	1 450	267.0
Total	17	42.23	14 750 606	55 887	263.9

Table 2 Survey of operation of drainage machines

Machine type	Average operation efficiency		Reduction coefficient for all machines
	m/h	m/year	
Hoes-Gigant	195.0	195 000	1.10/ heavy clay soil
Hoes-Super-Gigant	290.0	290 000	1.25/ very heavy soil
Barth-K-170	195.0	195 000	1.35-1.50/ installing filter
Barth-K-171	230.0	230 000	material
Barth-K-200	250.0	250 000	1.50-2.00/ for pipes with
Barth-K-250	290.0	290 000	100-220 mm diameter
Mastenbroek 25/26	290.0	290 000	1.35-1.75/ depth of 1.30 to 1.70 m

With machines up to seven years old, the standard operation amounts to 1000 effective hours annually with a 10% reduction (100 hrs) in every subsequent year.

Under normal conditions the following work force is needed for the operation of drainage machine:

– Manager/university degree in hydrotechnics	1 person
– Foreman/college degree/high qualification	1 person
– Machine operator/skilled	2 persons
– Cross-country vehicle driver/skilled	1 person
– Auxiliary personnel/unskilled	2–4 persons
Total	7–9 persons

The number of auxiliary personnel depends on the drainage elements and operation conditions (outflows, couplings and fittings). In case several drainage machines are in operation in one particular location, the total number of involved persons may be reduced.

Mole ploughs are mainly home made. For subsoiling fixed single or multiple arm tools are used. There exists a need for more and/or better devices for breaking through soil compactions at the surface.

In spite of the recommendations to construction teams and engineers who control the execution of drainage works, that implementation only should be executed in sufficiently dry soils and that construction has to be postponed or interrupted if the soil structure risks to suffer from construction machinery on the site, still the implementation of drainage often takes place under too wet and adverse conditions. Therefore, inspection must be done in order to control the proper use of subvention funds.

3.5 Problems associated with drainage works

In implementing drainage and land consolidation certain problems of technical and organizational nature are encountered:

- Non-coordinated execution of drainage and land consolidation works;
- Non-coordinated planning, implementation, supervision and construction of drainage;
- Unsatisfactory maintenance of drainage facilities and equipment;
- Non-implementation of supplementary drainage measures;
- Lack of skilled manpower;
- Lack of appropriate machines for maintaining the drainage and implementing supplementary measures.

4 Prospects of drainage in future

In the year 2000 construction of drainage is foreseen for an area of 450 000 ha as shown in Table 3.

Table 3 Drainage works in Yugoslavia in the year 2000

Republic or autonomous province	Planned drainage works		Source
	ha	%	
Slovenia	60 000	14	(Matičič)
Croatia	150 000	33	(Tomić)
Serbia	60 000	14	(Katalina)
Voyvodina	100 000	22	(Stojsic/Belić/ Skorić)
Bosnia and Herzegovina	80 000	17	(Vlahinić)
Total	450 000	100	

To increase the work efficiency in land consolidation and in functioning of the melioration systems, all the problems mentioned in Section 3.5 must be avoided.

Land consolidation is a part of the measures aiming at increased crop production. The land is divided among many owners and that impedes profitable production. Therefore, land consolidation, along with melioration, represents a part of the measures aiming at profitable and stable high crop yield and simultaneous execution of land consolidation and melioration is needed. However, practice has shown that in many cases land consolidation followed melioration, which is wrong from the viewpoint of economical and high-quality land development.

During land development planning it also occurred that wishes of environmentalists for conservation at times post festum interfered with the completed melioration plan, which in turn influenced the drainage plan. In this respect agreements have to be reached between melioration planners and investors on one side and environmentalists on the other side before planning starts. It is important to stress the necessity of solving problems primarily due to interests and needs of the entire society.

Implementation of drainage and of supplementary measures requires adequate professional and technical supervision. In this respect the lack of trained specialists with technical and agricultural skills (agricultural engineers, drainage engineers, etc.) is felt.

In the period 1973-85 enormous financial resources were spent on melioration. The implemented drainage and melioration work represents an immense social wealth, that greatly obliges the agricultural organizations and Water Districts, co-operating in the implementation of the melioration plan, to regular maintenance of the constructed facilities. Evaluation and control of the drainage efficiency in existing melioration systems in this period (performed by the Department of Melioration and Land Consolidation of the Biotechnical Faculty) give an insight in the actual state of melioration systems, and show the necessity for regular maintenance, because the percentage of areas with non-functioning drainage is increasing every year.

To ensure successful drainage operation, prompt discharge of drain water is needed, which in turn necessitates appropriate execution of the primary and secondary drainage systems (drainage recipients). In the past, also in Yugoslavia, too little attention was paid to maintenance of the ditches. The ditches are often overgrown, clogged, and sometimes filled with waste. At some places cattle passes over ditches, resulting in sliding ditch slopes, and some culverts are not properly dimensioned. Numerous drainage outflows are clogged or covered due to side-slope sliding or are blocked due to ochre clogging, resulting in non-functioning of the system.

To enhance drainage efficiency, regular execution of supplementary drainage measures is a must. On heavy clay soils, only a drainage system is not a sufficient measure to improve air-water properties of that soil.

Any drainage system that does not ensure water flow from the surface to the drains (e.g. rain water on the surface of the soil) must be regarded as inefficient. That is why heavy clay soils need additional treatment, namely:

- Mechanical subsoiling or vibration subsoiling;
- Moling.

Both measures improve the permeability of the soil. Also improved are soil structure and permeability in the lower horizons, enabling development of plant roots at greater depths. The soil permeability changes from year to year due to the employment of machines and the conditions in which these are employed. So impermeable layers can be formed in the soil, impeding rain water on its way towards drains and making it necessary to break these layers by means of subsoiling or vibrating. Subsoiling, vibrating subsoiling and alternate moling must therefore be practised on a regular basis as a supplementary drainage measure. Which supplementary measure must be applied depends on the depth at which the impermeability problem arises. Maintaining soil structure and permeability on drained soil is of exceptional importance, as a drain does not draw water from the upper layer, but accepts water that comes to it by gravity. This, however, cannot take place when soils are compacted due to the employment of agricultural machines in wet conditions.

At present there is on the market a lack of machines for maintaining melioration systems (open ditches and drainage cleaning) as well as of machines for implementation of supplementary drainage measures (moling, subsoiling, etc.). However, the situation is improving, partly due to the increased interest of national producers, who started production of certain machines, partly due to home made equipment (home made mole ploughs), and last but not least due to the increased efforts of foreign producers.

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Some aspects of organizing the maintenance of drainage systems in Czechoslovakia

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1 Introduction

This paper aims at discussing several aspects of drainage projects maintenance in Czechoslovakia including socio-economical factors that may be regarded as particularly important. As the situation may differ from those in many countries of the world, I would like to present first some general ideas about agriculture and farming systems in Czechoslovakia and about the role of drainage under Czechoslovak conditions.

Czechoslovakia covers an area of 128 000 km², of which 68 500 km² are nowadays agricultural land. Arable land covers 48 610 km². Of the entire working population 13% is employed within agriculture contributing 6.2% to the state yearly income. Characteristic for arable farming is the wide variety of geomorphological and soil physical conditions over the country. The lowest parts, flatlands with the best soils, are at about 200 m above sea level while the highest point of the country reaches more than 2 600 m. Agricultural land under cultivation (forests excepted) can be found locally at an altitude up to 1 400 m, intensively exploited arable land up to 1 000 m.

Almost all the common soil types can be found in the country and apart from some highly fertile soils in the lowlands one can hardly speak about any uniformity or even homogeneity from a physical point of view. The cropping pattern is rather extensive; wheat, sugar beet, maize and vegetables are the main crops grown on the low flatlands while potatoes, rye, oats and forage prevail elsewhere.

According to data of 1985 the total gross agricultural production amounted to US$ 8.74 milliard, out of which US$ 3.98 milliard came from arable farming. These figures look rather good for a relatively small country if one considers the variety of basic factors affecting the agricultural process. But beside the optimistic figures there are points more or less closely connected with already solved and still existing drainage problems and with the maintenance of drainage systems, that require to be analysed within the framework of general circumstances.

Before the second world war and shortly afterwards the organization of the agriculture in Czechoslovakia was based on private land holdings. Family farms were predominant and the farm size was usually between 3 and 15 ha. Parcelling of the agricultural land resulted from long-term physical and social conditions and although it was far from optimal according to present-day conception, it reflected more or less the geomorphological and hydrological picture of the country. After the second world war the entire organization of the agriculture in Czechoslovakia changed completely and followed the Soviet scheme of agriculture. During the period 1950-59 about 95% of the land holdings disappeared and two new forms of farming were introduced: cooperative farms and state farms. It is not the aim of this paper to discuss that procedure with its control in top-bottom direction but two characteristic phenomena are essential for our topic.

By so-called ploughing away the balks, single fields were joined in such a manner that new fields of more than 15 ha in a single plot were no exception. The cropping pattern was changed and the area of such a cooperative or state farm is now almost 3 000 ha on an average. The whole action was planned and implemented without having a look at possible effects on the agrohydrological, soil physical, erosion control or ecological situation of the areas and of the whole region. On one hand the situation of that period didn't give much room to go deeply into these aspects and on the other hand, there was still a lack of knowledge and experience. Former drainage systems lost their function and the traditional way of maintenance by the local farmers was abolished. Partly because of that and much more because of the influence of negative factors that arose from the new situation, soon afterwards 60% of all the soils could be classified as soils having a low or very low potential with respect to fertility and to yield. The majority consisted of soils with newly arisen drainage problems, waterlogged grasslands and pastures, soils with extremely high deviations in physical and chemical properties, devastated land and finally soils liable to all kind of erosion. Although these effects and consequences were simply overlooked during the period when the new schemes were made, later on they became a problem of the first order. A reliable investigation estimated an area of 1 743 000 ha to be drained, about one quarter of all agricultural land. The problem, suddenly regarded as a really huge one, seemed perhaps too huge to be solved with a cool head. All attention and effort with official support were put on design and execution of new drainage projects, but the maintenance was again underestimated. Moreover, new organizations dealing with drainage didn't even incorporate any scheme of maintenance and no budget was established for this purpose. And what are the practical results? The area still to be drained is at present reduced by about 1013 000 ha, and about 730 000 ha are still waiting for drainage. But in addition the need for reconstruction of drainage projects that are not properly functioning due to insufficient maintenance or no maintenance at all, presents at the moment a figure of 361 000 ha, thus 35% of the entire area that has been drained.

Over a very short period the basic conditions for farming were changed including such points as legislation, real estate evaluation and all the remaining socio-economical relations. The farmers, who had been cultivating their land throughout generations, were facing a new, strange situation without much chance to be seriously listened to. Then the cooperation itself, at least at the beginning, was more a simple word than the real cooperative spirit. The feeling of being insufficiently involved led further to indifference and even to irresponsibility, and resulted in neglecting maintenance of drainage structures, which depended at that time only upon their own activity.

2 Today's state of organization and practice of drainage maintenance

2.1 Rules for maintenance

The abstract from the general methodology for the organization of drainage maintenance, that has recently been elaborated by the Ministry of Agriculture, says besides other rules:

a. All institutions involved in drainage projects preparation, starting from feasibility study and continuing with design, financing, execution and operation, are obliged by law to conform their activity to new standards and regulations established by the ministry;
b. In order to achieve long-term functioning of the drainage system, all institutions involved in carrying out drainage projects must be able to provide for:
   - Sophisticated design, covering all financial, technical and technological requirements for maintenance;
   - Regular inspection of the installed system;
   - Cleaning when necessary.

   Further specifications are:
   In order to achieve reliable inspection, monitoring and maintenance, it is a prerequisite to map out the situation how the drainage system was actually installed (so-called as-built data) and the record should mainly cover:
   - Precise drawings of drains, manholes, collectors and outlet structures;
   - Elevation and longitudional sections;
   - Some reference points of structures.

   The task of inspection and checking distinguishes three levels:
   - The delivery check looking for the quality of structures, free profiles of drainage pipes, straight lining and prescribed slope of pipes;
   - The routine inspection at least once a year and during the first year after installation as often as necessary, in order to find out the real quality and efficiency of the system and so to enable users to judge it within the allowed time;
   - The thorough checking of the drainage system when it appears to be necessary;
c. In order to secure good conditions for the main outlets, a strict cooperation with organizations operating under the Ministry of Water Management is ordered (see further);
d. Special attention must be given to provide for sufficient maintenance equipment. If suitable machinery has to be imported from free market countries, it is the duty of the ministry to obtain the hard currency reservation;
e. A new system for the financing of maintenance has been introduced, based on sharing the expenses between the cooperative (or state) farms themselves and the state subsidy, in proportion to the yearly income-outcome balance of the farms.

2.2 The organizational structures

Three ministries are more or less involved in the preparation and maintenance of the drainage projects:
- Ministry of Agriculture and Food Production (MA);
- Ministry of Water and Forestry Management (MW);
- Ministry of Public Works (MP).

A simple scheme, showing the institutions directly involved, is presented in Figure 1.

The symbols in Figure 1 stand for:
a1 Government Service for Land and Water Use
a2 State Board for Management in Agriculture
a3 Waterboards
b1 Project designing institutions belonging to MA
b2 Project designing institutions belonging to MW
c1 Enterprises specialized in execution of drainage projects
c2 Executive enterprises, operating mainly in public works, but in some cases also in drainage projects.

The Ministry of Agriculture (MA) is fully responsible as the main institution for drawing up the technical regulations that after justification must be followed by all the units subordinated to the ministry (a1, a2, b1, c1 and the farms themselves).

MA takes the responsibility for negotation with other departments which are placed on the highest level of management. It has to approve and sign the drainage project

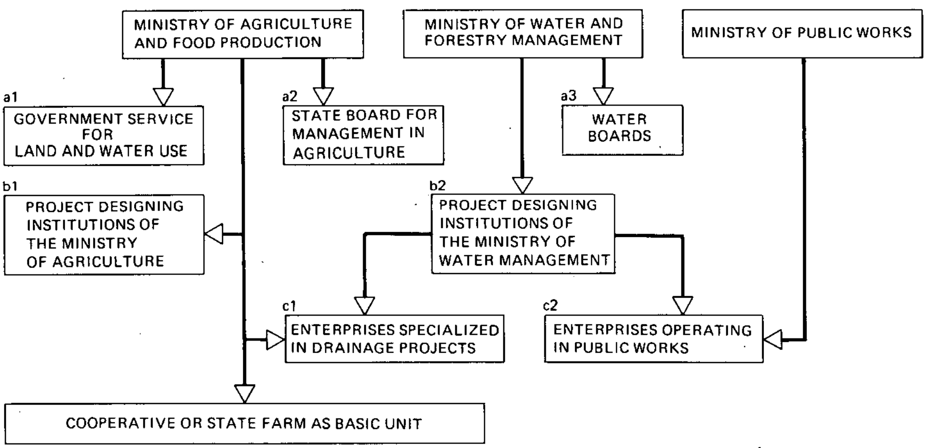

Figure 1 Scheme of directly involved institutions

budget with special attention for the budget part reserved for maintenance. Moreover, MA is the only institution that can permit the purchase of imported machinery for maintenance.

Under the control of MA are about 35.000 km of watercourses, so called 'agricultural watercourses' with a catchment area less than 50 km^2. It means that these courses have to be maintained within the range of agriculture without participation of the Ministry of Water and Forestry Management.

The institutions supposed to fulfil the main part of the management and control of maintenance (a1, a2 and a3) take care of the investment policy and, in a later stage, of passing the subsidy for maintenance to the farms. They must submit the feasibility studies and project schemes to MA in order to get final approval before the design is made. Recently obtaining the approval has become a real problem because of a strict attitude of MA towards projects with regard to maintenance. These organizations have to keep in close contact with both the design making institutes and the future users (farms) for finding the best solution to meet the regulations and at the same time the real facilities. This way to secure maintenance must be carried on without excuses. The Government Service for Land and Water Use (a1) makes the contracts with the farms and the designing institutes and then they list together the as-built data during the execution. Later on this team ensures the delivery check and the inspection over the first year.

The maintenance is done by the farms. The farms according to the rules have to provide for both machinery and labour. The machinery is often developed in the farm's workshops or just adapted from commonly produced agricultural machinery. The amount of money to be spent on maintenance is proportional to their yearly income. In fact, the budget approved by MA as subsidy for maintenance is a flexible one. MA, of course, has a very good record of the economical situation of each farm as it establishes compulsory plans for all the farms.

The Ministry of Water and Forestry Management (MW) is responsible for the maintenance of main courses according to the classification, which means courses with a catchment area larger than 50 km^2 as a rule. The inner structure of MW with regard to maintenance is completely different. Highly specialized waterboards (a3) were established already 30 years ago. They have their own staff, own budget and machinery. Generally these waterboards provide for very good maintenance of the main watercourses. About 25% of the drainage projects are designed by the institutes belonging to MW. Unfortunately the new regulations of MA are not approved within MW, so the situation becomes more complicated including the financial aspects. Some of these projects do not provide for maintenance at all but, for many different reasons, are still being executed, e.g. via enterprises belonging to the Ministry of Public Works (c2).

From the whole system it is clear, that there are no specialized institutes for the maintenance of drainage systems. The reason is, among others, that farms must have quite large workshops, where the cost of equipment is not much affected by buying or adapting special machinery for maintenance and also the labour possibilities on these farms are not much reduced in this sense.

It may be too early to evaluate this new system of drainage projects maintenance, but some remarks can already be made:

- The weakest point of the system seems to be the coordination between different ministries and their subordinate parts;
- Concerning the maintenance, it does not seem to be a sound solution to divide the watercourses into 'agricultural' and 'non-agricultural' courses;
- In spite of planning and MA's responsibility for the budgets, there is still a critical lack of machinery for maintenance;
- The system of financing based on the fact that under all circumstances maintenance will not be neglected due to financial reasons, seems to be very positive;
- Although the system solves the involvement in drainage maintenance at all levels, a comprehensive scheme for evaluation of the quality of maintenance is still lacking.

3 Conclusions

The subject of organizing drainage maintenance is so wide and complex that one must enter fields that at first sight, have nothing to do with drainage in order to understand really the problem. But often there is no other way to solve it. The Czechoslovak conditions can serve as a good example.

If one wants to rely on farmers cooperation, and this may apply not only to drainage maintenance, it is necessary to define in the entire organizational structure the room for the farmers themselves, for their activity, for using their experience, for giving them the chance to be really involved. This can hardly be secured by a top-bottom down organization.

How serious the drainage problem seems to be, it is wise never to stop thinking and acting in favour of maintenance, in spite of the fact that the official attitude towards maintenance may not be positive at the moment. If one waits too long before the system of maintenance is officially set up, the development of the surrounding circumstances might have gone too far ahead. Then the introduction of an optimal system is almost impossible and one gets too many institutions involved.

The only solution for the maintenance of drainage projects is not always to establish specialized institutions or enterprises. In the Czechoslovak situation of cooperative farming such a solution would even mix up the whole lot.

At last, the subject of drainage system maintenance has been seriously picked up in Czechoslovakia and the future will show whether the chosen scheme will work. But the way can be long and thorny before you tackle such a 'simple' problem, as this contribution has tried to show.

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Drainage in Spanish land reclamation projects

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1 Introduction

In 1983 arable land in Spain covered an area of 20.5 million ha, from which approximately 2.9 million were under irrigation (MAPA 1985). Although only 14% of the total cultivated land was under irrigation, production of irrigated land amounted to half of the total agricultural production. Therefore productivity of irrigated agriculture was six times that of dry farming.

These data show the importance if irrigation in Spanish agriculture, and why irrigation was the first water management practice applied in Spanish land reclamation projects. However, land drainage became a need as some irrigated areas were affected by waterlogging and secondary salinization. Moreover, drainage was needed to reclaim problematic soils, since the best lands are nowadays irrigated and to intensify irrigated agriculture, for instance by changing rice fields into horticultural production.

The experience achieved in drainage of heavy soils in the Marismas Plain, salt affected soils in the Ebro basin, and organic soils in polder areas of Eastern Spain is described in this paper. Prospects for draining sandy soils in the Ebro delta and planosols in Central Spain are also indicated. The Spanish river basins are shown in Figure 1, which can be used as a reference map for the forthcoming figures.

2 Drainage of heavy soils in the Marismas

2.1 Natural conditions

The Marismas area is located in the Guadalquivir estuary in Southern Spain. The total area covers 136 000 ha, of which 33 000 ha are irrigated on the left bank by the Lower Guadalquivir Irrigation Canal, 6 600 ha are included in the Almonte-Marismas Project and 30 000 ha are rice fields (Figure 2).

The climate is Mediterranean with Atlantic influence. The rainy season is lasting from October to April with an average rainfall of 570 mm. Soils are fine-textured, with a clay fraction higher than 65%. Soil structure is good in the top 15 cm, the subsurface horizon is prismatic with crack development, and below 60 cm the soil is structureless. Hydraulic conductivity depends on soil structure and therefore decreases with depth; below 70-80 cm the soil is almost impervious. There is a shallow groundwater table which under natural conditions is strongly saline.

Cereals and sugar beet are the main winter crops. Summer crops are irrigated with

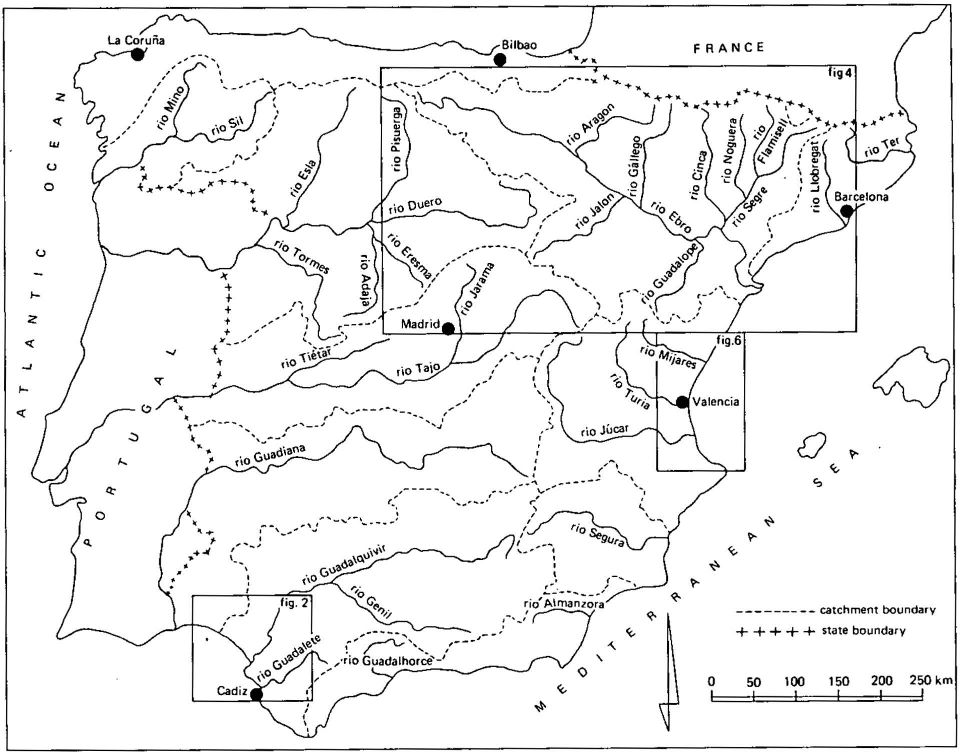

Fig. 1 Spanish river basins

water of good quality by means of furrows, but sprinkler irrigation is used in the earlier growth stages of cotton, which is the main crop.

2.2 The drainage system

2.2.1 Engineering characteristics

On the left bank three polders were reclaimed, protected by a dike to avoid the entrance of surface water. The subsurface drainage system consists of tile drains at spacings of 10 m running with a $1^{0}/_{00}$ slope at an average depth of 1 m. The laterals discharge in secondary collector drains spaced each 500 m and these into primary collectors constructed at spacings of 2000 m. The main drains discharge in the river through a gate, which is closed at high tide, and also by means of pumping stations (Figure 3).

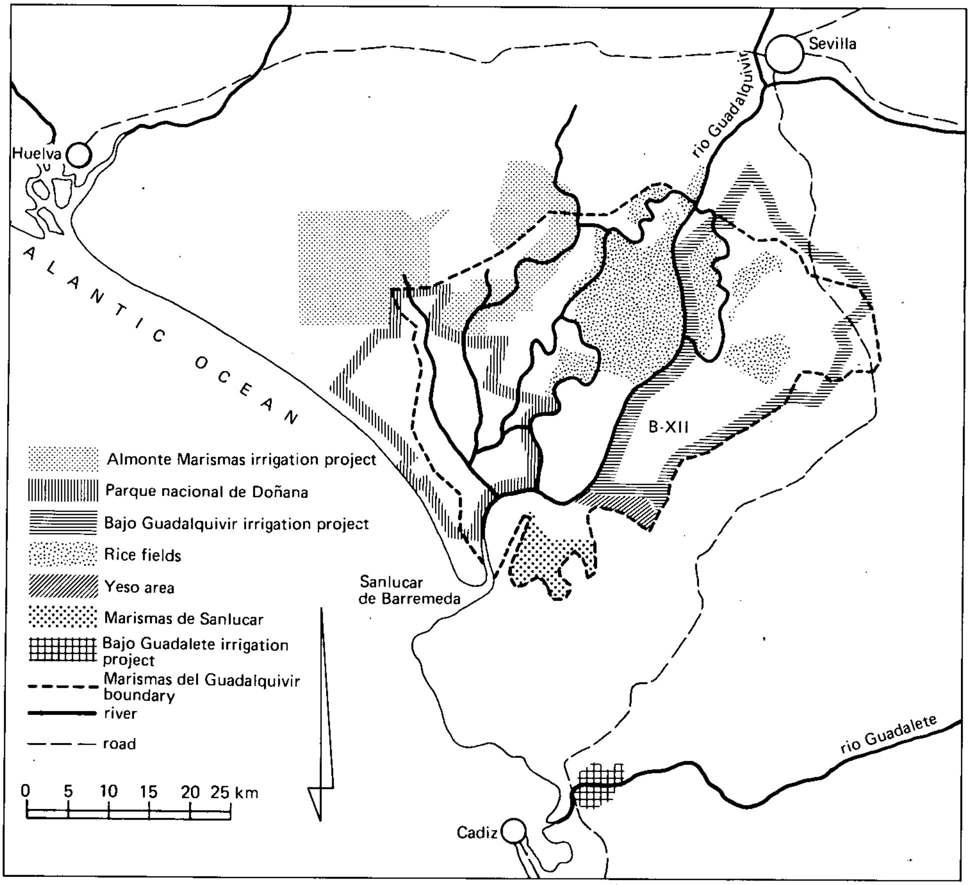

Figure 2 Land reclamation projects in the Marismas del Guadalquivir

Fields drains were laid during the dry season with trencher machines. The trench remained open for some time to allow the spoil to become structured. Thus the backfill is permeable and the entrance of subsurface flow increases in spite of the drain being placed in a layer of low hydraulic conductivity. After drainage subsoiling was carried out to increase topsoil permeability.

Drainage with trenchless machines was experimented with unsatisfactory results, probably because the pipe was installed in a layer of very low permeability and no permeable backfill was used to connect the drain with the upper layers of the soil profile. In 1978 the relation between drainage costs with trenchless machine and with trencher machine was 0.75.

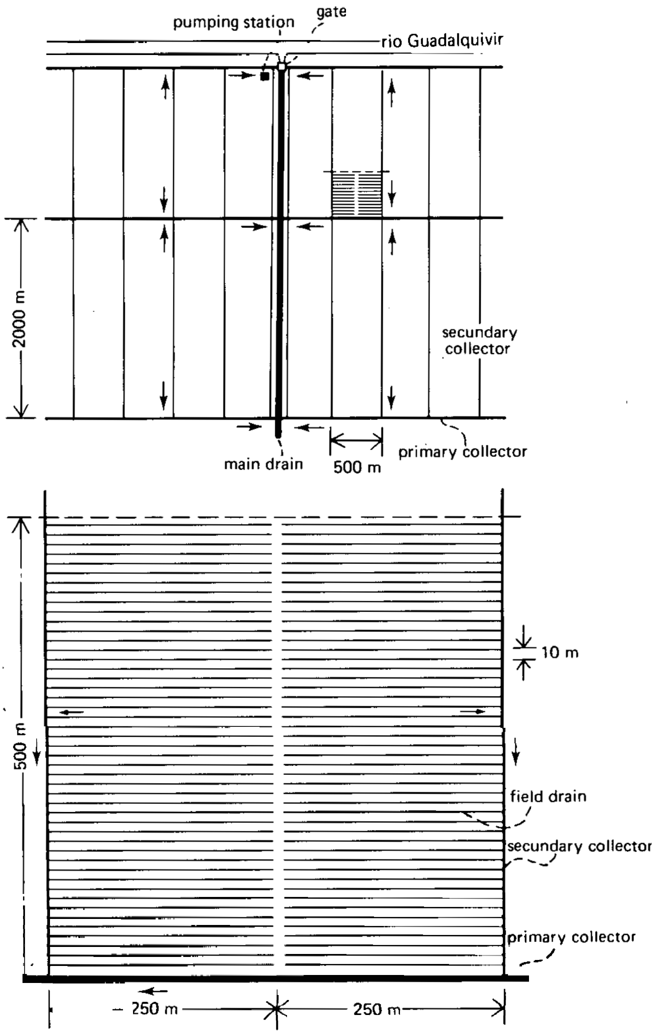

Figure 3 Drainage system in B XII of the Lower area

2.2.2 Drainage materials and costs

Drainage costs for both PVC and clay tiles are shown in Table 1. Since the cost difference is small, clay pipes were preferred by farmers because of their greater diameter. Therefore, only 600 ha have been drained with PVC.

Table 1 Drainage costs in pesetas per ha in 1985*

	PVC ∅ 50 mm	Clay ∅ 80 mm
Drainage machines (220 m/h)	52864	56697
Labour cost	10761	14899
Pipe (1000 m) and lateral outlets	47000	43000
Filling of the trench	1481	1481
Subsoiling	7000	7000
	119106	123077

* Average currency rate in 1985: US$ 1.00 = 170 pts

2.2.3 Maintenance and costs

Operation and maintenance of an irrigation area of 14000 ha is the responsibility of a division of the Bajo Guadalquivir Water Management Organization. Maintenance of collector and main drains is done on demand of individual farmers every two or three years; on average the annual cost is 1000 pts/ha. Mean annual pumping costs, including operation and maintenance of the pumping stations, are 1050 pts/ha.

2.3 Drainage system evaluation

Since 1983 the drainage system in Sector B-XII is being evaluated, as the farmers demand drain spacings of 5 m that would allow a faster desalinization. It was also monitored on an experimental farm on the right bank from 1972 to 1974.

Field observations show that during winter and the irrigation season in summer non-steady state flow conditions occur. Before a water application the water level is just above the drain depth, and discharge is negligible because drains are located in a layer with low hydraulic conductivity. After a watering the watertable rises everywhere to the toplayer. Then water flows directly through the drain trench and through the permeable layer. During tail recession the drawdown observed in piezometers agrees fairly well with that obtained by applying the Boussinesq theory. In areas where drip irrigation is used, steady state conditions occur; the drain discharge is very low due to the low hydraulic conductivity of a soil that is kept continuously wet.

Drainable pore space and hydraulic conductivity depend on crack development in the horizon with prismatic structure. If cracking is obtained by means of sound water management, the hydraulic conductivity varies from 0.4 to 0.6 m/d in the upper 65 cm and the pore space decreases with depth from 0.03 to 0.01. Where the soil is closed due to continuous wetting, the hydraulic conductivity is low from the soil surface downward (from 0.1 to 0.05 m/d).

If the hydraulic conductivity is kept at about 0.5 m/d, a drawdown of the watertable from the soil surface to 30 cm occurs in one day and to 50 cm in two days. Below this depth tail recession is very slow; nevertheless the water level is close to drain depth before the next water application. These conditions are suitable for summer crops, and they can be used as non-steady state drainage criteria.

During winter surface run-off after heavy rainfall is rapidly discharged by surface drains if the land has been smoothed.

No silting up was observed in drains after several years of service if they were properly installed and the tile outlets were maintained clean. There were no differences in performance between PVC and clay pipes besides a difference owing to the diameter.

The main maintenance problem is bank erosion when surface run-off flows directly towards the ditch instead of flowing through a surface pipe. If erosion occurs, water flow through the collector is impeded, the water level rises above the outlets of the laterals and the whole system does not work. Besides, where saline shrubs (suaeda fructicosa) grow on the ditch banks, very fine roots enter the pipe and clog the lateral.

In summary, the key points to keep the system working are firstly to maintain the hydraulic conductivity of the soil by introducing winter cereals in the crop rotation, which allows periodical subsoiling, alternate wetting and drying and maintaining hydraulic conductivity. Secondly, to keep the tile outlets clean and to avoid water losses due to surface run-off during the irrigation season, which increase the irrigation efficiency.

2.4 Prospects for the future

The findings obtained from the drainage evaluation of Sector B-XII were divulgated through the water management organization resulting in a conspicuous improvement of the water management in this sector. This achievement encourages continuous monitoring of presently drained lands. An increase of the irrigated acreage on the left bank depends on water saving achieved by improving the water management in the presently irrigated areas. So the Marismas de Sanlucar Project, which has already been drained, could be finished. On the right bank new reclamation projects are not foreseen since there is a need to preserve the Coto de Doñana wildlife park (Figure 2).

However, there is a need to improve leaching of non-irrigated soils that allows the cultivation of winter crops. For that purpose a cheaper drainage system is required, since the present cost of a standard drainage system is only economically feasible for irrigated soils. For this reason a mole drainage experimental programme has been carried out. Only results of one year of experience are available but they are very promising. If they are confirmed in the next years, mole drainage will be applied on non-irrigated soils of the Marismas.

3 Drainage of salt affected soils in the Ebro basin

3.1 Hydrological and soil conditions

The Bardenas – Alto Aragón irrigation scheme uses the hydraulic resources of three

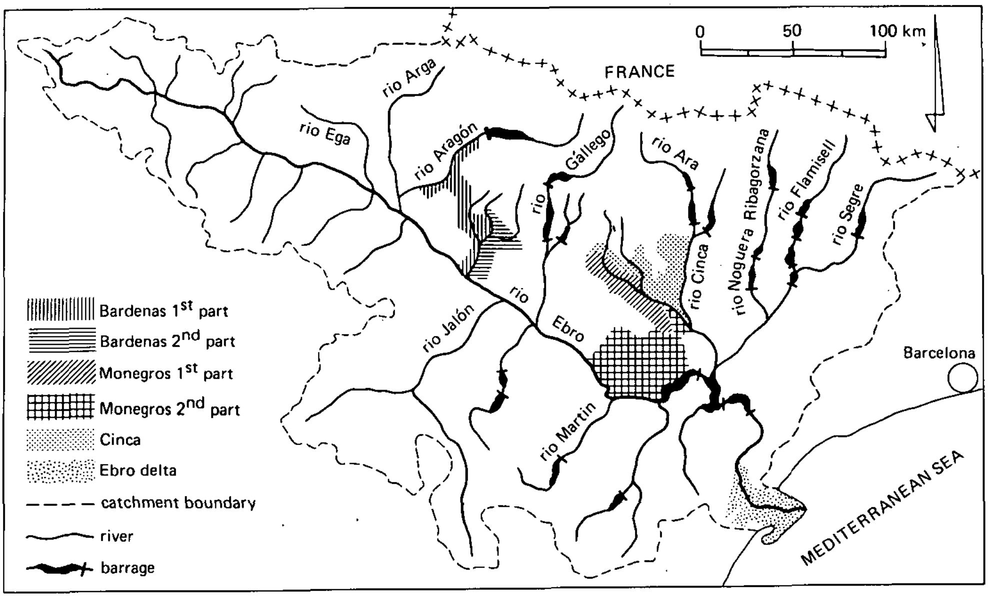

Figure 4 The Bardebas.Alto Aragon irrigation project

main tributaries of the Ebro river along its middle reach. The project includes a total area of approximately 260 000 ha (Figure 4).

About 90 000 ha of the presently irrigated area are affected by salinity, although irrigation water is of good quality. Primary salinity is inherent to soil parent materials derived from Tertiary saline rocks. Besides, secondary salinization occurs due to the existence of saline groundwater, recharged in part by seepage from adjacent uplands (Martínez Beltrán 1978).

Drainage requirements depend on topographical, hydrological and soil conditions which are closely related to the geomorphology of the region.

There are fluvio-colluvial valleys and alluvial plains with silty clay soils, where hydraulic conductivity decreases with depth down to an impervious layer located at a depth between 1 and 1.5 m. In these soils there is a shallow groundwater table recharged by rainfall, irrigation and seepage from the surrounding hills (Figure 5).

There are also silty loam and silty clay loam alluvial soils with a very fine stratification in the subsurface layer. Internal drainage is impeded since hydraulic conductivity for vertical flow is almost zero. Sometimes coarse alluvium is present underneath the stratified layer. There is not a continuous water body but discontinuous confined aquifers in the coarse deep layers. Rainfall or irrigation water remains on the soil surface until it evaporates and surface run-off is common even on levelled soils (Figure 6).

Between residual mesas, situated in the highest position, and low-lying valleys and plains, transitional glacis occur. Slopes are eroded in their upper part and the saline

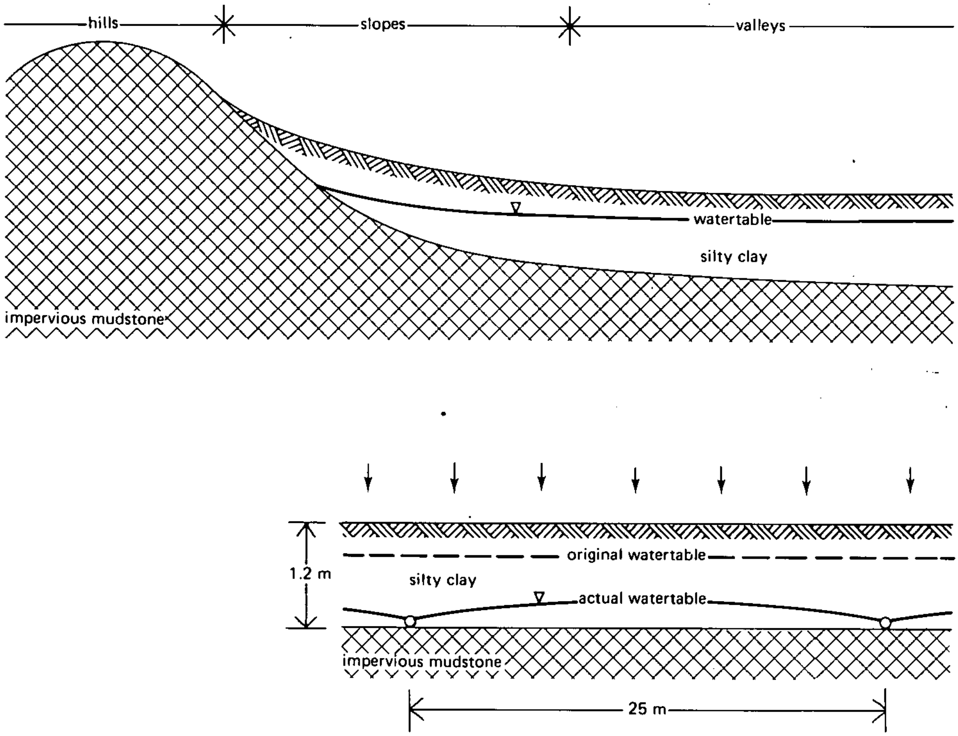

Figure 5 Subsurface drainage in fluvio-colluvial valleys and plains

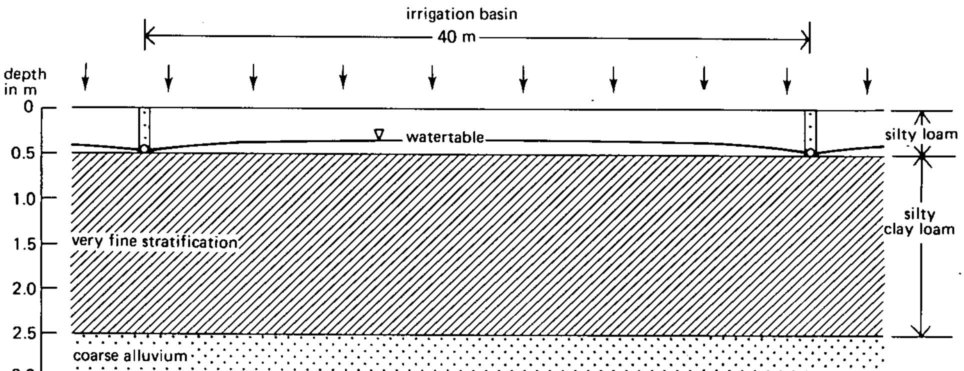

Figure 6 Alluvial soils with restricted internal drainage

and impervious sediments reach the soil surface. The soils become gradually colluvial in the middle and lower parts of the slopes. Under natural conditions there is no indication of a real watertable in these soils, but only local seepage coming from the adjacent mesas where a perched watertable is present during the irrigation season. Where land levelling has caused the outcropping of fine-grained sediments, the surface layer becomes saline and impervious and leaching is extremely difficult. Moreover, natural drainage is altered and local seepage occurs from the upper irrigated basins to the lower ones when water is applied (Figure 7).

3.2 Present drainage systems

The soils with saline groundwater table are drained by means of open ditches spaced on an average at 50 m. This system matches drainage requirements for barley irrigated in spring, but is unsuitable for irrigated crops such as lucerne and maize.

Alluvial soils with impeded internal drainage remain undrained. Salinity is still high because water percolation and leaching is restricted to the topsoil improved by subsoiling. Therefore soil productivity is very low.

In sloping lands of the Monegros area where levelling altered natural drainage, a reclamation project was carried out in the late seventies. An expensive composite drainage system was laid out with 2 or 3 laterals per irrigation basin and a collector pipe running in the slope direction. The design of this system was based on drainage principles for flat areas with an extensive aquifer. Monitoring of the drainage system has shown that only those drains which intercept local seepage, work, but the laterals laid in the impervious layer usually run dry.

3.3 Drainage solutions

A subsurface drainage system was evaluated on an experimental field established on alluvial soils with a saline watertable (Figure 5). The results obtained after four years of investigation showed that spacings of 25 m for tile drains laid on the impervious barrier are sufficient to lower the watertable rise of about 0.7 m caused by irrigation losses in about 12 days between two consecutive waterings. After 4 days the watertable is deeper than 0.5 m. This system also allows a watertable drawdown in winter from the soil surface to a depth of 0.65 m in about 8 days, which is adequate for winter cereals. After an initial leaching period of nine months moderately salt resistant crops, such as barley and sugar beet, were irrigated. As desalinization continued, less tolerant crops as wheat, lucerne and finally maize were grown.

In a drainage experiment on soils with restricted internal drainage it was observed that water flows directly into the drain trench through the upper layer, in which the stratification was disrupted by levelling and subsoiling. Therefore subsurface drains worked in fact as covered surface drains (Figure 6). There is no deep percolation and therefore no desalinization. Improvement of these soils should be based on deep subsoiling to increase percolation, leaching and desalinization of the top layer. Drainage

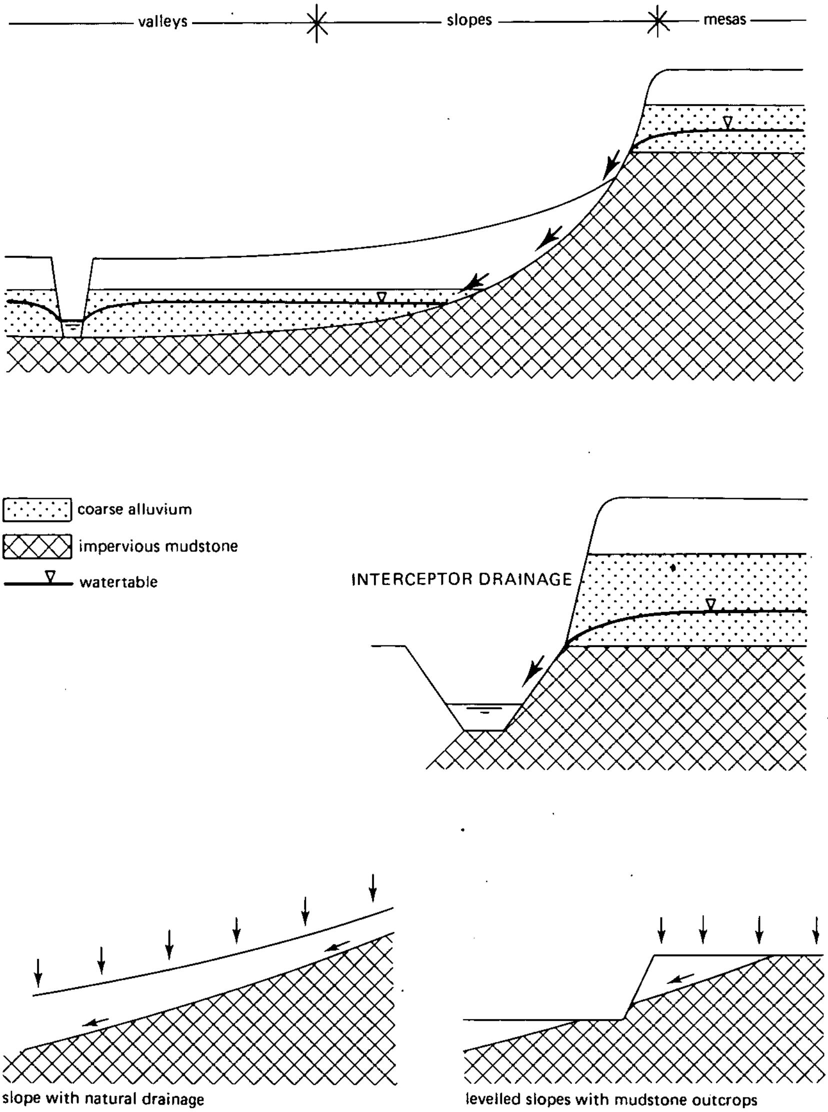

Figure 7 Interceptor drainage on eroded and colluvial slopes

only requires shallow covered tiles to allow interflow through the upper layer disrupted by subsoiling. Since the suitability of these soils for irrigation is limited, they should be excluded from new irrigation projects.

On sloping lands with a saline subsoil selection of a suitable irrigation method such as sprinkling or contour furrows for preserving good natural drainage, in addition to interceptor drainage will prevent secondary salinization of the topsoil (Figure 7). In areas presently levelled a shallow interceptor drain is needed between every two irrigation basins.

3.4 Conclusions

The results obtained from the experimental fields have not been properly diffused. Therefore a link between drainage engineers and water management organizations is urgently needed.

Moreover, drainage costs of levelled sloping lands were in 1978 from 1.75 to 2.25 times those of the Marismas Project. These costs discouraged the farmers and together with the lack of information, these were the major causes why reclamation of saline soils has slowly progressed in the last years.

However, better knowledge of drainage for reclaiming salt affected soils has been helpful in land evaluation surveys to deliminate new irrigation projects, where soils with less salinization hazard were selected.

4 Drainage of organic and sandy soils and polder areas of Eastern Spain

4.1 Natural conditions

In Eastern Spain lowlying areas exist along the Mediterranean coast from Northern Alicante up to the Ebro delta (Figure 8). Here rice was grown in 1982 on 20 000 ha, horticultural crops on about 5600 ha and 6200 ha of former rice fields remained uncultivated and covered by reed (Gil 1982). In the Ebro delta from a total area of 25 000 ha about 15 000 ha are rice fields (Figure 4).

In these coastal areas soil variability is great since sandy soils occur jointly with peat and clay soils, but a watertable is always present. Although rice is the most suitable crop for undrained land, there is a trend to transform rice fields into horticultural production by means of polder development, including irrigation and drainage.

In the Ebro delta a drainage system was designed in 1969. The main drainage network including pumping stations was constructed. Composite drainage systems have been installed on a few farms with drain spacings between 80 and 100 m in sandy soils. A systematic field drainage evaluation has not yet been carried out.

The experience obtained in a pilot polder of 1000 ha will now be presented. The project is situated in a lacustrine formation between a sandy coastal fringe and inland colluvial soils. Most soils consist of a clay toplayer of 40 cm covering a raw peat layer. Underneath a fine sandy layer saturated with water is found at variable depth. This aquifer is semi-confined by the upper layers of peat and clay and is limited by an impervious barrier at a depth between 5 and 15 m. Under natural conditions the aquifer is mainly recharged by seepage from the adjacent highlying areas. Besides surface water enters the area during heavy autumn rainfall, when high water levels occur in the drainage outlets.

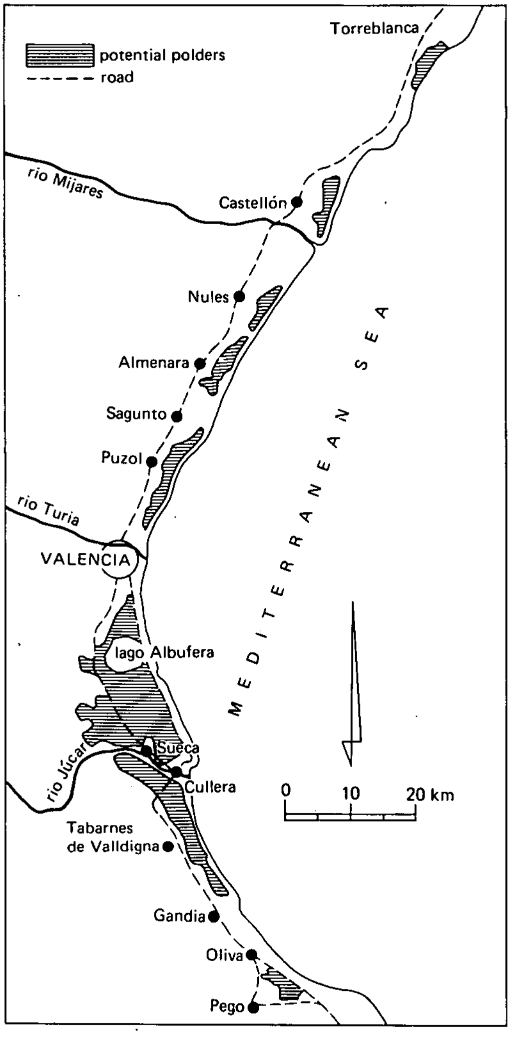

Figure 8 Potential polders in Eastern Spain

4.2 The drainage system

The drainage system consists of primary and secondary collector drains, and two main canals which conduct water towards two pumping stations, from where the drainage flow is discharged into two watercourses (Figure 9). The design discharge of the pumping stations was 60 mm/d which covers the drainage requirement of horticultural crops for a rainfall return period of 10 years.

4.3 Field drainage investigations

The field drainage system has been tested on an experimental plot. The first approach consisted of laterals at 25 m spacings laid at a depth of 1.2 m in the peat layer. This appeared unsatisfactory since many problems occurred to achieve the required pipe slope, and moreover the radial resistance was high, due to the low permeability of the peat. As a result, the watertable depth was unsuitable for the crops.

Entrance resistance was totally eliminated by stabilizing the drain trench with gravel. In order to reduce the radial resistance the drain depth was lowered to reach the sandy permeable layer. With field drains at 50 m spacing laid at a depth of 1.8 m, the watertable remained fairly constant at a depth of 1 m for a steady discharge of about 22 m/d. Transmissivity, experimentally derived with the Ernst equation was about $60 m^2/d$, the aquifer thickness being 8 m and the hydraulic conductivity of the sand 7.5 m/d.

The drainage criterion for steady state flow to be applied in the final design could be a watertable depth of 0.7 m. Then drain spacings could be wider than 50 m if the transmissivity is similar to that of the experimental plot.

It should be noted that estimation of the hydraulic conductivity of the raw peat layer caused a wrong design. The mistake was due to the fact that the hydraulic conductivity was measured by the auger hole method when the watertable was close to the soil surface. Surface flow and interflow towards the auger hole occurred and the water level rose very fast, not corresponding with the permeability of the peat. Measurements made later at lower watertables gave results in accordance with the value of 0.09 m/d that was derived from the relationship between hydraulic head and discharge on the experimental plot.

4.4 Prospects for the future

Future drainage development in these coastal areas will depend on the trend to convert present rice fields into horticultural projects and on the tendency for conservation of wet areas presently uncultivated.

In the Ebro delta a programme of field drainage evaluation under different soil conditions is being scheduled and results are expected for the next year.

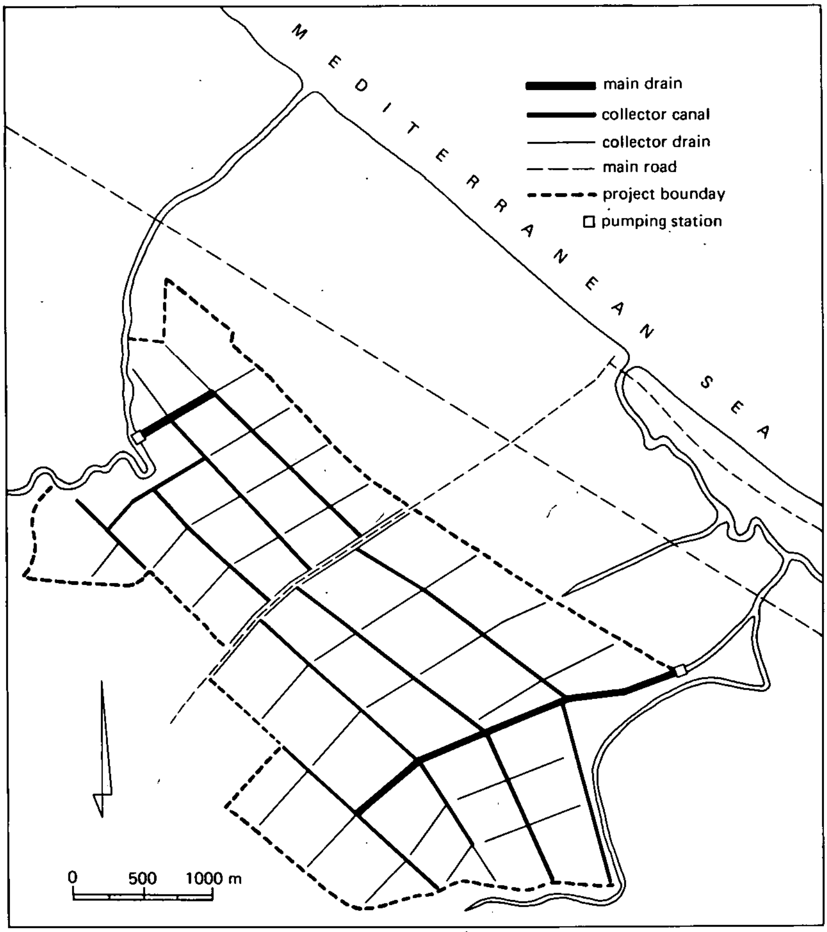

Figure 9 Drainage system in polder area Pego-Oliva

5 Programme for draining planosols in Central Spain

The Tiétar river is a Tajo tributary which is located in Central Spain south of the Gredos Mountains (Figure 1). In the Tiétar basin there is a great plain where planosols and sandy soils with a gentle slope occupy about 150 000 ha.

In this area winter crops cannot be grown due to a perched watertable on an impervious clay layer. In summer tobacco and asparagus are grown in the deepest planosols by irrigating with water from the Tiétar river.

If no drainage facilities are provided, salinity problems are expected in new irrigation projects, where water from the Tajo river will be used. Moreover, the drainage of planosols can increase the agricultural production of this region by growing winter crops in areas with a more favourable texture of the topsoil.

Therefore, next year drainage investigations will start in this plain, once soil surveys have been completed.

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Development of land drainage in Egypt

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1 Introduction

The land area in Egypt for agricultural production consists of 5.5 million feddan (1 feddan = 1.04 acre) of old lands and 0.9 million feddan of reclaimed lands. The agricultural area represents 3.5% of the Egyptian territory (1.0 million km^2 leaving 96.5% as arid desert lands. Egypt has a population of 50 million (estimated in 1986), increasing at an annual rate of 2.6%. The per capita cultivated area which was 0.19 feddan in 1960 is at present about 0.14 feddan. Nearly all Egyptian agriculture is irrigated with Nile water. The water supply from the Nile amounts to 55 500 million m^3 per year. Since the completion of the High Aswan Dam (1967) irrigation is possible throughout the year (perennial). All agricultural lands are double cropped (200% cropping intensity). The cropping pattern is wheat and berseem in winter and cotton and rice as cash crops in summer while maize and sorghum are the major subsistence crops. In addition there are vegetables, orchards, and sugarcane.

Egypt's arable land, although limited in area, is among the best in the world in terms of soil, water and climatic conditions. Egyptian crop yields are already substantially above world averages. However, there is a considerable potential for further increase of yields through improved drainage.

2 Drainage projects in Egypt

2.1 Historical development of land drainage

After the introduction of perennial irrigation and high cropping intensities, the use of water per unit area has increased sharply. Consequently the natural drainage system could not longer cope with the increased percolation losses from irrigation and lot of land became waterlogged and/or salt-affected. To overcome these problems open drains were excavated. In the late 1930's investigations started into covered field drainage that eliminates land losses. In 1956, a programme was launched to provide the whole Nile Valley with tile drains within 30 years. A UNDP/FAO pilot project was implemented in 1961-64 to establish design criteria and to test the feasibility of mechanized tile laying. Based on this study the first Nile Delta drainage project encompassing 950 000 feddan (400 000 ha) was identified and financed by the World Bank. This project was executed during the period 1971-80 being the world's largest drainage scheme. This project was followed by other World Bank supported projects which cover an area of 3.1 million feddan by 1987. The projects have also attracted other donors including USAID, EEC, CIDA, The Netherlands Government and the World Food Programme. Beside these outside funded projects, the Ministry of Irrigation carries out similar tile drainage projects.

2.2 Present status and areas provided with open and covered drainage

The intensive land drainage programme which was initiated in the 1970's includes:
- The construction of open collector drains;
- The deepening and widening of existing open drains;
- The construction of additional pumping stations;
- The installation of field tile drainage.

By June 1987, an area of about 3.1 million feddan in the Delta and Upper Egypt will be completed with subsurface drainage systems and improved open drainage channels (Figure 1). A summary of the data of the completed drainage works is shown in Table 1.

Table 1 Areas completed with drainage works as of 30.06.1986

Area	Open drains (1000 fed)	Tile drains (1000 fed)
Nile Delta		
– Government of Egypt	1893	619
– WB Nile Delta I	926	950
– WB Nile Delta II	794	392
– Dutch Project	–	44
Subtotal (A)	3613	2005
Upper Egypt		
– Government of Egypt	996	285
– WB Upper Egypt I	303	300
– WB Upper Egypt II	500	335
Subtotal (B)	1799	920
Total (A+B)	5412	2925

In the recently reclaimed lands, the following areas were provided with drainage including covered field drains:

– North Tahrir and Thawra farms	42 000 fed
– Mariut	45 000 fed
– Mechanized farm	10 000 fed
Total	97 000 fed

At present another 48 000 feddan forming the sugar-beet farm are provided with subsurface drains in a three stage project of which the first stage is completed.

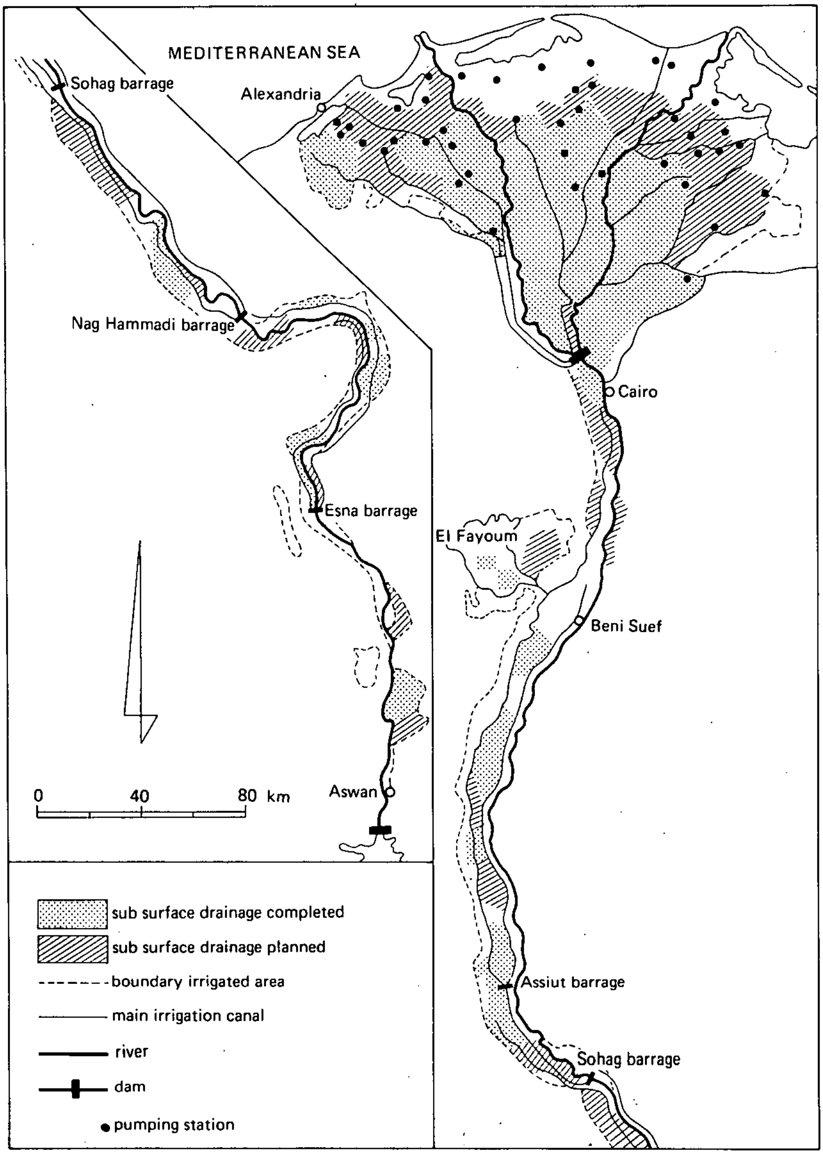

Figure 1 Location of drainage projects in Egypt

2.3 Main areas for future drainage

The future programme for land drainage in Egypt consists of another 1.33 million feddan with open and tile drains to be implemented during the next 10 years. These projects will be implemented either directly by the government own resources or with financial support from international agencies.

The Fifth Drainage Project (1985-89) is mainly financed by the World Bank. The project covers an area of 465 000 feddan in the Delta and Upper Egypt and involves tile drainage construction and modelling of open drains in 280 000 feddan. The Canadian International Development Agency (CIDA) finances an Integrated Soil and Water Improvement Project (ISAWIP) covering an area of 80 000 feddan in the Nile Delta (1987-92) to be provided with tile drainage. The Hamoul Project (65 000 feddan) is financed by the European Economic Community and involves among others tile drainage construction.

3 Drainage criteria

Despite the dynamic nature of the watertable in the irrigated areas of Egypt the criteria adopted describe steady state conditions. The cropping pattern includes crops with different water requirements, rooting depths, and salt and waterlogging tolerances. Agriculture follows a two or three years rotational pattern and thus crops with a clearly different water management regime may follow each other in the same field. The field drainage system lay-out is the composite gridiron type consisting of field drains (laterals) and collectors (mains).

3.1 Watertable depth

A minimum static watertable depth of 1.0 m is required to maintain favourable soil water conditions for the relatively deeply rooting plants (cotton). However, recent monitoring of crop yields in the Nile Delta showed that cotton yields started to decrease at an average watertable depth during the growing season of less than 0.9 m.

3.2 Drain depth

For reason of economy and outlet depth (main open drains) a maximum field drain depth of 1.5 m is possible. As the average field drain length is 200 m and the slope varies between 0.1 and 0.2% the average drain depth varies between 1.30 and 1.40 m.

3.3 Drainage coefficient

a. For drain spacing computation
A steady drainage rate of 1.0 mm/day is considered a sufficient design criterion for a dewatering zone of 1.0 m below soil surface. This rate is sufficient to control the salinity level of the soil water and to allow the growth of all kinds of crops.
b. For drain pipe capacity
A peak lateral drain discharge of 4 mm/day is rarely exceeded. Therefore a lateral drain pipe of 50 mm inner diameter is quite sufficient to meet the requirement of evacuating this discharge safely without over-pressure, even for a spacing of 60 m. However, the minimum inside pipe diameter used is 72 mm.
The design discharge rate for collector capacity in non-rice areas is taken as 2.0 mm/day including a safety factor of 100 per cent for the calculation of the pipe diameters. In rice growing areas a drainage coefficient of 4.0 mm/day is adopted including a 33 per cent factor of safety.
c. Modified drainage system in rice growing areas
A new lay-out of drainage systems in rice growing areas is introduced to eliminate the problem of unnecessary high drainage rates during the rice season in addition to other operational advantages. The new concept provides each crop unit a separate subcollector with at its outlet a control gate (Figure 2). The gate is closed during the season in which the crop unit is cultivated with rice and is kept open during other crop seasons. In this case the design drainage rate for calculating pipe diameters is kept the same as for non-rice areas (2.0 mm/day).

4 Machines and materials used in drainage construction

4.1 Machinery

The drainage projects in Egypt involve different activities which require a variety of machines and supporting equipment.

Draglines of 1.2 m^3 bucket capacity, and backhoes or hydraulic excavators of 0.75 m^3 bucket capacity are used for digging new main open drains or deepening and widening old existing drains. Lateral drain trenchers (trench box of 1.70 m depth and 0.25 m width) and heavy duty collector drain trenchers (trench box 2.70 m depth and 0.50 m width) are used for installation of covered drains. Supporting equipment is used like low-bed loaders for transport of equipment, wheel loaders, bulldozers, laser units for grade control, agricultural tractors with trailers, trucks for material transport, fuel trailers and mobile workshops.

4.2 Pipes manufacturing

Corrugated PVC pipes with 80 mm outside diameter are produced in 11 extruder units (6 in Upper Egypt and 5 in the Nile Delta). Peak annual production requirements

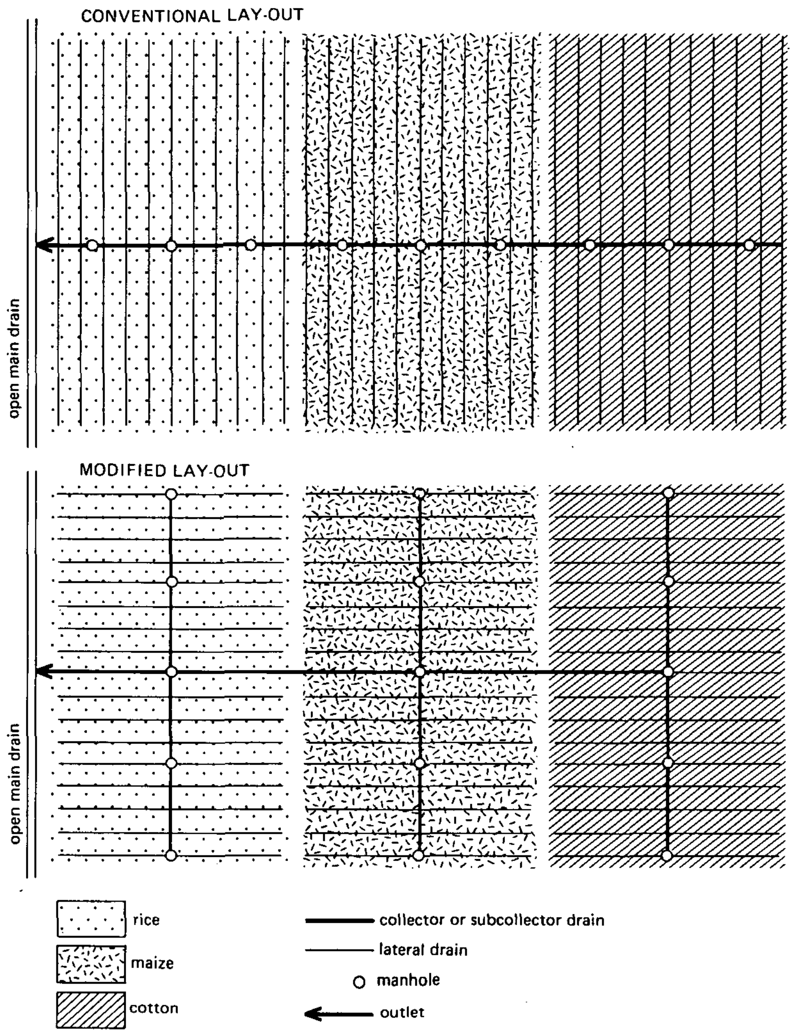

Figure 2 Drainage systems with conventional and modified lay-out in areas with rice in the crop rotation

for the next phase are estimated at 18 400 km. Concrete and reinforced concrete pipes of different diameters for collectors are produced on project sites or at central pipe factories.

4.3 Envelope material

Graded gravel (natural or crushed) is used as envelope material for laterals in unstable soils. Crushing and sieving equipment is available at the central pipe factories. The criteria currently applied for providing envelope material is the use of 5 cm envelope for drains spaced at 60 m or more and for unstable soils. Recent use of envelope material is more related to the soil physical properties. The clay content of the soil is considered a good stability index of the soil. Soils with a clay content of more than 30 per cent can be considered stable and no gravel envelope should be used.

The use of pre-wrapped synthetic envelope material is still restricted to trials and pilot schemes.

5 Cost development

5.1 Cost of construction

The total cost of drainage projects in Egypt is determined by the cost of the following components:

a. Installation of field drains which is dependent on the drain spacing and the need for envelope material. At present, the average cost of installation of field drains is about LE 170 per feddan (Avarage currency rate end 1986: US$ 1.00 = LE 1,34);
b. Crop compensation for damage resulting from construction activities during installation of the covered drains. The present average rate for compensation is LE 10 per feddan;
c. Deepening and widening of existing main open drains or digging of new ones;
d. Construction of drainage pump stations or increasing the capacity of existing pump stations;
e. Pre-drainage field investigations and design of covered and open drains;
f. Management, administration and supervision of drainage projects;
g. Operation and maintenance of subsurface and open drainage systems;
h. Training and evaluation programmes.

5.2 Cost recovery

The Egyptian law provides for the direct and full recovery of the cost of field drainage during a 20 year period. Provisions are also made for the indirect recovery of maintenance cost through the annual land tax after the completion of drainage works.

6 Project organization and management

6.1 Executive agency

The Egyptian Public Authority for Drainage Projects (EPADP), established in 1973 and belonging to the Ministry of Irrigation, is entrusted with the implementation of

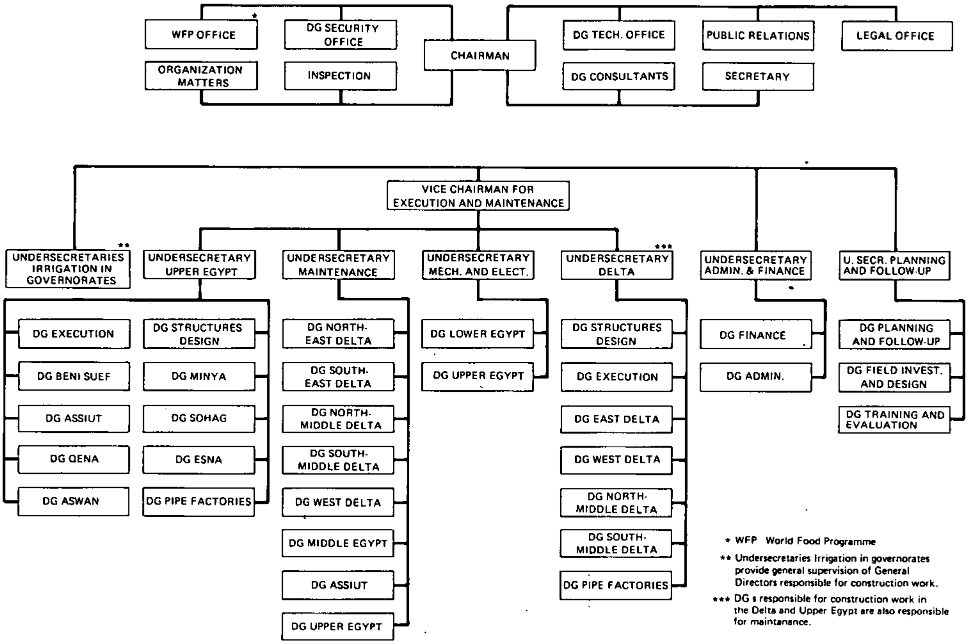

Figure 3 Organization chart of EPADP

the drainage projects. The organization of EPADP is shown in Figure 3. The activities of EPADP involve field investigations, planning, design, procurement of equipment and civil works, budgeting and operation of budget accounts. In the reclaimed areas the Ministry of Irrigation is only responsible for the implementation of the main systems. The secondary and field systems are the responsibility of the Ministry of Land Reclamation.

6.2 Research and consulting institutions

The Drainage Research Institute (DRI) was established in 1977 within the framework of the Water Research Center of the Ministry of Irrigation to conduct applied research, monitoring, testing and evaluation of drainage methodologies and techniques. Its activities are intended to support the implementation programme of EPADP and to solve their technical problems.

The Egyptian-Dutch Advisory Panel on Land Drainage in Egypt was created in 1975 within the framework of the technical cooperation between Egypt and The Netherlands. The panel consists in principal of fourteen members of high managerial level, working in land drainage and related fields. The panel meets twice every year. The main objective of the panel is to assist EPADP, DRI and the Ministry of Irrigation in their effort to combat drainage and salinity problems in Egypt.

6.3 Contractors and subcontractors

Earth work for remodelling of open drains, is carried out by local public sector contractors. Structures to be rebuilt in open drains are awarded to local contractors in the private and public sectors following local procedures for tendering. For the construction of tile drains previously contractors were selected through international competitive bidding. The equipment was imported by EPADP and advanced to the contractors in the form of a mobilization award. Recently EPADP allowed contractors to purchase equipment directly.

7 Operation and maintenance of drainage projects

7.1 Organization

EPADP has established a well structured organization to take the responsibility for the operation and maintenance of all completed drainage works (see Figure 3). The area with completed drainage projects is divided into 8 maintenance directorates, 47 maintenance centers and 214 subcentres. The annual programme for open main drain maintenance is implemented by public sector contractors employed directly by the maintenance directorates. The maintenance programme of covered drains is carried out by the centers and subcenters. Each subcenter is responsible for 5000 feddan and one center maintains tile drains in an area of 40 000 to 50 000 feddan.

7.2 Activities and equipment

Periodic maintenance of open drains is a pre-requisite for satisfactory performance of both the open and tile drainage systems. Weed is the main problem in open drains. Weed control is done manually in 45 per cent of the drains and mechanically in 37 per cent by draglines and excavators. Chemical control of weed is carried out in the rest of the drains. High pressure flushing machines are used for covered drain cleaning. Each flushing machine is operated by an agricultural tractor and supported with a water tank trailer and a booster pump. Bamboo rods are used too for manual cleaning of pipes.

8 Comments and conclusion

The drainage design criteria adopted in Egypt lead to satisfactory results in controlling watertable and salinity levels, and ultimately lead to higher crop yields. However, these criteria need further verification and adaptation for specific geohydrologic and agronomic conditions. At present the criteria are reviewed on the basis of field data from pilot areas and monitoring of existing drainage systems.

The main problem areas which still need further consideration by the implementation and research institutions in Egypt are:

- Quality control of completed construction works such as:
  - Covered drain depth and slope;
  - Gradation of gravel envelope;
  - Uniformity of the gravel envelope layer around the pipe;
  - Installation of covered drains in unstable sandy soils;
  - Joints between laterals and collectors.
- Criteria of using envelope materials in medium to weak soils.
- Use of synthetic envelope material.
- Better organization of construction activities especially the timely supply of materials, spare parts and fuel.

During the last five years considerable improvement in these problem areas were made based on technical studies and field trials and testing of improved methodologies and techniques.

Twenty-five years of drainage in Israel

E. Henkin

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1 Background

Drainage development over a period of time is a function of five factors: requirements, budgets, organization, professional standards and equipment available. In Israel over the past 25 years, drainage development has been oriented to integrate optimally the last three factors, which are directly influenced by efforts of drainage personnel to solve the problems imposed by the first two factors. Hereunder the progress of drainage in rural areas of Israel, excluding municipal drainage will be discussed.

In order to understand and to evaluate drainage development, it is necessary to have relevant background data on physical conditions. Although Israel is geographically a small country, it is blessed with very heterogeneous conditions as illustrated by the 30 great soil orders and over 400 pedological soil types defined in soil surveys. Although classified as a semi-arid region, the annual rainfall varies from 25 mm in the south to 1000 mm in northern Galilee. The topography varies from 400 m below sea level to 2000 m above sea level, creating a mountainous topography in the eastern part of the country, level areas in the valleys, coastal and southern plains and a transient rolling topography between the plains and mountains.

2 Organization and budget priorities

In order to coordinate and to prevent duplication, the governmental responsibility for physical land treatment projects, soil conservation, agricultural drainage, channel improvement, farm dams, and local sewage effluent storage for utilization has been concentrated within the Soil Conservation and Drainage Division (SCDD) of the Ministry of Agriculture. This integration and concentration of responsibility allows flexibility in using agronomic and engineering disciplines to solve the basic water management problems in providing and maintaining optimum water quantity and quality for crop cultivation and development.

The implementation of area drainage projects (area drainage is defined as projects draining watersheds greater than 100 ha) is the responsibility of 23 Drainage Districts. These Drainage Districts are public corporations operating under the jurisdiction of the Drainage and Flood Protection Law enacted in 1957. The majority of the Drainage District members represents the municipal authorities within the Drainage District watershed.

The budgets for area drainage development and maintenance derive almost equally from the central government and special drainage levies imposed by the municipal authorities. The Soil Conservation and Drainage Division is responsible to the government for the professional and administrative operation of these Districts.

The Drainage Law fixes that any activity within a defined stream bed has to be coordinated with the Drainage District. This includes stream bed improvement, maintenance, diversions, dams, anti-malaria control and sewage effluent disposal.

Local agricultural drainage projects are implemented by individual farming settlements. The government provides loans and grants for those projects, whose plans are approved by the SCDD. The outlets for local drainage projects are coordinated with the Drainage District.

Over the past 25 years budget priorities for rural drainage activities were:

a. Flood protection of built-up rural areas;
b. Flood protection of agricultural areas;
c. Disposal of surface run-off from irrigated areas;
d. Control of groundwater table to enable early cultivation and salinity control;
e. Accomodating channel alignment with appropriate agro-technology.

3 Drainage projects

During the rapid expansion of agricultural settlement between 1949-65, inadequate attention was given to drainage problems in the physical planning. As a result there were frequent inundations of settlements and cultivated fields which were located inadvertently in flood plains and small waterways. The first budget priority was given to these areas. Flooding of major streams was frequent, mainly within the coastal plain area and flooding of minor catchments occurred sporadic in the hilly and mountainous areas.

The main ephemeral stream beds, draining the western catchment areas and emptying into the Mediterranean Sea, were first regulated for discharge probabilities of 10-20%. These projects included the Western Galilee, Hilazon, Kishon, Carmel Range, Tananim, Hadera, Alexander, Poleg, Yarkon, Sorek, Lachish and Shikma watersheds. The regulation of these main stream beds, except for isolated stretches, has eliminated flooding in rural areas for 10-20% probability discharges.

The regulation of these streams included fixing of channel depths in order to provide drainage outlets for the adjoining cultivated areas and coordinating of channel alignments with cultivation practices. This regulation of the main streams enabled the implementation of agricultural drainage on 3000 ha each year. At present, surface and subsurface drainage measures have been implemented on almost 50% of the irrigated area in Israel.

The draining of the Huleh Basin, the singular largest drainage project in Israel, was started in the 50's and completed by 1970. This project involved the drainage of a 2000 ha lake and the surrounding swampy area, varying from 4000-7000 ha depending on seasonal rainfall. The drainage of this area with 4000 ha of peat soils created additional problems. Due to the high nitrate content of the drained peats, a potential and serious environmental problem evolved due to the leaching of nutrients that could cause eutrophication of Lake Kinneret located 20 km downstream. In addition there were serious problems of soil subsidence and soil burning.

The solution of the subsidence, burning and environmental problems, created by draining the Huleh Basin was as formidable as the original problem of draining the basin itself. The problems are being solved by maintaining the groundwater level as high as possible without interfering in crop development, firstly through cultivation in most of the area of leguminous plants which have nitrate fixation properties and provide a permanent cover to prevent wind erosion, and secondly through hermetically sealing off the area to prevent leaching from outside flooding, and thirdly through providing flap-gates for internal drainage.

The draining of the Jezreel (Esdraelon) Valley in conjunction with the regulation of the Kishon river bed is an excellent example of integrated soil and water conservation. Up until 35 years ago most of the Jezreel Valley was swamp land, which at best could only be cultivated in the dry season. Due to drainage problems, grain yields were inversely proportional to the amount of seasonal rainfall.

The reclamation of the valley began with deepening and straightening the Kishon river bed in order to provide an outlet for agricultural drainage and to prevent flooding. Surface and subsurface drainage facilities were consequently constructed on 6000 ha. In 1970 a basin-wide programme was initiated to construct farm dams with capacities of 300 000-700 000 m^3 to store run-off from marginal resources such as rainfall, seasonal springs, agricultural return drainage and to utilize the sewage effluent. By 1985, 70 farm-sized dams had been constructed.

By integrating watershed management practices, the same elements that had created drainage, cultivation and environmental problems were utilized in creating a basis for developing a productive agriculture. Today almost the whole western Jezreel Valley is irrigated by integrating the use of waters from marginal resources and 'imported' water from the National Water Carrier. The irrigation of these lands has created new potential drainage and salinization problems, and high watertables from reservoir seepage.

4 Agricultural drainage

4.1 Surface drainage

Surface drainage of agricultural lands which has been implemented in conjunction with stream bed regulation has three main objectives:

a. Draining-off surplus rainfall to allow early spring cultivation;
b. Prevention of localized wet spots to allow continuous cultivation;
c. Integration of irrigation and drainage in physical planning to optimize water distribution and to increase cultivation efficiency.

In the plain areas with slopes up to 2%, the main surface drainage measures are diversion ditches, land levelling, field ditches and the use of bedding as a standard cultivation practice. In areas with slopes over 2%, soil conservation measures, including grassed waterways and parallel terracing, are incorporated with land forming (elimination of surface irregularities). In the past 10 years, concentration has been placed on the reduction of run-off by introducing chemical and agro-technical measures that increase infiltration rates and surface detention.

4.2 Subsurface drainage

Subsurface drainage has been developed on two depth-levels for two different purposes. In the 500-700 mm rainfall areas, perforated plastic corrugated tubing is placed at depths of 0.80-1.20 m with the main purpose of lowering seasonal perched watertables to enable early spring cultivation. Shallow subsurface drainage is also placed in waterways with tight clay soils to drain more quickly these sensitive areas and allow continuous cultivation. Shallow drainage has mainly been placed in the Jezreel and Upper Galilee Valleys.

In the lower rainfall areas and in localized areas within the higher rainfall areas, the main object of subsurface drainage is to control salinity and to prevent the rise of artesian watertables. Under these conditions, drainage facilities are installed at depths of 1.80-2.80 m. This type of drainage has been extensively used in the Jordan and Beisan Valleys (200-300 mm of annual rainfall) and in the Arava between the Dead Sea and Eilat (25-50 mm of annual rainfall).

5 Future drainage development

Due to the limitation of the overall water supply, development of new agricultural lands will be very much constrained in the future. The main drainage thrust will be in providing soil and water conditions that will enable maximum production given the present water supply in the actual irrigated areas.

Major stream bed and channel regulation will be continued in order to complete the unfinished sections and to handle the larger discharges resulting from increased rural and urban infra-structural development.

Continuous irrigation will cause a rise in watertables and in groundwater salinity. This rise in salinity levels will be accelerated due to increased use for field crops of treated sewage effluent, which has 100 ppm more salinity than the original domestic supply level. Under those conditions the installation of deep drainage facilities will be essential to maintain agricultural production.

On sloping areas within the 200-500 mm rainfall isohyets, the emphasis will be put on efforts to reduce run-off by increasing infiltration rates and surface detention. Local research has shown that infiltration can be substantially increased by adding electrolytes derived from industrial phospho-gypsum by-products which improve soil structure and prevent crust formation from rain splash. Further efforts will be made to increase the detention and retention of surface run-off by introducing cultivation methods which will pond water in cultivated furrows and beds by pitting and listering.

6 Drainage design criteria and methods

Due to perennial budget constraints and lack of valid economic evaluation data, drainage has been and for the coming years will remain, an art rather than a pure science. Technical decisions relating to drainage design criteria and methods will continue to be based mainly on individual experience and weighted evaluations of expected costs and benefits. Hereunder are criteria developed in Israel from local experience and budget constraints in the past.

6.1 Channel discharge capacity

The design discharge capacity of channels in rural areas can be determined on the basis of discharge probability based on run-off records, if available, or can be determined from computations by extrapolating available rainfall, soil and land use data. Discharge probabilities of 10-15% are used for cultivated areas, and 4-10% are used for built-up rural areas. To the basic physical data, a judgement factor has been introduced. The judgement factor is evaluated on the following factors:

a. he value of the crop or area protected by the channel;
b. The damage and period of flooding if channel overtopping occurs;
c. The degree of irreversibility of the damage.

For structures which are likely to be destroyed or severely damaged by 'above-design' discharges, other criteria are used than for earth-work. Frequently earth channels are designed with a reduced velocity criterion related to 50% probability flow but due to natural topographic conditions they can carry discharges to 5% probability flow. Structures are initially designed and constructed to be stable at 4% probability.

Until 7 years ago, discharges from watersheds smaller than 4000 ha were not measured in Israël. A programme was initiated by the SCDD to measure peak flows from watersheds from 1-2000 ha. During this short period a rain storm of 10% probability (determined from long term rainfall records) occurred. The maximum discharge from this rainfall was used as a base for the determination of the discharge design for almost all small watersheds in the country. Extrapolation was done on the basis of the Rational Run-off Theory ($Q = CIA$) where the constant 'C' was determined according to soil pedological classifications. A pedological classification incorporates a measure of land use, slope and infiltration capacity.

6.2 Channel stabilization

The design of stable channels (not rivers) is usually based on maintaining average flow velocity within fixed limits. The use of the transient forces theory is frequently mentioned in the literature but not generally used in practice. The design velocities are determined on the basis of the Manning formula.

For given conditions of discharge and slope, velocity control can be obtained by decreasing the slope by using drop structures, increasing the Manning coefficient of roughness or by decreasing the hydraulic radius for a given channel section by increasing the wetted perimeter.

6.3 Grassed waterways

Since drop structures were found to be an expensive solution and decreasing the hydraulic radius has physical limitations, in the last 15 years efforts for channel stabilization have been directed to develop cultivated grassed waterways and natural channel vegetation. Vegetation serves two purposes in channel stabilization:

a. It increases the Manning roughness coefficient and consequently it decreases the velocity;
b. It increases the allowable design velocity.

The allowable channel velocities for 1 m depth flows used in Israel are shown in Table 1. For flows up to 2 m depths the allowable velocities can be increased up to 20% and should be decreased by 20% for flow depths between 0.30-1.00 m.

Table 1 Allowable design velocities for 1 m depth flows in Israel

	Design velocities (m/s)		
	Natural vegetation Annual rainfall < 500 mm	> 500 mm	Grassed waterways
Light textured soils	0.60-0.90	0.80-1.20	0.90-1.30
Medium textured soils	1.00-1.20	1.20-1.50	1.50-1.80
Heavy textured soils	1.10-1.30	1.40-1.80	1.80-2.20

Vegetation in grassed waterways under local conditions should have qualities of being erosion resistant, produce minimum seed quantities in order not to spread to cultivated areas, require a minimum quantity of water especially during the summer, and be established by standard cultivation practices. It proves difficult to find a grass variety meeting all these requirements, especially the last one.

The main varieties of vegetation used to stabilize waterways are:

a. Annuals seeded in September-October: wheat, barley, rye, vetch;
b. Perennials seeded in April-September and irrigated: Love grass (eragrostis curvula); Rhodes grass (chloris gana); Bermuda grass NK 37 (cynodon dactylon var. NK 37);
c. Perennials transplanted in May-September: Paspalum (paspalum distechum); coastal Bermuda (cynodon dactylon var. coastal Bermuda); Panicum (panicum coloratum); pangola (digitaria decumbens).

The applicable Manning coefficient of roughness 'n' for these grasses in Israel in relation to the degree of vegetal retardation (Rhee, 1954) is classified 'D'.

6.4 Bed sills

An important measure introduced during the last 15 years to stabilize channel beds are bed sills. Bed sills are simply cut-offs which may be constructed from rock-concrete, gabions, large loose rock, timber or plating which crest is equal with stream bed level with depths that can vary from 0.6-2.5 m. The basic idea of a sill is, similar to that of a terrace, to shorten the length of flow that gullying can develop.

In channels, sills are not generally used as a singular stabilizing element but are associated with the development of a natural or cultivated vegetation. Hereunder are the empirically determined allowable velocities and bed sill spacing formulae.

Maximum allowable stream velocities in channels with bed sills are as follows:

- For cohesive soils with stabilized vegetation 3.5 m/sec;
- For cohesive soils without vegetation 2.5 m/sec;
- For non-cohesive soils 1.8 m/sec.

The spacing formulae commonly applied in Israel are the following:

$$\text{Maximum spacing} = \frac{100\ D}{V}$$

$$\text{Spacing for cohesive soils} = \frac{0.5\ D}{S\text{-}S_1}$$

$$\text{Spacing for non-cohesive soils} = \frac{0.3\ D}{S}$$

in which

D = sill depth (m)
V = computed velocity (m/s)
S = slope (m/m)
S_1 = slope for allowable velocity (m/m) $= \frac{(V_1 n)^2}{R_1^{\ 2/3}}$
V_1 = allowable velocity (m/s)
R_1 = hydraulic radius of channel section with allowable velocity V_1 (m)
n = roughness coefficient

These suggested formulae are valid for computed spacings between 10-60 m. Bed sills have generally been used to stabilize defined channel beds draining watersheds of up to 4000 ha. In one instance a braided stream bed emptying into the Dead Sea with a discharge of 100 m³/sec, having a longitudinal slope of 2% and transporting a stoney bed load, was successfully stabilized by 2.5 m deep bed sills.

6.5 Subsurface drainage

Design criteria for subsurface drainage have been empirically developed by evaluating costs, hydraulic, hydrologic, agronomic and soil data.

Drainage coefficients have not yet been scientifically developed. At present subsurface drainage systems have been designed to remove 4 mm/day and no system has thus far suffered from under-design.

The present design parameters are:

	Spacing	Depth
a. Drainage for semi-humid conditions and seasonal high watertables	20- 35 m	0.80-1.20 m
b. Drainage for salinity and permanent watertable control	70-100 m	1.80-2.40 m
c. Special drainage for greenhouses	0.50 m	3-6 m

The use of envelope materials in subsurface drainage remains an enigma. The main envelope material is fine gravel. In heavy soils, envelopes are designed with depths of 15-20 cm above the pipe. Frequently in gromosolic soils, where the A layer is much more permeable than the B layer and due to topographic and agronomic considerations the pipe is placed in the B layer, and the envelope thickness is increased in order to serve as a transient between the A and B soil layers. Studies have shown that in heavy soils the functioning of the pipes with and without envelopes was identical in the first years of operation. With time, the excavated material over the pipe compacted and the systems with envelopes operated more efficiently.

In light soils, it was found necessary to use geotextile covering of the pipe together with gravel to prevent sedimentation. If tubing with geotextile covering is not available, the cost becomes extremely high.

In draining certain swampy areas with high iron oxide concentrations, severe problems of ochre were encountered. The problem was studied by micro-biologists who isolated the Leptothrix Desrophorus bacteria which caused the ochre. At their suggestion the system was designed in such a way that anaerobic conditions were obtained by placing an elbow at the outlet to create submergence. These systems have operated effectively for several years.

7 Costs

Costs, being a function of basic physical conditions, design standard equipment available, size of individual projects and scale of country-wide projects are difficult to compare. Hereunder are local costs of drainage converted to US$.

7.1 Subsurface drainage

In Israel there is only one drainage contractor with a trencher and only one company that produces perforated corrugated plastic tubing. This equipment places 70-100 km per year. Drains deeper than 2.5 m are dug by excavators and concrete pipes are laid by hand.

A subsurface drainage system for semi-humid conditions, with 30 m spacing and 0.80-1.20 m depth, will cost US$ 2000-2500 per ha including the outlet facility.

Deep drainage with 90 m spacing for watertable and salinity control in sandy soils will also cost US$ 2000-2500 per ha. The geotextile envelope which has to be hand-wrapped is a major factor in the cost.

7.2 Surface drainage

In Israel the basic cost of moving 1 m^3 of earth by a self-loading rubber-tired motor scraper over distances up to 100 m is US$ 0.60-0.80. At these rates levelling costs US$ 600-800 per ha and land forming US$ 200-300 per ha.

Waterways draining areas of 20-70 ha will cost US$ 0.50-0.75 per m length and are frequently dug by motor-graders.

The establishment of grassed waterways including growing and collecting the parent material, cultivation, fertilization, hand planting, irrigation pipes, water and labour costs US$ 0.40-0.60 per m^2.

Costs of lining a channel with loose rock are US$ 3.00-5.00 per m^2.

8 Maintenance

Maintenance of drainage projects is a universal problem since for psychological and local political reasons, budgets are usually more readily granted for implementation of new projects rather than for maintenance and improving maintenance technology in existing projects. In an attempt to deal with this problem a special maintenance advisory team, funded equally from the government budget and the Drainage Districts, was created under the guidance of the Research Unit of the SCDD. The function of this team is to develop appropriate technology and to advise the Drainage Districts on maintenance problems.

The main problem in channel maintenance is the control of the vegetation within the stream bed. Control of vegetation is necessary to retain the designed discharge capacity of the channel, to enable efficient anti-malaria control and to prevent the spreading of potential weed seeds. It should be emphasized that the goal is to control and not to eliminate the vegetation and that the vegetation continues to stabilize the stream bed from erosion.

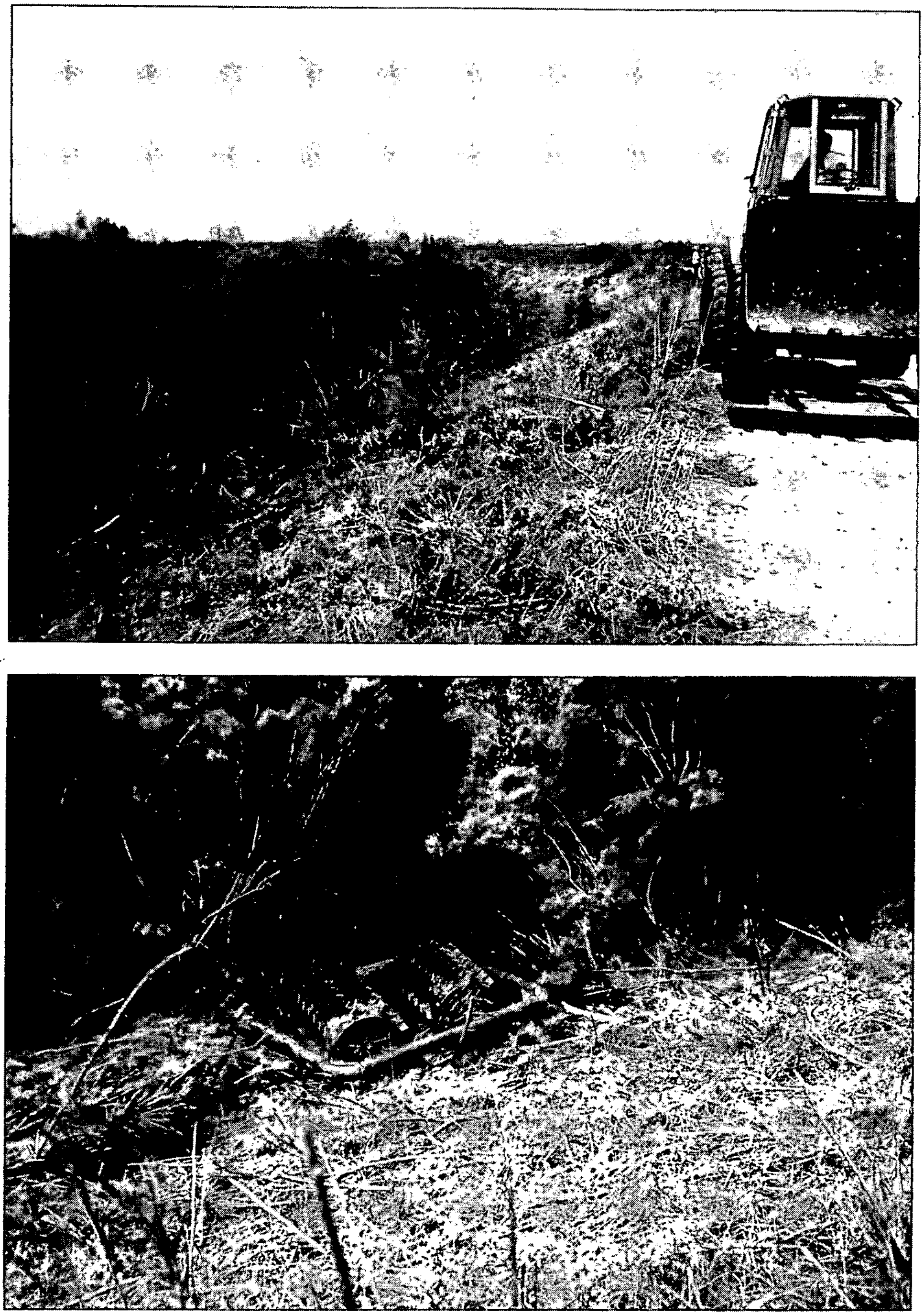

Figure 1 Padded roller with lugged-clain clodbuster

The main types of equipment developed and adapted for vegetation control are:

a. Orchard mowers (flail and blade type)
   Orchard mowers are operated by 40 h.p. farm tractors travelling on minimum channel side slopes of 1:3.5 (vertical to horizontal). Costs: US$ 50-60 per ha;
b. Hydraulic mowers
   Hydraulic mowers are operated by 70-90 h.p. rubber-wheeled tractors travelling along the channel maintenance road, and operating side mowers that can be fixed at any angle. The length of the mower is 3-5 m; used mainly for grass-type vegetation with steep channel side slopes. Costs: US$ 150-250 per ha;
c. Lugged-chain clodbuster (Figure 1, top)
   The lugged-chain clodbuster is constructed by welding lugs on a chain, varying in length, weighing about 25 kg per m and with a 350 kg weight at the end. It is operated by rubber-tired shovel dozers travelling along the channel maintenance road and extending the lugged-chain along the channel slope. The lugged-chain breaks down rough vegetation for future burning or collection. The operation requires 3-6 passes and costs US$ 70-100 per ha;
d. Padded roller and lugged-chain clodbuster (Figure 1, bottom)
   The lugged-chain is used together with a padded roller type device to clear channels having mixed grass, shrub, and woody vegetation and up to 1 m water on the channel bottom. The equipment is operated by a shovel dozer travelling along the channel maintenance road. Costs: US$ 80-120 per ha.

Different types of herbicides are used where mechanical equipment cannot operate or is inefficient. 80-90% of the total maintenance costs is used for chemical sprays. Costs: US$ 0.60-1.00 per m^2.

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A review of planning strategies of salinity control and reclamation projects in Pakistan

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1 Background and extent of the problem

1.1 Background

The problem of waterlogging and salinity in Pakistan is typical for irrigated agriculture where adequate drainage is not provided. The causes are fairly well known and well documented. These causes shall be only briefly stated.

In the latter half of the 19th century, the British undertook the construction of weir controlled irrigation systems in the Indus plain. Soon after the commissioning of these canals the groundwater table started to rise steadily. A substantial contribution to the watertable build-up was seepage from canals and watercourses. Deep percolation losses from irrigation also contributed to the problem. Development of road and railway networks without proper cross drainage facilities along with the construction of flood and irrigation bunds compounded the problem by obstructing the natural drainage. Heavy monsoon rains resulted in ponding of the depressions, thus increasing the volume of water percolating to the groundwater.

Soil salinity in Pakistan is a product of climatic conditions, original soil chemistry, land use, irrigation practices, and the shallow depth of the watertable.

1.2 Extent of the problem

The Indus Plain covers a gross culturable command area of 36.5 million acres. Out of this 32.6 million acres are irrigated (including both perennial an non-perennial areas). The irrigation system in the Indus Plain encompasses two large storage reservoirs, 17 barrages, 8 link canals, and 40 000 miles of irrigation conveyance systems. Before the construction of this network, the watertable in the center of the doabs (the land strips between two rivers) ranged between 75 and 100 feet. The seepage from the unlined irrigation channels and on-farm percolation losses combined with the blockage of natural drainage resulted in a rise of the watertable at a rate of 0.5 ft to more than 2 ft per year depending upon the hydrogeological features of the specific areas. This trend is shown in Figure 1. Before anything could be done on a proper scale, the watertable had risen to within a few feet from the ground surface. This was the start of the occurrence of salinity and waterlogging problems.

The first large scale studies were undertaken in 1953 under the Colombo Plan. The results of the photographic survey were available in 1958. Seventeen per cent of the area was mapped as waterlogged (predominantly poorly drained), seven per cent was predominantly severely saline while an additional sixteen per cent had saline patches. Due to difference of opinion on the definition of 'waterlogged and salinized land' different figures are available in different reports. There was, however, no difference of opinion that the situation was alarming and it was generally believed that Pakistan was loosing in the Indus Plain 100 000 acres of cultivated land each year. The government took serious note of this and published the problem as 'Pakistan's Enemy No. 1'. The newly created 'Pakistan Water and Power Development Authority' (WAPDA) was made responsible for fighting the twin menace of salinity and high watertable conditions.

2 Planning concepts

2.1 Early planning strategies

The problem first appeared in the Punjab (central part of Pakistan) and the provincial government at that time established a 'Drainage Board' as early as 1917. The first large scale anti-waterlogging measures were undertaken in 1933, which comprised construction of seepage-cum-surface drains in the affected areas. By 1947, 2270 miles

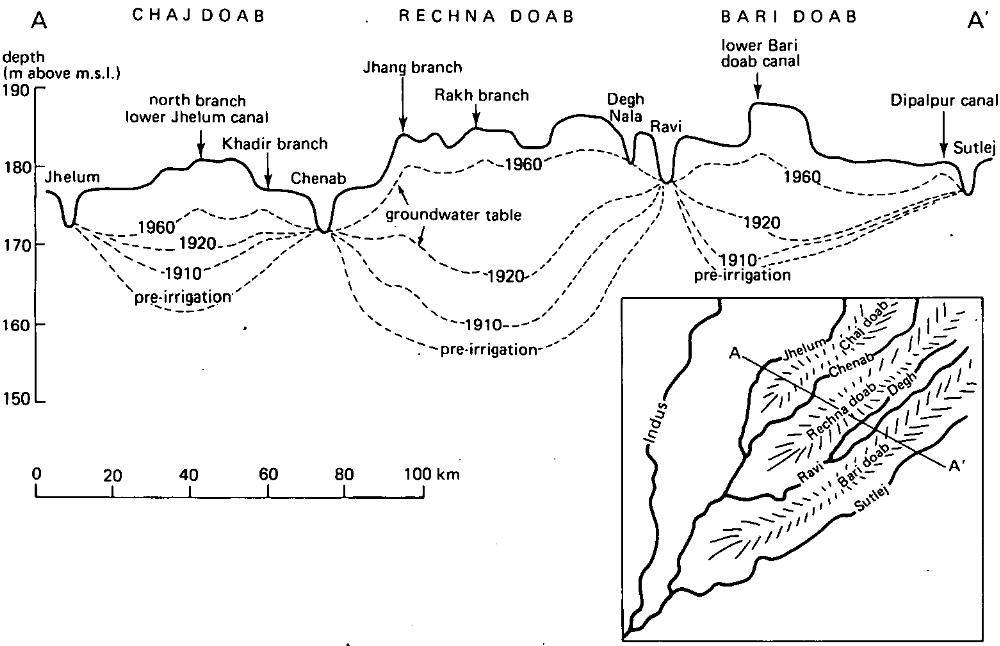


Figure 1 Groundwater table profiles in Punjab (Northeast Pakistan)

of such drains had been constructed. Due to flat topography, improper design, and inadequate provision of lateral tributary drains, the system did not work well as it could not arrest the rise of the watertable. Consequently the interest in the extension of the surface drainage systems started to decline.

Lining of canals as a preventive measure was first attempted in 1943 and a few canals including two of the link canals under the 'Indus Basin Replacement Works Programme' were lined with a double layer of brick lining. The cost was so prohibitive that a further lining programme could not progress. The first small scale subsurface drainage project was initiated around 1940. Tubewells were planned as a means for intercepting the canal seepage. A total of 1257 tubewells were installed first at a distance of 60 ft from the canal and thereafter at 600 ft. This could provide relief in a small strip of land along the canals but obviously could not solve the problem in areas further away from the channels.

Experts of United Nations visited Pakistan in 1950 and recognizing the usefulness of tubewells as a drainage measure recommended a few tubewell drainage pilot projects. As a consequence, 202 tubewells were installed in the Rechna Doab (1965-60).

Other measures that were planned but for various reasons could not be implemented on a large scale, included:

a. Preventive measures
   - Frequent and extensive canal closures;
   - Lowering of canal water levels;
   - Conversion of areas from perennial to non-perennial irrigation.

b. Curative measures
   - Reclamation through rice cultivation;
   - Tree plantation.

While conceptually most of these measures offered solutions, none was applied either extensively or intensively. The onslaught was at such a scale that stepping up of the efforts was sought with international assistance. In the meantime the wet cycle during the 50's further aggravated the problem of waterlogging.

2.2 Planning strategies developed by WAPDA and its consultants

To fulfil its obligation, WAPDA put in gigantic efforts at international level for detailed investigations. In addition to the World Bank Study Group, a large number of foreign consulting firms was involved in the study and planning of projects.

While the detailed investigations in other parts of the Indus Plain were still in progress, the first Salinity Control and Reclamation Project (SCARP-I) was planned for implementation. Under this project 2041 tubewells were put into operation progressively by March 1963. The project covered an area of 1.2 million acres.

The adopted development approach primarily constituted subsurface drainage by installing tubewells wherever feasible and utilizing their effluent to supplement irrigation water supplies directly or by mixing with canal water. In addition, the surface drainage system was also be enlarged to deal with surface run-off. Soil reclamation was envisaged to the extent attained through drainage provided under these projects.

Further reclamation efforts were suggested to be undertaken by the farmers themselves.

The overall approach, planning concept, and design criteria developed by various experts and consultants had only minor differences. Tipton & Kalmbach (USA) inclu-

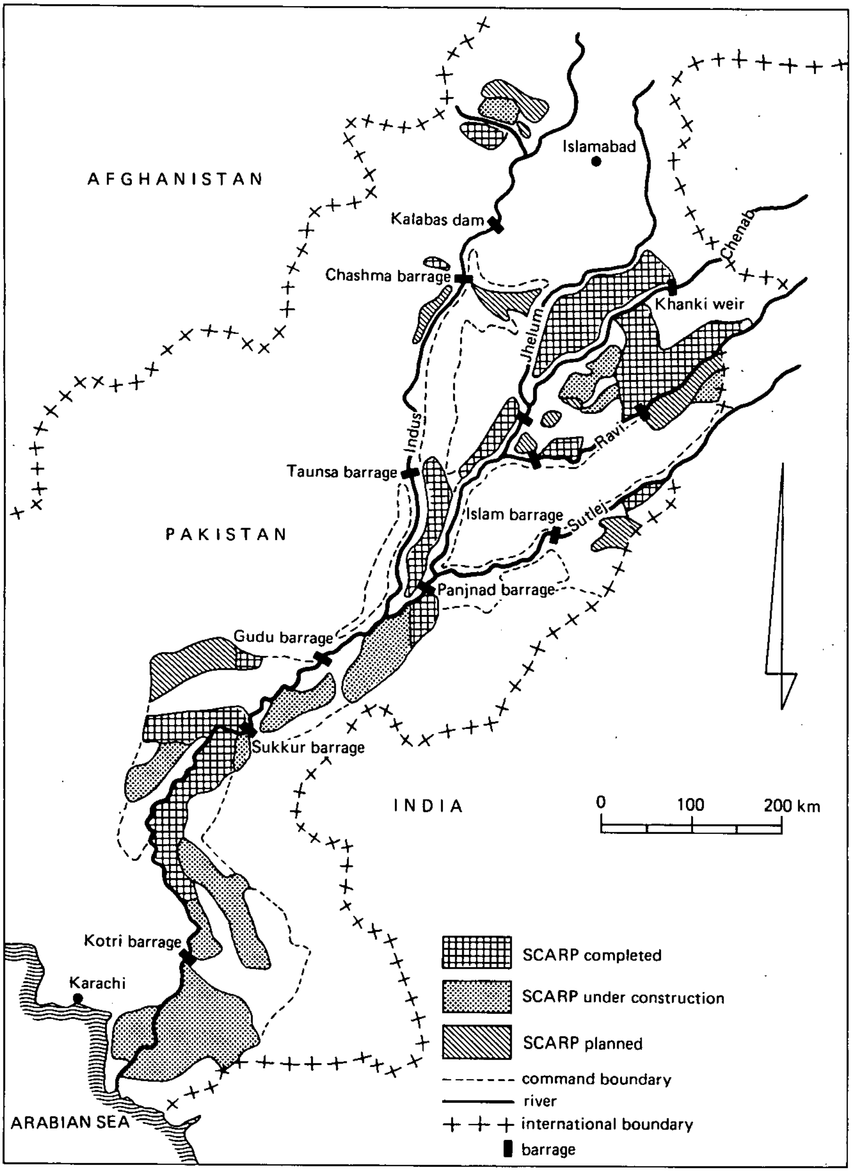


Figure 2 Completed, under construction, and planned reclamation projects in Pakistan

ded a design criterion that required recovering the entire recharge of 20 MAF (Million Acre Feet) plus an additional mining of 20 MAF per annum so that the watertable is deflated to 70-100 ft below ground level i.e. the pre-irrigation level. It was stipulated that initially one MAF of highly saline water would be exported to the sea.

The World Bank Plan on the other hand suggested a balanced pumping to stabilize the watertable at 10 to 15 ft from the ground surface. This plan was adopted and thereafter a large number of projects have been completed up to June 1985. Figure 2 shows the completed, the on-going, and the planned projects.

3 Achievements and shortcomings of completed projects

By June 1985 WAPDA had completed 32 reclamation projects covering a gross area of 8.77 million acres. This included the construction of 12819 tubewells and 2131 miles of surface drains at a total cost of Rs. 4955.00 million.

The projects in execution include 15 reclamation projects covering a gross area of 6.99 million acres, involving construction of 3841 tubewells and 8979 miles of drains of which 4669 miles of tile drains. The total estimated cost of these schemes is Rs. 10215.00 million.

There can be no doubt that the SCARP-projects have provided some relief to the affected lands but it is also generally agreed that the objectives were only partially achieved. The SCARPs also had a great impact through their demonstrative effect. This is evidenced by the construction of private tubewells which number increased from a few thousands at the start of the programme to over 200 000 by June 1985. The small capacity private tubewells in SCARP areas greatly helped in reducing the waterlogging and salinity conditions. Cropping intensities also increased but there are many other factors involved and the exclusive contribution of the SCARPs has not yet been evaluated.

After 30 years of struggle, and with billions of Rupees invested, Pakistan is still far away from solving the problem. Table 1 shows that the groundwater table is still rising towards the surface.

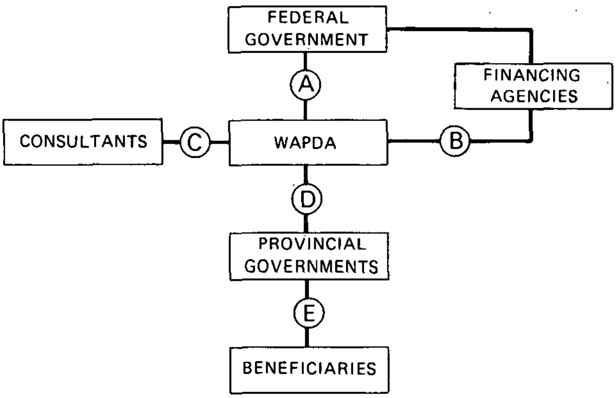
Table 1 Watertable depth in the Indus Plain of Pakistan

Survey period	Total area	Very poorly drained (0-3 ft)	Poorly drained (3-6 ft)	Moderately drained (6-10 ft)	Well drained (> 10 ft)	Misc. type
1953-75*:						
in million acres	24.75	0.58	2.64	5.66	15.24	0.63
in per cent	100	2	11	23	62	2
1977-79**:						
in million acres	41.28	27.40	6.28	8.27	22.94	1.05
in percent	100	7	15	20	55	3

* Previous surveys
** Based on WAPDA's latest survey of 41 million acres of irrigated area

4 Evaluation of the completed SCARPs

To understand what went wrong, the management set-up and communication links between the various agencies involved in planning, designing, financing, implementing, and maintaining of the projects need to be known. This is shown in the following diagram:



The various agencies involved are elaborated hereunder.

WAPDA
WAPDA is the executing agency responsible for identifying, investigating, planning, designing, constructing, and then handing over the completed projects to the provincial governments after an initial operation of one year.

Federal government
The federal government approves and finances the project either directly or in case of large projects, jointly with international financing donor agencies.

Consultants
As a condition for the effectiveness of the loan and also as dictated by the nature of a project, WAPDA is required to engage consulting firms which in the past have mostly been foreign firms.

Provincial governments
Provincial governments are responsible for operation and maintenance of the projects and for collecting water fee rates from the farmers. The revenue receipts in excess of the operation and maintenance costs are to be used for repayment of the loan.

The role of the above agencies has been questioned in many respects. Particularly in planning deficiencies, time limits, efficiency in getting the work completed, and lack of operational and maintenance skill.

Coordination with federal government (Link A)

The major problem between WAPDA and the federal government has been the inadequate funding, resulting in delayed completion of the projects. The project appraisal and feasibility studies were generally biased in favour of higher benefit-cost ratios, with the result that there was a large gap in the estimated and actual costs. Apart from upsetting the cost effectiveness of the project, it also involved additional time consuming procedures in getting the revised cost estimates sanctioned by the government.

Role of financing agencies (Link B)

Link B is generally problem free apart from the cases where co-financing is involved and more than one agency provides financial means for a single project. There are serious coordination problems, lack of understanding and lengthy channels to arrive at decisions in planning and designing stages of the project. Elaborate procurement guidelines and rigorous procedures of some of the financing agencies also tend to delay the project.

Role of consultants (Link C)

Link C relates to the basic work of planning and designing the projects by the consultants either independently or jointly with WAPDA. In the context of the completed projects the following serious deficiencies can be stipulated:

- Some of the assumptions and design criteria adopted by these firms eventually proved to be highly idealized. A specific reference is drawn to the design of the earlier SCARPs where the optimism in planning concept was that low quality water was fit for application either directly or after mixing with canal water. Water of 1500 to 4000 ppm was expected to be mixed with canal supplies. It was too ambitious to achieve it in practice as the farmers had little knowledge and background on how to mix water. It was wrong to apply the law of averages for determining mixing ratios;
- Although each tubewell is a discrete project, proper attention was not given to individual tubewell siting and design. The concept of aggregation and group design did not work;
- Reliance on expensive imported equipment eroded the cost effectiveness of the project;
- The foreign consultants concentrated on the scientific and engineering solutions of the problem and did not take into account the cultural and socio-economic bias of various farming communities. Their planning also did not have any relationship with the management capabilities of the beneficiaries;
- There was a lack of emphasis on preventive measures such as the rehabilitation of surface drainage and irrigation systems and the improvement of on-farm water management practices;
- There was no significant local participation in planning, designing and implementing the earlier projects;
- The consultants usually worked strictly within the 'terms of reference' and did not always produce the best engineering solution of the problem. In certain cases the

employer's biased approach to a particular solution also influenced the work of the consultants;

- Design of large capacity tubewells without considering the existing carrying capacities of the watercourses created operational, maintenance, and distribution problems;
- Mild steel pipes and strainers were designed and used despite the corrosive nature of the water in the aquifer;
- The planning concepts were immune to evaluation or to criticism as no significant provision for monitoring and evaluation was made as part of the project plan;
- Possibilities of salt water intrusion from the lower aquifers were not taken into account;
- Surface drains being the backbone of any drainage system were not given the proper attention.

Implementation deficiencies

In the implementation stage the typical problems experienced were delays and excess spending. The element of delay was not so much due to organizational inefficiencies but due to inadequate funding. Some of the project preparatory work could have been concurrently started while the project was appraised.

The excess spending was on account of (a) the initial estimate being unrealistic with a view to get the project approved and (b) the reliance on high technology particularly for the tubewells.

Operation and maintenance problems

By far the most serious problems have been experienced in the operation and maintenance of the tubewells as well as the surface drains. The expertise of the provincial departments has not yet developed to the level of appreciating the implication of continued operation of these tubewells. As some of these tubewells started pumping brackish water the farmers became dissatisfied and took the programme as a curse. A number of tubewells had to be abandoned on this account.

The trade unionism of the tubewell operation staff was one of the major hurdles for the maintenance agency to have effective control on the utilization of these tubewells. The operators usually absconded from their duties leaving operations in the hands of farmers or their workers who played with the sophisticated starting mechanism causing a number of mechanical and electrical breakdowns. The deep well axial-flow pumps could only be repaired in the departmental workshops and the spare parts were not readily available.

Excessive billing for energy consumption also increased operation and maintenance costs.

5 Current planning concepts

In view of the lessons learnt from the completed projects, the on-going accelerated plan for waterlogging and salinity control has been revised. The new approach equally emphasises on preventive and curative measures. In first instance every effort will be made to prevent occurrence of waterlogging and salinity. But wherever it cannot be controlled by preventive measures, appropriate curative methods will be adopted.

Preventive strategies
- Effective on-farm water management to reduce losses in the irrigation system;
- Tree planting along irrigation channels;
- Lining of minor irrigation channels;
- Launching of irrigation and drainage system rehabilitation projects;
- Extension of field drains by the provincial agricultural departments and maintenance through water users associations;
- Public tubewells in the fresh groundwater zone shall be transferred to the private sector;
- Once a reclamation project has been implemented then the provincial governments should not increase the water supply in that area without the permission of the federal government.

Curative strategies
- Priority would be given to the reclamation of disastrous areas underlain by saline groundwater depending upon the productivity potential of land, types of crops grown, and density of population, etc;
- Reclamation of areas underlain by fresh groundwater should be the responsibility of the private sector, with the exception of those areas which cannot be reclaimed by vertical drainage. The government shall provide a closely spaced electrical grid, an advance loan and subsidies to encourage installation of tubewells;
- Research institutes and farming associations shall be closely associated in developing site specific solutions to the drainage problem;
- Tile drains shall be installed where the aquifer is not suitable for tubewells or where the groundwater is highly saline.

A Four Year Reclamation Plan (1986-90) has been prepared on the basis of the new approach for a total financial outlay of Rs. 15 000 million to reclaim 4.5 million acres.

6 Subsurface pipe drain versus tubewells

The physical properties of the aquifer throughout the Indus Plain are suitable for either method of drainage except in some areas where the aquifer conditions are not suitable for tubewells. There are a number of factors that need to be considered in selecting one method or the other.

General dissatisfaction with the performance of the tubewells, particularly the deterioration of water quality by salt water intrusion in saline areas has tended to swing the balance in favour of subsurface pipe drains. The problems relating to operation and maintenance of tubewells have already been enumerated. The pipe drains on the other hand offer the prospect of relatively trouble free maintenance.

The tubewell provides a temporary relief and a few years of continuous wet spell could reverse the declining watertable trend. This has already been experienced during the heavy monsoon rains of the early 70's.

At present three tile drainage projects are under construction in Pakistan. It will take a long time before these are monitored and evaluated for their effectiveness and operational performance. However a major constraint in pipe drainage is the relatively high initial capital investment. A study was carried out by ILACO for SCARP-VI to determine the cost effectiveness of the two alternatives. They found that on the basis of average annual cost, the two alternatives were equally cost effective.

The effluent from the tubewell has generally a higher mineral content and involves a large quantity of water for disposal. For pipe drains this quantity is limited and is only present when the watertable is high.

At present both methods are being considered and are being adopted according to the physical properties of the respective project areas.

7 Conclusions and recommendations

The foregoing review of the waterlogging and salinity problems shows that while a number of corrective actions has been taken in the field of project planning, there are still a number of issues that need to be tackled seriously for effectively dealing with the problem at national level:

- Surface drainage, particularly the extension of field drains to the farm level has still not attracted the attention of the planners. The existing overall length of the drains is approximately one third of the irrigation conveyance system. The length of the drainage system should preferably match the length of the irrigation canal system;
- Maintenance of the surface drains is far from satisfactory due to the problem of a flat gradient resulting in low velocities and sedimentation. Methods of controlling erosion on the side slopes and sloughing problems are the most serious maintenance constraints that need immediate attention;
- In the interest of efficiency, there is a need to streamline and to simplify the procurement procedures of the financing agencies. It is also desirable that co-financing has to be avoided as much as possible;
- There is a need to explore the possibility of making the organization responsible for implementation also responsible for operation and maintenance;
- Farmers associations should be actively involved not only in the identification of the project but also during the planning and implementation stages;
- Measures should be taken to check the untreated city sewage and industrial waste entering the surface drains. For this purpose a legislative act may be necessary;
- With a view to reduce the cost of subsurface pipe drainage a research programme needs to be undertaken to study the most economical system, including envelope material, pipe size, pipe depth, and method of installation;
- All projects should be backed up with research to develop low cost technology suited to Pakistani conditions. The recently established International Waterlogging and Salinity Research Institute should be involved to play its role in a most meaningful way.

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Introduction of subsurface drainage in Pakistan East Khairpur Tile Drainage: a pilot project

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1 Introduction

Irrigated agriculture dominates the economy of Pakistan. It accounts for about one-third of the GNP, employs nearly two-third of the labour force and is practiced on more than 30 million acres. Although it accounts for 90% of the total agricultural production aided in the recent past by (a) introduction of high yielding crop varieties, (b) rise in use of fertilizer, and (c) increase in number of private tubewells, the future growth is threatened by increasing problems of waterlogging and salinization.

A comprehensive programme of Salinity Control and Reclamation Projects (SCARP) has been undertaken in that direction. In the Sind province these projects were identified within the framework of a development plan presented in the Lower Indus Project report in the mid-sixties on the study carried out by the Water and Power Development Authority (WAPDA) with the advice of Hunting Technical Services and Sir M. MacDonald and Partners (England).

The East Khairpur Tile Drainage Project covers an area of about 36000 acres and is one of the interrelated projects envisaged in the plan for the development of land and water resources of the Sind province (Figure 1). Priority is given to the development of fresh groundwater resources followed by tubewell drainage projects in the saline groundwater areas and lastly tile drainage projects in areas where the physical conditions do not allow for tubewells. Selection of priorities is based on economic and social criteria.

An exception to this general order of priorities was given to the East Khairpur Tile Drainage Project which is effectively an integral part of the earlier completed SCARP Khairpur but not suitable for tubewell drainage. East Khairpur had thus been undertaken as a pilot drainage project for introduction of modern techniques which would be required for extensive tile drainage works in an area of about 1.4 million acres with poor discharge from aquifers or other adverse characteristics (bed rock at a shallow depth of 13-14 m below ground level in the case of East Khairpur), which made the area unsuitable for any other type of drainage activity.

The top soil is mainly medium to fine textured with low drainability, becoming coarser textured in the northern part with medium drainability. The depth of occurrence of the sand layer varied from near the surface to depths greater than 12 ft below ground surface. About half of the area has a thickness of the sand layer of less than 6.5 ft. With such a shallow depth of the sandy layers and the watertable generally at a depth varying from 0-5 ft below ground surface the soils were extremely sloughly,

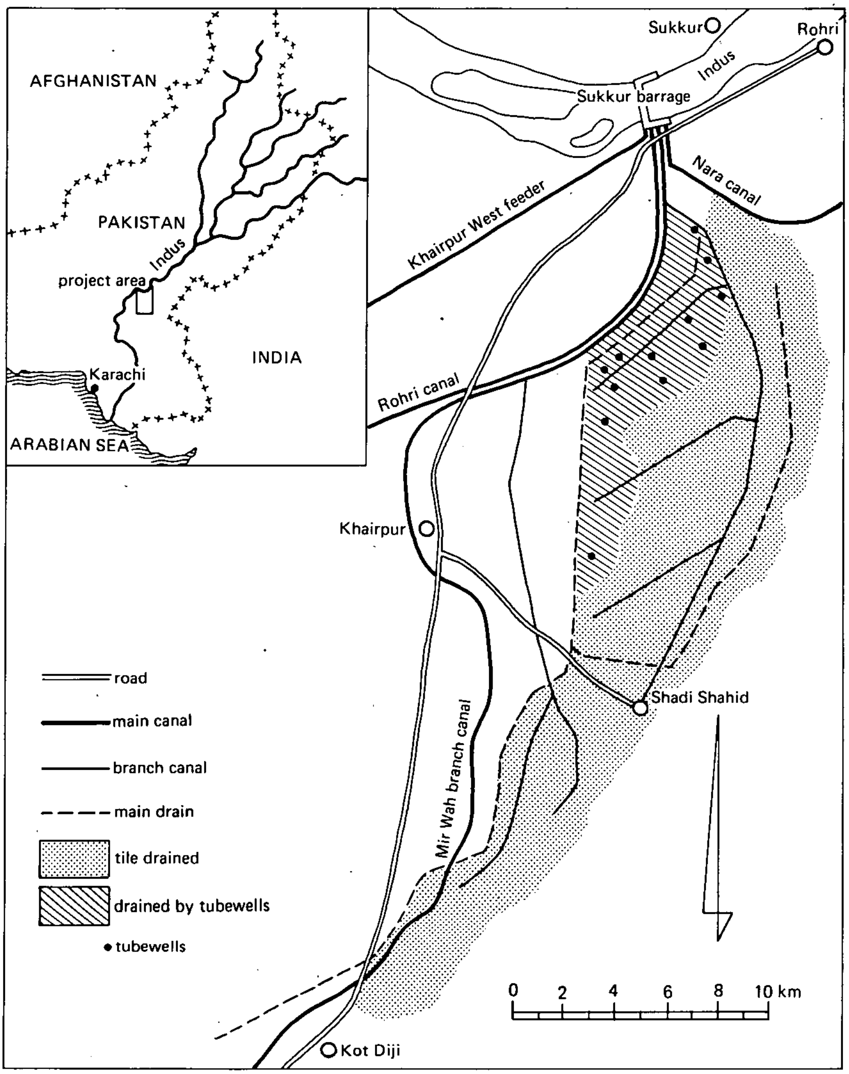

Figure 1 East Khairpur Tile Drainage projekt in Pakistan

and therefore the suitability of the alternative of deep open drains has been completely ruled out.

The pilot project has three objectives:

- To demonstrate the suitability of tile drains on a representative scale in the field by the construction of a prototype project;
- To confirm the basic principle of tile drain design and construction techniques by monitoring;

- To complete the development of a small area unsuitable for tubewell drainage adjacent to the SCARP Khairpur Tubewell Project.

A World Bank mission appraised the project and ILACO from The Netherlands was appointed as consultant in June 1977 to provide technical assistance for the design, planning and construction works.

2 Project implementation

The project appraised and approved as a multidisciplinary scheme, consisted of the following works:
- The installation of a subsurface tile drainage system and surface disposal drain including buried tiles and collector drains, pump stations and small surface drains;
- The enlargement and remodelling of irrigation canals and structures and the reconstruction of irrigation outlets serving the project area;
- The improvement of existing watercourses;
- The construction of a wider and improved road network and associated structures;
- The reorganization and intensification of agricultural extension services provided by SCARP Khairpur Agricultural Wing under the Sind Irrigation and Power Department;
- The procurement of equipment, materials, vehicles, supplies and spare parts for carrying out the construction work, the operation and maintenance of facilities constructed under the project and the construction of tubewells in the project area and adjacent lands.

The project construction started from early 1977 and the consultant prepared a project plan report in May 1979. Meanwhile the orders for the import of project machinery and equipment were placed, the preliminary work was started such as construction of the residential colony and offices, widening and improvement of roads, enlargement and remodelling of irrigation canals and structures, and intensification of agricultural extension services.

The major project work component was the construction of the subsurface drainage system together with pump stations and the main surface drain for the disposal of the drainage effluent.

A normal composite system with lateral drains joining the collector drain at right angles has been designed. At each junction between lateral and collector drain a manhole has been provided. For lateral drains corrugated 100 mm P.V.C. pipes were used and for collector drains unreinforced concrete pipes of 1 m length with nominal internal diameters of 9, 12 and 15 inches were laid with a slope of 0.03% and at a depth of 3 to 3.5 m below ground surface. The pipes were made of sulphate resistant cement and manufactured locally. For collector drains concrete pipes were selected for the following reasons:
- The cost estimates presented in the World Bank Appraisal Report were based on the installation of cement concrete collector pipes using a heavy duty machine excavating the trench below the watertable with a protective steel box attached;
- The concrete pipes were cheaper when compared with the cost of rigid P.V.C. pipes.

The drainable surplus has been estimated at 2 mm/day being field irrigation losses. The canal seepage losses vary over the project area from 0.5 to 1.5 mm/day. The drainable surplus therefore ranges from 2.5 to 3.5 mm/day.

The drain spacings and drain depths have been designed keeping into consideration the soil permeability values and the balance between the cost of tile drain construction and the resalinization of the soil profile.

The spacing ranges from 50 to 150 m, the average drain depth is 1.8 m, the slope of the tile lines is 0.1% and the length is maximum 400 m.

The gravel from natural deposits located in the eastern part of the project area at the toe of the hills was screened and used as envelope material. The thickness of the gravel under and above the pipes was taken at about 3 inches.

Various types of equipment and machinery in sufficient quantity were procured for the construction of the project as WAPDA was responsible for the force account construction of the project. This was clearly spelled out in the appraisal report by the World Bank with a view to enable WAPDA in building sufficient expertise which would be quite useful in the construction of similar projects in the Sind province in the future.

Instead of a heavy duty machine for laying of cement concrete collector pipes a horizontal dewatering machine was procured. The reason was that heavy duty machines were still under testing at that time. A new method of horizontal dewatering, developed in Europe for laying of gas pipe lines under waterlogged conditions, was considered as an alternate suitable for laying pipes under project conditions.

The implementation of the project started with the construction of sumps for the pump stations and a drain for disposal of the drainage effluent. After satisfactory commissioning of the equipment and training of local staff as per agreement with the suppliers, the work on the construction of collector and lateral drains started in March 1980.

The project major component of the work involved construction of 37 tile drainage units with 175 km of collector drains, 1000 km of lateral drains and 35 km of disposal drains with a design capacity of 100 m^3/sec discharge at the outfall.

The project was approved with a construction schedule of five years to start in January 1977. The construction period for the major component of the works was three years. Since the actual work started in March 1980 (with a delay of about two years) the completion of the project was then envisaged in June 1984 after completion of the watercourses improvement works to be carried out as a follow-up of the construction of the lateral drains. However installation of concrete collector drain pipes in the heavy waterlogged and unstable soil turned out to be more difficult with the system of horizontal dewatering than expected. The progress of work was slow and remained behind schedule. The total progress achieved up to June 1982 was only 25%. By that time only 38 km of the required 176 km collector pipe length had been installed and at that rate an additional nine years were required to complete these drains.

It was therefore decided to use an alternative method for installing collector drains without dewatering and to replace the 12 inch diameter and smaller concrete pipes with recently manufactured large diameter corrugated and perforated plastic pipes. Only the 15 inch diameter concrete pipes would still be used. The plastic pipes would be laid by a big trencher with gravel envelope, and the idea was that this would dewater the area above the collector drain pipe, facilitating the connection of lateral drains at a later stage thus rendering the provision of a manhole at each junction unnecessary.

The big trencher and big diameter plastic pipes (polyethylene) were imported in 1983-84 for carrying out the balance work on the laying of 12 inch diameter and smaller collector drain plastic pipes. Some delay occurred due to modification of the big trencher to suit local conditions and the work on the installation of the collector drains was finally completed in February 1986. During the construction manholes were provided at all intersection points and ends. The one at the end of the line was for inspection purposes only.

The installation of small diameter lateral drain pipes was carried out through special drainage trenchers equipped with devices to lay pipes at the required depth and grade and to provide the necessary gravel envelope both above and below the pipe in a single operation. The work on the installation of the lateral drains was finally completed in March 1986.

It may be worth mentioning that the work on the installation of collector and lateral drains was carried out by a departmental task-force tight up from March 1980 to March 1986. The total number of these skilled, semi-skilled and un-skilled staff was about 300. It is heartening to say that 63% of the project construction progress was attained in the last 18 months (Figure 2).

The last item of work was the improvement of the existing watercourses as a follow-up of the lateral drains. This work was carried out through petty contractors and was completed in June 1986. The salient features of the project are given in Table 1.

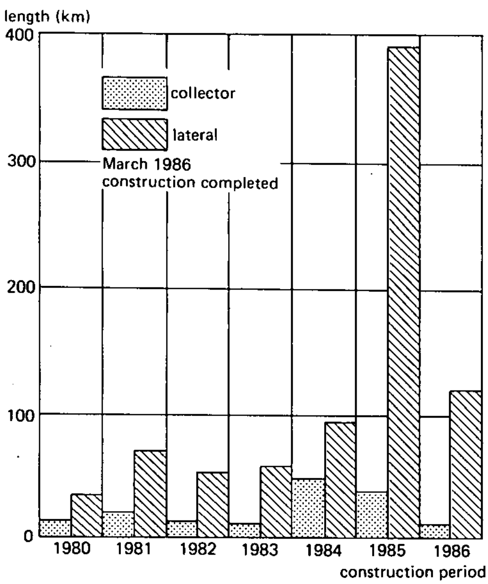

Figure 2 Progress of collector and lateral drain installation

Table 1 Salient features of the project

General	
Present cropping intensity	119%
Future cropping intensity	145%
Total command area	44000 acres
Drainage	
Total project area	44000 acres
Total area provided with tile drainage	36000 acres
Length of P.V.C. lateral drains	823 km
Length of collector drains	153 km
Length of disposal drains	33 km
Number of pump stations	37
Number of pumps installed in sumps	90
Total power requirement	1.8 million kWh
Irrigation	
Length of canals remodelled in Patni command area	42 km
Length of canals remodelled in Sathio Wah and Mir Wah command areas	7 km
Area to be served by remodelled watercourses	27000 acres
Roads	
Length of constructed bituminuous roads	17 km

3 Project costs

In the absence of a local precedent the World Bank mission appraised the project on price levels prevailing in December 1975 for similar works in Egypt, Europe and North America. The project costs were estimated at about US$ 28 million. The foreign exchange component was US$ 14.0 million or 50% of the total costs.

The government of Pakistan approved PC-I of the project in 1976 at a total cost estimate of Rs. 372.2 million with a foreign exchange component of Rs. 178.7 million inclusive interest during construction. Due to delay in the completion of the project the cost estimates were revised at 1983 prices and PC-I was approved in 1985 at a total cost estimate of Rs. 630.03 million with a foreign exchange component of Rs. 199.85 million (Table 2). The project cost estimates were prepared on the unit rates of works established locally with experience gained during the implementation of the project.

The actual cost of the project on the finalization of accounts comes to Rs. 575.000 million with a foreign exchange component of Rs. 189.00 million. The rates per acre have been worked out and are given hereunder:

- Rate of tile drainage including all other development works Rs. 16335/acre
- Rate of tile drainage only Rs. 14549/acre

Table 2 Summary of cost estimates (in million rupees)

Item	Description	Local	Foreign	Total
I	Civil works			
	Drainage system	77.18	45.17	122.35
	Canal remodelling	2.45	9.40	11.85
	Watercourse reconstruction	10.10	3.40	13.50
	Road improvement	4.30	6.21	10.51
		94.03	64.18	158.21
II	Equipment, vehicles and material to be imported			
	Drainage system	14.01	88.36	102.37
	Canal remodelling	0.06	2.11	2.17
	Road improvement	0.06	0.90	0.96
	SCARP Khairpur	0.10	1.90	2.00
		14.23	93.27	107.50
III	Agricultural equipment and vehicles to be imported			
	Agricultural extension equipment	0.41	–	0.41
IV	Consultants and training	10.26	13.16	23.42
V	Engineering and administration			
	Staffing and housing	32.50	2.35	34.86
	Crop compensation	3.49	–	3.49
	Buildings	21.51	–	21.51
		57.50	2.35	59.85
Basic project costs (Total I to V)		176.43	172.96	349.39
VI	Physical contingencies	12.83	10.84	23.67
VII	Expected price increase	18.15	8.55	26.70
VIII	Aerial photography and erts surveys	3.02	7.5	10.52
IX	Custom duties and taxes	76.68	–	76.68
X	Land acquisition	3.46	–	3.46
Total I to X		290.57	199.85	490.42
XI	Interest during construction local currency component at 14% per annum	138.70	–	138.70
XII	Service charges on foreign loan at rate of 1%	0.91	–	0.91
Grand total I to XII		430.18	199.85	630.03

The unit costs are considered on the high side when compared with similar costs in other countries of the world. One reason is that the project has been constructed in an area which is very flat (general slope of about 6 inches/mile) thus provision of pump stations for evacuation of drainage effluent of small units is necessary. This is not required in areas with steeper slopes. The other reason is that the project was implemented by a departmental task-force as a pilot project to train local people in this modern technology. The completion of the project took double the time i.e. about 10 years against 5 years as planned. This delay has added more costs in administration, overhead, interest and consultant charges apart from escalation of all important ingredients for the construction of the project. Had the project been completed in the planned construction schedule, five years ago the cost of tile drainage would have been not more than Rs. 8000/acre (estimated). This cost per acre could be considered as most reasonable for future tile drainage projects in the country.

In fact the lack of speed in the construction of this project was a major constraint. During the implementation of the project the machinery could not be used optimally due to many difficulties encountered. It has been observed that the machinery utilization was nearly 35% of the available machine time.

The World Bank mission in its appraisal report has estimated the annual operation and maintenance costs of tile drainage at Rs. 25/acre. The project estimate of annual operation and maintenance costs on 1986 prices has been worked out at Rs. 30/acre.

4 Conclusion

The project was a major challenge and many difficulties were encountered during construction of the project. Famous experts visiting the project during construction recognized that the project was being constructed under the most difficult conditions in the world.

Although the project was delayed due to reasons given earlier, the impact of the project on the agricultural development has been remarkable. Surveys carried out in late 1985 show a sharp increase in the annual cropping intensity from 90% in 1975 to over 150% in 1985, compared to the 145% anticipated future annual cropping intensity after completion of the project. The increase in the annual cropping intensity was more than planned even during construction which is due to the following reasons:

- Increase in the capacity of the irrigation system;
- Recovery of abandoned areas and bringing them back into cultivation as the installed drainage system allowed for effective leaching of the saline soils;
- Improvement of existing watercourses on the principle of on-farm water management resulting in less seepage losses and more water available for irrigation and reclamation.

It is expected that with the continued efforts to recover land and water, the annual cropping intensity will ultimately reach a figure of 160% in 1990 against 145% anticipated in the development plan.

The yields of cotton and other crops have remained stable during the period 1975 to 1985 but wheat and sorghum have shown a significant increase. This is shown in Table 3.

Table 3 Wheat and sorghum yields in 1975 and 1985 respectively

Crop	Yield in maunds/acre*	
	1975	1985
Sorghum	6.0	14.0
Wheat	15.0	22.0

* 1 maund/acre = 92.5 kg/ha

It has also come to our notice that in some areas the maximum wheat yield has been of the order of 60 maunds/acre.

It can now be said with confidence that this pilot project though delayed due to various bottlenecks, is still feasible and that the technology of horizontal drainage has a great potential.

Most important is the detailed monitoring on a scientific basis which will confirm the parameters used for the design. The discharge from the drainage units has been monitored during construction from January 1984 onwards. The discharge has remained in the order of 30% of the design rate. This may be due to the following reasons:

- Irrigation supplies from the canals are still less than the capacity on which they have been remodelled;
- Actual drainable surplus is less than what has been estimated in the design.

Such parameters can only be confirmed after detailed monitoring has been carried out.

Development of drainage in Turkey over the last 25 years and its prospects for the future

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1 Physiography and land use

The total area of Turkey is 780 580 km² of which 23 500 km² is situated in Europe. The land under cultivation at present is 27 699 010 ha. Pasture and grazing land covers 21 745 690 ha and forests 15 135 090 ha. An account of the land use pattern in Turkey is given in Table 1.

Table 1 Land use pattern in Turkey (TOPRAKSU 1978)

Type of land use		Area	
		ha	%
1	Cultivated agricultural land		
	Dryland farming	22 607 340	
	Irrigated area	2 990 880	
	Vineyard and orchards	2 100 790	
		27 699 010	35.6
2	Pasture and grazing land	21 745 690	28.0
3	Forests and shrubs		
	Forests	15 135 090	
	Bushes and shrubs	8 333 380	
		23 468 470	30.2
4	Settlements	569 400	0.7
5	Unproductive land	3 212 180	4.1
6	Lakes	1 102 390	1.4
		77 797 140	100.0

Turkey has a population of 50 million. About 55 per cent of the population lives in rural areas and 61 per cent of the labour is employed in agriculture. Physiographically, Turkey can be divided into four regions with different characteristics.

Coastal lands

In the north and in the south high mountain ranges stretch parallel to the coast, forming small terraces and bottom lands with the exception of some large alluvial deltas formed by the rivers. The alluvial soils comprise the largest and most important group of arable soils. Elevations vary from sea level to 150 m. Salinity and drainage constitute the main problems in the coastal lands.

Central Anatolian Plateau
A high plateau located in the central part of the country, is divided by rivers into many irregular areas. This region has different landscapes, such as mountains, bench lands, closed basins and some narrow alluvial plains. The elevation varies from 800 to 1500 m. Most of this plateau is suited for agricultural use, especially for grain production.

Mountain lands
This area shows a very rough relief and has steep slopes with elevations generally between 1500 and 4000 m. Vegetal cover changes from weedy, mostly barren rocky surface to dense forests.

Basin lands of Thrace
The whole European part of the country except the Istrance Mountain Ranges consists of basin lands. It is an open and divided plain having an undulating topography in the center. Most of these basin lands are suitable for agriculture.

2 Climate and rainfall

Turkey has in general a semi-arid climate with extreme temperatures. Almost the whole Anatolian plateau has hot, dry, dusty summers and cold, windy, damp winters, but in the Eastern Anatolian region the summers are cool and short and the winters are severe and long. The Mediterranean climate with short, wet winters and long, warm, sunny summers, prevails in the southern and western part of the country.

The average annual rainfall is 670 mm, but varies from a minimum of 220 mm to a maximum of 2420 mm. There is a great variation in space and time. Meteorological data show that over 90% of Turkey has not enough soil water during the crop growing season, and for good agricultural production irrigation is essential in most parts of the country.

3 Drainage and salinity problems with regard to soil conditions

The soils of Turkey vary considerably in fertility. The soils of the Central Anatolian Plateau reflect the semi-arid steppe condition of the region. Here low rainfall coupled with sparse plant cover of short grasses has resulted in the formation of limestone as parent material. The character of the terrain handicaps the development of deep natural soils in this highland area and most of the soils are thin and easily erodable. Overgrazing and deforestation of the sloping lands have led to an intensification of the soil erosion problem.

More productive soils, comprising of clay and lime underlain by deep sand-silt and clay strata are found in the coastal and lowland regions of Turkey. These areas cover nearly one-seventh of the total cropland of Turkey. The capabilities of these alluvial soils for crop production range from low, due to frequent flooding or low natural fertility, to very high. They have greater potential for increased agricultural production than any other group of soils.

According to the General Improved Soil Map of Turkey which is prepared by TOPRAKSU (1966-1971), 2 775 110 ha of cultivated land has drainage problems, which is 3.6 per cent of the total area of 77 797 140 ha.

On the other hand 1 518 720 ha of cultivated land (2.0% of the total area) has salinity or alkalinity (sodium) problems. These soil types are classified into five categories according to the extent of the problem:

Light saline soils	: 0.15-0.35% soluble salts, ESP < 15;
Saline soils	: Soluble salts $> 0.35\%$, ESP < 15;
Alkali (sodic) soils	: Soluble salts $< 0.15\%$, ESP > 15;
Light saline and alkali soils	: 0.15-0.35% soluble salts, ESP > 15;
Saline and alkali soils	: Soluble salts $> 0.35\%$, ESP > 15.

Dominant salts accumulated in the soils are chlorides ($NaCl$, $CaCl_2$, $MgCl_2$), sulphates (Na_2SO_4, $MgSO_4$), nitrates ($NaNO_3$, KNO_3), carbonates and bicarbonates (Na_2CO_3, $NaHCO_3$), and boron salts in certain areas. Sodium salts occur most frequently, but calcium and magnesium compounds are common too.

4 The main areas where surface or subsurface drainage has been installed in the past 25 years

Although very simple individual surface and subsurface drainage systems have been found in Anatolia since Roman and Ottoman time, only extensive and planned work on this subject has been started since 1950 on a project basis. In those years and a few years ago, some big irrigation projects such as Seyhan, Cumra, Menemen and Alpu were completed and irrigated agriculture was started in these rather flat alluvial and hydromorfic alluvial soils. As soon as irrigation started crop yields doubled. But the following years irrigated agriculture brought new problems to the farmers such as high watertables, salinity and alkalinity. On the other hand new dams and irrigation schemes came under construction whereby sufficient drainage had to be provided.

In the 1960's an intensive land reclamation and drainage program was initiated by the government with the assistance of international organizations, such as the International Development Agency (IDA), European Investment Bank (EIB) and International Bank for Reconstruction and Development (IBRD). As a result of this programme surface and subsurface drainage works have been started in 21 big irrigation projects (Table 2 and Figure 1). Surface and subsurface drainage works are mostly completed in these projects. However, in the coastal plains the lowlands below 2.00 m elevation which require pumping for drainwater disposal are for economic reason still in a future drainage project phase.

Table 2 The most important land development and drainage projects in the last 25 years in Turkey

Name of the project	Total area (ha)	Land levelling		Subsurface drainage		Surface drainage (ha)	Land reclamation (ha)	Land consolidation (ha)
		area (ha)	cut or fill (m^3/ha)	area (ha)	lateral length (m/ha)			
Seyhan (Adana)	181 300	139 100	750	47 300	100	139 100	–	–
Gediz (Manisa)	110 495	69 620	665	45 400	100	69 620	32 350	69 620
Akçay (Nazilli)	18 050	13 150	700	3 517	100	–	1 863	–
Berdan I, II (Tarsus)	27 706	17 520	452	11 160	100	5 265	3 374	–
Uluirmak (Nigde)	21 095	17 750	700	11 860	75	–	4 415	1 400
Köprücay (Antalya)	24 215	18 000	577	7 526	87	18 000	840	14 000
Igdir (Kars)	67 473	66 000	700	36 093	125	66 000	36 093	–
Ercis (Van)	2 300	1 600	700	1 000	100	–	–	–
Kazova (Tokat)	22 950	15 000	560	3 860	100	15 000	2 100	–
Alpu (Eskisehir)	23 200	17 940	700	9 300	100	–	–	10 000
M. Kemalpasa (Bursa)	16 250	13 200	700	6 861	75	–	–	–
Silifke (Mersin)	6 005	3 300	572	2 350	100	3 300	–	–
Cumra (Konya)	5 800	4 500	700	1 000	125	–	2 500	4 500
Nusaybin (Mardin)	8 600	6 500	800	1 800	100	–	–	–
Sarimsakli (Kayseri)	12 405	8 900	830	1 350	100	8 900	–	–
Ceyhan (Adana)	107 996	97 200	639	6 050	138	97 200	2 000	–
Carsamba (Samsun)	50 000	20 000	600	33 173	125	20 000	–	–
Bafra (Samsun)	30 000	15 000	600	10 122	125	15 000	10 000	–
Kartalkaya (K.Maras)	23 368	18 527	700	2 100	100	6 000	–	–
Erzincan	10 520	10 099	685	5 000	100	2 000	8 000	–
Bigadiç (Balikesir)	3 403	2 492	647	2 500	115	1 500	–	–
Total	773 131	575 398	–	249 322	–	466 885	103 535	99 520

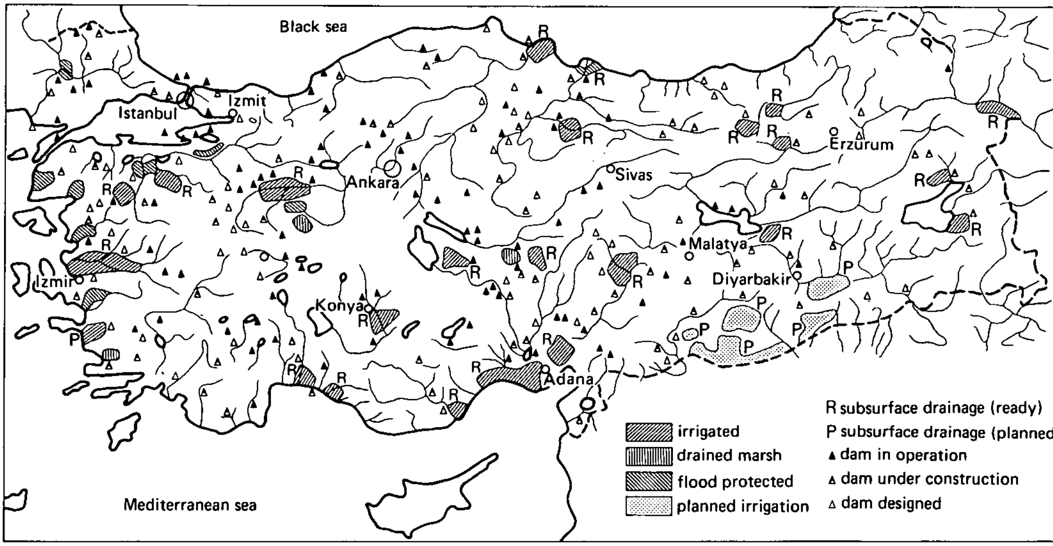

Figure 1 Dams and irrigation/drainage projects in operation, under construction, and planned in Turkey

Besides those 21 big projects there have been many separate drainage projects all over the country. According to the 1986 statistics of Köy Hizmetleri (Village Affairs) General Directorate, land development, installation of surface and subsurface drainage systems and application of soil amendment was carried out by this organization in 1985 on 752 470 ha. Subsurface drainage was installed on 427 220 ha. Approximately 20 000 ha has been proposed for subsurface drainage installation in 1986.

Gediz River Valley Drainage Project (near Izmir)
The Gediz River Valley Drainage Planning Office was founded in 1963. Thereafter intensive subsurface drainage installation began with financial support of the European Investment Bank in 1964. In approximately 46 000 ha subsurface drainage systems have been installed since that time. Another 24 000 ha still requires subsurface drainage or rehabilitation works (such as installing plastic drain pipes instead of broken or clogged tile drains). Land consolidation projects and drainage projects will be applied together in most of these areas.

5 Future irrigation and drainage projects

According to the State Hydraulic Works (DSI), the governmental authority dealing with the construction of dams and big irrigation projects, by the end of 1986 100 dams and hydroelectric power plants were in operation. Only 9 dams are for domestic water supply, 4 for hydroelectric power and 1 for flood control purpose. The other 86 dams were constructed mostly for irrigation purposes.

On the other hand 66 dams are under construction; among these the Ataturk Dam on the Firat River (Euphrates) which has 48 700 x 10^6 m^3 water storage capacity and will irrigate 870 000 ha of dryland in south-eastern Turkey and will produce 8900 x 10^6 kWh hydroelectric power each year. With this capacity it will be one of the most important dams in the world. When these 66 dams are completed 1 509 150 ha new land will be irrigated. There are also 30 dams in final design and it is expected that 228 280 ha will be irrigated from these dams; 31 dams are in project phase and planned to irrigate 364 200 ha.

Today the total irrigated area is about 3.5 million ha. So when all these projects are completed, the total area irrigated will be doubled by the end of this century. All this irrigated land will require somehow surface or subsurface drainage.

Subsurface drainage installations are still going on in most of the former drainage projects such as Gediz, Carsamba and Bafra projects. The projects in Table 3 are the most important irrigation and drainage projects of Turkey in the near future. All these plains will receive irrigation water and electric power for pumping from the Ataturk Dam which will be completed in 1989. Irrigation in Urfa-Harran Plain will start in 1991.

Table 3 Future irrigation and drainage projects of Turkey

Name of the project	Area (ha)
Urga-Harran Plains Gravity Irrigation	142 000
Lower Mardin-Ceylanpinar Plains Gravity Irrigation	158 000
Upper Mardin Plain Pumping Irrigation	190 000
Siverek-Hilvan Plains Pumping Irrigation	180 000
Bozova Plain Pumping Irrigation	55 000
Suruc-Basiki and Birecik Plains Pumping Irrigation	145 000
Total	870 000

6 Drainage criteria in relation to various types of land use

6.1 Surface drainage criteria

Open drainage canal capacities for disposal of surface run-off are calculated according to one of the following run-off prediction methods:

1 The curve number method of the US Soil Conservation Service, for watersheds up to 800 ha;
2 The SCS standardized hydrograph method, for watersheds bigger than 800 ha;
3 The rational equation method, for flood control structures.

After calculation of surface run-off, Manning's flow equation is used and open drainage canal dimensions are determined.

6.2 Subsurface drainage criteria

A detailed groundwater table map and barrier map is prepared during the survey of the drainage area. Augerholes are drilled in gridpoints 400 m apart up to 3.0 m depth. Hydraulic conductivity values (K) are determined by means of these augerholes. The average of 4 to 6 values in neighbourhood holes are used for calculating drain spacings. The drainage coefficient is assumed 2 mm/day for irrigated areas. After collecting these data the Toksöz and Kirkham nomograph in Figure 2 is used for calculating the drain spacing.

The following is an example of drain spacing calculation in Manisa- Saruhanli-Nuriye project in 1985.
Given: Average hydraulic conductivity (K) of 6 auger holes

K = 0.56 m/day h = 8.00 m (depth to barrier)
H = 0.60 m R = 2 mm/day (drainage coefficient)
2r = 0.10 m (drain pipe diameter)

Solution:

$$L = \frac{H}{h}\left(\frac{K}{R} - 1\right) = \frac{0.60}{8.00}\left(\frac{0.56}{0.002} - 1\right) = 21.5 \text{ and } \frac{h}{2r} = \frac{8.00}{0.10} = 80$$

Using the nomograph in Figure 2 gives

$$\frac{2S}{h} = 8.5 \text{ and } S = 8 \times 8.5 = 68.0 \text{ m},$$

which is the calculated drain spacing for that particular area.

The groundwater table is kept generally 0.90 to 1.50 m below ground level depending on the rootzone of the major crops and taking into account the salinity of the groundwater. For this reason lateral drains are laid at a depth varying from 1.50 to 2.10 m, but in most cases at 1.80 m below the surface.

7 Drainage construction

The trencher is the most common and convenient machine for installing subsurface drainage systems. Former trenchers made in U.S.A. are replaced by German or Dutch made trenchers which are lighter and faster (Figure 3).

Excavators are used in constructing or cleaning of open drainage canals (Figure 4).

The flexible perforated PVC pipes are used for agricultural drainage applications. They are manufactured in Turkey as 50-200 m coils with a diameter range of 50 mm to 200 mm. Its flexible quality enables easy installation into the trenches and its spiral

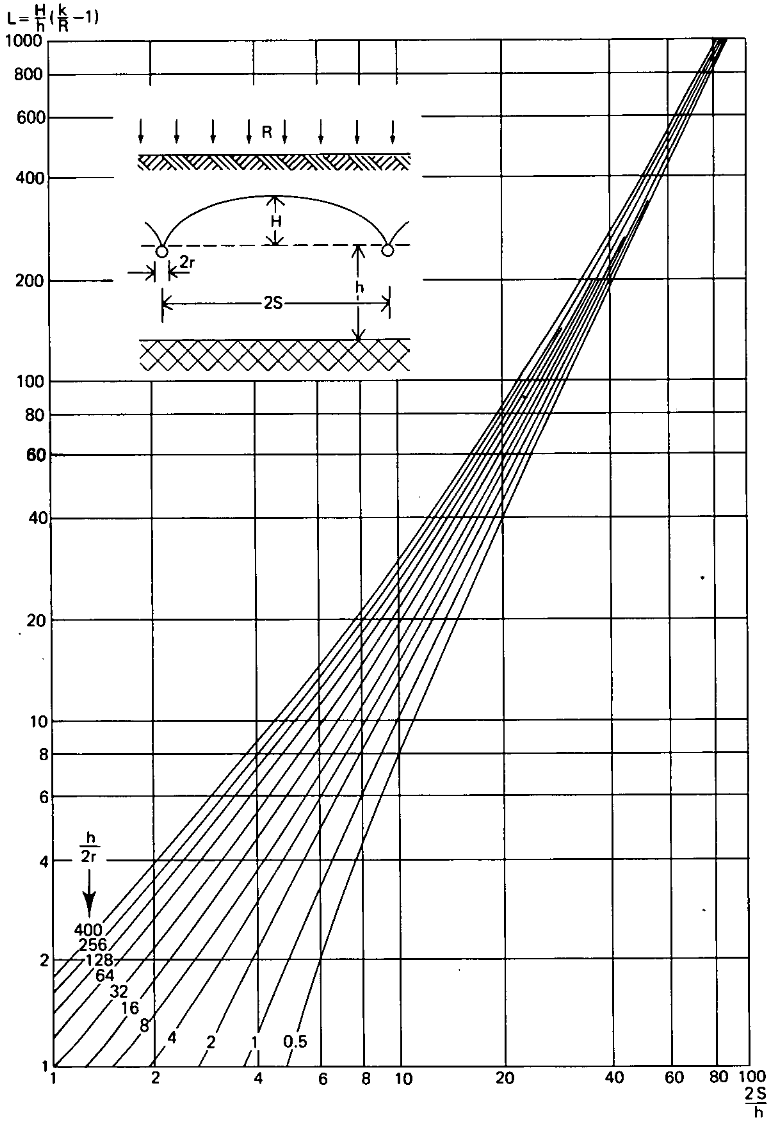

Figure 2 Nomograph for solution of Kirkham's equation (after Toksöz)

construction gives it a higher resistance to various pressures. Sand and gravel envelopes (8 to 10 mm) around the plastic pipes are used as filter material (Figure 5).

According to 1986 prices subsurface drainage installation cost per ha is about 90 000 TL or US$ 120. Costs for surveying, design and control of the construction are not included into these figures.

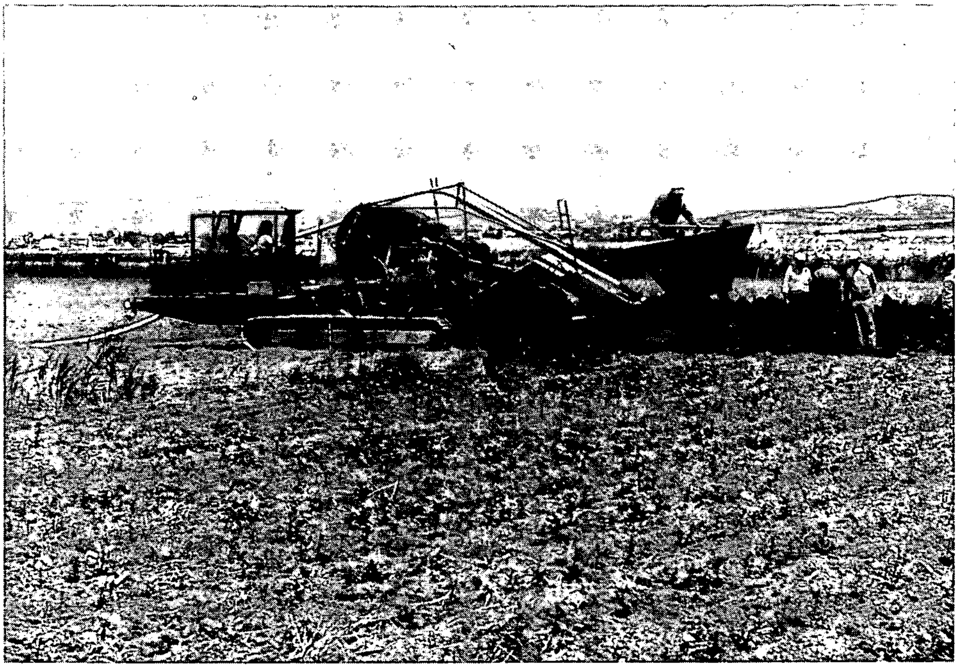

Fig 3 German made Schaeff trencher in operation in Lutfiye near Manisa (1986)

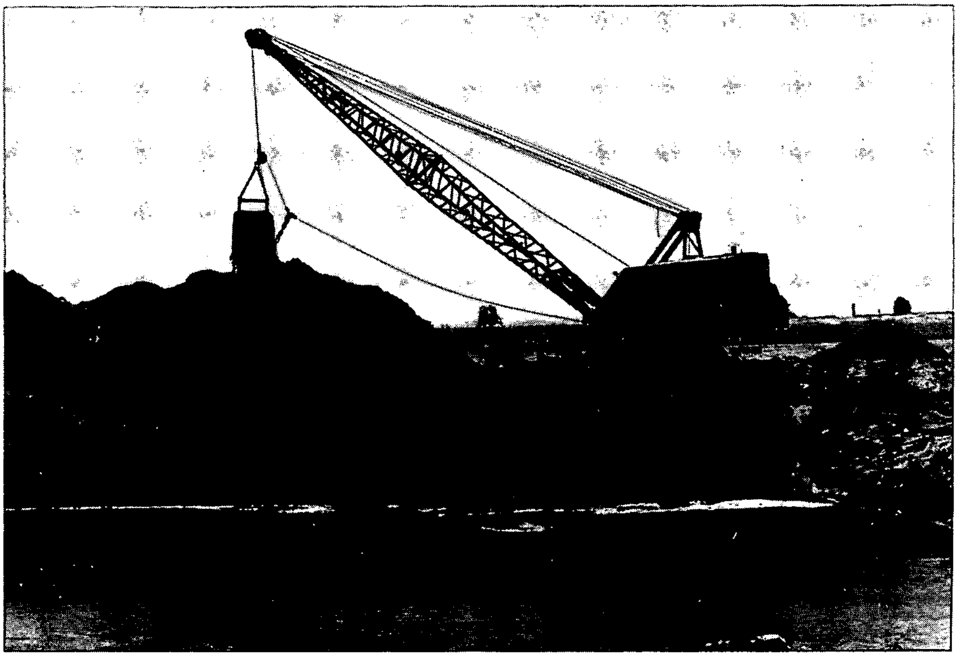

Figure 4 An excavator cleaning the bed of Kum Creek in Manisa (1986]

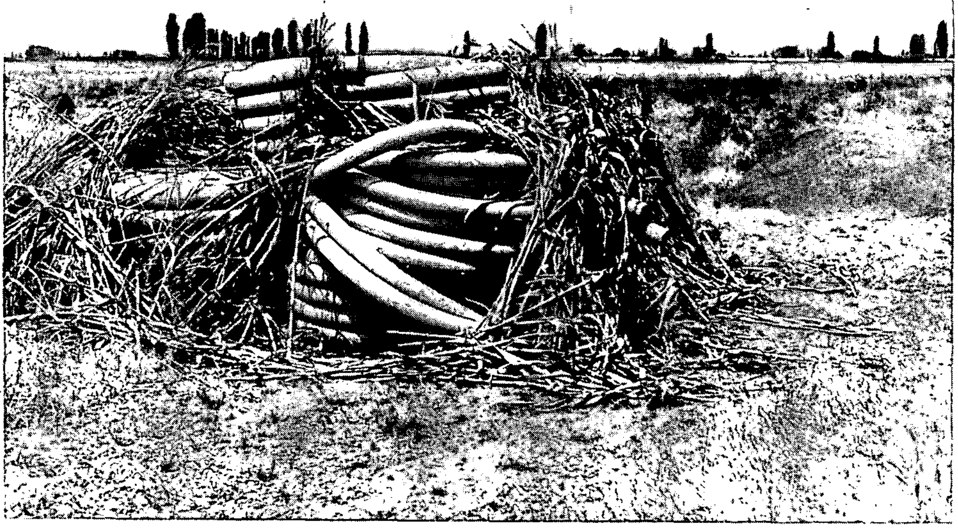

Figure 5 PVC drain pipes, sand and gravel filter material: ready for use in Lutfiye project (1986)

8 Project organization, management and maintenance

All drainage survey, design and inspection work is carried out by the government. But the construction work is carried out by private contractors. There are two governmental organizations dealing with drainage systems in Turkey.

DSI (State Hydraulic Works) works on big flood control structures, such as construction of flood protecting dams, large capacity drainage canals and management of these structures. The same organization is responsible for the management and maintenance of these structures.

Köy Hizmetleri (Village Affairs) General Directorate is responsible for the survey, design, and installation of farm drainage systems. This includes mostly subsurface drainage systems, small capacity open drainage canals and small dams for irrigation and flood control. The same organization is also responsible for improvement of saline and alkali soils, for land consolidation, land levelling, small irrigation projects, etc.

Management and maintenance of all these installations are carried out either by farmers cooperations, unions or village's administrative authorities under the control of local officers of Köy Hizmetleri General Directorates.

9 Problems and bottlenecks in drainage systems

Although regular maintenance and cleaning of silt and weed control in open (main) drainage canals are periodically carried out by DSI, stabilization of canal embankments, siltation and weed problems are not completely solved for open drainage canals. Weeds and siltation minimize the original design capacities of open drains. As a result, subsurface drainage systems cannot discharge as free flow into these canals. Sometimes submerged flow occurs from drainage laterals and sometimes they are completely clogged because of siltation. This situation is rather common in the lowlands where there is not enough slope for open drainage canals.

Also the management and maintenance work of subsurface drainage systems is not very regular. Farmers, farmer's cooperatives or related governmental agencies (Köy Hizmetleri) carry out cleaning and repair of installed subsurface drainage systems in case clogging or a visible damage occurs to the pipes or to the old siltation boxes. Clearly there must be a better coordination between the related governmental agencies, DSI, Köy Hizmetleri and farmers on the management and the maintenance of the drainage systems after installation.

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Development of drainage in the Middle Awash Valley in Ethiopia

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1 Introduction

Drainage development in Ethiopia is relatively recent. Only few areas benefit from agricultural drainage at present. In the highlands where most of the rainfed agriculture is located, the introduction of proper drainage systems could increase agricultural production. No attempt has been made to reclaim lands that suffer from lack of drainage for agricultural production.

In the lowlands where most of agricultural development is uneconomical without irrigation, the importance of drainage has been realized. In the earlier irrigated agricultural developments no provision was made for drainage. Most of these areas are now suffering from waterlogging or salinity due to absence of proper drainage systems. In the more recent developments, surface drainage systems are implemented together with the irrigation system.

The potential for drainage development is high in the rainfed and irrigated agricultural sectors. In the irrigation subsector alone some 2 million ha of land has been identified for possible large scale irrigated agricultural development in the coming decades. Most of these areas cannot be economically productive without drainage.

At present irrigation development has concentrated along the Awash River Basin. Of the net potential irrigable lands in the basin about 67 000 ha have been developed. The major crops are cotton, sugarcane, banana, maize and some horticultural crops.

In the Middle Awash Valley alone some 17 800 ha is under irrigation (Figure 1). The soils of the area consist mostly of alluvial sediments. The sediments are often characterized by high contents of silt, the texture ranging from clay to silty clay loam, silt loam with some sandy loam, loamy sand and fine sand. The Middle Awash Valley is located in an area with a semi-arid climate and a bi-annual rainfall pattern. The mean annual rainfall is 560 mm. Mean monthly temperatures range from 22.5°C in December to 38.5°C in June. The annual potential evaporation is estimated at 2400 mm. The Awash River has a pronounced seasonal regime and flooding is a frequent event during August and September. Extensive catchments to the east and west of the river drain towards the Awash river and are characterized by short duration flood peaks resulting from storm rainfall.

Irrigation development has concentrated in the Middle Awash Valley as a result of the high yields achieved. An average of 35 quintals/ha of seed cotton on the recently developed Amibara Scheme has been achieved. These yields cannot be sustained without proper drainage provision. As a result of this awareness, the study and implementation of drainage projects has commenced in this region.

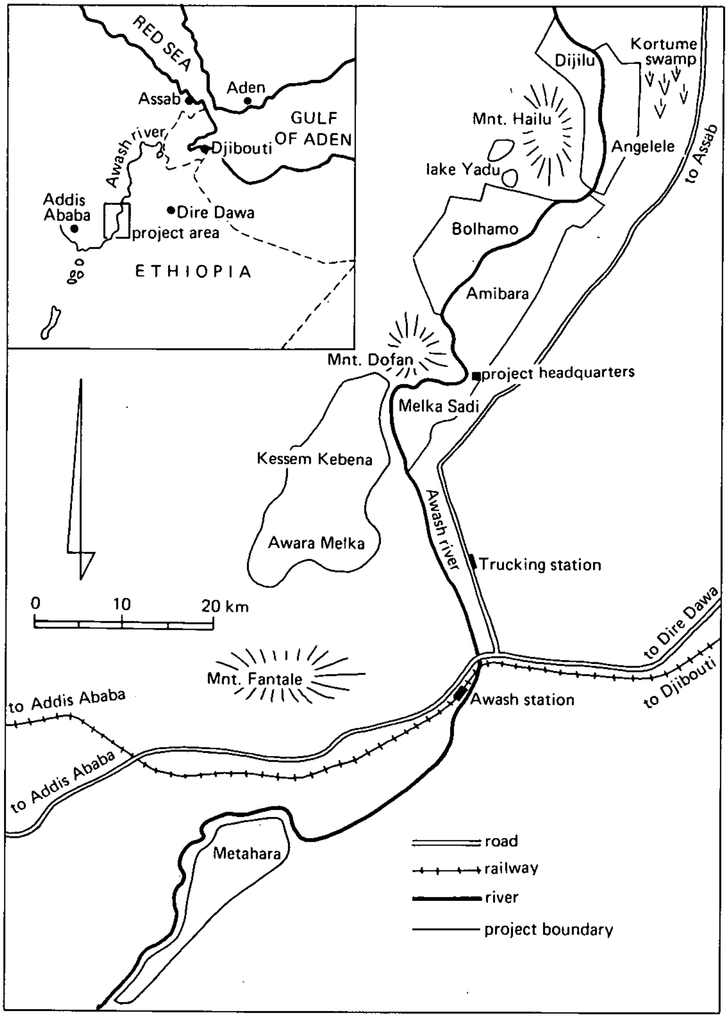

Figure 1 Location of Middle Awash Development project in Ethiopia

2 Drainage requirements

In the Middle Awash Valley drainage for an irrigation unit which usually has a size of about 10 000 ha requires two systems, an internal and an external drainage system.

The internal system drains off excess water to a disposal point at the project boundary. This system provides: drainage of excess surface water from rainfall and irrigation, excess canal water and groundwater.

For drainage of excess surface water well designed land levelling of irrigated plots is essential. Field ditches that transport water to higher order drains are constructed at the end of each field, that has an average size of 20 ha.

Irrigation canals are provided with tail escape structures so that any excess or unwanted canal flow can directly be discharged into a drainage canal. This system increases the flexibility in the operation of the irrigation system.

Groundwater drainage for salinity control is the most important and probably the most expensive and difficult part of the drainage system. Irrigation and drainage studies have indicated that land brought under irrigation will suffer from a rising groundwater table and salinization after implementation of irrigation projects. Piezometers and observation wells in the Amibara area have shown that the groundwater rises at an average rate of about 1 m each year so that salinity will start to appear within ten years after the introduction of irrigation. To control this occurrence deep subsurface or open drains should be constructed before the groundwater reaches the rootzone and soil salinity starts to affect yields. In this respect measures should be taken before the groundwater comes within 2 m below ground level.

The external drainage system collects excess water both from the internal system and from outside the irrigation unit boundary for conveyance to the final disposal point. The land suitable for irrigation development suffers from two sources of flooding as a result of the topography of the area. The irrigated land reflects the recent geomorphological history of the Middle Awash Valley, where an extensive alluvial plain has been built-up by deposits from the Awash River. The irrigated areas lie on both riverbanks and are in general bounded by escarpments which gently slope towards the land suitable for cultivation. Because of this topographic condition the irrigated lands must be protected against flooding by riverwater or from local run-off.

Earth banks with an average height of about 2 m are constructed parallel to the river to protect the irrigated areas from river flooding. Where appropriate, flood channels are provided to drain flood water in order to prevent stagnation and recharge to the groundwater of the irrigated area.

The irrigated areas are bounded on one side by an escarpment that rapidly generates floods of high magnitudes. Earth dikes with parallel drainage channels are constructed for protection against this run-off.

3 Progress of drainage construction and future prospects

Large scale irrigated agricultural development in the Middle Awash Valley started about 15 years ago. At the initial stage of development, drainage was not considered essential and some of the earlier developed farms lack proper drainage systems. At present most of these farms are suffering from waterlogging and soil salinity. In the more recently developed farms proper surface drainage and flood protection is provided and proper planning for subsurface drainage implementation is incorporated.

At present, besides the Gewane area, some 15 000 ha are under irrigated agricultural production, mainly cotton but also banana, citrus, tobacco. A surface drainage system is only provided for about 7200 ha. Implementation of large scale subsurface drainage has not yet started. The recent Amibara Master Drainage Plan Study indicated that

in 1985 some 2500 ha of the irrigated land needed immediate drainage implementation and that by 1990 subsurface drainage will be needed on some 5000 ha. An irrigable area of about 39 650 ha has been studied to feasibility level in all aspects including soils for land classification, irrigability and drainability classifications and outline design of all components. Detail design for subsurface drainage covers about 5000 ha, while surface drainage design covers about 24 200 ha. Construction of surface drainage has been implemented on about 48% of the area under irrigation while subsurface drainage only covers a pilot area of 30 ha. There is a considerable potential for future drainage work as shown in Table 1. This programme is based on the premises that:
- Sustained irrigated development without drainage cannot be economically productive;
- Surface drainage should be constructed together with the irrigation system;
- Groundwater will rise to within the rootzone and that salinity and waterlogging will start to affect the yields about 10 years after irrigation implementation.

According to this programme, all areas that are currently under irrigation need surface drainage immediately and subsurface drainage in 1995, when construction starting in 1986. The areas that would be brought under irrigation in 1990 should have surface drainage completed at the same time with irrigation implementation and subsurface drainage in 2000. The potential in 2000 as given in Table 1 is that 39 650 ha will need surface drainage and about 28 800 will need subsurface drainage.

The implementation of drainage work as indicated in Table 1 will be governed by the following important factors:
- Priority of irrigation development;
- Availability of technical know-how for study, design and implementation;
- Availability of financial resources;
- Organizational capability for irrigation and drainage projects implementation;
- Availability of drainage construction materials.

4 Drainage criteria

The formulation of drainage criteria was influenced by:
- The efficiency of the irrigation system;
- The drainage requirement for removing excess irrigation, rainfall, run-off and river flooding;
- The crop tolerance to waterlogging and salinity;
- The soil, ranging from heavy clay to sand;
- Topography: the slope of land adjacent to irrigated areas and its steepness or the presence of constructions along the river affect the width of flood channels and the dike heights necessary for flood protection and routing;
- Vegetation: the degree of vegetative cover along the river and on the areas adjacent to the irrigated areas influence the provision of flood protection structures.

A summary of drainage criteria used in the design of Melka Sadi Amibara System

Table 1 Indicative drainage implementation programme

	1985 ha			1990 ha			1995 ha			2000 ha			Total ha		
	Irr	Sur dr	Sub dr	Irr	Sur dr	Sub dr	Irr	Sur dr	Sub dr	Irr	Sur dr	Sub dr	Irr	Sur dr	Sub dr
Kesem & Kebena	1200	–	–	4000	5200	1000	6800	6800	–	–	–	6000	12000	12000	7000
Bolhamo	1400	–	–	5600	7000	–	–	–	1050	–	–	3550	7000	7000	4600
Melka Sadi & Amibara	12400	7200	30	1800	7000	4720	–	–	5550	–	–	3900	14200	14200	14200
Angelele Digilu	–	–	–	3000	3000	–	1500	1500	–	1950	1950	3000	6450	6450	3000
Total	15000	7200	30	14400	22200	5720	8300	8300	6600	1950	1950	16450	39650	39650	28800

Note: The development schedule should be used only as an indication of the future prospect as envisaged by the author.
It does not reflect government programme or commitment. The areas are estimates which are accurate enough for this presentation.

(5000 ha) is given in Annex A. Some important considerations in the formulation of the criteria are briefly outlined below.

A major consideration in designing surface drainage is the tolerance of the crop to waterlogging. Well established plants will tolerate a 'wet-foot' condition for up to 24 hours and any rainfall excess falling on fields that have just been irrigated will have to be drained within 24 hours. Based on this assumption run-off coefficients were calculated using rainfall data from the area. Observations have shown that drainage systems based on the above assumption have, on the average, worked well.

With regard to excess canal water, practical operational considerations have indicated that for field and tertiary drains full canal rejections should be accommodated. For secondary, primary or main drains a factor of 0.15 l/s/ha, estimated from rejection flows, was applied. The channel capacity is based on the assumption of the design rainfall excess and the irrigation excess not occurring at the same time. Even though at times such an event has occurred, it did not cause major damage.

The Middle Awash Valley is subjected to annual flooding by the Awash River. A design flood with a 20 years return period was used for determining dike heights. For the protection of farms from adjacent run-off, a rainfall analysis to determine the run-off coefficient was made and a 10 years return period flood was used for the dike heights.

The drainage criteria for subsurface drainage were based on the rate at which the watertable must be lowered after an instantaneous rise resulting from irrigation. The subsurface drain should satisfy the requirement of cotton, the major cash crop. The rate of drawdown, drainable excess and drainage depth is determined for this crop. Criteria for cotton are assumed satisfactory for other crops. The drainable excess was estimated for a field irrigation efficiency with 25% percolation. This gives a drainable excess of about 2.5 mm/day. This value was confirmed by pilot drainage trials conducted on 30 ha and by the observed rate of groundwater rise. The drain depth is determined by the balance between the salinization during the fallow season and the leaching during the irrigation season to a level not detrimental to crop growth. Taking into account the soil hydrological characteristics, a drain depth of about 2 m below ground surface was found satisfactory. The drain spacing was then optimized for a series of drawdown criteria ranging from a slow rate of recession as one extreme for wide spacing and a rapid rate of recession as the opposite extreme for narrow spacing. The subsurface drainage design parameters for cotton on soils of different drainability classes are summarized in Table 2.

Table 2 Subsurface drainage design parameters for cotton

Soil drainability class	K (m/day)	D (m)	u	hm (m)	ho (m)	ht (m)
Ia	2.0	0.1	.09	.01	1.79	1.07
				.10	1.70	0.98
				.40	1.40	0.68
				.80	1.00	0.28
				1.00	0.80	0.08
				1.05	0.75	0.03
Ib	2.0	0.7	.09	1.05	0.75	0.03
Ic	2.0	1.7	.09	1.05	0.75	0.03
Id	2.0	3.2	.09	1.05	0.75	0.03
IIa	1.4	0.1	.07	1.05	0.75	0.03
IIb	1.4	0.7	.07	1.05	0.75	0.03
IIc	1.4	1.7	.07	1.05	0.75	0.03
IId	1.4	3.2	.07	1.05	0.75	0.03

Note: hm = minimum permissible depth of watertable below ground surface
ho = initial watertable height above drain
ht = final watertable height above drain
D = depth from drains to impermeable layer
K = saturated hydraulic conductivity
u = drainable pore space

The same set of values for hm, ho, and ht as given for class Ia has been used to generate drain spacings for each soil drainability class.
Soil drainability class I = coarse texture/silt loam, sandy loam, loam etc.
Soil drainability class II = other textural class except clay
Sub-class a: impermeable layer: less than 2.00 m
b: impermeable layer: 2.00-3.00 m
c: impermeable layer: 3.00-4.00 m
d: impermeable layer: more than 4.00 m

5 Method of construction

A major surface drainage construction project has been implemented on an area of about 7000 ha in the Amibara Irrigation Project and construction was carried out by contractors engaged through competitive bidding.

The flood protection embankments are designed as a trapezoidal section with minimum of 3 m top width, 2:1 side slopes and average height of around 2 m.

Drainage channels with capacities above 400 l/s are excavated using a backacting hydraulic excavator. Drains of less than 400 l/s capacity are constructed by labourers using shovels and pickaxe or by grader machine.

All excess water is returned to the Awash river. The outfall structures are designed to prevent back flow at high river stages and also to discharge excess drain water at the same time. For this purpose the outfall structures are provided with one-way gates and rejection spillways.

Subsurface drainage has been constructed on a pilot project of 30 ha. There is no experience in this respect in the country. Large scale subsurface drainage on 5000 ha will be undertaken soon. It is expected that the implementation will be completed in 1990. The installation of drain pipes both for lateral and collector drains will be carried out by drainage trenching machines. Comparative analysis has shown that the use of such machines will make the construction faster and cheaper than other methods such as use of labour. The perforated pipes are to be produced on the site by a pipe making plant. The comparative estimates made with other means of providing pipes show this to be economically attractive and technically feasible. Deep open drainage channels would be excavated by hydraulic backacting equipment and trimmed by hand. The use of motorized scrapers might be appropriate for the construction of flood embankments and associated drain channels.

6 Drainage development cost

Actual costs for pipe drainage are not available as this kind of work has not yet been executed on a large scale in Ethiopia. The surface drainage work has been executed between 1979 to 1983 on the Ambira Irrigation Project. Unit rates based on 1978 tenders were applied for costing. These rates were updated to 1985 prices in the Master Drainage Study and then used for estimating drainage development cost on an area of 14 200 ha over a period of 15 years. Some cost unit rates are summarized in Table 3.

Table 3 Cost per unit rate (1985 prices)

Description	Unit	Cost unit rate* (Birr)
Excavation for structures	m^3	11.9
Excavation for drains and place in embankments	m^3	3.6
Compact fill in embankments	m^3	2.5
Reinforced concrete	m^3	284
Reinforced steel	kg	2.9
Masonry	m^3	165
Reinforced concrete pipe – 600 mm	m	284
Reinforced concrete pipe – 150 mm	m	426
Supply and installation 60 mm PVC field laterals and surrounds	m	4.6
Supply and installation PVC collector pipe – 150 mm	m	10.8
Supply and installation PVC collector pipe – 225 mm	m	19.6
Supply and installation PVC collector pipe – 300 mm	m	33.0

* Includes 10% allowance for minor items
1 US$ = Birr 2.07

The drainage implementation cost for 14 200 ha at 1985 prices is estimated to be US$ 3100/ha. This includes construction of flood protection works, land improvement, construction of associated structures and provision for housing and for supervising operation and maintenance.

7 Project organization and management

The Water Resources Development Authority (WRDA), under the National Water Resources Commission, is the national body responsible for the development and utilization of surface water resources in the country. The power and duties of the Authority include study of water resources, implementation of water resources projects and administration of their operation and maintenance.

By virtue of this power the Authority has undertaken the study, design and implementation of irrigation and drainage projects and after implementation operates and maintains these projects. For project implementation the Authority establishes project executing offices with specific mandates. These executing offices usually carry out feasibility studies of projects or their implementation.

Once the implementation of projects are completed, they are handed over to other institutions responsible for production operation. The Authority has a department which is responsible for operation of major water structures, their maintenance, the administration of water utilization and the levying of charges for operation and maintenance costs and the repayment of loans obtained for project development.

The Authority usually engages the services of specialized consulting firms or experts for project preparation, design and supervision.

The Authority has executed the following projects in the Middle Awash Valley:

– Irrigation feasibility study	39 000 ha
– Design for irrigation	11 000 ha
– Irrigation implementation	10 000 ha
– Drainage study and outline design	14 000 ha
– Detailed drainage design	5 000 ha

8 Maintenance of drainage systems

At present maintenance is limited to surface drainage and flood protection systems along with other irrigation structures. The maintenance is organized, based on the facilities and equipment required to carry out specific aspects.

The main consideration is whether a maintenance activity can be executed economically and technically by machine or labour. In this respect, maintenance activities that mainly require labour are the responsibility of production operating entities and those that require machines and skilled manpower are the responsibility of the Water Resources Development Authority. The maintenance responsibility is divided as follows:

- Production Operation Entities are responsible for maintenance of tertiary and field drains, less than about 400 l/s. They employ labourers for maintenance activities;
- WRDA is responsible for all high-order drains, drains mutually used by more than one entity even if the capacity is small, flood protection dikes etc. WRDA has a maintenance organization in the Middle Awash Valley equipped with machines such as excavators, dozers, graders, dump trucks and appropriate skilled manpower to manage the maintenance work and to operate and maintain the machines.

The most important maintenance requirement is the removal of weeds and desilting of channels. The weeding and desilting work has to be done at least once a year and in some cases twice.

Repair to gates, structures, etc. are also done annually. So far the maintenance activities on the existing development are effective and satisfactory.

9 Conclusion

Agricultural drainage has recently started in Ethiopia. The Middle Awash Valley is one of the priority areas for drainage construction. Surface drainage has been implemented with irrigation development. A Master Plan for subsurface drainage construction has been prepared. The awareness exists that without proper drainage sustained irrigated agricultural development cannot be maintained in places like the Middle Awash Valley.

In order to achieve the target for drainage implementation in the region, particular attention should be given to the following points:

- Commitment and planning of irrigation and drainage projects including financial requirements;
- Build-up of organizational and technical capability and capacity through training and assistance to undertake drainage projects;
- Constant and accurate recording, monitoring and evaluation of irrigation practices and timely observation of the occurrence of drainage problems;
- Continuous research activity on the unique irrigation and drainage problems of the region;
- Build-up of construction capability and capacity;
- Preparing drainage materials.

Annex A

Design criteria[1]

Criterion	Assigned value	Design consideration
1 Flood dikes		
1.1 Awash River Flood Protection Dike		
River dike to withstand return period flood of	20 years	Optimized cost/benefit
Minimum freeboard	0.5 m	Contingency/safety factor
Dike top width	3.0 m	Vehicular access
Side slopes	1 in 2	Stability
Cross fall to dike top (towards river)	1 in 30	Surface drainage
Topsoil stripping under embankment (minimum)	0.15 m	Elimination of preferential seepage path/ stability
Compaction to embankment (Proctor density)	95%	Stability/seepage
Minimum reserve between dike and adjacent riverway	100 m	Flood reserve for attenuation, safety reserve against high velocity/erosion of dike
1.2 Eastern catchment flood dike and drain		
Dike to withstand return period flood of	10 year	Qualitative assessment of appropriate period
Minimum freeboard	0.5 m	Contingency/safety factor
Dike top width	3.0 m	Vehicular access
Side slopes	1 in 2	Stability
Minimum reserve between dike and drain	50 m	Limit velocity/erosion adjacent to dike
Minimum reserve between dike and toe of adjacent foothills	150 m	Flood reserve
Topsoil stripping under embankment (minimum)	0.15 m	Elimination of preferential seepage path/ stability
Compaction to embankment (Proctor density)	95%	Stability/seepage
Minimum width of flood channel	20 m	Provision of preferential flow path
Minimum depth of flood channel (cut and fill balance)	0.5 m	Provision of preferential flow path

[1]) Water Resources Development Authority 'Master Drainage Plan for Melka Sadi and Amibara Area, Vol. 7 Annex D; Engineering,' Halcrow, July 1985.

2 Subsurface drainage

2.1 In field pipe drains

Drainage rates – cotton	2.5 mm/day	Drainable excess from
Drainage rates – banana	3.4 mm/day	irrigation, including canal seepages
Minimum pipe gradient	0.1%	Siltation and laying tolerance (small diameters)
Siltation allowance	20% reduction in capacity	Pilot drainage scheme results/FAO Irrigation and Drainage Paper 38
Maximum length of pipe run	400 m	Access for maintenance practical limit
Minimum depth of drains at head of lateral or low point along lateral	1.6 m	Watertable/salinity control
Pipe filter surround	75 mm minimum thickness	Enhanced hydraulic entry/ soil stability

2.2 Collector pipe drains

Drainage rates – cotton	2.5 mm/day	As above
Drainage rates – banana	3.4 mm/day	
Minimum pipe gradient	0.05%	Siltation and laying tolerance
Siltation allowance	20% reduction in capacity	FAO Irrigation and Drainage Paper 38
Maximum length of pipe run between inspection chambers	300 m	Access for maintenance practical limit
Areal reduction factor – 225 & 300 mm(id)	0.7	FAO Irrigation and
Areal reduction factor – 150 mm(id)	0.8	Drainage Papers, 28 and 38

3 Surface drainage

3.1 Shallow surface drains

Field drains:
Drain section determined by construction considerations (using ditcher bucket). This criterion exceeds run-off considerations.

Bed width	0.5 m	Minimum practical for
Depth	0.5 m	mechanical excavation
Side slopes	1 in 1.5	Soils stability
Minimum gradient	0.05%	Hydraulic capacity
Mannings 'n'	0.03	Coefficient for grass/weeds

Tertiary drains:		
Drainage coefficient	1.2 l/sec/ha or tertiary canal rejection flow (100% design)	1 in 5 year rainfall/run-off estimate
Bed width	0.75 m	Nominal standards for
Minimum gradient	0.05%	velocity roughness and
Mannings 'n'	0.03	contingency allowance (in freeboard)
Minimum freeboard	0.25 m	
Secondary drains:		
Drainage coefficient	1.2 l/sec/ha or secondary canal rejection flow (100% design)	As tertiary drains, roughness coefficient based on maintained flow section
Mannings 'n'	0.025	
Minimum freeboard	0.25 m	
Main drain:		
Drainage coefficient	1.0 l/sec/ha or sum of canal rejection flow (100% design)	1 in 5 year 24 hour rainfall/run-off estimate
Mannings 'n'	0.025	Maintained flow section
Minimum freeboard	0.50 m	Contingency

3.2 Deep surface drains (conveying subsurface drainage flows)

Normal flow discharge coefficient	0.35 l/sec/ha	Combined rejection and subsurface drainage flows
Mannings 'n' secondary and main drain	0.025	Maintained flow section
Normal flow level, below centre-line of subsurface pipe outlets	0.15 m	Operational contingency allowance/ facilitate inspection
Maximum drain depth without berm	3.5 m	Stability/access for maintenance
Side slopes	1 in 1.5	Soil stability
Berm width (where required)	4.0 m	Minimum access for maintenance
Design flood flow, sum of	0.35 l/sec/	Superimposing flood
design normal flow and surface	ha + 1.0 l/	run-off on normal
storm run-off (or rejection)	sec/ha =	operating condition
flows for secondary main drains	1.35 l/sec/ha	
Minimum freeboard Main drain	0.5 m	Contingency allowances
Secondary drain	0.25 m	

3.3 Desirable velocities in open drains

Minimum (for normal flow)	0.4 m/sec	Prevention of bilharzia snail
Maximum (for peak flow)	0.8 m/sec	Scour velocity

4 Drainage structures

Maximum culvert headloss at normal flow	0.05 m	Cost minimization
Minimum pipe velocity	Not less than drain velocity	Silt prevention
Maximum pipe velocity	3.0 m/sec	Energy dissipation
Factor of safety on seepage (exit gradients)	5.0	
Angle of internal friction of backfill	30°	Soil stability
Cohesion of backfill	0	
Safe bearing capacity of foundations	100 kN/m^2	
Assumed nominal concrete strenght at 28 days	20 N/mm^2	Standard strength class
Filter gradings (for rip-rap)	Designed to USBR recommendations	Stability/ permeability of underlying soil

The Melka Sadi Pilot Drainage Scheme

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1 Introduction

The origin of the Melka Sadi Pilot Drainage Scheme located in the Amibara Irrigation Project (AIP) lies in an increasing awareness of the problems presented by rising groundwater tables under irrigation, which during recent years have resulted locally in waterlogging, considerable losses in crop yields and salinization of once fully productive areas. By 1983 substantial areas of Melka Sadi Banana Farm had been abandoned and the adjacent cotton producing areas were increasingly affected. A drainage study in 1981 indicated that about 1200 ha would need drainage and partly reclamation.

A pilot drainage scheme was estimated useful for evaluating the technical feasibility of alternative drainage options, and providing data required for the design of drainage of the affected areas. Construction of the experimental site began in early 1983, with the main objective of evaluating drain spacing, pipe surrounds and drainage materials. Reclamation and leaching trials were designed to assess the feasibility of reclaiming saline-sodic soils without the use of amendments.

The pilot scheme itself comprises a comprehensively instrumented experimental site occupying some 30 ha of alluvial soils in Melka Sadi, and incorporates a range of drainage treatments. A detailed soil survey was conducted to provide basic data for evaluating drain performance and reclamation trials. The majority of the site comprises soils abandoned due to salinization, although a 5 ha block was under bananas of marginal production.

Monitoring of trials started in December 1983 and ended in July 1984. The environmental background, the experimental design, the data obtained, the details of the analysis and the conclusions were presented in three volumes.

2 Experimental design and objectives

2.1 Objectives

The experimental objectives can be summarized as follows:
- Verification of the parameters used for design, including the drainage criteria and hydropedological factors;
- Study of groundwater flow towards drains;
- Determination of the most appropriate combination of drain pipes and envelope material by studying the entrance resistance and watertable drawdown characteristics;

– Examination of the practicability of reclaiming the saline and saline-sodic soils by leaching, without the addition of amendments.

2.2 Soil and groundwater survey

A soil survey on a fixed grid with a density of 1 observation per ha was conducted to enable a correlation of field test results with soil conditions. Soil physical and hydrological properties were measured. Full chemical analysis was conducted on samples taken from soil profile pits. The position and quality of groundwater was measured and groundwater contour and salinity maps depicting initial conditions were plotted.

2.3 Experimental design

For design purposes, based on measurement of soil hydropedological properties, a hydraulic conductivity value of 0.8 m/day for the whole drainage profile was assumed, and the drainable pore space was assumed to be 0.1. An impermeable layer was assumed at a depth of 3 m below ground surface. Based on the consideration of non-steady state irrigated conditions, the drainage criterion was formulated and drain spacings calculated using the modified Glover-Dumm, corrected Glover-Dumm and Boussinesq equations. In selecting spacings for the trials, consideration was given to FAO recommendations that the widest and narrowest spacing should be at least 100% greater and smaller than the theoretically calculated one. The average drain spacing calculated with the three drainage equations was approximately 40 m, and spacings of 75 m, 40 m and 20 m were therefore chosen for test purposes.

Trials for evaluating drainage materials were also conducted. Three different filter materials were tested, comprising locally available red ash, gravel and a factory made fabric filter. The performance of these materials was assessed with reference to a 'control' in which no filter material was used. Entry resistance was measured using an arrangement of piezometers adjacent to the pipe.

All plastic pipes used in the trials were imported corrugated PVC. Pipe diameter was fixed at 60 mm, although 80 mm diameter pipes were used for the 75 mm spacing and slot size at 1 mm with the exception of one test plot in which 2 mm slots were used.

Two leaching basins of 3 m were constructed close to sampled profile pits. The basins were subdivided into four sub-basins so that at each basin two experimental treatments, consisting of 10 cm and 20 cm application depth of leaching water respectively, could be carried out.

The leaching resulting from periodic applications of irrigation water during the course of drainage testing was also monitored, by taking monthly soil samples from profile pits together with samples of irrigation and drainage water. This information was used to support the results obtained from leaching basin trials.

2.4 Construction

Construction work on the Pilot Scheme commenced in April 1983 and was substantially completed by October of the same year.

As the groundwater was high, approximately 1 m below surface during installation of drains, pumping was required every 25 m during trench construction. Water draining into the trench was pumped directly into the pre-constructed collector drains. This operation was extremely difficult, and complicated by pump failures and rainfall.

Labour was divided into three crews; a fifteen men gang for trench digging, a fifteen men gang for pipe laying and a ten men gang for moving filter material. Three labourers were required to operate the pumps. The following equipment was also utilized:

1 hydraulic excavator (Akerman H1 6c)
1 D7 Dozer (for trench backfilling)
1 grader
1 dump truck (transport of filter on site)
1 + 1 loader and dump truck (for filter transport, source to site)

With this combination of machine and labour, an average output of 18 m/hour was achieved and a maximum output of 28 m/hour. This low output was due to inexperience, pump failure, and generally inappropriate equipment. Furthermore, work was interrupted during and after rainfall. Table 1 summarizes some of the unit costs.

Table 1 Unit costs of Melka Sadi pilot drainage scheme

Description	Unit	Rate Birr
Bush clearing and root grubbing	ha	1400
Compacted fill-in embankment	m^3	5.00
Excavation of open collector drains	m^3	5.00
Disposal of excess spoil up to 500 m	m^3	4.00
Excavate, lay pipe and filter and backfill for subsurface field drains	m	20.00
Supply of 80 mm perforated, corrugated PVC pipe (air freighted from U.K.)	m	8.25
Supply of 60 mm perforated, corrugated PVCB pipe (air freighted from U.K.)	m	5.90
Supply crushed graded filter envelope	m^3	67.00
Supply red ash filter envelope	m^3	12.00
Grading and compacting access track	m^2	2.60
Supply, spread and compact gravel in roadbase (200 mm thick)	m^2	7.00
Excavation for structures	m^3	15.40
Masonry in structure	m^3	287.00
Concrete class 21/37	m^3	600.00
Supply of 50 mm smooth PVC pipes	m	3.80

3 Result of analysis

A detailed analysis of the data obtained during 8 months was undertaken. There is considerable variability in the calculated values of hydraulic conductivity, although the results generally confirm the field observations that KD values vary between 0.5 and 3.0 m^2/day, with an impermeable layer between 2.5 m and 3.5 m below surface. This variability reflects the soil conditions encountered at the experimental site, in particular the considerable degree of soil stratification observed during the soil survey.

The entrance resistance of pipes with filter envelopes was appreciably lower than those with no pipe surround. Entrance resistance of pipes with gravel or red ash envelope was negligible, and changed little over time. The entrance resistance of the factory made filter was about ten times greater than gravel or red ash filters and appeared to increase slightly over time.

The achieved drainage criteria for fields under both Melka Sadi Sate Farm (MSSF) and AIP irrigation schedules are compared with the design drainage criteria in Table 2. Under both irrigation schedules, the gross field applications were considerably in excess of the design value. Similarly, the irrigation intervals substantially exceeded the intended design interval between irrigations. The most important inferences obtained from Table 2 are:

- A deeper drawdown depth than the designed one was attained since the maximum watertable depth increased;
- The minimum design water depth was exceeded for short periods up to five days under the AIP irrigation schedule;
- The observed drain discharge rate exceeds the calculated discharge rate because dewatering of pipes takes place in a shorter period than the irrigation interval;
- The correlation between calculated drawdown and observed drawdown is good under the AIP irrigation schedule but poor under MSSF irrigation.

Results obtained from the leaching basin trials showed that once leaching commenced, a rapid falling ECe was measured throughout the soil profile, being most noticeable in the upper soil profile initially. The rate of leaching appeared to be greatest with the 20 cm application depth of leaching water. In this case, non-saline conditions were created in the upper 60 cm of the soil profile within five days. By contrast, up to 30 days were required in the case of the 10 cm application depth. In both cases, a considerably longer period was required, approximately 60 days, to create non-saline conditions to a depth of 200 cm. The results are summarized in Table 3. Throughout the leaching period, only minor fluctuations in infiltration rates and pH levels at various depths in the soil profile were observed, indicating no development of alkali conditions.

The results of water balance calculations were not conclusive primarily because, with the exception of one field collector, complete drain discharge data were not available. Nevertheless, certain features of the water balance are clearly identifiable. Soil water content rises sharply to field capacity following irrigation, after which the drains discharge heavily. Towards the end of the irrigation cycle, soil water deficits attain about 100 mm over 2 m depth of soil. In almost all cases the drains start flowing very soon after irrigation. For these fields, the leaching fraction was estimated at about 50%, much more than would be expected under cropping conditions.

A salt balance, which was calculated for one of the fields, shows that after a period of net accumulation of salts before trials began in April 1984, net removal of salts took place during the period April-August 1984 as a result of leaching. The rate of desalinization, which was broadly in agreement with rates observed in the leaching basin trials, appeared to decrease during the five monitoring periods.

Table 2 Designed and achieved drainage criteria

Design parameters	Design drainage criterion	Achieved drainage criterion under AIP irrigation	Achieved drainage criterion under MSSF irrigation
Gross field application	100 mm	190 mm	426 mm
Irrigation interval	15 days	22 days	31 days
Drainable excess	30 mm	38 mm	110.67 mm
Calculated discharge rate	2.00 mm/day	1.72 mm/day	3.57 mm/day
Observed discharge rate		2.98 mm/day	4.61 mm/day
Drainable pore space	0.10	0.07	0.07
Calculated h	0.3 m	0.54 m	0.58 m
Minimum watertable depth	1.30	1.18 m	1.50 m
Maximum watertable depth	1.60	1.83 m	1.87 m
Observed h		0.65 m	0.37 m
ho	0.70 m	0.82 m	0.50 m
ht	0.40 m	0.17 m	0.13 m

Where:
h = Change in height of watertable or drawdown
ho = Height of watertable above drain depth at time t = 0 days
ht = Height of watertable above drain depth at time t = 15 days

Table 3 Results of leaching trials

Depth of application (cm)	Days required to lower ECe to less than 4 mmhos/cm at depths			Depth of water required to lower ECe to less than 4 mmhos/cm at depths		
	60 cm	120 cm	200 cm	60 cm	120 cm	200 cm
20	4	8	47	50	100	240
20	4	5	8	55	70	110
20	5	16	45	50	120	230
20	25	42	58	160	190	255
10	30	65	80	85	140	150
10	15	23	40	65	80	110
10	97	83	110	340	295	410
10	55	22	15	260	135	100

4 Conclusion

The Pilot Drainage Scheme has demonstrated the effectiveness of subsurface drainage in lowering watertables, and the feasibility of reclaiming saline-sodic soils without the use of special amendments.

Based on the formulated design criteria, drain spacing was shown to be in the range of 50 to 60 m, which is wider than was originally envisaged owing to a higher transmissivity. The hydraulic conductivity was estimated at 2 m/day and the drainable pore space was estimated to be in the order of 0.07. The existence of an impermeable layer at about 2.5 to 3 m below surface was confirmed, indicating that vertical drainage should not be feasible if similar conditions to those at the experimental site prevail elsewhere in the project.

The trials with filter materials clearly demonstrated the advantage, measured in terms of entrance resistance, of using gravel or red ash as pipe surround. Calculations showed that without use of a suitable filter, drain spacings would need to be halved in order to achieve the design watertable control. The effects of pipe surround for minimizing siltation could not be fully investigated in the time available.

Reclamation studies have shown that provided drainage is installed, salinity levels can be reduced rapidly to levels favourable for plant growth. Colonization of the once abandoned trial site by a diverse range of species confirms these findings. Gypsum, which was observed to occur in a finely divided form, appears sufficient for cation exchange during reclamation, and sodic conditions did not develop as a result of leaching.

Certain detailed aspects of the experimental programme will require further study to clarify interpretations of the available data. The Pilot Drainage Scheme can be used as a site for long-term drainage research. Possible research topics are:
- Continuation of drain performance evaluation;
- Investigation of impermeable layer;
- Drain material testing;
- Water and salt balance studies;
- Refinement of drainage criteria;
- Drain siltation;
- Agronomy.

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Drainage and land reclamation in Peru

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1 Introduction

Peru is a country of 1 285 215 km^2, divided in three natural regions, the Coast, a desert where agriculture is possible only under irrigation; the Sierra, high mountains with sufficient seasonal precipitation for one crop a year, where irrigation is tried as an option for a second crop; and the Jungle, a very humid zone, covered by a dense forest, and hardly used for intensive agricultural purposes. The land use pattern of the Peruvian regions is presented in Table 1.

Table 1 The land use pattern of the Peruvian Regions

Description	Total	Coast (area in 1000 ha)	Sierra	Jungle
Total surface area	128 521	14 400	33 517	80 604
Potential agricultural land	4 887	1 527	1 500	1 860
Land under cultivation	2 442	928	1 200	314
Irrigable land	1 642	1 018	463	161
Land under irrigation	904	647	223	34
Pasture	17 915	1 622	10 576	5 717
Population (June 1986)	20.2 Millions	50%	38%	12%

Although different in characteristics, origin and economic importance, the three regions have drainage problems.

The Coast
The coast has the most important drainage problems to be solved. Most of the problems are associated with soil salinity. Approximately 250 000 ha (30% of the best agricultural land) needs some kind of reclamation work. The origin of the problem is the low irrigation efficiency, the marine origin of the soils and the very low natural drainability of the lowlands.

The Sierra
There are approximately 120 000 ha affected by high watertables, especially on the lower part of the inter-Andean valleys and areas surrounding lakes and lagoons. The solution is usually related to the presence of drainage water disposal facilities.

The Jungle

The best agricultural lands are affected by drainage problems, due to excess precipitation, river floods and flat lands. Until now these lands are cultivated with pasture and rice, without much drainage improvement.

2 Most important drainage and land reclamation projects

Most drainage and land reclamation in Peru is concentrated on the Coast (Figure 1). In 1963 30% of the coastal agricultural lands was estimated to be affected by drainage and salinity problems. In 1976 this figure was estimated at 34%, while in 1986 the estimation was 32% (Table 2).

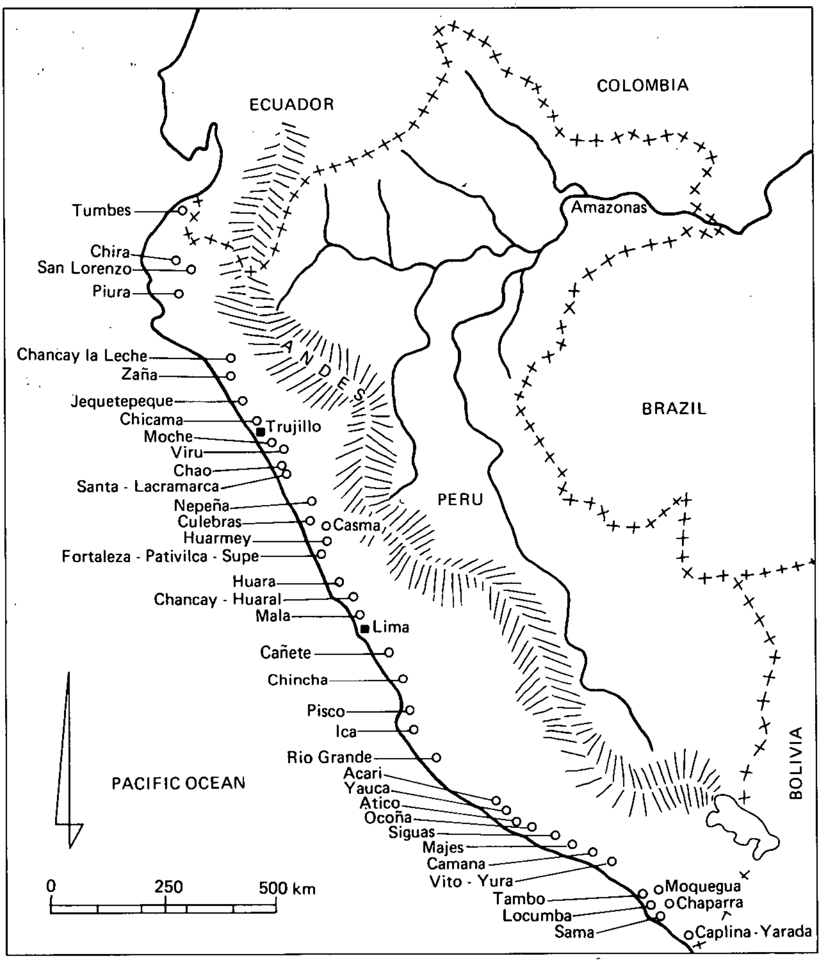

Figure 1 Valleys on the Peruvian coast with drainage and salinity problems

Table 2 Drainage and salinity problems in coastal valleys (ha)

Valley	Total agricultural area	1986 evaluation			
		Light salinity and drainage problems	Moderate salinity problems	Moderate to severe salinity and drainage problems	Total affected area
Tumbes	12 226	1 339	–	7 201	8 540
Chira	33 344	9 103	189	7 550	16 842
Piura (Medio y Bajo)	64 700	15 000	–	10 000	25 000
Alto Piura	46 000	N.D.	N.D.	N.D.	12 000
Col. San Lorenzo	38 000	5 000	3 000	5 000	13 000
Chancay-La Leche	106 299	26 911	166	20 000	47 077
Zaña	18 250	3 685	2 604	1 189	7 478
Jequetepeque	46 996	19 700	526	3 251	23 477
Chicama	71 593	4 428	16 097	5 822	26 347
Moche	10 447	806	1 574	141	2 521
Chao	7 288	–	521	274	795
Virú	11 119	643	2 869	757	4 269
Santa-Lacramarca	17 690	336	2 016	1 240	3 592
Nepeña	10 400	2 100	1 560	120	3 780
Culebras	1 735	380	–	–	380
Casma	13 151	1 150	1 130	900	3 180
Huarmey	2 250	290	490	290	1 070
Fortaleza-Pativilca y Supe	24 430	1 248	15	1 656	2 919
Huaura	37 360	3 420	508	2 052	5 980
Chancay-Huaral	22 600	1 770	610	2 020	4 400
Mala	8 000	–	440	1 150	1 590
Cañete	24 050	816	2 000	–	2 816
Chincha	24 000	–	800	1 460	2 260
Pisco	18 383	5 000	–	2 500	7 500
Ica	32 216	1 195	1 000	375	2 570
Rio Grande	23 876	–	114	66	180
Acari	5 042	–	–	964	964
Yuaca	1 536	218	577	173	968
Chaparra	1 062	N.D.	N.D.	N.D.	110
Atico	140	6	–	–	6
Ocoña	782	370	–	19	389
Camaná	6 003	1 000	200	–	1 200
Majes	6 289	305	–	–	305
Siguas	2 633	277	–	235	512
Vitor	5 562	251	–	879	1 130
Tambo	10 198	–	3 000	–	3 000
Locumba	3 210	N.D.	N.D.	N.D.	3 179
Sama	2 896	–	1 444	1 452	2 896
Moquegua	2 589	–	4	45	289
Caplina-Yarada	7 953	3 500	4 453	–	7 953
Total	782 298				252 464

During the last ten years some projects have been executed and approximately 24 000 ha have been rehabilitated, whereas 16 000 ha are under rehabilitation. Still the total area affected has been reduced only by 2576 ha. The reason for that is an increase of the problems and some deterioration of the existing infrastructure. Recent studies demonstrate that the problems in some areas were under-estimated.

3 Drainage projects under execution

3.1 General

In 1974, a special commission of Peruvian engineers and Dutch technical advisors nominated by the Ministry of Agriculture, formulated the National Plan of Drainage and Land Reclamation along the Coast with recommendations on stages and execution priorities. This was the origin of PLANREHATIC, the government entity responsible for the execution of the National Plan of Drainage and Land Reclamation.

3.2 Main components of rehabilitation plan

- Improvement of the main irrigation infrastructure in the valleys (intakes, channels, measurements, distribution and crossing structures);
- Improvement of the irrigation and drainage infrastructure at farm level in the areas affected by drainage and salinity problems;
- Improvement of the farmers and water users organizations, implementation of a service for technical assistance, especially for operation and maintenance of the infrastructure and improvement of the irrigation efficiency at farm level;
- Provision to the water users of machinery and appropriate workshop for operation and maintenance.

3.3 Rehabilitation stages

3.3.1 Rehatic I

This project was executed between 1974 and 1986 and was partially financed by the World Bank. The total investment was in the order of US$ 47.8 million (28.5 million in works, 3.7 million in machinery and equipment, and 15.6 million for engineering service, supervision and administration). Details of the REHATIC I project are presented in Table 3.

Table 3 Details of the REHATIC I Project

Area (ha)	Mala	Cañete	Pisco	Camaná	Majes	Tambo	Total
Irrigated area	4 800	24 000	19 000	6 800	5 900	8 640	69 140
Irrigation improvement	2 000	9 200	4 900	6 800	3 350	7 000	33 250
Drainage and reclamation requirements	1 250	3 695	5 370	3 017	3 350	2 374	19 056
Field drainage requirement	862	1 882	934	918	2 384	1 403	8 383

3.3.2 Rehatic II (Lower Piura)

The lower Piura valley is part of the Chira-Piura Irrigation Project. This valley has a cultivated surface of 50 000 ha. The area affected by drainage and salinity problems is approximately 35 000 ha. As part of the first stage of the Chira-Piura Project, 164 km of main drains have been improved and 97 km of new collector drains have been excavated, and 195 km of existing collectors have been improved. Approximately 25 000 ha are still affected by salinity and drainage problems due to lack of farm drains.

The feasibility study of the remaining area was prepared by REHATIC in 1979. The World Bank gave a loan of approximately US$ 90 million for the construction of the drainage systems. Unfortunately during the execution period (1983), the lower Piura was flooded by very unusual high precipitation, that delayed the execution of the work. At this moment drainage problems still affect 25 000 ha.

3.3.3 Rehatic III

The feasibility study of this stage has been completed by DEPEREHATIC. This project consists of seven small projects: two in the Sierra and five at the Coast. The total irrigated area to be improved is 69 554 ha, of which 49 478 ha need drainage and soil reclamation.

The total investment is in the order of US$ 118.8 million, including US$ 86.6 million for machinery and equipment and US$ 25.8 million for engineering services, administration and supervision.

The report is being reviewed by the World Bank, being interested in partial financing of this project.

The final design prepared by DEPEREHATIC will be completed during 1987.

3.3.4 Other drainage projects

a. Chancay-La Leche (Lambayeque)
   This is a project of 91 600 ha, executed between 1966 and 1980. The drainage and salinity problems in this area affect approximately 30 000 ha. Because of technical, economical and social reasons, this project is considered of first priority. Until now

the main drainage system has been constructed. The subsurface farm drain requirements have been estimated at 4000 km and the total cost at approximately US$ 25 million.

b. Jequetepeque-Saña
This irrigation and drainage improvement project is under execution. According to an evaluation, there are in this zone approximately 6000 ha with drainage problems and 15 000 ha with soil salinity problems due to shortage of irrigation water.

c. Chavimochic project
The main objective of this project under execution is to improve the irrigation water availability by derivation a part of the water from the Santa river. CHAVIMOCHIC is an integrated 4 valley project (Chao, Virú, Moche and Chicama), situated in La Libertad Department, approximately 600 km north of Lima. The actual drainage problems in those valleys affect 12 871 ha. In future with more irrigation, more problems are expected, especially if the present volume of groundwater that is pumped (287 million m^3) will be reduced. Soil salinity affects 21 061 ha, mainly due to lack if irrigation water. The CHAVIMOCHIC project includes improvement of existing drains, excavation of new drains, installation of approximately 1000 km of subsurface drains and yearly replacement of approximately 150 km of old subsurface drains. The most important features of the CHAVIMOCHIC project are presented in Table 4.

Table 4 Pertinent features of the CHAVIMOCHIC project

Area (ha)	Chao	Virú	Moche	Chicama	Total
Total project area	10 668	24 519	15 961	80 600	131 748
Under irrigation	2 000	6 000	8 000	46 000	62 000
Irrigation improvement	5 023	11 625	10 702	65 640	92 990
New land	5 665	12 894	5 259	14 960	38 778
Soil salinity problems	521	2 869	1 574	16 097	21 061
Drainage problems	274	1 400	947	10 250	12 871

4 Drainage technology development

The drainage technology development over the last 20 years is according to the following schedule:

Fase I	Agrarian University, La Molina 1968
– Training	The University with the technical cooperation of the Dutch Government organized a drainage course in Peru, attended by Peruvian engineers.
Fase II	CENDRET 1968-1971
– Training	With technical cooperation of the Dutch Government:

– Research – Basic studies	– Drainage and land reclamation courses were organized, attended by 68 engineers. – Two experimental plots were executed to demonstrate construction procedures, different kind of materials and evaluation of results. – Evaluation of drainage and salinity problems in each valley on the Coast was started.
Fase III – Training – Research – Basic studies – Design and execution of large scale projects	SUDRET 1972-1979 With technical cooperation of the Dutch Government: – Drainage and land reclamation courses were organized attended by 52 engineers. – Two new experimental plots were executed. – San Lorenzo Drainage Project (8300 ha) was projects executed. – Evaluation of drainage and salinity problems in coastal valleys was completed. – PLANREHATIC was started, the study of REHATIC I (6 valleys: 40 000 ha).

Fase IV
– Large scale drainage project study
– Execution of large scale projects
	DEPEREHATIC 1976-1986
	With technical and financial cooperation of the Dutch Government.
	DEPECHP 1980-1986
	– Feasibility study, final design and execution of two drainage projects:
	  – REHATIC I (40 000 ha)
	  – REHATIC II (50 000 ha)
	– Feasibility study of REHATIC III was completed (69 554 ha).

5 Peruvian experience with drainage and land reclamation

Although drainage is an old practice in Peru, until 1986 it was more an empirical practice than a technique, apart from some projects executed by foreign companies. Because of that, drainage projects were usually considered expensive and an uneconomical investment.

As a result of the drainage programme development, Peru has at this moment more than 100 engineers with experience in all the aspects and stages of drainage project development, even though some aspects remain unsolved.

Stocktaking of the qualifications reveals the following:

– Basic studies: there is great experience and capacity;

- Large scale project studies and design: the government and Peruvian private companies have professionals with good experience;
- Work execution: the Peruvian companies have demonstrated great capacity and experience to execute almost total projects. The main constraint is lack of experience to install tile drains at farm level;
- Subsurface drainage: the only large scale project executed was done by a specialized foreign company. No Peruvian company is experienced to do this type of work;
- Supervision: there are enough Peruvian companies and professionals with technical capability to do this job;
- Maintenance: this is one of the main problems without solution. It is basically a problem of proper organization and some administrative and legal regulations;
- Improvement of saline soils: there are enough professionals with experience, but the actual execution is the responsibility of the farmers. Lack of training of farmers causes a delay in the improvement of saline soils.

6 Drainage material and machinery

6.1 Subsurface pipe drains

There is no adequate drain pipe production in Peru. Clay pipe without collar is the most common type of pipe used for farm drainage in Peru. This pipe is not suitable to be installed by a trenching machine, because of unstable soil conditions. In the past years those pipes were installed by hand, but at present it is too slow and costly.

The solution is the use of corrugated plastic pipe, but there is no Peruvian factory interested to produce this pipe. DEPEREHATIC has installed between 1983 and 1985 400 km of corrugated plastic pipe (100 and 65 mm inside diameter and made in Peru), with a machine bought in Europe by a foreign contractor.

Main problems with clay pipes are:
- Very difficult to install correctly in unstable soils (very common in Peru);
- The volume and quality of pipes, produced in Peru, are low (irregular cut and easy to break), making installation by machine problematic;
- The installation by hand is too slow and especially unfavourable in areas under cultivation;
- The width of the excavation at the surface is 6-15 times the width made with a trenching machine, which is unfavourable.

Main problems with concrete pipes are:
- The Peruvian agricultural soils have usually a very high content of calcium sulphate; consequently concrete pipes have to be made with sulphate resistant cement, making the pipe more expensive;
- Because of the thickness of the pipe walls and especially the collar, a wider trench is required;
- The normal length of concrete pipes is one meter, to reduce it to 0.5 m or less will increase drastically the cost;

– The volume of production of this type of pipe is quite low.

6.2 Filter material

The best Peruvian experience in relation to filter material is to use gravel and coarse sand. This type of material exists almost everywhere at very reasonable cost and has been successfully installed by hand and trenching machine.

6.3 Pipe drain collectors

This is not an extensive practice; only concrete pipes have been used until now.

6.4 Drainage machines

a. Trenching machine
   Between 1971 and 1983 Peru purchased five trenching machines in the Netherlands, three of them were bought by the government and two by private companies. All have worked relatively a few hours and are in good working order.
   The main reasons for their limited use are:
   – Difficulty in getting appropriate drain pipes;
   – Difficulty in organizing farm drainage work (economical, social and political aspects);
   – Insufficient budget;
   – Lack of irrigation water for those areas to be reclaimed.
b. Pipe drain cleaning machines
   Five high pressure drain flushing machines have been purchased and are used to clean subsurface farm drain pipes. There are some problems with this practice:
   – Organizational problems cause that the cleaning of the pipe lines is very irregular;
   – Defective drainline installation causes that the cleaning is difficult and sometimes impossible.
c. Ditch cleaning machine
   This operation is usually made with normal retro-excavators, some equipped with a mowing bucket and a cutterbar for reed. A lot of work is still made with hand labour or combined. This cleaning operation is required at least once a year, but because of organizational problems. This is not always fulfilled.

7 Rehabilitation cost

7.1 Investment cost

Drainage projects in Peru are usually related to soil salinity and irrigation problems. Because of that an average of 43% of reclamation investment is used to improve the irrigation system (lining of canals, improvement of intake structures, improvement of groundwater wells and equipment).

The drainage work itself represents approximately 38% of the investment, including main drain systems, farm drains and land preparation for leaching.

The balance of the investment (19%) is used in machinery, equipment and buildings for operation and maintenance. This investment is initially under the responsibility of the project authority and lateron transferred to the water users. A breakdown of the investment costs in drainage projects is presented in Table 5.

Table 5 Typical investment in drainage projects

Type of investment	Area (ha)	Investment $/ha
Irrigation improvement	27 900	743
Drainage work	14 456	1 267
Machinery, buildings and equipment for operation and maintenance	58 440	157

7.2 Operation and maintenance

The operation and maintenance of any drainage project is organized at irrigation district level. It is programmed together with the operation and maintenance of the irrigation system.

Peruvian legislation is clear about the responsibilities of each organization. Unfortunately the cooperation and discipline between farmers, water users and governmental organizations is poor. Therefore operation and maintenance is inadequate.

The main problems for adequate operation and maintenance are the lack of sufficient funds and the absence of an authority with more power.

According to the Peruvian law, farmers are obliged to contribute in cash for the total expenses of operation and maintenance. Subsequently they have to be organized in water users associations, but in reality, because of political reasons the farmers contribution is fixed. Due to the inadequate collecting system, only 5 to 10% of the actual cost is collected. As a result there is a gradual deterioration of the drainage works.

There are many studies devoted to the cost of operation and maintenance and the amount to be charged to the farmers. Something has been put into practice, at least for a reasonable time. The political decision to accept exceptions and periodical reductions has weakened the technical requirements.

Drainage problems in India

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1 General

Almost the whole of India is situated in the tropical or sub-tropical region. Most of the rainfall is concentrated in a period of about 3 months of the monsoon season. Figure 1 shows the isohyets of normal annual rainfall and also the boundaries of the various states forming the Federal Union of India. The areas subject to annual flooding and drainage congestion lie in the States of Uttar Pradesh, Bihar, West Bengal, Assam, Orissa and Andhra Pradesh. The annual rainfall in these areas varies between 1000 and 1500 mm. However, vast areas in the Punjab, Haryana and parts of Rajasthan also suffer from surface drainage problems due to the flat terrain and inadequacy of natural drainage, even though the annual rainfall is somewhat lower than 1000 mm. Areas in the flat plateaus of Madhya Pradesh also suffer occasionally from drainage congestion during spells of heavy monsoon rain lasting for 2 or 3 days.

The development of flood control and drainage in India started on a big scale only after the disastrous floods of 1954. Since then a total length of 26 119 km of drainage channels have been constructed in various States upto March 1985. Table 1 shows the progress of physical works in flood protection and drainage completed upto March 1985. The National Commission on Floods assessed that a total area of about 40 million ha is liable to floods and drainage congestion. Out of this, it was estimated that only about 80% or 32 million ha could be afforded reasonable protection. From Table 1 it will be seen that, upto March 1985, about 13 million ha is benefitted by flood protection and drainage measures. Separate figures for drainage are not available.

2 Waterlogging and salinization

The largest areas provided with surface drainage are located in the Punjab and Haryana in northern India. This is due to the fact that the natural drainage was most deficient in these States. Also these States contain the largest percentage of irrigated areas. Irrigation in the last few decades has led to a steady rise of the watertable, and to counteract this, an extensive programme was started to minimize groundwater recharge by improving surface drainage, lining canals and distributaries, and more recently, tertiary canals and watercourses. Figure 2 shows waterlogged areas, where the watertable is within one metre from the ground surface. Watertable contours of 3 metres and 6 metres are also shown in Figure 2. These areas in the States of Punjab, Haryana and Rajasthan can become affected by waterlogging and soil salinization, if remedial measures are not taken in time.

In the northern parts of Punjab and Haryana, the groundwater is fresh. In these areas, the increased abstraction from wells has kept the watertable under control. On the other hand, in the irrigated areas of Rajasthan and adjoining southwestern parts of Punjab and Haryana, the rainfall is low. The groundwater is brackish to saline in these areas.

Figure 3 shows the electrical conductivity (EC) of the groundwater expressed in micromhos per centimetre. Generally water with an EC value less than 2000 micromhos/cm is considered fresh and suitable for irrigation. Brackish water (EC between 2000 and 4000 micromhos/cm) is marginally usable. Water with an EC value greater than 4000 micromhos/cm is considered unsuitable for irrigation. Only the shallowest portions of groundwater are fresh and the EC value increases with depth. Extending

Table 1 Progress of physical works completed up to March, 1985

State/Union Territory	Length of embankments (km)	Length of drainage channels (km)	Town protection works (no's)	Villages raised (no's)	Area benefitted (in lakh ha)*
Andhra Pradesh	478	9400	15	21	9.93
Assam	4405	799	60	–	15.28
Bihar	2720	365	47	–	18.44
Gujarat	408	271	29	30	4.30
Haryana	556	3079	–	90	16.21
Himachal Pradesh	58	11	–	–	0.09
Jamnu & Kashmir	46	10	6	–	0.58
Karnataka	–	–	–	–	0.02
Kerala	82	12	3	6	0.24
Madhya Pradesh	13	–	29	–	0.02
Maharashtra	26	–	23	–	0.01
Manipur	273	76	1	1	0.80
Meghalaya	102	–	8	2	0.88
Orissa	997	103	13	29	4.53
Punjab	1021	6515	3	–	26.49
Rajasthan	140	170	16	–	0.40
Sikkim	–	–	2	–	–
Tamil Nadu	8	19	–	–	0.83
Tripura	103	94	10	–	0.27
Uttar Pradesh	1666	3429	64	4511	13.67
West Bengal	910	1284	44	–	16.22
Delhi	83	453	–	–	0.78
Goa, Daman & Diu	8	10	2	6	–
Pondicherry	59	19	–	–	0.07
Total	14162	26119	375	4696	130.06

* 1 lakh ha = 100 000 ha

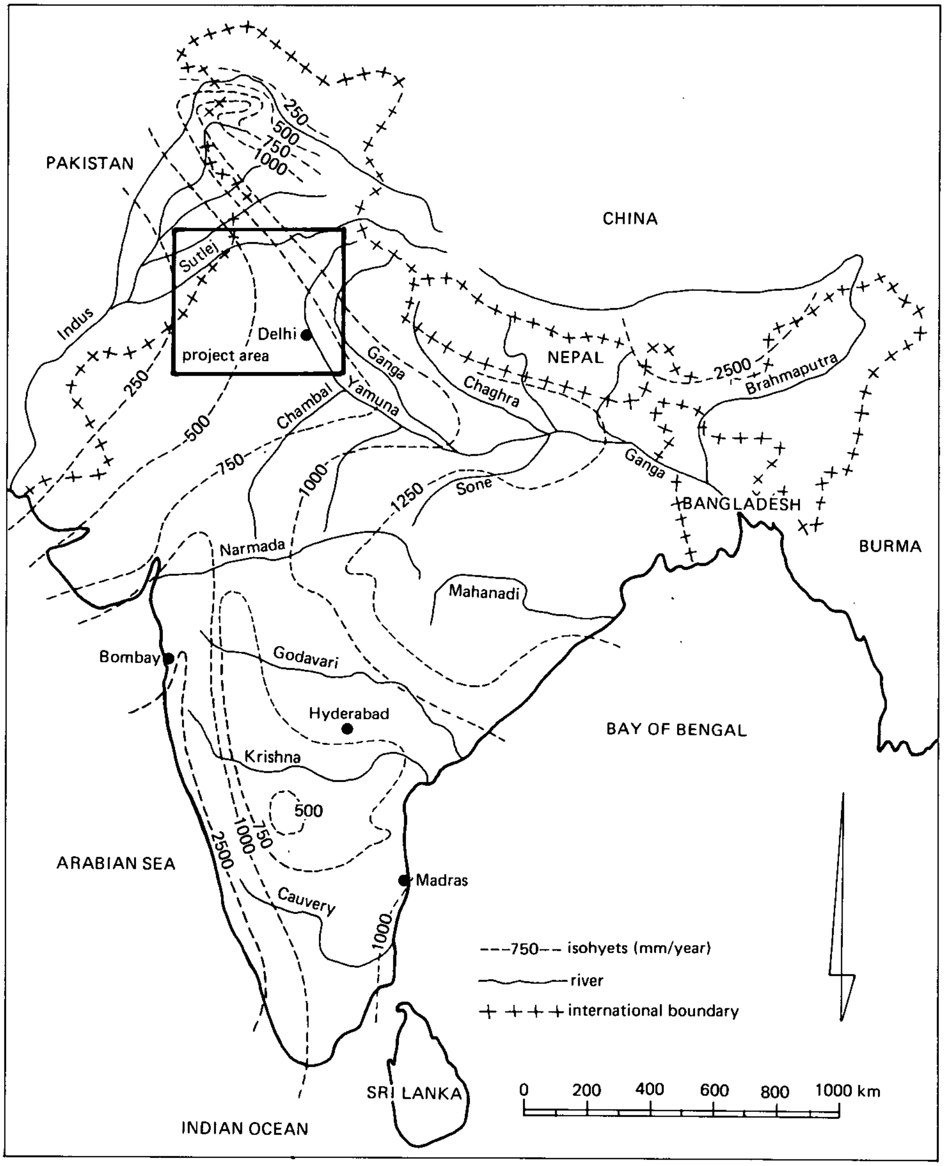

Figure 1 Mean annual rainfall in India

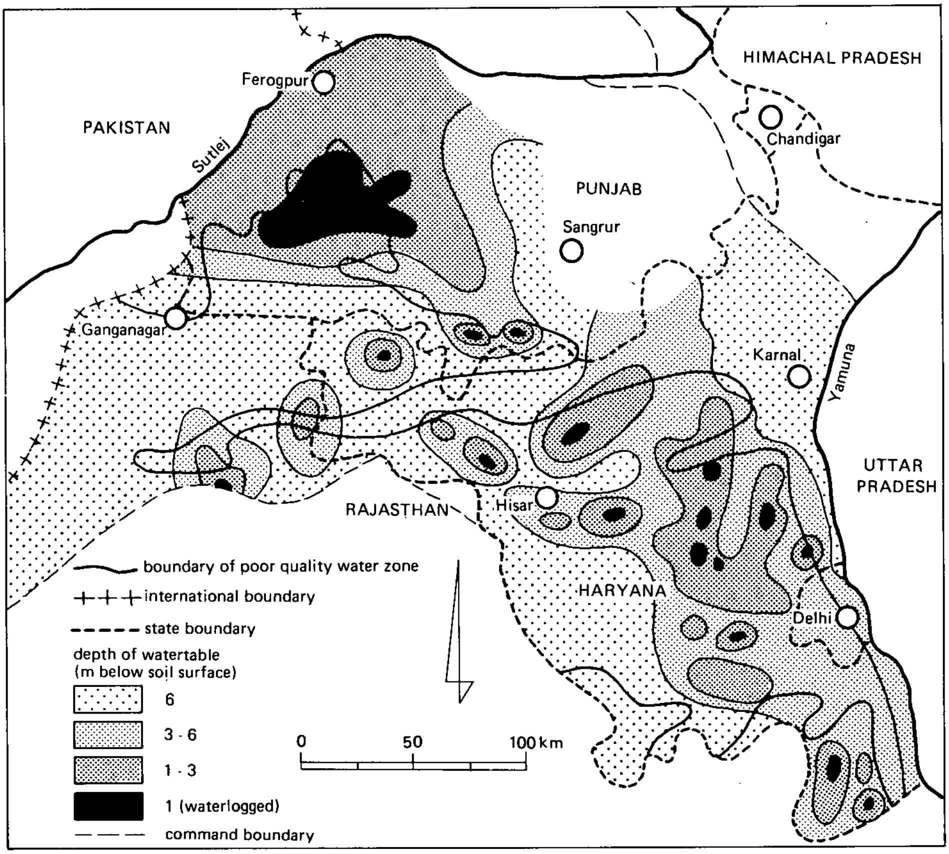

Figure 2 Waterlogged and critical areas in Punjab and Haryana

the irrigated area, the abstraction of the brackish groundwater by irrigation wells, diminished or stopped almost entirely. Thus, because of the introduction of irrigation in these areas, the watertable started rising, causing waterlogging and salinization problems. In some areas there has been a shift from cotton cultivation to rice crops. Subsurface drainage has so far not been installed, except experimentally, because of the high cost involved in relation to the value of crops produced.

A considerable length of drainage channels has been constructed in the State of Andhra Pradesh especially to speed up drainage of the areas around Colleru lake in the Krishna-Godavari delta. In the Sunderbans area of the Ganga river delta in West Bengal State, there are numerous estuaries subject to tidal action. The saucer-shaped land between the tidal creeks has been reclaimed by constructing embankments. Sluice gates and connecting link channels have been constructed to facilitate drainage during periods of low tide. Although drainage by gravity is slow, pumping is rarely resorted

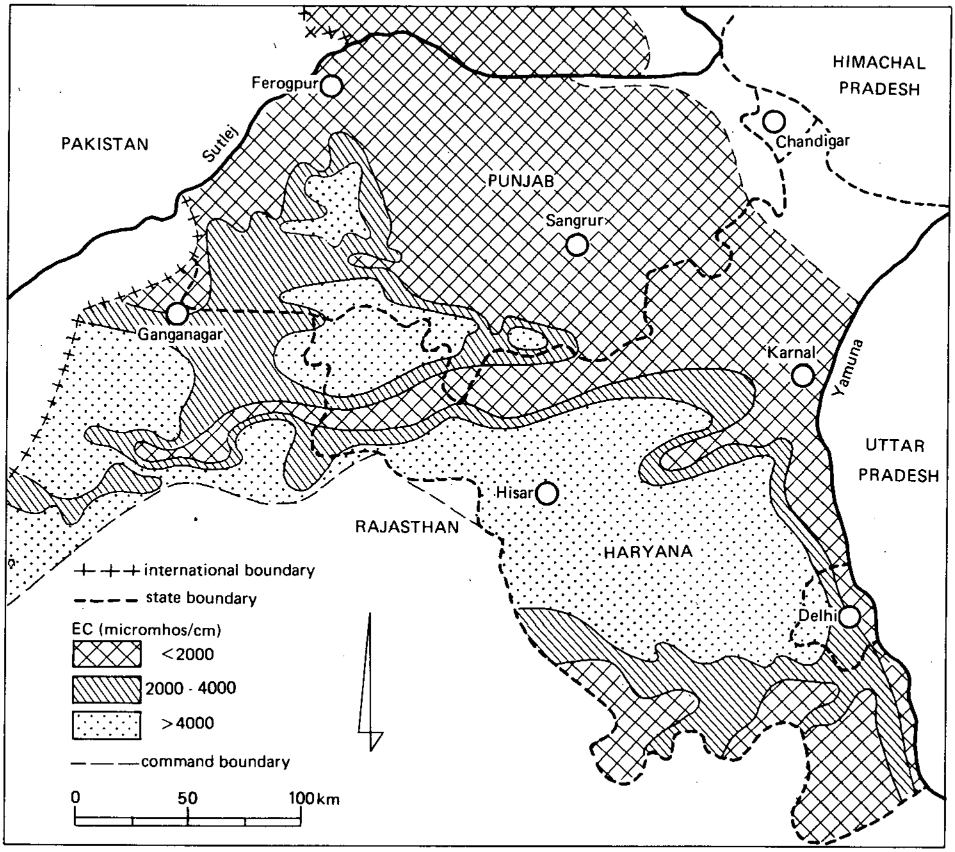

Figure 3 Groundwater quality in Punjab and Haryana

to. Subsurface drainage is not installed, because it is not required during the paddy growing season, and during the dry season, a second crop cannot be grown because of the shortage of fresh water for irrigation. Salinization does not seem to be much of a problem. However, salinization is a problem in the low-lying semi-arid areas along the Saurashtra coast in the State of Gujarat in western India.

3 Run-off

Areas where surface drainage is a problem is the Mokamah Tal area in Bihar State where run-off from upland areas remains locked up for several months because of high flood levels in the Ganga river at the outfall of the natural streams draining the area. Other areas, where drainage congestion occurs, is on the country side of flood protection embankments, such as along the Kosi river in northern Bihar. Here, sediment deposition on the berms of the embanked river tends to choke up the existing outfalls of streams draining the areas, protected by the embankments. Long drainage channels, running parallel to the embankments, have therefore to be constructed on a flatter slope to reach a suitable outfall point downstream, which is above the river flood levels. Even so, there is lockage of drainage during periods of high floods in the river. Similarly there is drainage congestion near the confluence of tributaries with the main river, especially where both are embanked. Other areas of drainage congestion are so-called 'chaurs', which are ox-bow lakes along abandoned courses of alluvial rivers, especially in northern Bihar.

Sometimes inter-state problems have arisen in the drainage of low-lying areas in some of the northern States like Punjab, Haryana, Rajasthan, Uttar Pradesh and the Union Territory of Delhi. Sometimes the upstream riparian States have constructed artificial drainage channels or improved natural drains, and consequently flood run-off from these areas has exceeded the discharging capacity of existing natural or artificial drains in the downstream riparian States. In such cases, there are difficulties and delays in arriving at amicable solutions regarding the design features of an integrated drainage system and/or the liability for the cost. Sometimes, difficulties also arise in bearing the cost of improvement of cross-drainage works in roads and railway lines intersecting the drainage lines.

4 Design criteria

Because of large variations in the frequencies of high intensity long duration storms, in topography, in soil characteristics, and in nature of crops grown, different practices have developed in various States in the design criteria for drains. Many of these are based on recommendations of Technical Committees set up by State Governments in the past. Brief details are given below:

- The Reddy Committee, Delhi (1953), recommended that rural drains in Delhi be designed for 0.10 $m^3/sec.km^2$ (10 $cusecs/mile^2$) which could be the run-off from a 3-day storm rainfall of 5 years frequency to be drained in three days assuming a run-off coefficient of 15%;
- The West Bengal Flood Enquiry Committee (1959) also considered a 3-day rainfall of 5 years frequency, but increased the period of disposal to 14 days, as the main crop during the monsoon season is paddy which can withstand longer submergence. The Committee recommended a net run-off of 19 mm (3/4 inch) per day for deltaic rural areas, 38 mm ($1^1/_2$ inch) per day for semi-urban areas and agricultural areas having steep slopes, and a still higher index of 76 mm to 114 mm (3 to 4 inches) per day for urban areas. For the design of cross-drainage structures the Committee recommended 25% higher discharges. The run-off index of 19 mm (3/4 inch) per day corresponds roughly to 0.22 $m^3/sec.km^2$ (about 20 $cusecs/mile^2$);
- The North Bihar Drainage Committee (1967) recommended the disposal of a 3-day maximum rainfall of 15 years return period in a period of 10 days. This works out to 0.10 $m^3/sec.km^2$ (10 $cusecs/mile^2$). In the case of masonry structures the design

discharge recommended by the Committee was based on a 3-day rainfall of 50 years return period to be drained in 10 days, which works out to 0.20 $m^3/sec.km^2$ (18 cusecs/mile²);

- The Indian Standard Guidelines for planning and design of surface drains (IS-8835-1978) recommends that run-off from a 3-day storm rainfall should be disposed of in a period depending on the tolerance of individual crops as indicated below:
  - Paddy — 7 to 10 days
  - Maize, bajra (millets) and other similar crops — 3 days
  - Sugarcane and bananas — 7 days
  - Cotton — 3 days
  - Vegetables — 1 day;
- The following run-off coefficients were recommended for plain areas with different soils:
  - Loam, lightly cultivated or covered — 0.40
  - Loam, largely cultivated and suburbs with gardens, lawns, macadamized roads — 0.30
  - Sandy soils, light growth — 0.20
  - Parks, lawns, meadows, gardens, cultivated area — 0.05-0.20
  - Plateaus lightly covered — 0.70
  - Clayey soils stiff and bare, and clayey soils lightly covered — 0.55

Cross-drainage structures are to be designed for a 3-day rainfall of 50 years frequency, the time of disposal remaining the same depending on the type of crop. 'In fixing the waterways care should be taken to see that afflux is within the permissible limits'. In India the permissible limit is generally considered as two feet (0.6 m). The drains, which are generally unlined earthen channels are designed by Manning's formula (coefficient of rugosity = 0.025). The full supply level of the drains at their outfall into a river, is kept higher than the dominant flood level, which is defined as that stage of a river which is not exceeded for more than three days at a stretch for 75% of the flood events in a ten year period of record.

5 Construction, cost and maintenance

Generally, manual labour is used for constructing drainage channels. Sometimes for larger drains, draglines are used for excavation as well as desilting of drains. In urban areas, the channels may be lined in order to reduce the land width required. Sometimes the smaller drainage channels in city areas are covered. Generally only link drains and outfall drains into natural rivers or streams are constructed. Tertiary or field drains are rarely constructed.

A rough idea of the cost of flood control and drainage in India can be obtained from Table 2.

The figures for expenditure and area benefitted shown in Table 2 include figures for flood protection embankments, river bank protection, etc. However, the criteria for approval of embankment and drainage schemes are similar, i.e. that the benefit-cost

Table 2 Cost of flood control and drainage in India

Period	Expenditure	Area benefitted	Global cost per ha	
	(millions Rupees)	(million ha)	Rupees(Rs)	U.S. $
1954-56	132	1.00	132	10
1956-61	480	2.24	214	16.5
1961-66	820	2.19	374	29
1966-69	420	0.46	913	70
1969-74	1620	2.15	753	58
1974-77	1791	1.44	1244	96

ratio should exceed 1.5. So the figures of cost per ha may be taken as an indication for the cost of surface drainage projects.

For maintenance of embankments an Expert Committee, set up by the Ministry of Irrigation, recommended in January 1983 the following annual provisions for maintenance of drainage channels:

Discharge upto 5 m^3/sec Rs. 2000/km
Discharge between 5 to 15 m^3/sec Rs. 2500/km
Discharge above 15 m^3/sec Rs. 5000/km

The above rates are applicable for non-tidal channels. In case of channels in tidal areas, these rates are to be increased by 50%.

The construction and maintenance of drainage projects is generally carried out by the Irrigation and Flood Control Departments of State Governments. They have the usual hierarchy with Assistant Engineers at the lowest professional level, supervised by the Executive Engineers, Superintending Engineers and Chief Engineers. The construction is generally done through contractors on the basis of open tenders. Maintenance is generally done departmentally.

The maintenance problems which arise are usually due to insufficient allocation of funds, silting of drains and weed growth. Generally the weed removal and desilting is done manually.

Subsurface drainage has been tried in pilot projects by using tile drains installed in manually excavated trenches. Machinery for laying perforated PVC pipe drains have not yet come into use, because subsurface drainage is generally considered uneconomic in the prevailing agro-economic situation in India.

Land drainage in the Atlantic region of Costa Rica

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1 Introduction

Costa Rica is a small tropical country located in the southern part of Central America with an area of 51 000 km^2 and a population of approximately 2 500 000 inhabitants. It is in between the latitudes 8 and 11 degrees North and the longitudes 82 and 86 degrees West and has borders with the Republic of Nicaragua in the north and with the Republic of Panama in the south-east. Furthermore Costa Rica has a coast-line with the Caribbean Sea in the east, and with the Pacific in the west and south-west.

The climate is predominantly warm (mean annual temperature varies from 28 to 32°C) and humid in the lowlands and coastal areas lower than 500 m above sea level (the Atlantic and Pacific regions), temperate in between 900-1500 m above sea level and cool in the mountainous regions. There is a great variety of microclimates due to the irregularity of the topography in Costa Rica.

Figure 1 shows the mean annual rainfall in Costa Rica, varying between 1000-7000 mm. Mean rainfall values are 1600 mm at the Central plateau, 1900 mm in the Pacific region and 3500 mm in the Atlantic region.

Since colonial times the agricultural activities have been the main source for economic development of the country. The main agricultural products are coffee, sugarcane and rice. In the Atlantic and Pacific humid regions bananas, oil palm, cacao, corn, pineapple and recently tropical and ornamental plants are cultivated.

2 Drainage problems and solutions

According to governmental investigations, Costa Rica has extensive areas with very good soils, although some areas have drainage problems. It has been estimated that in the Atlantic region out of a total area of 300 000 ha with drainage and flood control problems (temporary, seasonal, or permanent), an area of 250 000 ha with high agricultural potential could be reclaimed by drainage and flood control measures. At the moment, in spite of the almost uniform rainfall distribution except in critical periods with more than 400 mm per month, these areas are hardly used for agricultural purposes.

The development of the areas in the Atlantic region is mostly initiated by private companies, who are introducing drainage and flood control measures. They built dikes and cleared waterways near the plantations together with land smoothing. Results were not always positive, sometimes even negative. Flash floods during the wet season in the sediment-loaded rivers with small hydraulic cross-sections caused flooding and as a consequence high groundwater levels in the plantations.

In recent years the banana production of Standard Fruit Company and some others has increased considerably due to the introduction of subsurface drainage systems, especially in areas with medium and coarse textured soils where pipe drains were installed. Corrugated pipes (Rib-loc and ADS) have been used. In sandy or silty textured soils, the pipe drains were mostly prewrapped with a spun bounded nylon filter. The high hydraulic conductivity values of these soils in the banana plantations are an advantage for the proper functioning of the installed subsurface drains (see Table 1).

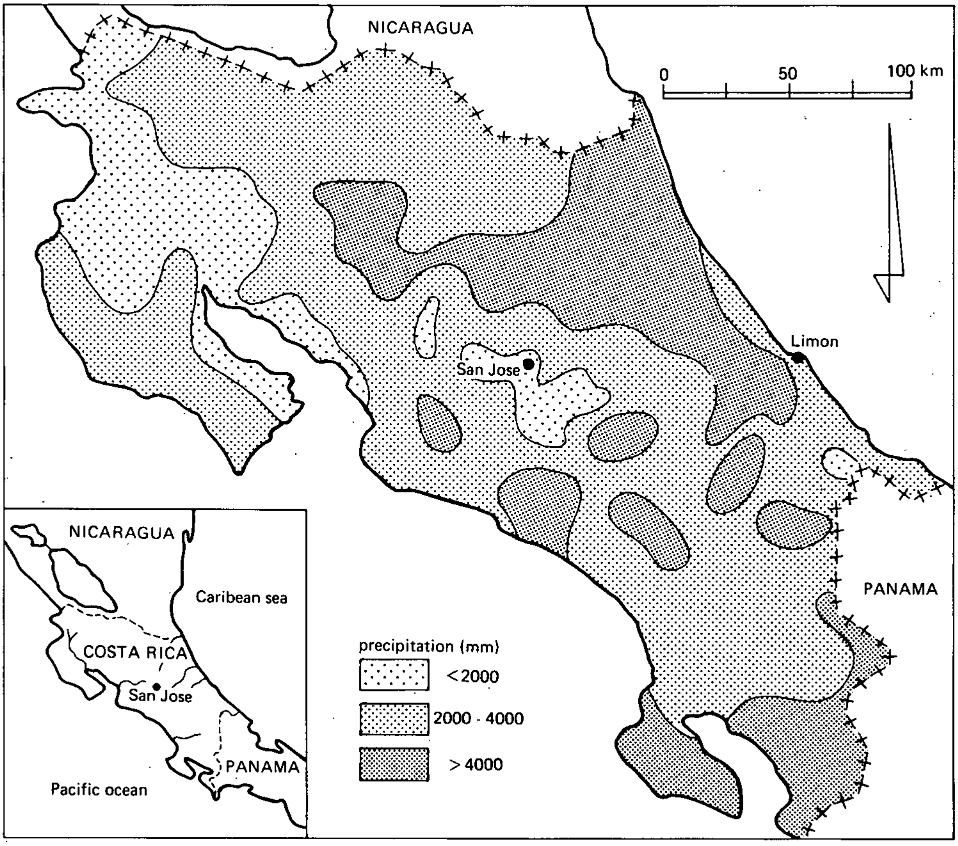

Figure 1 Mean annual rainfall inCosta Rica

Table 1 Hydraulic conductivity values of soils in different areas of La Estrella Valle, Limon, Costa Rica

Place	K(m/d)	Place	K(m/d)	Place	K(m/d)	Place	K(m/d)
M-8	9.39	N-3-1	4.09	0-1-1	16.70	Q-1-3	8.45
M-9	15.96	N-3-2	16.74	0-1	7.71	Q-1-3	8.84
M-10	11.63					Q-1-4	16.48
M-11	20.15						
M-25	12.70						
M-26	15.65						
M-27	17.00						

(Source: Fernandez and Aguilar, 1981)

Some of the general criteria used in the design of these drainage systems are:
- The watertable must decrease to a depth of 1.10-1.20 m in 24 hours;
- The formulas to calculate the drain spacing are the Hooghoudt formula for homogeneous soils and the Ernst formula for stratified soils;
- The drainage coefficient is 60-70 mm/day, which value is derived from a 3-day average rainfall of 100-125 mm/day for a return period of 5 years. These intensities are in general smaller than the soil infiltration values in these plantations (5-15 cm/hour).

The reliability of the above described drainage design criteria has been evaluated by measuring watertable levels and drain discharges. The hydraulic conductivity values elaborated by this method were similar or higher than the values previously determined by applying the auger-hole method.

The construction of the pipe drainage systems is done manually to avoid damages within the plantations. Machinery is only used for digging of the collectors and main drains.

The main steps during the construction of the pipe drains are:
- Surveying and levelling of the pipe lines in the field;
- Installation of wooden stakes at every 20 m of the pipe line indicating the respective cuts for control of the trench bottom slope (3-4%);
- Man-made excavation of the trench to the required depth;
- Installation of the drain pipes at the trench bottom, sometimes a filtermaterial is placed in an extra operation;
- Backfill of the trench with the excavated soil.

Careful supervision is needed during the whole construction period.

The drain spacing varies between 20-45 m, while the mean drain depth ranges from 1.2-1.8 m and the maximum pipe line length is more than 300 m (see Figure 2). A jetting nozzle is used for cleaning these pipe drains.

With an average total pipe line length of 300-400 m per ha, the average cost of these pipe drainage systems amounts to US$ 1200-1500/ha including open drains, pipes, filtermaterial, etc.

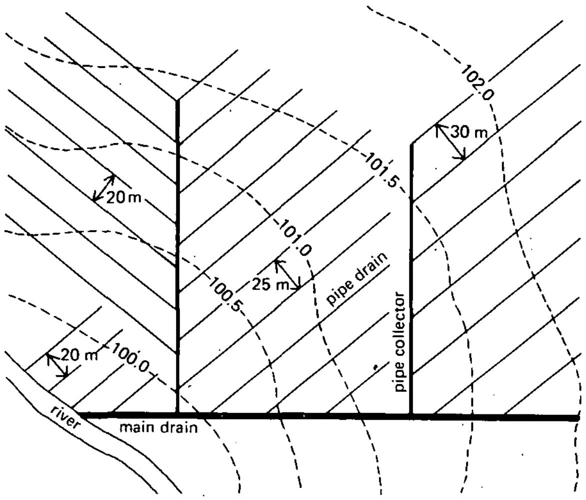

Figure 2 Typical lay-out of a subsurface drainage system in a banana plantation in the Atlantic region of Costa Rica

3 Other drainage programmes

The Costa Rican government policy is to stimulate these types of projects for improving agricultural production. The aims of these projects are:
- To reactivate agricultural production in the country;
- To increase national production levels and to create jobs for the population in the Atlantic region of Costa Rica.

Some of the main actions to attain these purposes are:
- The creation of the National Service of Groundwater, Irrigation and Land Drainage (SENARA) in 1983 to give an impulse to the farming development in the country through drainage, irrigation and flood control;
- The National Development Plan 1982-86 gave priority to the farming sector, setting the basis for adequate watershed management for flood control in the Atlantic region;
- A technical cooperation programme signed with the government of Japan in May 1985.

Due to these actions the Costa Rican government, represented by SENARA, and the government of Japan, represented by the Japan International Cooperation Agency (JICA), signed an agreement in order to obtain technical assistance for an agricultural development project in the northeastern part of the Atlantic region. This agreement considers the study and development of three watersheds along the rivers Reventazon, Pacuare and Chirripo covering a total area of 64 000 ha (pilot areas). It also considers the establishment of a pilot watershed to be used as an experimental and demonstration area.

The criteria for the selection of the three watersheds were:
- Good agricultural soils;
- Good accessibility to the main population centers.

The estimated cost for the development of the pilot areas and the feasibility studies in the pilot watershed is US$ 300 000 and 700 000 respectively. The agreement sets a tentative 20-months period for the field work and 23-months for the final results.

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Aspects of design, construction, and operation and maintenance of lowland development in Indonesia

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1 General introduction

1.1 Historical background

Increasing population and tremendous pressure on land resources in Java, Bali and Lombok has moved the Government of Indonesia to settle unoccupied areas in the other islands, mainly Sumatera, Kalimantan and Irian Jaya.

The transmigration programme has an important role to play in the agricultural development of Indonesia. Agriculture provides employment for more than half of the working population and is the source of almost one third of the country's gross domestic product (GDP). It is of prime importance to nearly 80% of the population in the rural areas. Self-sufficiency in rice, which was achieved around 1982 can only be guaranteed in future if the production rises to meet the increased demand. Because of its agricultural potential, attention has increasingly turned to coastal swampland in Sumatera, Kalimantan and Irian Jaya to support this agricultural development.

Historically, coastal and near coastal swampland along tidal river estuaries in Sumatera and Kalimantan has attracted migrating Banjarese from South Kalimantan and Buginese from South Sulawesi, who have spontaneously reclaimed an area of more than 300 000 ha by digging shallow canals slightly above low tides, perpendicular to the rivers. Through these canals adjacent land can be drained and sometimes irrigated. This has enabled settlers to grow rice, vegetables, and a variety of other food and tree crops. Planned swampland reclamation began by the Dutch as early as 1939 at Purwosari near Banjarmasin in South Kalimantan, followed in the 1950's and early 1960's by six small government-sponsored projects in South and West Kalimantan. But it was only during its first five year programme, Repelita I 1969-73, that the Government of Indonesia began reclaiming large areas, penetrating inland from coastal rivers.

Two universities – University of Gajah Mada, Yogyakarta, (UGM) and Institute of Technology, Bandung (ITB) – were enrolled to assist in designing the reclamation projects, and each followed a distinct design pattern. UGM designing projects for Kalimantan, employed a 'herring-bone' or fork-like lay-out of canals with reservoirs at their ends (to flush out toxic water from the canal system during low tides) whereas ITB, designing projects for South Sumatera, employed a rectangular grid lay-out of canals without reservoirs.

1.2 Development approach

In formulating the policy aspects of lowland development in Indonesia two development options can be distinguished: a high-cost development option and a low-cost development option which is geared to a quickly maturing project. Each has its own advantages and disadvantages.

The rational, underlying the selection of those two options cannot sufficiently be justified from the view point of budgetary constraints only. If high development costs per ha are acceptable, newly reclaimed land can be developed intensively and sizeable crop surplusses can be anticipated within a few years. This, in turn, will result in high income. If the farm size is geared to a targetted income per ha, the planned farm size can be small and, consequently, a large number of settlers can be accommodated. There is, however, one factor that disturbs this positive picture. As nearly all transmigrants originate from the over-populated islands where they are used to a subsistence economy, they tend to reduce risks which may affect their lives. The optimum use of an intensively developed farm requires a profit oriented mentality. Adapting the farmers' mentality will take a long time, during which the farmer will not be able to develop his land intensively.

Since this option is not compatible with budgetary constraints prevailing in the country, the only remaining option to be adopted is the one of low-cost development. With the low-cost development approach, newly reclaimed land can be developed extensively only and marketable surplusses will materialize later. The subsequent lower return per ha will require large farms to generate reasonable incomes which will be in the neighbourhood of the targetted income. This also fits in with the legal framework, which specifies that the holdings allotted to new settlers, should not be less than 2 ha.

Besides budgetary advantages, low-cost development offers some attractive advantages in future absorption capacity of the projects. Under low-cost development, the productivity of the soil can still be increased in future whenever funds are available for further investment. With this in mind, the area to be developed will still have the capacity to absorb the future generation of farmers.

Under the low-cost development approach, the degree of land reclamation will only allow subsistence agriculture. Other inputs, as organization and agro-supporting services will have to be on a level that guarantees at least this subsistence income. When a new generation of farmers emerges in an area and increased food production is required to sustain the increased population, supporting efforts should be stepped up. At that point the land potential should have been developed to such a level that output can be increased. Additional provisions such as a better water management system, irrigation, low lift pumping, etc. will bring the area to full development. Finally these lowland areas could be developed into polders by closing off rivers or estuaries resulting in the creation of large fresh water basins with multipurpose water management and ample irrigation water supply.

2 Designing infrastructure

2.1 Typical features of the existing hydraulic infrastructure

The existing hydraulic infrastructure in the already reclaimed schemes which were based on the low-cost development approach, have typical features in common. These include a navigation canal and a network of surface drainage canals regulated by tertiary control structures. The canals evacuate excess surface water during the wet season and maintain optimal water levels for the cultivation of rice, while field bunds and structures may prevent harmful overdrainage of peats and of potential acid-sulphate soils during the dry season. Transportation in and out of the area is served by navigation canals. Manually excavated tertiary canals, generally situated along the boundaries of each farm plot and sized to evacuate excess water from each tertiary, are commonly equipped with a timber stop-log structure to control the water levels.

2.2 Scope and design criteria

The main objective of the lowland development projects is to reclaim and to convert swamps into agricultural land and to settle transmigrants. Design criteria are used to set up the infrastructure which should fit the planned superstructure and should not jeopardize upgrading measures which might be implemented in future, such as irrigation facilities.

2.2.1 Design criteria

Criteria used as the basis for designing the hydraulic infrastructure and the related superstructure were set as follows:

a. Rice cultivation requirements are:
   - Water level: 10-15 cm above field level during the first 6 weeks after transplanting, thereafter up to 25 cm above field level;
   - Drainage: No submergence of plants for more than 3 consecutive days, thereafter the water level is to be brought back to the desired level within 3 days;
   - Salinity: No flooding with saline water is permitted. The conductivity of the soil should be kept as low as possible; an EC of 8 mS/cm already gives a yield reduction of 50%;
   - Acidity: Acidity formation must be controlled and acid must timely be removed from the rootzone.

b. Home-garden crop requirements are:
   - Drainage: The groundwater level should be kept at 50 cm below field level. The upper 40-60 cm of the soil must be well aerated. No waterlogging except for very short periods;

- Salinity: Intrusion of saline water must be prevented. An EC of 8 mS/cm already gives a yield reduction of more than 50%;
- Acidity: Acids must timely be removed from the rootzone.

c. Superstructure and transport:

The main features of the recommended settlement pattern are:
- Habitation zones arranged in strips along a major road or a primary drain;
- Groups of 20 to 40 farmers, living near each other, as the basic settlement unit (called a hamlet), in which a leadership pattern can develop;
- A maximum distance of 2 km between the farmer's house and the farthest land parcel assigned to him;
- Areas of living should be protected against floods and be properly drained.

The transport requirements are:
- Drainage canals connecting hamlets with the main rivers should allow for navigation with 3 tonnes barges. The dimensions of the barges have to be: width 1.7-2.0 m, draft 0.5-0.6 m, while navigation during 12 hrs per day is deemed sufficient. Therefore, the bottom level of the above mentioned drainage canals should be one metre below the lowest mean water level, and the bottom width should be two metres;
- The rice fields and homesteads should be approachable through small dirt-roads accessible for pedestrians and small carts.

2.2.2 Lay-out of canal network and hamlet area

a. Unit concept

As topographical and soil conditions are similar over large areas in tidal lands, applying standarized lay-outs seems to be possible. The use of standard lay-outs will save on time required for the design work, and it has therefore been incorporated in the approach for the projects under review. Three successive units are distinguished, viz. primary, secondary, and tertiary units.

The primary unit is the largest one, and consists of the area drained by one primary canal. Along the primary canal hamlets are protected stripwise, the rice fields are located behind the hamlets. Each primary unit is divided into a number of tertiary units.

Each tertiary unit generally comprises of 16 rice fields drained by a tertiary canal, and 16 home-yards which together constitute half of a hamlet. In between rice fields and home-yards a collector canal is envisaged, separating two zones with different modes of water management viz. high water levels in the rice fields and low water levels in the home-yards.

At regular intervals, the collector canal debouches into the primary canal via a secondary canal, projected in between two hamlets. Six tertiary units are combined into a secondary unit, drained by a secondary canal.

b. Taylor made lay-out

The standard lay-out can be applied in large, relatively flat areas, allowing the tertiary canals to run horizontally or at a slight downwards slope towards the collector. In general, the maximum allowable difference in (average) field level within one unit is set at 25 cm, provided that the lower-lying fields are located at the downstream end of the tertiary canal. If not, such differences should only incidentally occur and never be more than approx. 10-15 cm.

As example, the following conditions may compel deviations from the standard lay-out:

- Occurrence of a general pattern of valleys and ridges, tortuous configuration of the contour lines, more or less following the meandering course of the main river, but no pronounced field level slope yet. Here, especially if a primary canal near the main river happens to be located on a ridge, the tertiary canals should be projected parallel to the contour lines, resulting in herring-bone lay-outs for the primary unit. Adjustments are to be made when two consecutive tertiary canals are not parallel;
- As above, with a pronounced slope of the fieldlevel. Here the tertiary canals should more or less follow the contour lines which may sometimes even result in bend tertiaries;
- Occurrence of small enclosed valleys (or ridges). If such a valley coincides with the standard location of the collector canal, the collector can be shifted to the lowest point of the secondary unit;
- If locally pronounced slopes occur, the tertiary unit can be split into several independent subunits by some extra tertiary structures.

A standard hamlet area accommodates the home-yards of one or two tertiary units. Drainage of the hamlet is accomplished by a number of parallel drains at intervals of about 40 m or less. They are perpendicular to the primary drain and are intercepted by the main hamlet drain, projected along the primary road on the hamlet side, which debouches via a structure into the secondary drain. This is the first step. Thereafter, detailing of the lay-out (deepening of the drains and digging of extra drains in the home-yards) is supposed to be done by the farmers. Transport is made possible by roads along the hamlet drains. In each hamlet an area of 0.15 ha is reserved for storage and drying of rice. Home-yards are situated in between the hamlet drains.

3 Construction

The lowland development in Indonesia is mainly aimed at agricultural development and the physical reclamation work is dominated by the hydraulic infrastructure which consists mainly of earth works. The reclamation works in lowland development generally start with land clearing of the right of way of major canals, followed by excavation of the main canal network simultaneously with the construction of flood protection dikes of which most material are from the earth disposed off by canal excavations. Next land clearing of agricultural production plots, hamlet/village areas which is done manually together with excavation of the tertiary canals and finally the construction of the civil works such as housing, bridges, jetties etc. Conditions prevailing in tidal lands have a direct bearing on the construction method, the type of equipment and the efficiency of the reclamation works.

The tidal lands are waterlogged and often inundated, while the soils have an extremely low bearing capacity (200 g/cm^2). Pyrites are present in the soil in an irregular pattern and in various concentrations. Tidal lands are covered with vegetation which varies from reeds (very seldom) to heavy forests (more often). The thin layer of (half) ripened topsoil is sensitive to disturbances. By and large a number of adverse factors allow little latitude in the selection of the construction methods. To date, in general the main reclamation works, viz. embankments, clearing of the right of way of the primary and secondary canals, the excavation of all canals except the smallest canals, are done mechanically, since the use of hand labour is precluded in view of the immense size of the reclamation operation, the recruitment and organizational problems of labour due to the remoteness of the project areas and the inhabitated areas. However, to avoid disturbances of the topsoil in the agricultural production areas, these plots are carefully cleared by hand labour, even though the large number of labourers involved. Soil conditions hardly influence capacities of hand clearing, but vegetation does, as can be seen in Table 1.

Table 1 Clearing capacity by hand and chain saw

Vegetation	Requirement in hours/ha	
	Manual labour	Chain saw
Bush	500	15
Light swamp forest	100	35
Heavy swamp forest	500	45

As mentioned above, the paramount characteristic of the tidal lands is the low bearing capacity of the soils. The selection of equipment type for reclamation works is basically a balance between bearing capacity of the soil and the capacity of the equipment. Up to present, there is no special equipment which has been used for reclamation work. Types of equipment which are commonly used are hydraulic excavator and cutter dredger. However, the use of cutter dredger for the construction of major canals is not recommended because of the risk that potential acid clays from the underground flow over the future agricultural areas, which upon oxidation will acidify the topsoil. This will render them unsuitable for agriculture for a certain span of time. Dragline excavators are hardly used due to the shortage of well trained operators. Excavation in the dry is precluded owing to the difficulty of dewatering due to the high permeability of the soil (transmissivity (KD) of unripe clay soil is between 2000 and 4000 m^2/day).

The main problem in the construction stage is coupled with non-technical aspects such as the remoteness of the areas which raise difficulties in mobilizing equipment, logistics and labourers; the environmental conditions of the areas which are originally not suitable for human life in respect of poor accessibility, covered by forest, potential diseases, poor quality of water, etc. The construction cost of the hydraulic infrastructure ranges from 300 000 Rupiahs to 500 000 Rupiahs per ha (1 US$ = 1660 Rupiahs).

4 Operation and maintenance

4.1 General background

To maintain the proper functioning of the existing hydraulic infrastructures in the already reclaimed swampland is the prime objective of the operation and maintenance activities which are now being implemented .

To use the terminology of 'project cycle', reclamation projects are initiated from a survey, investigation and design phase (SID), followed thereafter by construction, and operation and maintenance in the end (O & M). SID activities will produce design drawings, where the quality to a certain extent is usually dictated by the degree of accuracy which is determined by factors related to: scale, method of surveys, heterogeneity of natural features to be observed, and assessment of design values. Where it could not be avoided to make some assumptions, just a few are mentioned. With these design drawings, constructions of reclamation works are carried out. To a certain extent, some improvement, corrections or revisions are possible to be worked out during the construction phase. However, the quality of the reclamation works, even if construction supervision is done properly, is strongly influenced by construction methods, type of equipment used and site specific factors.

As is commonly known, swampland in its virgin state often hampers to a certain extent, the desired quality of reclamation works. In addition, it should be mentioned that the knowledge and experience in the field of reclamation works in Indonesia is relatively new, compared to those in experienced countries, e.g. The Netherlands.

All those factors have its own share in contributing to the degree of quality and performance of reclamation works. With this recognition, O & M activities constitute a component in a 'project cycle' which will give feed back, that would in turn improve the process of SID and construction implementation. Then, through such 'sequence', a body of knowledge in swampland reclamation will be established, as an accumulation of the ever increasing local experience.

Given that the objective of reclamation of swampland -which conservatively is said to have marginal potential- is to use it for agriculture and new settlements, with all socio-economic activities of the people to take place on it, then, the complexity of the tasks of the O & M will clearly appear. The productivity of the land and its worthtiness for settlement are taken as yard-sticks for the effectiveness of swampland reclamation. This approach is logical and it implicitely conceives land as a medium of agricultural production and as a medium of human settlement.

The matters mentioned above, will be reflected in the multifacetted and closely interrelated factors as follows: institutions and their management; water users with all their different interests, social traditions, economic background and level of education; an infrastructural network of reclaimed swampland built on the principle of low-cost/low technology; physical constraints which are typical for swampland as water and soil related problems; different farming system which prevails in the area; and in the last, limitations on funds which are available both at central and local government level.

Elsewhere in this paper many aspects mentioned above are described in more detail.

From them, further information concerning the way of thinking of the Government of Indonesia can be obtained.

4.2 Problems and operational policy

Carrying out O & M involves various institutions, each with its own responsibility and authority. The level ranges from central, local, down to the lowest hierarchy of institutions, i.e. the water users organization that exists at village level. The current regulation is that, when a project has been formally completed, the responsibility will be transferred to the local government, while the central government c.q. Ministry of Public Works will give guidance only. The organization of O & M at local level is divided over several hierarchical levels of authority and administrative units. There may certainly be some exceptions, if necessary, considering the area covered. The hierarchical level ranges from province, kabupaten (regency), kecamatan (district) down to village level where water users organizations exist. In reality the ideal one does not have to be a practical one. A large amount of central government involvement is still needed, because of the limited capability of the local government either in funds or in staff. That fact should be admitted as, indeed, the O & M for swampland is relatively new. The current activities of the O & M are just in an intensive initiation phase.

The operational task, which, at this moment means making existing reclaimed schemes functioning, is not a complicated one as the inherent technology is basically simple. Complicated structures like sluices, locks and pumping stations have not been built yet, only some smaller tertiary water management structures, made of timber. Only a few older schemes, constructed in the Dutch period such as Rawa Kurik (Irian Jaya), Metaren Polder (Central Kalimantan), and Alabia Polder (South Kalimantan), have pumping stations and water regulation gates. However, these projects have not given the benefits as expected, since the beneficiaries have not been either willing nor able to adopt such sophisticated and expensive systems.

Meanwhile, the maintenance task is much more complicated since the degradation of the infrastructural network proceeds at a relatively high rate. The high rate is due to two causes. The first is nature induced, resulting in landslides of canal banks, bush growth, and sedimentation of canals. The second is man induced. At this moment, it appears that the second is the major cause. As mentioned above, the skill and motivation of the beneficiaries is influenced by their interests, but also, and this is more decisive, their educational, social and economic background. Also there is a general misconception among them that the maintenance of the canal is the responsibility of the government instead of theirs, even although they realize that the canal network is important to them.

For us, the Government of Indonesia, the development of the country does not merely have physical dimensions, but it also places human components as key factors which have to be developed firstly to ensure that they will consciously and actively participate with all their understanding, motivation and willingness.

Accordingly, the effectiveness of maintenance activities cannot be sufficiently measured in engineering terms only. Awareness of the people, especially they who take direct benefit from the infrastructural network, should be taken into account. In this context, training and extension programs are placed as first priority in carrying out O & M. They will act, as it is expected, as catalysts for development.

Nature induced effects, which deteriorate the canal network as mentioned above, are happening at a relatively intensive rate. This is only normal as the technology applied is still a simple one and the soils in swampland are generally unripened which causes easily slides. Moreover, water regulating structures have not been installed (except at tertiary level) and the extreme behaviour of the flow (discharge, velocity, and water level fluctuations) is not reduced.

O & M as an integral part of the water management system should meet the requirements of the prevailing cultivation activities that are carried out. In this case, nowadays, the effort of optimizing the use of water resources in reclaimed swampland focusses on the tertiary block, in other words on farm level. Within this small hydrological unit, managing the water in order to meet the needs, may be easier and more adequate. The experience shows that, for several reasons, the interests of the farmer are served at best in this way.

In a developed country, such as The Netherlands, O & M is generally funded by beneficiaries through their contributions. It is not so in Indonesia. The funds are provided by either the central or local government and allocated depending on the budget capability, based on current rules and national priorities. However, based on the equality principle, the government allocates funds for O & M to any reclaimed swampland project. That is why, one may understand, the amount of money allocated per unit of reclaimed land is below the amount required.

Land remodelling in Tung Kula Ronghai region of Northeast Thailand

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1 Introduction

This paper describes the background and constraints that have caused the Tung Kula Ronghai (TKR) to be one of the most depressed areas in Thailand, followed by a description of the concept of Land Remodelling, and how this solution is being adopted to overcome many of the natural constraints of this area to provide an improved environment for rice cultivation and reduce the probability of crop loss caused by flooding and droughts.

2 Tung Kula Ronghai and its problems

2.1 General

Tung Kula Ronghai ('Plain of the weeping Kula people') comprises a low-lying area of 3370 km^2 in the centre of the large basin-shaped Korat Plateau of northeastern Thailand (Figure 1). The area had been settled only recently due to population pressure in other areas of the Northeast. The present population amounts to about 400 000 inhabitants (density 120/km^2).

2.2 Topography

The Tung is drained by the Nam Mun river which flows in eastern direction to the Mekong River and a number of smaller tributaries, such as the Lam Sieo Yai, and Lam Tao, flowing through the Tung from north-west to east. Run-off from the upper catchments of these rivers is discharged into the Tung causing frequent and prolonged flooding (Figure 1). In an average flood year significant parts in the Tung, usually strips of 2-5 km wide along these rivers are inundated. The areas between the rivers are extensive alluvial plains with occasional sand ridges which rise to about 20 m. These alluvial plains are extremely flat with little natural relief and very low gradients (average 1:15 000). Therefore direct rainfall on these plains is drained by overland flow (from paddy field to paddy field) for many kilometres causing a very slow evacuation of excess water.

2.3 Climate

The climate of the Northeast is classified as Tropical Savanna type, according to Köppen's Climatic Classification (Griffiths 1978). Three seasons can be distinguished: the rainy season, the winter season (cool) and the summer season (dry and hot) (Meteorology Dept. 1977). These three seasons are influenced by the Southwest and the Northeast monsoons. About 80% of the annual rainfall of 1300 mm falls from May to October. However, the distribution of this rainfall is highly variable. The wet season rice production is adversely affected by dry spell periods of 2-6 weeks which commonly occur in June and July as well as excessive rains in August and September which causes flooding. Evaporation greatly exceeds precipitation from November to April and the temperature rises markedly in March and April. There are no prospects for dry season cropping due to the absence of irrigation water.

2.4 Soils

The soils of the Tung are sandy, and with a low natural fertility. They have a poor waterholding capacity and tend to dry and crack quickly during dry spells if insufficient water is empounded on the fields as a stored supply to last over the dry period. Saliniza-

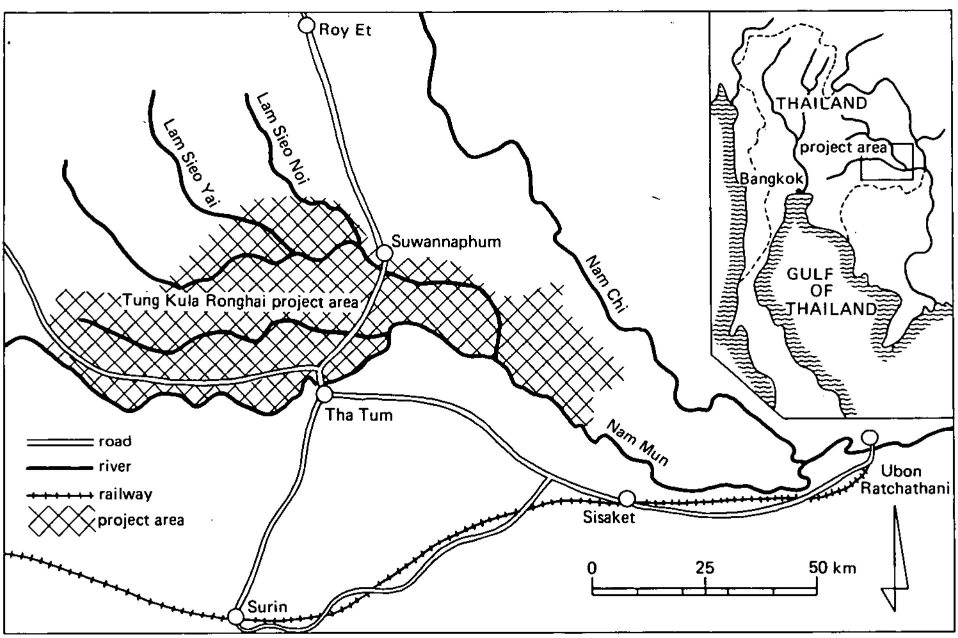

Figure 1 Location of Tung Ronghai area in Thailand

tion is an increasing problem, even for rice production. Therefore improved water control, fertilizers and additional organic matter are of vital importance for improving rice yields.

2.5 Water resources

The water resources of TKR also restrain development. Because of the flat topography there is limited potential for large scale storage of wet season surface flows for dry season irrigation. Quality and quantity of the groundwater is variable and therefore also has limited potential.

2.6 Farming

The dominant farming activity (approximately 80%) in TKR is rainfed wet season rice production on the lowlands. Other activities include fishing, buffalo, cattle, poultry and pig keeping. Average farm size is about 4 ha. The difficult environment inhibits agricultural production and depresses income causing the people in TKR to be among the poorest in Thailand. About 60% of the families relies on off-farm work to supplement their incomes.

3 Project background

Land remodelling is a component of the Thai-Australian Tung Kula Ronghai Project (TATKRP). TATKRP is a multi-component, integrated rural development project funded jointly by the Royal Thai Government and the Australian Development Assistance Bureau (ADAB) which aims to overcome some of the problems and uplift farmers' incomes. Technical assistance is being provided by an Australian consulting firm, McGowan Intern. Pty. Ltd.

Implementation of the land remodelling component has been undertaken by the Engineering Division of the Department of Land Development (DLD) of the Ministry of Agriculture and Co-operatives. Construction started in 1983 and in its present 5 year phase the project is regarded as a pilot implementation project aimed at researching and refining the appropriate techniques. A total of 12000 ha will be constructed during this phase which is only 10% of the potential land remodellable area in TKR. This phase is scheduled to be completed in 1989 after which the rate of development is expected to accelerate.

4 Land remodelling concept and benefits

Land remodelling is a system of controlled drainage to improve in general the environment for wet season rice cultivation and more specifically, it aims to reduce the probability of crop loss caused by flooding and drought.

It consists of the construction of a network of drains to improve the drainage capability of the area. These drains are provided with check structures designed and located in such a way to prevent overdrainage, while at the same time they allow the controlled passage of flood water. The check structures also provide water storage for supplementary irrigation. This concept can be applied to poorly drained alluvial plains where slopes are flatter than 1:10 000.

The operation of the system can be illustrated by comparing rainfall distribution and crop water requirements (Figure 2). Some remarks are:

- The volume of water stored for irrigation is limited but is sufficient to at least ensure supplies for rice nurseries which occupy only 5 to 7% of the cultivated area. Water shortages normally coincide with the nursery stage of the rice crop;
- The drainage facilities provide flood mitigation due to faster evacuation of direct rainfall on the alluvial plains but do not protect against flooding from the rivers. The development is generally confined to areas above the influence of the 1 in 5 year river floods.

Figure 3 shows the estimated crop yield benefits expected from the improved water management capabilities provided by the land remodelling system. It is based on an

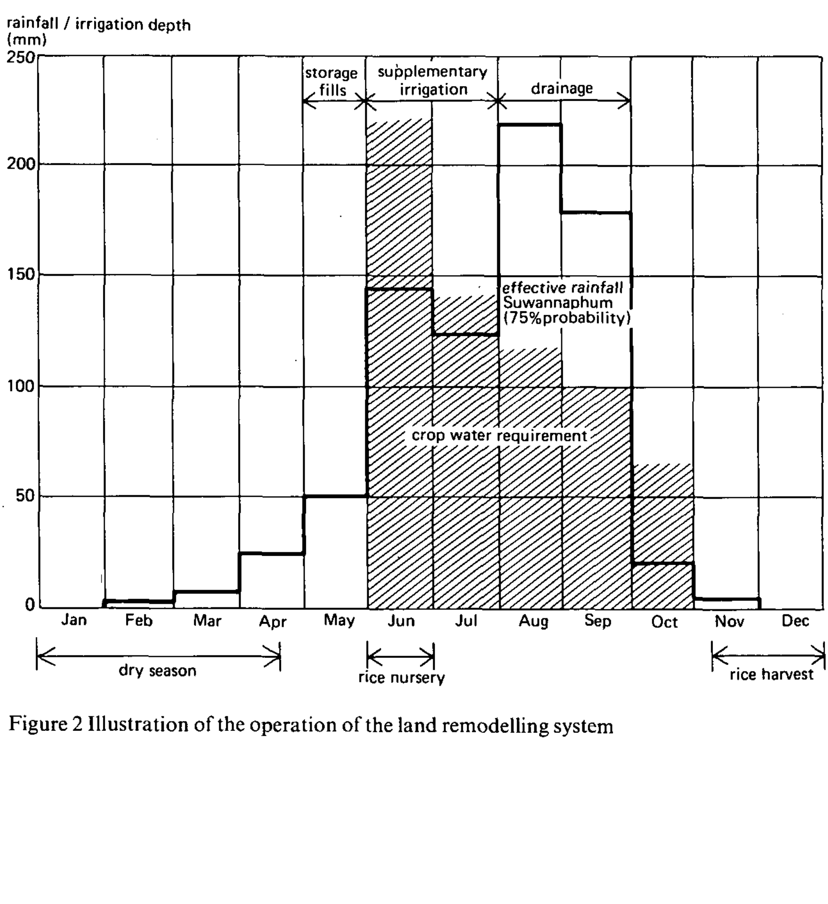

Figure 2 Illustration of the operation of the land remodelling system

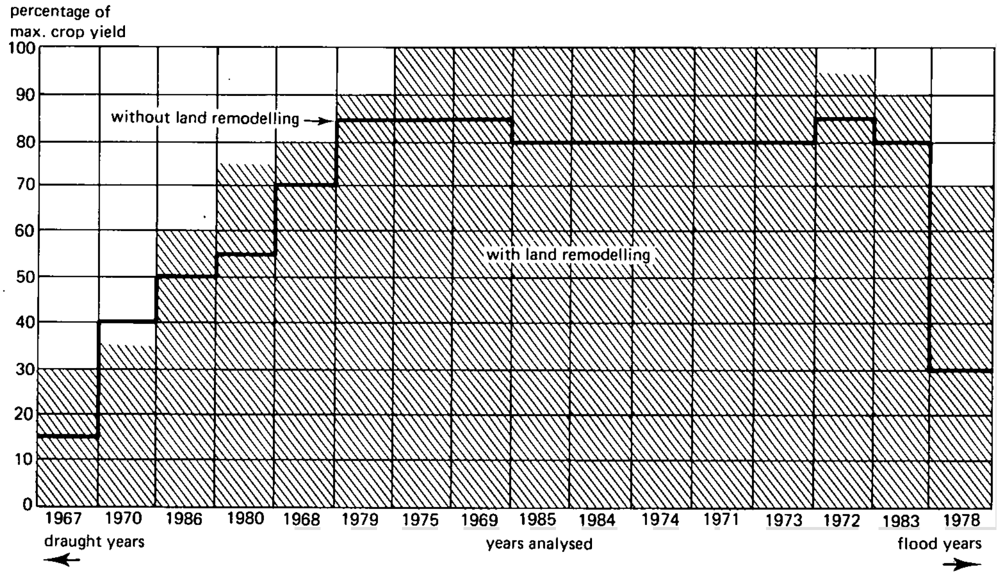

Figure 3 Estimated crop yield benefits from land remodelling
Note: 100% crop yield indicates that the crop did not suffer from either flooding or water deficit

analysis of the field moisture conditions during the cropping season which were simulated from historical daily rainfall occurrences. Also it takes into account the systems ability to provide supplementary irrigation when there is a water deficit or to drain adequately fields when there is excess water. It was assumed that there will be a 100% crop yield when the crop does not suffer from either water deficit or excessive flooding. Although land remodelling development is expected to improve crop yield in other ways too (e.g. more crop inputs, better farming practices, etc.), these are not included in the estimated crop yield benefits. From improved water management alone, average crop yields are expected to increase by about 20%.

Land remodelling also provides a number of additional benefits. The most significant of these is the provision of access into the rice growing areas. Wherever a drain is constructed the excavated soil is used to construct a farm road. While the benefits of the improved drainage are only enjoyed in years of flooding, the benefits of the farm roads can be noticed every year. These roads make it possible for farmers to enter the areas during the wet season with fertilizer, machinery and labour which is impossible without land remodelling development. Farmers normally live away from their farms in villages or towns and commute. At present farms are better attended because it is more convenient for farmers to commute daily by bicycle or vehicle whereas before it meant a long walk. There is also an increasing tendency to construct houses on the farm. Further benefits are derived from the expanded fish habitat and the drains provide a route for fish to enter the ricefields where they can breed and grow. A final benefit of the introduction of a network of drains is the possibility to divide rice growing areas into separate definable units which will greatly assist in extension and development assistance provided to the farming communities.

5 Land remodelling design

5.1 Design criteria

Drains are located at approximately 1 km spacing so that every farm is within 500 metres of a drain (and road). A typical cross-section of these drains is shown in Figure 4.

Sizes of the drains and associated structures are selected to allow evacuation of the 1 in 5 year 3-day peak rainfall (200 mm) within 6 days (3.8 l/sec.ha), based on the assumption that the rice plant can generally tolerate flooding up to 6 days without serious yield reduction.

5.2 Lay-out

Lay-out of the drains is determined from a study of cadastral maps, natural land formations, and drainage patterns. Orthophotos of 1:10 000 scale with 0.1 m spot levels are used to assess topographic features. Natural drains, where they exist, are incorporated but lay-out is severely constrained by land ownership boundaries which sometimes reduces the efficiency of the design. However, because of the flatness of the area (level variations generally within 10-20 cm), this is not a serious handicap.

5.3 Cells

The land is divided into units of approximately the same natural land level. These units are called 'cells'. They vary in size from 600-1500 ha depending on the relative flatness of the land. Weirs are constructed at the outfall of each cell and have the crests set at 30 cm below the average field level to prevent overdrainage. Given the

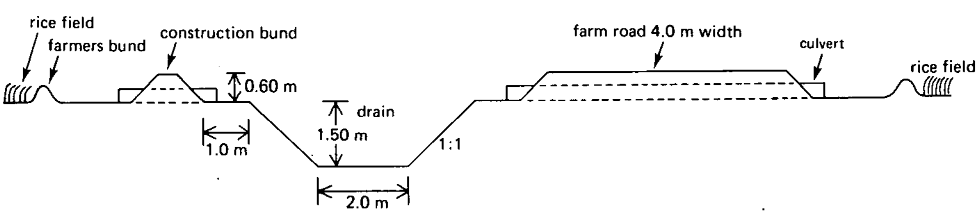

Figure 4 Typical cross-section of drain, farm road and bunds

vastly improved drainage capabilities, it is important to control the rate of outflow to prevent excessive flooding in the downstream cells. The weirs are designed in such a way that they regulate automatically excessive outflows by surcharging to the extent that they impede run-off from the fields. This effects the distribution of flooding at shallower depths over a larger area in a number of cells.

As land remodelling develops within an area, a great number of cells are built up, each at a different level. Each cell passes its drainage water to the cell below it and the lowest cell passes the water to the river system. The system is similar, only on a much larger scale, to what is seen in rice fields where water passes from one field to another field downstream. Naturally, the lower cells require larger drains than the upper cells as they have to carry more water. The cost of cell construction therefore increases downstream towards the rivers. The development within a subcatchment is in an upstream direction.

5.4 Cell systems

In accordance with the process of research intended during the pilot implementation phase of the project, variations in design are being tested. In particular two cell systems with significant conceptual differences are under study at present.
Figure 5 illustrates the different lay-outs of the two systems:

a. Open-cell grid drainage system. This was the first system adopted and this concept is applied in all constructions up till now. All drains within this cell system are interconnected on a grid pattern with escape weirs and equalizing pipes provided at the cell boundaries. The network allows flood water to distribute itself in the cell and find its own level. Water may also enter or leave the cell by weirs and culverts in response to the relative water levels. Due to the low relief in the land surface there may also be flow across subcatchment boundaries. Because the quantities and directions of flow in the drains could not be easily assessed, drains were oversized to offset the lack of detailed knowledge. It became apparent that a more detailed study of the catchments serviced by each drain was necessary to refine designs which led to the development of the 'closed-cell trunk/branch drainage system.
b. Closed-cell trunk/branch drainage system. Present designs adopt this concept. In this system, cells are closed at their boundaries and connected only by a trunk drain running through a series of cells within a defined catchment area. Smaller branch drains enter the trunk drain laterally to drain each isolated cell. In this way the catchment area for each trunk drain can be determined accurately and hence hydraulic design of structures can be refined. This approach has enabled a reduction in drain dimensions and therefore reduced costs.

5.5 Monitoring designs

A data collection network to record water levels and rainfall has been established to monitor hydrological and hydraulic performances of the systems. In this way advantages and disadvantages can be assessed and designs refined accordingly.

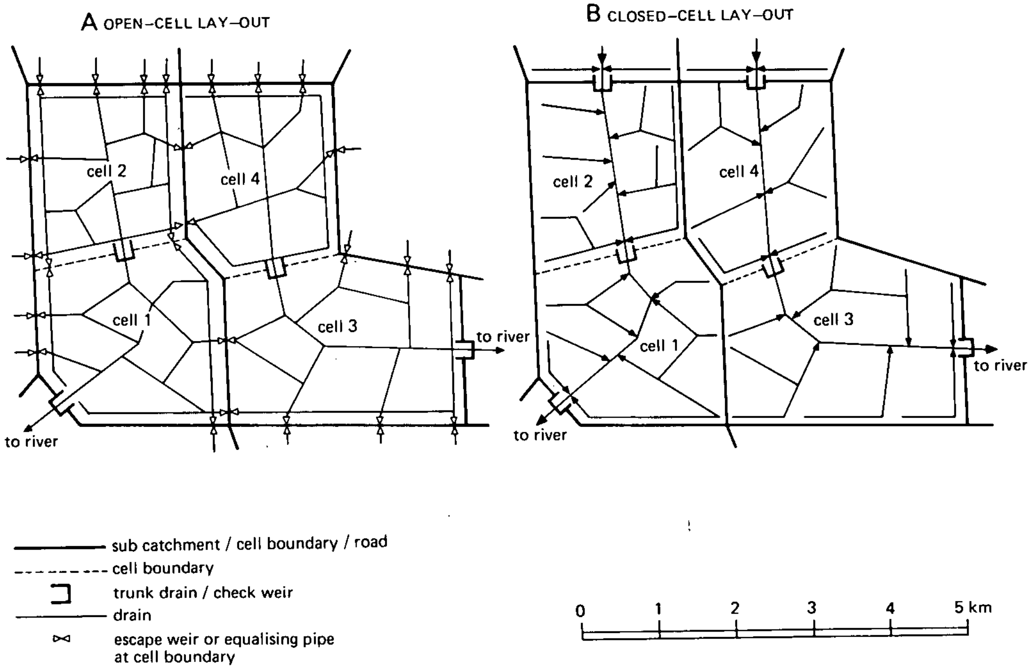

Figure 5 Different lay-outs of cell system

6 Land remodelling construction

Construction of land remodelling can only be carried out during the dry season. This reduces the construction season each year to the period between January and April. The main tool for construction of the drains is a hydraulic excavator which is fitted with a special trapezoidal bucket made to the size of the drains being constructed. With a 100 kW hydraulic excavator it is possible to dig over 500 metres of drain per day. Roads are constructed by trimming the spoil from drains with a bulldozer and compacting the top layer with a sheep-foot roller. Although this provides only a relatively low standard road, they are adequate for normal farm traffic.

7 Land remodelling costs

Construction of land remodelling started in 1983 and at present there are some 5800 ha operational. Average construction cost to date is US$ 200 per ha.

8 Land remodelling extension

Support from other government departments is an integral part of land remodelling development to ensure that maximum benefits are extended to farmers. The Department of Agriculture and Land Development has crop research programmes focussed specifically on land remodelled areas. The Department of Agricultural Extension assists by demonstrating farming techniques which capitalize on the improved water management facilities. The Department of Fisheries is also active in the area studying the effect on fish migration and providing stocks of fingerlings for drains. In addition, the Community Development Department is in the process of identifying community needs and assisting coordination of support groups for scheme management.

9 Conclusion

Results of a baseline socio-economic survey, conducted by Khon Kaen University in December 1985, show that the effects of land remodelling are well accepted by most farmers. Farmers also claim that they have experienced less flooding and that they use the stored water for supplementary irrigation. However, climatic conditions up till now have not been severe enough to demonstrate obvious yield increases. Nevertheless the farming community says that they benefit by the development and that they are especially pleased with the improved access roads and increased fishing opportunities.

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Discussions

Discussions

Discussion of Session 1

Question from Mr. Martínez Beltràn (Spain)
What are the costs of gravel mole drains in comparison with standard mole drains?
Answer of Mr. Galvin (Ireland)
The costs of gravel moles, spaced at 1.50 m, are 900-1300 Irish pounds per ha. The variation is due mainly to the transport costs of the gravel (graded between 20 and 40 mm). The costs of standard mole drains are 500-600 Irish pounds per ha. On experimental sites the capacity of gravel moles is studied. For example in gravel moles, spaced at 1.30 m and having a cross section of 140x70 mm^2 and where collector drains are spaced at 50 m, peak discharge rates of 110 mm/day are recorded. It should be noted that for normal farm drainage, the gravel mole cross section is usually 80x70 mm^2.

Question from Mr. Bhatti (Pakistan)
What is the role of the synthetic sheet below a pipe drain?
Answer of Mr. Mortensen (Denmark)
In unstable soils the pipe drain has to be protected against siltation of soil particles, which could otherwise enter from below. Under our conditions very often a thin synthetic sheet is placed beneath the pipe, with gravel or sawdust on the sides and above the pipe drain.

Question from Mr. Jokhio (Pakistan) and Mr. Abdel-Dayem (Egypt)
Sawdust used as envelope material and its success over time. Does it need more maintenance cost?
Answer of Mr. Mortensen (Denmark)
In Denmark sawdust is very often used as an envelope material for agricultural subsurface drainage. There are very good experiences with the use of conifer sawdust. The sawdust decays with time, but under our conditions there are drains, enveloped with sawdust, which are functioning for over 30-40 years. The use of sawdust as envelope material does not imply more maintenance costs. Ochre formation is a problem in Denmark, but drainage water is purified from iron in special iron extraction plants.

Comment of Mr. van der Molen and Mr. van Someren (The Netherlands)
On the use of organic envelope materials:
In irrigated soils of the (semi-)arid tropics organic envelope materials have usually failed.

Comment of Mr. Henkin (Israel) on ochre control:
The problem of ochre formation occurred in Israel in a marshy soil, in an area south of the Dead Sea. The problem was studied by a micro-biologist, who identified the clogging material as a result of the Leptothrix Desrophorous bacteria. Ochre control

was obtained by creating anaerobic conditions in the drainage system by placing an elbow at the outlet and reducing the slope. This solution was very soon effective (within 1-2 days) and the process seems continuously reversible.

Comment of Mr. Matičič (Yugoslavia) on ochre control:

There are ochre problems in the pseudo-gley soils of Slovenia and Bosnia (Yugoslavia), where trenches were filled with chipped wood as permeable backfill material. These drains didn't function well.

Comment of Mr. Ochs (World Bank) on ochre control:

There is ochre formation in all kinds of soils, especially in peat and muck soils, and in any climate of the USA. Biocides in polyethylene pipes (10% more costly) can be effective, but for how long is this working? Small quantities of biocide have been observed in drainage water, but it decomposes.

Comment of Mr. Csontos (Hungary) on ochre control:

In Hungary ochre formation is a minor problem in clay soils and it only occurs where groundwater contains iron. Plastic pipes are more susceptible to the problem than clay pipes.

Question from Mr. Cavelaars (The Netherlands)

In Table 3 of Mr. Morris' paper drainage performances are given. What are the causes for failure?

Answer of Mr. Morris (Scotland)

A detailed investigation was undertaken at each of the sites where drainage performance was classified as sub-optimal or poor to identify the reasons for this. In more than 50% of the cases the primary reason for drain failure was due to a drain trenchline permeability problem. In approximately 25% of the cases the presence of ochre was the reason for poor drainage. In the remainder cases the cause of failure was due to inadequate design.

Question from Mr. Abdel-Dayem (Egypt)

Are there alternative envelope materials tried instead of gravel to reduce the construction cost?

Answer of Mr. Morris (Scotland)

Because of the high cost of gravel, alternatives to its use have been sought. This has included the use of other naturally occurring materials and industrial waste products. Where there is no local source of gravel or crushed rock, the use of these materials supposes local importance. The use of soil stabilizers on the natural soil as trench backfill has also been examined, but it proved not to be an attractive or viable alternative.

Comment of Mr. Spoor (England)

Alternatives to gravel or stone as a permeable backfill material above pipes in the form of stable clinker and power station waste materials are used and selection usually depends on availability and transport costs. The major aim in schemes where permeable fill is required is to minimize the quantity used. This can be done by minimizing the width of the trench. In schemes where subsoiling and moling operations are to be carried out a minimum trench width of 100 mm is used.

Question from Mr. Feyen (Belgium)
The different contributions from West European countries show a sharp decline in drainage efforts by the governments, but an increase in small scale drainage works and do-it-yourself-drainage practices. Those have, however, a low efficiency. What can be done to protect the farmers from incompetence of drainage contractors?
Answer of Mr. Morris (Scotland)
In Scotland there is no licence nor formal training required for a contractor to construct drainage systems. Most of the work in this area is carried out with backacting equipment, because many Scottish farms already have such a versatile machine for other uses on the farm. Interest has also been expressed by groups of farmers in getting together in a consortium to acquire single purpose drainage machines.

Question from Mr. Smedema (The Netherlands)
Some years ago there was a tendency in going from single systems to composite systems. What is the present situation?
Answer of Mr. Wesseling (The Netherlands)
I do not see the application of composite systems in flat humid regions for two reasons:
a. additional structures for control and maintenance (manholes) make a composite system more expensive;
b. large composite systems require lower water levels at the outlet, so pumping cost increases considerably;
c. a third reason could be that nowadays drainage is a matter of private farmers and projects are not large enough to allow composite systems.

Question from Mr. Mihnea (Romania)
What is the total energy requirement for mole drainage?
Answer of Mr. Spoor (England)
The energy requirement for mole drainage is dependent upon the depth of drainage and the shear strength of the soil. Traction is one of the most important considerations. The following power units are commonly used in UK for moling operations and indicate the energy and traction requirements:
a. for installing moles at a depth of 0.5-0.6 m in strong clay soils with dry bulk density 1.5-1.7 gr/cm^3 and moisture content at or below plastic limit, a 100 HP crawler tractor or 150-200 HP 4-wheel drive tractor is required;
b. for installing moles at a depth of 0.45-0.50 m in weaker clay soils with dry bulk density 1.1-1.3 gr/cm^3 and moisture content at or above plastic limit, a 70 HP crawler tractor or 100 HP 4-wheel drive tractor is required.

Discussion of Session 2

Question from Mr. Singh (India)
In Mr. Jokhio's paper on the East Khairpur Tile Drainage Project a capital cost of US$ 1000 per acre is given. The annual interest and operation and maintenance chargesare 12 to 15%, which means about US$ 120 to 150 per acre. Could the author indicate

the expected as well as the actual income from crop production per acre before and after the project was completed?

Answer of Mr. Jokhio (Pakistan)

The East Khairpur Tile Drainage Project was started as a pilot project in Pakistan. The cost per acre has increased due to the fact that the construction period was planned for five years, but it took actually ten years. As indicated in my paper if the project had been completed in the planned period, which in future will happen, the cost would be half, so the price may be set at about US$ 500 per acre. Crop production showed a promising picture. Initially the cropping intensity was only 90% and the projected one was 145%, but observations after construction showed a cropping intensity of 150%. Also crop yields have increased one and a half times and in some areas even four times. Another fact is that people, who abandoned their land due to increasing waterlogging and salinity, are quickly coming back to recultivate their areas as a consequence of the introduction of tile drainage.

Question from Mr. Ochs (World Bank)

Is internal deflection of plastic pipes after installation checked when impacts from trench caving are prevalent in the East Khairpur Tile Drainage Project?

Answer of Mr. Jokhio (Pakistan)

Observations have shown that water is flowing continuously from the drains, but there was no exact checking how the pipes have been installed. However the system seems to work all right. The project area is divided into smaller units and every unit has an independent pumping station, operational since 1982. There are no indications at the moment that drain outflows are diminishing. On the contrary an increase in irrigation water supply gives higher drain discharges, which has been observed in the manholes and at the sumps.

Question from Mr. Abdel-Dayem (Egypt)

What is the size of the dewatering laterals in the East Khairpur Drainage Project? Is it not too expensive to use gravel envelope?

Answer of Mr. Jokhio (Pakistan)

The dewatering system is a 100 mm diameter pipe pre-wrapped with nylon, which is also used for laterals. It is laid at a depth of 4 m by machine. This is only for dewatering the area and when the collector pipes are installed, this system is abandoned. The cost of gravel is about 10% of the total cost, because gravel is in big quantities available near the project area (within 4-5 km) and only screening had to be paid for.

Question from Mr. Rao (India)

Could Mr. Jokhio give some information on the energy requirement of pumping from collectors to surface drains in the East Khairpur Tile Drainage Project? How much will be the recurring cost of drainage per ha including operation and maintenance?

Answer of Mr. Jokhio (Pakistan)

The design drainable surplus in the East Khairpur Tile Drainage Project is 2-3 mm/day. Due to the slow irrigation development in the Project the water quantity at the pumping stations is so low that small drainage pumps are installed of 5-7.5 HP. At present these pumps with an automatic control system are operating 40% of the time. When the irrigation water supply in the Project will be increased in the next year, as planned by the Irrigation Department, then every pumping station has one stand-by pump with low capacity. The area of each sump unit is about 800 acres. The maintenance costs are estimated at US$ 1.50 per acre annually.

Question from Mr. Woudeneh (Ethiopia)
Is pump maintenance in a composite drainage system considered to be a problem? Are there any problems faced and how is the maintenance organized?
Answer of Mr. Jokhio (Pakistan)
The organization for maintenance is available, but at present no pump maintenance is done, because the project has just been completed. No maintenance problems are expected in the near future.
Comment of Mr. Woudeneh
In Ethiopia it is difficult to maintain mechanical equipment. When it breaks down, there are no skilled people to repair it. This fact was raised when the implementation of a drainage system was proposed in one of our studies. How is this fact and the failure of tubewells for drainage, as mentioned by one of the speakers, related?
Comment of Mr. Bhatti (Pakistan)
The tubewell failures are mostly related to problems with the strainers and the gravel pack around it, but not with the tubewell itself and the turbine pump. The advantage of a tile drain system is that no strainers and gravel pack are required, because it is a simple system.

Question from Mr. Hendrickx (The Netherlands)
Monitoring is necessary for drainage research and for controlling the proper functioning of the system. In which manner can one monitor adequately the components of salt and water balances, given the very variable nature of salt and water fluxes in the field?
Answer of Mr. Boumans (The Netherlands)
In general it is recommended to establish a monitoring programme as simple as possible. This can be done at two levels. For example a first level monitoring programme encompasses the recording of drain discharges, salinity of drain outflows, land use pattern, crop development and crop yields. This should enable to find a direct relation between the drainage system and its functioning. A second level programme takes also into consideration groundwater levels and salinity of soils and of groundwater outflows. A large scale monitoring programme is not recommended. Instead spotwise monitoring could be carried out, preferably in collaboration with research institutes for collecting and evaluating the data. In general each area under study needs its own programme, depending on available means (equipment, staff) and the aim of the monitoring: like just to evaluate a project or to work out research targets.

Question from Mr. Oosterbaan (The Netherlands)
Mr. Boumans stated in his presentation that deep drainage is required on fallow land with upward seepage of groundwater in arid areas to prevent salinization. Is deep

drainage not very costly, especially when it concerns fallow land that is not producing any crop?

Answer of Mr. Boumans (The Netherlands)

A fallow or non-cultivation period is very common in agricultural rotation systems. Only when water is available throughout the year, crops can be cultivated the whole year around. In arid regions the summer crop water requirement is much more than the winter or spring requirement. Two examples. First Iraq where during summer four times more water is needed than in winter to irrigate one ha; second Tunesia where the summer crop water requirement is twice the spring requirement. If water use has to be economized than an agricultural rotation system with winter and spring crops should be considered and part of the summer cultivation should be left out. In my opinion this is the major reason for leaving a part of the land fallow during summer. Another reason is that if the design of an irrigation system would be based on 100% summer cultivation, then the canal capacities have to be increased. Again Iraq where the design of irrigation systems is actually based on 100 or 80% winter cropping, and only 25% of the land can be irrigated in summer. If the design was based on summer cultivation the canal capacities should have been increased four times. It is not economic to use water in periods with the highest evapotranspiration.

Comment of Mr. Rao (India)

The question is related to the depth of drainage, which is affecting the cost of a project. In arid areas leaching of soils is needed and to design proper drainage systems in those areas the criterion that a minimum amount of water has to pass through the root zone is more important than maintaining a critical watertable depth. When the cropping intensity is very low, would it not be more economic to implement a deeper drainage system?

Comment of Mr. Boumans

Even without talking about critical depth, it has many advantages and it seems economic to have deep drainage in many areas in the arid regions. Recently Smedema and Boumans analysed the drainage costs in relation to depth and gain in drain spacing. It shows that there is not much difference when increasing the drain depth from the point of construction costs (only pumping costs will increase). The study indicates also that for irrigated arid areas the economic optimum of drain depth is in the order of 2 m with the criterion to maintain the average watertable at about 0.90 m below the ground surface. Another advantage of deep drains is that they run continuously, so there is no risk of silting up.

Question from Mr. Sevenhuysen (The Netherlands)

Is knowledge of plant-water or plant-salt relationships a limiting factor to drainage designs in relation to operational soil-water knowledge?

Answer of Mr. Boumans (The Netherlands)

The drainage criteria can be approached by a crop yield-water relationship, but no sufficient information is yet available. Drainage is a practical science. It is a field with a lot of work still to be done. The optimum drainage has a quite flat maximum, so we are already happy to be within that optimum.

Discussion of Session 3

Question from Mr. Neefjes (The Netherlands)
In the presentations about drainage in the humid temperate as well as in the arid regions it became clear that drainage systems are sometimes overdesigned. Mr. Boumans stated that available data show that we are anyhow close to the economical optimum with the actual drainage criteria. Mr. Smedema showed the importance of flow types contributing to the discharge of excess water for the cultivation of dry-foot crops, while Mr. Bhuiyan presented an experiment where submergence resistance of rice varieties is evaluated. Can Mr. Smedema and Mr. Bhuiyan elaborate their ideas to establish quantitative drainage criteria?
Answer of Mr. Smedema (The Netherlands)
Concerning drainage criteria for dry-foot crops some research has been done by Carter (Baton Rouge, Louisiana, USA) in sugar cane areas, where drainage improvements are introduced by a combination of surface and subsurface pipe drainage systems. Surprisingly it appears that criteria for subsurface drainage in these sugar cane areas are almost similar to the criteria used in the temperate regions (7 mm/day at a watertable head of 50 cm) in spite of the different rainfall conditions. An explanation could be that there is a limit as to how much water can pass through the soil and therefore the groundwater drainage criteria are apparently the same.
Answer of Mr. Bhuiyan (Philippines)
In rice cultivation the main problem is to drain the excess water on the surface (overland drainage) rather than groundwater drainage. Overland drainage criteria in rice fields are related to the rainfall pattern in those areas; for example what is the, either for a 5-year or a 10-year record interval, rainfall amount in an area within two or three days during the wet season (typhoon or cyclonic conditions), which can serve as a base for the drainage criterion in that area? In the Asian humid regions various values are used. These values are ranging from 5-13 l/sec.ha depending on type of rainfall and on crop cover (rice: only submergence conditions up to 50% of the height of the plant for not more than 3 days).

Question from Mr. Oosterbaan (The Netherlands)
Why used Mr. Smedema in Figure 2 of his paper plums as an example for the temperature effect in waterlogging? What variety of plums was used in the tropics and what in the temperate zone? Was there difference in intensity of waterlogging in the tropics or temperate zone that might also explain part of the yield reduction? Which were the tropical and temperate zones where Row and Catlin made their observations?
Answer of Mr. Smedema (The Netherlands)
It was the only information available in the literature to illustrate the temperature effect in relation to drainage response. In relation to the given figures I want to remark that whether these experiments were carried out under stagnant water conditions or under field conditions was not clear from the source. However I think that this could make a big difference because stagnant water conditions are likely to give much more damage. Under field conditions, where rainfall maintains saturated conditions, with the rainwater also oxygen enters into the soil. So the figures which are showing the

differences in response between the temperate and the tropical regions might be a bit deceiving. Under field conditions the responses due to high temperature conditions could be quite different because a lot of oxygen is dissolved in rain and consequently it is transported with the rainwater into the root zone. Therefore crops under field conditions may suffer less than under stagnant water conditions.

Comment of Mr. Oosterbaan

Where these experiments done in the same region or in different regions?

Comment of Mr. Smedema

Most likely these experiments were done under laboratory conditions.

Question from Mr. Rao (India)

A large part of the area in humid tropical regions has acid sulphate soils. Is it advisable to apply groundwater drainage in these soils? If not, which drainage measures do you recommend?

Answer of Mr. Smedema (The Netherlands)

I would rather not comment on this because there are in this room other persons, who are much more qualified to answer this question.

Comment of Mr. Ismail (Indonesia)

In the acid sulphate soils of the swampy areas in Indonesia Al and Fe sulphate oxidate during the dry season, which increases the acidity of the drainage water. The influence of the tidal effects is used to drain the acid water, and limestone is applied for neutralizing the acid in the soil.

Comment of Mr. van der Molen (The Netherlands)

Experiments in Vietnam are being done on these aspects and there are two strategies 1) to keep the soil wet as long as possible in order to prevent the oxygen to go into the soil and produce the acid and 2) to drain the soil and wash out the acid. Both strategies have their disadvantages and their advantages. It is a complicated matter if there is no limestone at hand. If limestone is available in the neighbourhood, the acidity can be neutralized by applying limestone. But if it is not available within 500 km from the area, it is very costly to apply lime. On the other hand keeping the soil permanently wet when there is a long dry season, is not easy. Washing out all acid, gives acid waters, which may spoil other areas. It is a complicated problem and not so easy to give a general solution. In a pilot area in Vietnam both strategies are studied.

Comment of Mr. Wiersinga (The Netherlands)

In Indonesia improvement of tidal swamp lands by washing out the acids will be tried out by combining tertiary canals and tidal gates in such a way that the water will circulate through the area: the incoming water will push the drain water out through the next tertiary canal. An additional remark on acid sulphate soils in Indonesia is that experience in rice cultivation shows that stagnant water is far more dangerous than the normal drying out of the soil during the dry season. In stagnant water areas, for example areas between two rivers, you find very locally (from one metre to the next) dying and living rice plants, due to differences in their elevation (from 10 to 20 cm): the higher rice plants keep alive and the lower ones die because of chemical processes after Fe- and Al-oxidation.

Comment of Mr. Sevenhuysen (The Netherlands)
A three-year research programme (a joint cooperation of Land and Water Institutes of the Netherlands/LAWOO) will start the next year in Indonesia focussing on identification and water management of acid sulphate soils as well as modelling of the deacidification of these soils.
Comment of Mr. Rao
In India there are some areas of acid sulphate soils with traditional rice cultivation. Some researchers in India propose to cultivate dry-foot crops in rotation with rice by providing subsurface drainage in those problem soils. My question was intended to know whether it is worthwhile to try subsurface drainage in those soils.

Question from Mr. Kabat (Czechoslovakia)
There is a lack of consideration in drainage theory and practice for the problem of what Mr. Smedema called 'interflow'. Can he shortly explain 'why? Is this problem not similar to the design of interceptor drains?
Answer of Mr. Smedema (The Netherlands)
Because the phenomenon of interflow is not very clear. As far as it is related to flow over hard pans, for example in the case of perched watertables, interflow might be compared with interceptor drainage. However, interflow also occurs when in the unsaturated zone the deep percolation of excess rain is impeded and this impeded water is exposed to a sufficient lateral gradient.

Question from Mr. Spoor (England)
Could Mr. Bhuiyan comment on the drainage measures to be taken to allow the rapid establishment of dry-land crops after paddy?
Answer of Mr. Bhuiyan (Philippines)
If upland crops or dry-land crops are intended to be cultivated after a rice crop in the rice cultivating areas the ponding of excess water must be avoided in those areas. This implies a drainage system to take care of the removal of excess water which is mostly found in the better irrigated areas, but not in ill-designed and ill-managed irrigation systems, where drainage is poor and often waterlogging is a problem. However, the efforts to establish diversified crops (upland or dry-foot crops) as a second crop after rice are limited to the lighter textured soils in which the internal drainage is good and the crop establishment is relatively easy. On the heavy soils the major problem will be crop establishment, because after the rice harvest the land remains wet and after the tillage operations the germination of the upland crop is poor. If the soil is too dry, the heavy soils are too hard on the surface and it is very difficult to operate the low-powered tillage machines that small farmers have. So land preparation and crop establishment are the first major obstacles towards establishing an upland crop in rice lands. This subject is, however, becoming more important since many countries are self-sufficient in rice. In those countries the modifications needed in their water control systems for growing a non-rice crop after rice are studied. But land preparation and crop establishment are still the major obstacles for heavy soil conditions. Until now upland crop cultivation in rice fields is limited to the lighter textured soils.

Comment of Mr. Abdel-Dayem (Egypt)
In Egypt the main problem is a rice crop in rotation with other crops (cotton, maize), because these crops require different water management. When subsurface drains are provided to the fields, this causes loss of irrigation water during a rice crop and farmers are illegaly closing the drains, which hampers maintenance. Consequently, due to the extent of the area (1 million acres) with these problems, the drainage lay-out was modified by introducing a system on the basis of crop pattern and crop lay-out in the different years. This allows proper operation through establishment of different crop units. Each unit is provided with subcollector drains which can be closed during rice cultivation. For a non-rice crop during the next season the drains are functioning normal. Such a drainage system makes a proper water management for each crop possible.
Comment of Mr. Singh (India)
On higher fields in humid areas of India (West-Bengal and adjoining areas) a second crop is planted (mustard, wheat) in the post-monsoon season (October) after an early paddy crop is harvested in August, because those fields have been sufficiently drained. On lower situated fields, which are drained out in December-January, a dry-season paddy is planted if irrigation water is available. So the area is limited and this crop is very profitable. In West-India, where wheat was the traditional crop, the watertable is rising due to leakage of irrigation water from canals and wells. As a result good paddy crops have been obtained. The Punjab and Haryana States are now also surplus growing regions for rice, so the rising watertable in the fresh groundwater areas of these regions is not harmful at all. In the saline groundwater areas of southwest Punjab and Haryana, where traditionally cotton was grown, the rising watertable has caused problems and the farmers had to switch to rice, which is not a paying crop and some land is left out of cultivation.
Comment of Mr. Singh (India)
On waterlogging in Sarda Canal Area:
I would like to mention that the figures for waterlogging in the Sarda Canal Area as presented by Mr. Bhuiyan are not supported by more detailed studies of the area. The correct figure is of the order of 7000 ha. Also the percentage of areas waterlogged in the Hirakud Project, Orissa, is on the high side.
Comment of Mr. Bhuiyan (Philippines)
Both figures, which I quoted, are from published literature.
Comment of Mr. Singh
I would like a correction as far as Sarda Canal Area concerns to be incorporated in the proceedings, because I have participated in several meetings where this specific point has been discussed and I am sure that the early mentioned figures, quoted in some papers by Mr. Chaturvedi in 1983 and used by Mr. Bhuiyan, have subsequently been verified to be much less.

Questions from Mr. Bhatti (Pakistan)
1. ow do Mr. Bhuiyan envisages removal of excess water from rice fields: by open ditches extending to individual fields or by subsurface pipe drains?
2. Maintaining 5-10 cm water does not seem to be practical in a rotational system.

The farmer wants to keep his fields wet until the next irrigation turn. Can Mr. Bhuiyan explain this?

Answer of Mr. Bhuiyan (Philippines)

1. Removal of excess water from rice fields using subsurface drainage systems is out of question for the Asian rice farmers. Firstly economically subsurface drainage is too expensive and secondly most of the benefits could already be achieved by applying surface drainage systems. Consequently, these measures are the most logical and economical ones for rice fields. Most irrigation systems have surface drainage facilities incorporated in their system, but these systems are often inadequately designed and not properly maintained. As a result there are problems to drain the excess water. If excess water removal through surface drainage provision is given due consideration in developing rice lands, most of the drainage problems are solved. However in rainfed areas without flood protection provisions like in most irrigated areas, the question of flood protection is more important, because in very low situated, low gradient basins only surface drainage will not solve the drainage problem in a reasonably short time due to insufficient head. As a result flood protection measures through polders, dikes, regulators, flap-gates, etc. are more relevant for those areas.
2. If water is delivered through rotation and as long as the field saturated conditions, a rice crop does very well. In terms of maintaining water in the field for a rice crop, there are no deleterious effects up to the point of saturation in the soil. If the soil water content is below saturation, at that point onwards the rice crop will be damaged. From the crop point of view any water depth between 0-15 cm is acceptable and if water is delivered through rotation any depth of water in that range is perfect.

Question from Mr. Mihnea (Romania)

Does there exist experience about subsurface drainage in rice cultivation?

Answer of Mr. Bhuiyan (Philippines)

In Japan considerable experience exists on subsurface drainage in rice fields. Due to a subsidy policy of the Japanese government farmers have actually almost 70-80% of their rice lands equipped with subsurface drainage systems. They drain excess water and farming operations are mechanized. Under those conditions gains are reported. But the Asian humid tropical conditions are quite different and there is no experience, not even a serious thought, about trying subsurface drainage in the Asian humid tropics.

Question from Mr. Cavelaars (The Netherlands)

It is commonly known that high rice yields can be obtained with low percolation rates. Have high percolation rates been studied in the Asian humid conditions?

Answer of Mr. Bhuiyan (Philippines)

It is not really known whether an induced higher percolation rate in heavy soils would improve the productivity of these soils. More research is needed along that line. However it is very academic, because in reality it is very impractical to think that in rice lands the percolation rates can really be increased.

Comment of Mr. Hulsbos (The Netherlands)
Induced percolation is considered in those areas where rice is cultivated in rotation with other crops. If rice is cultivated in a monoculture or in a double cropping or even three rice crops a year, it is a total different situation.

Question from Mr. Arar (FAO)
Does Mr. Smedema agree with the use of mole drains instead of the proposed deep trenches filled with permeable material to take care of the interflow? This might be more effective and even cheaper.
Answer of Mr. Smedema (The Netherlands)
I agree. But if we want groundwater drainage as well, than we also need a deep system. Mole drains can take care of the interflow, but not of groundwater drainage or watertable control. Experiments with subsurface drains in sugar cane (Queensland, Australia) and in bananas (Costa Rica) for groundwater control, even under the heavy rainfall conditions of the humid tropics, have shown good results.
Comment of Mr. Arar
Combining both systems will be useful.

Question from Mr. Arar (FAO)
In the slides presentation of Mr. Bhuiyan we have seen land preparation of rice fields, especially soil levelling and puddling of fields under water. One feels that the soil structure is completely destroyed and that the infiltration rate might become zero. It became also clear in the presentation that soil aeration is not important for increasing rice yields.
1. In view of the above does Mr. Bhuiyan agree that, to control the depth of water in rice fields, only a surface drainage system is required? What are the consequences of lowering the watertable in rice fields on yields?
2. Are experiments done to improve soil preparation methods and rice planting? For example no-slope, laser-graded basins and sowing rice seeds in dry soil prior to flooding or planting rice seedlings in the same way?

Answer of Mr. Bhuiyan (Philippines)
Concerning the question of destroying the soil structure, Mr. Arar is very right because that is the whole purpose of puddling. Puddling is done to ensure that percolation rates are low and that the water storage on the fields improves, so the farmer sees that his rice crop is not drying out during periods when rainfall or irrigation flow is low. The question of the effect of reduced percolation on the crop itself is an interesting one, because a rice plant has the unique capacity to take the needed oxygen from the atmosphere and to transport it through the plant to the roots in a very efficient way. As a result the roots do not normally suffer from lack of oxygen, even though the soil is in anaerobic conditions throughout the growth period. This uniqueness of rice makes this wet land culture so very possible and sustainable. From this point of view the question of improving the percolation rate through mechanical means does not have much relevance, except that there is a merit in cases with soil nutrition problems, which can be improved through lowering the watertable. On the IRRI farm the soil has a high boron content due to the irrigation water and it is evident that

leaching the boron through drainage helps to improve the soil, which is not necessarily associated with increased soil aeration. On the question of dry rice seeding experience and crop establishment in dryer soil regimes, I can answer that there are also other types of rice culture. For example upland rice is grown in the field without any puddling at all and minimal land preparation. Dry seeded rice is another crop establishment technique in which the seeds can be put into the soil by drilling a hole or just seeding in minimal ploughed conditions. Of course germination is less, but those practices exist. In my presentation the most important wet land types are shown, where ploughing and puddling is very common.

Comment of Mr. Arar

In clay soils puddling is not necessary to prevent percolation losses and internal drainage is negligible. As a result only surface drainage is required in rice cultivation. To leach harmful salts the 2 to 5 mm soil layer at the surface is very important, which determines the infiltration and is the limiting factor for the movement of salts or minerals into the soil by leaching. Puddling and smoothing under water are necessary for accurate land levelling. Has IRRI carried out under these conditions precise land levelling with laserbeam to get zero-slope and a good, uniform application depth of water, which, as Mr. Bhuiyan rightly emphasized, is very essential to obtain high rice yields and to avoid the destruction of the soil structure?

Comment of Mr. Bhuiyan

The close to soil surface watertable situation can take place in the wet season, but mostly not in the dry season. Often there is a perched watertable, which is not the real one, but it affects the crop performance immediately. In the dry season the watertable goes mostly downwards and farmers want to retain water in the paddy fields and puddling definitely does help to conserve water. IRRI research has amply proven that by allowing the perched watertable to go down and the soil to crack on the surface, which happens in heavy soils even at saturation level, the rice crop will be damaged. As a result any water-stress, particularly during the most susceptible crop growth stage which is the flowering stage and the reproductive period of the crop cycle, must be avoided if higher yields are wanted.

On the question of leaching harmful salts the climate has to be taken into consideration. The popular notion about the development of toxins under anaërobic conditions, does not seem to be true in the high temperature regime of the tropics. Soilchemists have shown that development of H_2S and other toxins, very common in temperate zones, does not actually take place in the tropics, because the high soil temperature and the low organic matter content help to breakdown the toxins very quickly. As a result the rootrot type problems are very unusual in the tropics and consequently the question of flushing the soil does not seem to be very important in the humid tropics.

Question from Mr. van der Molen (The Netherlands)

Floating rice can stand high water levels but has low productivity. Are there possibilities to breed higher yielding long-straw varieties to replace this floating rice?

Answer of Mr. Bhuiyan (Philippines)

Floating rice is low yielding because most of its energy is spent to keep it floating.

The elongation capacity, the very long stem that it has to support to be alive, does not leave much energy for producing grains. Therefore high yielding varieties for high water level conditions have received very low priority by IRRI breeders. They do not even think that in the next ten years there should be any effort to replace floating rice. The focus is, on what the breeders call, medium deep conditions up to about one m water depth, which seems to have good potential and those are the varieties they are working with. In my opinion they are probably right, because the whole phenology of the rice plant under floating conditions is very difficult.

Discussion of Session 4

Question from Mr. Lampe (The Netherlands)
Mr. Abdel-Dayem told us in his presentation that large diameters PE, PVC and PP pipes have been imported in Egypt for trials. Has a definite choice been made in Egypt to use in the future either PE, PVC or PP pipes?
Answer of Mr. Abdel-Dayem (Egypt)
The imported pipes have been used as collectors on different projects and have not been chosen on a basis of specific criteria. The pipe material used is often related to the overseas country cooperating in the project, e.g. Canadian projects use PE and European PVC.

Question from Mr. Cavelaars (The Netherlands)
What is the state of art for connections between laterals and collectors in Egypt?
Answer of Mr. Abdel-Dayem (Egypt)
In the past, glazed clayware cross pieces were used to connect concrete or tile laterals and collectors. Careful installation was necessary to avoid collector misalignment and siltation. PVC cross pieces are now used with plastic pipes. For maintenance purposes, manholes (diameter 0.75 m), either cast in place or precast units, are installed at distances varying from 120 m (min) to 180 m (max) to allow access for flushing machines. The total number of manholes in a system will be minimized, because some farmers are misusing these manholes (filled with trash). Manholes are necessary for maintenance purposes, because in developing countries it is impossible to ensure high standard of installation everywhere in large drainage schemes.
Comment of Mr. van Someren (The Netherlands)
I was informed that in Egypt, to avoid manholes and their problems, plastic junction pieces are installed, enabling the access of a flushing device directly into the lateral drain. Is this right?
Comment of Mr. Abdel-Dayem
This system was tried out on an experimental basis, but it has not yet been adopted widely. It will take time to convince contractors of the advantages of this system that indeed will reduce the actual problems with manholes.

Question from Mr. Murillo (Costa Rica)
What influence has slot position on entrance resistance in corrugated pipes?

Answer of Mr. Stuyt (The Netherlands)
I think there are two factors, which are important if we consider entrance resistance in conjunction to perforation patterns: a) the open area (the percentage of the drain pipe wall, which is perforated) and b) the distribution of perforations over the pipe. The research of Mr. Dierickx has indicated that, providing there is a minimum amount of open area (about 2.5% of wall area), there is little benefit from increasing it further. The distribution of the perforations has proved to be very important. When considering for instance clay tiles, theory predicts a higher entry resistance than for corrugated pipes, due to the larger spacing between the water entry points. The predicted large difference is not borne out in practice. Clay tiles perform very satisfactorily and differences are small. In my opinion this is caused partly by the fact that the soil itself will also determine the flow pattern towards the corrugations. Dig ups in the Netherlands showed that the water flow towards corrugations may also occur through macropores, which will develop towards the corrugations in the pipes. At certain spots there are high influx rates into pipes, whereas in other places, where the permeable backfill has a relatively low hydraulic conductivity, the flow into the pipe is negligible.

Question of Mr. Cavelaars (The Netherlands)
One hypothesis explaining the benefits of sawdust as a backfill material is that before the sawdust decomposes, it has stabilized the backfill and hence is no longer needed itself. Is there any experimental evidence to support or refuse this hypothesis?
Answer of Mr. Mortensen (Denmark)
In Denmark and in other Scandinavian countries there is a very good experience of using sawdust (from conifer trees) as an envelope material. Experiments have been made on decay rates and grain size analyses of sawdust. In Norway a 50% decay in about 20 years has been found. By applying a layer of 5 to 7 cm of sawdust, it will function well for a long period, under the rather cold conditions.
Comment of Mr. van Someren (The Netherlands)
In my opinion Mr. Mortensen is now touching the critical point, namely temperature, because in the Netherlands sawdust in experimental fields disappeared in two years. The lower temperatures in his country are likely to be the major reason for his greater success with sawdust.
Comment of Mr. Zijlstra (The Netherlands)
Some experiments with organic cover materials have been carried out in Peru using bands of flax straw. The results were disappointing. The materials decomposed in a few years, suggesting that organic materials are unsatisfactory in warm climatic areas.
Comment of Mr. Stuyt (The Netherlands)
Similar decomposition problems have been found to exist in The Netherlands with coconut fibre envelope (60% coconut fibre). In a recent dig-up of 1200 drains, mostly wrapped with fibre envelope, the fibre had decomposed in many cases, but there was no sanding up of the drain pipe. This raises the question 'Do these soils need any envelope at all?'. In certain cases this was unclear, because the structural stability of soils is a parameter which is difficult to evaluate. Therefore in my opinion research should continue to determine whether envelopes are needed in certain soils. The statement of Mr. Cavelaars is certainly valid for several Dutch soil types, that in the past

were called problem-soils. A long life envelope may still, however, be necessary to allow future maintenance works, particularly jetting. If the envelope has disappeared the high pressure jet (20 bar) could easily disturb the soil around the pipe causing future instability. The presence of a long lasting organic envelope or a synthetic envelope would significantly reduce the risk of this occurring.

Question from Mr. van Someren (The Netherlands)
What future is there for the trenchless drainage machine in irrigated areas in the arid regions, where the drains have to be laid at depths of more than 2.5 m?
Answer of Mr. Zijlstra (The Netherlands)
As far as my knowledge goes, the large trenchless machines can work satisfactorily up to a depth of 1.8 or 2.0 m; increasing the depth beyond this will increase the pull required greatly. In my opinion it will require very heavy machinery and it is doubtful whether sufficient traction can be developed to work through the difficult spots. If drains are to be placed deeper than 2 m, it would be wise not to think of trenchless drainage. Maybe there are participants with practical experience on this aspect.
Comment of Mr. van Someren
In the Mardan project (North Pakistan) with Canadian aid a big trenchless machine with a trenchbox of 25-30 cm width was imported.
Comment of Mr. Bhatti (Pakistan)
This was an unhappy experience, due to problems of placing the filter, as well as smearing and compaction of the soil. In the future no trenchless machine will be used in this project, where the collectors are installed at a depth of 12.5 feet (3.75 m).
Comment of Mr. Ochs (World Bank)
In the San Joaquin Valley of California a rather unique trenchless machine was used to lay corrugated plastic tubing, which was nicely surrounded with a gravel pack, all in one operation. Unfortunately the power requirements, when working at a depth of 2 m or more, were so tremendous that it just was not economic. This machine is not used anymore and my experience has been that two metres is about the (economical) limit for most of the trenchless equipment.

Question from Mr. van der Molen (The Netherlands)
At depths of two metres, will the trenchless machines not be working below critical depth making the soil more compact instead of less compact?
Answer of Mr. Spoor (England)
I agree with the previous comments about trenchless machines working below two metres. In my opinion as long as we try to do the job with a single tine, or as Mr. Ochs said, force it in, than it will be a disaster. If however, we use shallower tines ahead of the deep one, suitably positioned and with the possibilities of a two-stage operation, than I think the whole situation changes completely. Problems with critical depth and very high draught diminish considerably. The situations where it may be worth looking at trenchless machines for deep pipe installation in the future, are those where severe problems currently exist with trenching machines.
Comment of Mr. van Soest (The Netherlands)
I agree with the suggestion of ripping to reduce the pull, but there are still two major

concerns, namely, does ripping affect critical depth and how can we ensure good traction on the surface? In theory it is possible to stop irrigating before draining in irrigated areas to let the soil dry. In practice this is difficult to realize. Studies to improve the logistics of gravel handling would improve possibilities for using the trenchless system. In addition, drains would have to be designed for shallower installation than in some current projects.

Comment of Mr. Spoor

I am not quite sure what type of ripping is inferred in the last comment. If we use a single tine, immediately ahead of the deep tine then we will certainly reduce the draught, but we will bring critical depth closer to the surface and make soil matters worse at depth. The ripping that I am considering is shallower and consists of tines which are spaced on either side and ahead of the deep tine and this effectively weakens the soil there, so that we change the soil failure plane and move the critical depth much deeper.

Comment of Mr. van Soest

I agree. Ripping is only a technical addition to allow work at a greater depth, but it is probably not improving the quality of the installation.

Question from Mr. Bhatti (Pakistan)

In unstable saturated soil conditions, the effective width of the trench is the outside dimension of the trenchbox. For larger diameter pipes placed with gravel envelope, a very large trenchbox is required. Is it possible to devise a mechanism whereby gravel is placed around the pipe before the trench collapses?

Answer of Mr. Zijlstra (The Netherlands)

The trenchbox is fitted with a gravel hopper feeding two gravel chutes. Through the front chute a gravel bed is placed on the trench bottom. The corrugated plastic pipe is then laid on this gravel bed, and through the rear chute gravel is put down to cover the pipe on both sides and on top. The whole operation of laying the pipe with the gravel surround takes place inside the trenchbox. Collapsing of the trench after the passing of the trenchbox will not disturb the drain anymore, provided the correct trenchbox width is used and the thickness of gravel layer is correctly adjusted on both gravel chutes.

Comment of Mr. Cavelaars (The Netherlands)

On V-type trenchless drainage machines:

Mr. Zijlstra has commented on the V-type trenchless drainage machine, but actually this type is not a recent development, it is already some years old. A prototype (Willner machine), almost identical to the later machine, was already operating in 1961 (laying corrugated PVC pipes).

Comment of Mr. Zijlstra (The Netherlands)

Mr. Cavelaars is right. This is an old development and not a recent one. But the application, in my opinion, became only practical after the corrugated plastic pipe was introduced and after the perfection of laser grade control. Moreover the prototypes, that I have seen working in the Netherlands, didn't actually have sufficient depth of operation. Therefore only the developments of the last five to six years made this machine really suitable for practical use.

Comment of Mr. Stuyt (The Netherlands)
A further important development boosting the use of the V-type trenchless machine (in the Netherlands referred to as the delta plough) is that it is only in the last three years that this machine was allowed in the Government subsidized works in The Netherlands.

Question from Mr. Bhatti (Pakistan)
Research has been going on for quite some time at ICW on synthetic envelope materials. It was expected that Mr. Stuyt would have said something definite about it. Today we learned that the research shall further continue. How long will it take before the recommendations are formulated?
Answer of Mr. Stuyt (The Netherlands)
There are several reasons for not reporting. First I can't say that things are definite yet, simply due to the lack of data and secondly the project, which is currently running at ICW, is financed externally by sponsors and we can't release the data as yet. There are some results, but the sponsoring firms must have access to the results in the first place. A general view is given in my paper (Fig. 3 and 4) showing that the reliability of an envelope increases with envelope thickness. One frustrating point in this field is that we know that we can't simulate the functioning of envelope materials in the laboratory only. Phenomena, that occur in the field, are also playing a decisive role. The reliability of voluminous envelopes with a thickness exceeding about 8 mm is greater than the reliability of sheet envelopes. I have also seen in eastern USA however, that sheet envelopes (polyester knitted fabrics) can work very well, but they are mounted around larger diameter pipes. It is therefore up to us to find out what actually is the reason why a sheet envelope fails or is more likely to fail than a voluminous envelope. One of the drawbacks of the current research is that we cannot monitor the phenomena precisely with our permeameter set-up. We do not have the tools in our laboratory to exactly explain why in this case, with this soil and this envelope, clogging has started. There are quantitative data like hydraulic gradients and soil textural composition available, but structure and also the spatial variability of the flow around the drain pipes are playing a decisive role and cannot as yet be fully quantified. So I can't say anything definite yet and therefore I propose to use a new method: taking samples from the field, to look at both short and long term phenomena including micro-biological clogging and clogging by very fine particles. At the end of 1988 the results of this project will be published and new projects with new approaches will also start. In my opinion the permeameter flow tests have given us the maximum amount of information possible from this type of experiment (computer modelling and integration of field data). We know more or less what envelopes can do very well in certain soils, however the major problem is that the data are only regionally applicable and we cannot explain why the things happen that we monitor.
Comment of Mr. van Someren (The Netherlands)
We are looking forward very keenly to receiving the results, but in the meantime advice can be given that voluminous envelope material is better than thin, but that the thin ones (sheets) are suitable where sand has to be kept out of the drain rather than improving the permeability around the pipe. Concerning the voluminous envelope material

gravel we can say that it is expensive and difficult in logistics. Is there any substitute for gravel in irrigated areas?
Comment of Mr. Bhatti
The silence of the participants means that none of them has at the moment an alternative that can substitute gravel. Nobody is prepared to take the risk.

Question from Mr. Boumans (The Netherlands)
Are there, besides USA and Canada, (international) quality standards for the large diameter corrugated pipes? Is it right that the USA-standards require use of gravel for bedding and side-support, even in the case of nonperforated pipe?
Answer of Mr. Ochs (World Bank)
The standards for large diameter corrugated pipe are now up to 24 inches (ASTM-standard: F667), but the installation standards are currently being formulated (revising American Society of Agricultural Engineers-standards and ASTM-standards concerned with large diameter pipes). They say that sand or gravel is one option for supporting the side with a material that will not compress. Other options are being considered, but sand or gravel is the primary option and probably the option that will be selected on most occasions.

Question from Mr. Mortensen (Denmark)
In Mr. Stuyt's presentation the new synthetic gravel envelope was shown. What material and grain size composition was used and how was the prewrapping made? Is there research on and practical experience with the synthetic gravel envelope?
Answer of Mr. Stuyt (The Netherlands)
The polystyrene alternative was developed in 1978. In the version shown the polystyrene granules were wrapped with a very open sheet (mesh sheet as used to pack oranges), supplying a very large open area. Many people are afraid that the sand tightness of this envelope would be very low. Another alternative is the same polystyrene envelope wrapped with a foil, which in itself is perforated (comment of Dr. Wesseling some years ago: it is a bad product, because it is a pipe around a pipe). Data from field experiments in four pilot areas in the Netherlands, show that the sand tightness of the first alternative (mesh sheet) is lower than the one which is wrapped with perforated sheet. However not only the sand tightness is monitored, but also the hydraulic characteristics. The data shows that the difference between those two alternatives is smaller than would be expected on the basis of theoretical considerations. At present the diameters of the grains vary between 3 and 6 mm. It is still rather expensive, but the price might go down if more of these materials are being produced. Large quantities of polystyrene envelope have been installed in the Netherlands. It is a good alternative, but still more research is needed in pilot areas. How to produce this material? The pipe is laid through a sort of a windtunnel where the polystyrene granules are blown around the pipe and immediately the foil is wrapped and sealed. It is a difficult material to test, because all these grains are electrostatically loaded. Data from pilot areas shows that it is certainly not a material, which we should reject immediately.

Question from Mr. Boumans (The Netherlands)
In Egypt plastic pipes had much less silt deposition than concrete pipes. Are there similar experiences in other countries?
Answer of Mr. De la Torre (Peru)
We have the same experience in Peru.
Comment of Mr. van Someren (The Netherlands)
It is a matter of quality of the work. The perforations in the corrugated plastic pipes are per definition of a controlled uniform size, whereas the joints between the concrete or clay tiles may have a poor fit, depending as well on the pipe quality as on the laying accuracy. When carefully installed, the latter pipes need not to be more prone to failures.

Question from Mr. Singh (India)
Flushing of subsurface drains was mentioned in the first Session of this Symposium. What techniques are used for flushing? Is it also possible to clean clogged filters surrounding the pipes?
Answer of Mr. van Someren (The Netherlands)
During the forthcoming excursion the equipment, used for flushing subsurface drains will be shown. It generally consists of a high pressure pump, which forces a jet of water (via a flexible hose) through a nozzle into the drain. Because of the high water velocity the dirt is loosened and removed from the drain. The construction of the nozzle is such that not only the dirt from inside the drain is removed, but also most of choked perforations of the drain pipe can be opened up. However, in case a dense layer of dirt around the drain has developed, hampering the water inflow, it is generally impossible to cure this.
Comment of Mr. Stuyt (The Netherlands)
Only the pipe corrugations can be cleaned. A recent research project from the Dutch Yssel Lake Polder Authority has indicated that as soon as the clogging (in those cases micro-biological clogging caused by the oxygen level in the pipes) penetrates into the soil and the envelope is clogged, it is impossible to clean. Therefore early maintenance is very important.

Question from Mr. Martínez Beltrán (Spain)
What are the possibilities of saving gravel by reducing the trench width?
Answer of Mr. Zijlstra (The Netherlands)
I think the trench should not be wider than necessary to accommodate the pipe and the thickness of gravel filter that we want around the pipe. If the trench must be wider than it will take more gravel and it becomes a costly affair. The advantage of current trenching machines is that they enable trenches of the minimum required width to be excavated.

Question from Mr. van der Molen (The Netherlands)
Is root growth, especially tree roots, a problem in Israel?
Answer of Mr. Henkin (Israel)
The roots of certain types of tamarix trees clog up the drains. In general, root growth

can be taken out by cleaners, but if there are tamarisk roots or the roots of certain types of other trees then it is impossible to clean, especially when gravel is around the pipe.

Comment of Mr. van Someren (The Netherlands)

In the Mardan project (North Pakistan) all the trees within a distance of 100 feet along the drains were cut.

Comment of Mr. Cavelaars (The Netherlands)

I would like to expand the question. There is a lot of scattered information available about root growth in drains. The roots of field crops may increase siltation a little, but these roots will die after one year. The main problem comes with perennial plants like trees. What is happening with sugar cane? There is some information from Peru, where sugar cane was reported to grow into pipes at a depth of 1.5 m. Is there information available from any place around the world about this particular problem?

Comment of Mr. van Someren

Not to my knowledge.

Comment of Mr. Mihnea (Romania)

In experiments concerning the development of the root zone in irrigated sandy soils in Romania, it was found that the root zone was not deeper than 70 cm. Four years ago drains were installed at 1.0 to 1.2 m and up to now they are functioning well.

Question from Mr. van Aart (The Netherlands)

What are the prospects of the use of mole drainage for the reclamation of heavy marine clays in arid areas, e.g. in Egypt?

Answer of Mr. Spoor (England)

Experiments were carried out in Egypt to develop the mole drainage technique for saline alkali soils. Technically it was found quite possible to produce a mole system, which will leach these particular soils. When it was tried on a larger field scale there was collapse, but this was a function of the irrigation supply being cut off for three months. The soil dried during that time, it cracked and the mole drains failed. This failure would not have occurred with uninterrupted irrigation supply. The basic requirement is to install mole drains in these unstable soils without having any direct connection between the surface and the channel. Otherwise having good quality Nile water flowing directly into these mole channels formed in unstable soils, will cause immediately collapse. If this is prevented, then by the time the water gets to the channel, it is extremely saline and this buffers the sodium effect. In the experiments, mole drains functioned for 7 months with minimum deterioration. On an experimental scale therefore it is technically feasible and knowing the problems it would now be very interesting to take the next step and test the technique on a larger scale.

Question from Mr. Bhatti (Pakistan)

Under submerged conditions, for how long can a lateral drain stay blocked at the outlet without doing any harm?

Answer of Mr. van Someren (The Netherlands)

It is often assumed that newly laid drains (especially in clay soils) should not be left under back pressure conditions. This would hamper the process of maturing and soil structure development and so may be detrimental for the permeability around the drain. In a later stage periodic flooding of the drain trench is considered less harmful. In sandy soils the structure does not play a role, so here the problem does not exist.

Comment of Mr. van der Molen (The Netherlands)

In 1953 we had in the southwestern part of The Netherlands inundations for several months, but after the fields dried again there were hardly any problems with the drains. Only when the soil was highly alkaline, then sometimes the clay particles were washed out and a kind of milk came out. But that did no harm either, because it was such a fine suspension that it didn't settle in the drain. There are many cases where drains are under water during wet times, because of the main drainage system not having enough capacity. So if there are good drains with a good filter all around, in my opinion there will hardly be any damage. The same holds for sandy soils with gravel envelopes.

Comment of Mr. Stuyt (The Netherlands)

In several parts of The Netherlands the subsurface drainage system is also used for subsurface irrigation in the summer and in these areas there are no problems with those drains, even though they are submerged for considerable time periods.

Comment of Mr. Spoor (England)

From our drainage and soil tillage experiences, we have found that if waterlogging occurs soon after soil disturbance or drain installation the risk of soil structure collapse is very much greater, than if the soil has had a few weeks to stabilize before becoming waterlogged. Soil structural bonds, broken at the time of disturbance, reform during the 1-3 week period, increasing the resistance of the soil to breakdown when wetted.

Question from Mr. Bhatti (Pakistan)

Can Mr. Ochs inform us about the drainage performance of polypropylene pipes in the USA, where polypropylene pipes are not generally specified?

Answer of Mr. Ochs (World Bank)

There is hardly any difference between polyethylene and PVC pipes, although they have to be handled a little differently, especially in desert climates. Polypropylene is much like polyethylene and it handles much like polyethylene. There are no standards for polypropylene pipe in the USA, primarily because of the economic conditions. There are standards for PVC, but we seem to be able to make the polyethylene a little cheaper than the PVC. It is more an economic problem, a good product can be made from all three materials.

Question from Mr. Henkin (Israel)

From hydraulic and engineering point of view only (not economic) would there be any advantage in non-cohesive soils for using a synthetic sheet with gravel on top of it?

Answer of Mr. Stuyt (The Netherlands)

That depends on the hydraulic conductivity of the soil itself. In a sandy soil, the majority of the water will enter the pipe from underneath if there is no impermeable layer at a very shallow depth. In my opinion, therefore, it is more important to have a more highly conductive zone underneath the pipe than on top. From the siltation point of view, it is a good solution to have a synthetic sheet underneath and gravel on top. From a hydraulic viewpoint, I doubt that with gravel on top we would have a better functioning drain than if you would completely wrap the pipe with this sheet. This depends very much on the hydraulic conductivity of the soil and the soil structural stability. A badly structured soil is likely to cause problems in the long run. Pilot experiments are necessary to analyse this.

Question from Mr. van Someren (The Netherlands)
The use of trenchless drainage machines in non-irrigated areas is developing rather fast. Can we say that this technique has found general acceptance and will ultimately replace the trencher? What are still the constraints?
Answer of Mr. van Soest (The Netherlands)
What we as manufacturers do inevitably is to collect information on this subject and from this we extrapolate the possibilities to start a discussion on the use of this machine in other areas where it has not been accepted. Mr. Ochs told us about the first experiments in California and concluded that there is definitely a limit at a depth of two metres. However we will not exclude the possibility of going deeper, in particular for the soils in Pakistan. For economic reasons the trenchless technique (shallow drainage) is at the moment only applied in France due to the soil conditions in that country. In general the trend is to put in the collector system at a depth of two metres. But the real problem is the amount of funding available, because if undeep soils have to be drained, trenching techniques can't compete and in such conditions the trenchless technique is used. This happens at the moment in Finland where trenching is going to be replaced to some extent by trenchless techniques. There is probably a limit and it depends on how governmental services allow these techniques to be introduced or only to be used in certain soils. In the Netherlands for example the vertical plough was banned and only the delta plough (V-shape) was allowed and as a consequence improved considerably. In my opinion there will not be a very strong development in the direction of ploughs, but we as manufacturers keep an open mind. If under certain conditions drains have to be installed deeper than 2 m, the problem of how to place the filter (if necessary) has to be solved, because as was mentioned here before, the combination of filter and trenchless techniques fails at greater depth.

Question from Mr. Zijlstra (The Netherlands)
Are moles pulled in according to a certain constant grade requirement or at a certain constant depth below ground level?
Answer of Mr. Galvin (Ireland)
Usually in Ireland there are no problems with gradients and the mole ploughs are pulled to a constant depth below ground level (45-50cm).

Discussion of Session 5

Comment of Mr. Singh (India)
On projects and maintenance:
I fully agree with Mr. Ochs that new projects should not be constructed if existing

ones are not maintained properly. However, there are certain 'compulsions' in countries like India, where new projects continue to be taken up, even if earlier started projects can not be completed due to shortage of funds. In my opinion one of the reasons is that in these countries, especially in my country where all new projects are taken up by the government at their own cost, the beneficiaries do not have to pay the cost of drainage, irrigation, and flood control projects. Even for irrigation projects they pay only a nominal water rate, which is quite small in comparison with the operation and maintenance costs, leave alone the capital cost. Since the cultivators get the benefits more or less free, without paying any cost, everybody is keen for projects to be taken up in their own area. When there is a new state government, a new Chief Minister, a new Minister for Irrigation and Flood Control, new Members of Parlement, new Members of the Legislative Assemblies of States, etc. they try to put a lot of pressure for new projects to be taken up, benefitting their constituencies, and in this way increasing the list of projects, even though there are no funds to complete the existing projects, taken up previously.

Regarding maintenance a system of planned and non-planned projects is used in India. Planned projects involve new developments and they are given higher priority by the government. Non-planned projects are paid from government revenues and they are always short of money, so there are regular cuts in non-planned-expenditure, mostly on maintenance funds. Quite often the maintenance funds are just sufficient to pay the costs of regular establishment of staff on monthly basis and there is no money for the maintenance work to be done. Perhaps the solution could be that beneficiaries must pay some share of the cost. The National Commission on Floods, appointed some years ago and of which I was a part-time member, recommended that for flood control projects there should be a recovery of at least 1% of the cost, to pay a nominal charge for operation and maintenance and to make the people aware that they are participating, and have some stake. For drainage projects the recommendation was 3%, because the beneficiaries can be more closely identified. However the recommendation was not accepted by the government, because it was considered very difficult to implement.

Question from Mr. Bhatti (Pakistan)
In Pakistan provincial irrigation departments are responsible for maintenance of drainage systems. The experience is that most of their effort is centered on the distribution of irrigation water. Drainage is greatly neglected. In order to give due emphasis to drainage and its maintenance, would it not be feasible to have separate irrigation and drainage set-ups? Are there any examples of irrigation and drainage being separate organizations?

Answer of Mr. Abdel-Dayem (Egypt)
In the past when drainage activities started in Egypt maintenance didn't get enough attention. But with the progress of projects it was realized that those projects wouldn't anymore function if they were planned without establishing an organization to take care of operation and maintenance. The Egyptian Public Authority for Drainage Projects, which is entrusted with the pre-drainage investigations, the design, construction and maintenance of drainage systems, established a well-structured organization to

take the responsibility of operation and maintenance of all completed drainage works. The delta area is divided into 8 maintenance directorates and these are split-up in 47 maintenance centres with 214 subcentres. The annual open main drain maintenance is implemented by public sector contractors, employed directly by the maintenance directorates. The maintenance of covered drains (tiles) is carried out by the centres and subcentres: each subcentre is responsible for 5000 feddans (1 feddan = 1 acre) and a centre maintains tile drains in an area of 40 000 to 50 000 feddans. The equipment, required for those centres and subcentres, is provided by the government. Periodic maintenance of open drains is carried out according to a fixed programme. Weeds are the main problem in open drains. Weed control is done manually in 45% of the drains and mechanically by draglines and excavators in 37%. Chemical control of weeds is carried out in the rest of the drains. High-pressure flushing machines (operated by an agricultural tractor with a watertank) are used to clean tile drains. Bamboo rods are used in fields not easy accessible for these machines. The major problem in this respect are the roots of trees (see Discussion of Session 4). In Egypt the long collector drains are crossing irrigation channels and the roots of the trees on the banks of these channels can penetrate into the pipes. This root penetration causes overpressure in the system and sometimes clogs completely the pipes. Experiments for mechanical removal of these roots are subject to investigations. Concerning the question whether a joint or a separate organization for irrigation and drainage is preferable, I can answer that in Egypt there are separate organizations for irrigation and for drainage, both belonging to the Ministry of Irrigation. Subsequently there is coordination between the two organizations at high level, but they function independently.

Comment of Mr. Ochs (World Bank)

It is rather difficult to say which way to go. I advise whatever way as long as the work is done. But I would like to mention a point, which I neglected in my presentation. Very often when organizing a new maintenance group the tendency is to put people in this group who nobody else wants and also not to provide the financial support, neither the social nor moral support to this group. This is wrong. Perhaps it is necessary to include also an engineer, who is dynamic and gets the support and really wants to fight for his funds and his people to get the work done. This unique and strong individual in charge of a maintenance organization is much more needed than in the area of design. Furthermore I tend to hesitate to build up duplicate organizations for maintenance, because the costs increase by creating additional organizations. From the point of operation efficiency I prefer to create divisions within an organization that has the responsibility.

Comment of Mr. van der Molen (The Netherlands)

The man who makes a structure has a higher status in our country and elsewhere than the man who maintains the structure, although the latter one is as important, maybe more important. There is a general neglect of maintenance and the image of maintenance plays an important (negative) role in this respect.

Comment of Mr. Arar (FAO)

In this respect I would like to mention an experience in Jordan. The Jordan Valley Development Authority was created in the early sixties and is responsible for the implementation, operation and maintenance of irrigation and drainage systems. Farmers have to pay water fees for 1500 mm/year, which are doubled when farmers use excess water. Efforts of JVDA to create farmers associations for taking over the operation and maintenance of the system failed, due to the fact that the farmers could not organize themselves at that moment. So it is my opinion that in developing countries operation and maintenance of irrigation and drainage systems should be the responsibility of the organization charged with the implementation of the system. But unfortunately due to financial, social, and sometimes political reasons limited funds are allocated to maintenance and often those funds are spent in new projects, which are much more attractive than maintenance of existing projects. I agree with Mr. Ochs that, if systems are well constructed, the reduction in maintenance cost will be considerable and in my opinion there is a large scope for covered drainage, because if this system is constructed properly, the maintenance will be negligible.

Question from Mr. Bhuiyan (Philippines)
In most of the developing countries, engineers are trained to 'design and construct' rather than to 'maintain'. In water organizations, O&M work is often considered a 'second class' job. All this contributes to the problem of neglected maintenance of drainage (and irrigation) projects. What can the World Bank do to improve the conditions in the Bank-funded projects?
Answer of Mr. Ochs (World Bank)
Concerning the training for maintenance there are requirements for training of maintenance people that need to be met, but are probably not fulfilled at present due to the very few opportunities for special maintenance training. This should be solved. What can the World Bank do about this? Loan officers of the Bank very often are not supportive of this, because they tend to worry as bankers normally do about getting our money to loan and therefore, in the negotiation process we need also to convince the staff in the Bank of these aspects too. In my opinion there is a problem in our own organization on the emphasis that is required on maintenance. Personally I will try to do something about that in the future, which is a difficult job. Also discussions between countries and Bank about the different standpoints can contribute that something is done in this respect.
Comment from Mr. van Alphen (The Netherlands)
The message on maintenance and installation quality control is clear. However, it is my opinion that during loan negotiations these aspects are of minor consideration. If they were, many loans would not have come through.
Comment of Mr. Ochs
I agree with Mr. van Alphen.

Question from Mr. Vermes (Hungary)
Should an Environmental Impact Assessment (EIA) process be provided during the design of drainage and irrigation projects? If yes, are there guidelines or instructions available, e.g. at the World Bank for such an EIA study? Can Mr. Ochs quote examples where such EIA studies have been conducted for a drainage system, and its positive effect on the project or on the operation?

Answer of Mr. Ochs (World Bank)
As far as I know the World Bank does not have any guidelines on this at present. However, it is one of our efforts and a first draft to develop some guidelines for drainage systems is expected by March 1987. In some countries there are individual guidelines and they are probably of some use. In the USA a few years ago a law has been passed called the National Environmental Policy Act that requires all agencies at any time when federal funding is involved in a project to go through an environmental evaluation and an environmental assessment and develop environmental measures wherever it was found that there would be negative effects. In project development in the USA there are a few examples of environmental evaluations and assessments that were made. The Soil Conservation Service's procedure, US Department of Agriculture, involving drainage was quite good and provided an opportunity to evaluate environmental values and changes in these values. These can be evaluated in assessment procedures by using matrix type check sheets. These procedures are working quite well in the USA.
Comment of Mr. van der Molen (The Netherlands)
In our country exists a similar procedure, which is still in the process of being developed, because different interests have to be reconciled, but this is a problem everywhere. Even in one of our polders a wildlife area was built, which is at present one of the most famous nature reserves in our country. It is entirely artificial and water management measures are on a high level of refinement, especially for this wildlife. A rather accidental, also artificial, development of wildlife I have seen at the tail ends of irrigation systems in Pakistan.
Comment of Mr. Vermes
My question would like to stress this environmental impact assessment during the design and the planning process, because we are convinced that all kind of environmental and water quality control should start at the very beginning of the process by taking into consideration all different aspects. This is the cheapest way of environmental protection.

Question from Mr. Jurriëns (The Netherlands)
How can one expect farmers to maintain their drains: a) when main drains on which they debouch are not maintained by the responsible project or governmental organization and b) when the drains are used for irrigation, because of inadequate supply from the irrigation system?
Answer of Mr. Bos (The Netherlands)
This is indeed a problem, how to charge farmers to maintain drains, which are not part of their water course unit. When they are organized in water users associations, they can cover everything with respect to irrigation in that water course unit by themselves. But a drain or secondary drain between two water course units is part of their area as well as part of the area of an other water users association. In my opinion the only solution is that they both must be organized by a higher authority, in order to arrange that both have a part of the responsibility for that drain. For example in The Netherlands farmers have to clean their own drains, but they are not responsible for the main drains. This is the responsibility of the organization, who levies taxes

and organizes labour for cleaning the main drains. The same can be seen in other countries as mentioned in my paper. If there is no higher authority or organization to organize the maintenance, the drain between two water course units will be neglected. In irrigation projects in the coastal areas of Peru, I have seen that farmers blocked their drains due to insufficient irrigation water supply. This is again a problem that only irrigation and/or drainage organizations can solve by enforcing discipline among the farmers or the water users in carrying out their maintenance tasks. Without strong management and discipline it is very difficult to get the maintenance done.

Referring to the question about separate organizations for drainage and irrigation I would like to remark that in many countries both drainage and irrigation are the responsibility either of one ministry or of one authority or of one water development board. But, of course, the tasks will have to be delegated to departments, divisions, or sections in the organization, each responsible for a specific operation or maintenance task. It is my opinion that operation and maintenance tasks in water management projects should be organized in one irrigation and/or drainage organization.

Comment of Mr. van Steekelenburg (The Netherlands)

Concerning this aspect how to organize irrigation or drainage in the same organization, I would like to remark that as long as there is within one organization the combination of design and construction of new systems and at the same time operation and maintenance of systems, there always will be a kind of dominance of the design and construction people over those who operate and maintain. In my opinion irrigation and drainage should not be separated because both are part of the same activity, and should be in the same organization. But design and construction must be separated from operation and maintenance.

Comment of Mr. Ochs (World Bank)

I tend to agree with Mr. van Steekelenburg that in the same organization there must be a separate division for maintenance. But every country has different laws and different philosophies and I hate to say that this is the only way it can be done.

Question from Mr. Neefjes (The Netherlands)

In recent projects maintenance is organized on the initiative of ministries or high authorities. There are also successful maintenance organizations which go from the bottom up to the top like in the Netherlands and in Indonesia, because there legislation and cooperation developed during a long history from a collective need for proper water management. These decentralized systems developed and are now basically different from the top down to the bottom systems. Why people does not use these lessons and involve farmers in every stage of the set-up of such a system?

Answer of Mr. Bos (The Netherlands)

I agree with Mr. Neefjes that in those places in the world where originally farmers developed bottom up organizations themselves, they will function quite well. But the problem nowadays is that governments are starting huge irrigation projects in places where no bottom up organization exists neither in irrigation nor in drainage. If such an organization does not exist, only a top down organization will be the solution with more or less success. I also agree that the farmers must be involved already from the planning stage, but how to organize them is not an easy task. Take for example the preparation of land consolidation in The Netherlands, which sometimes takes 12 years before the farmers in a project vote to execute the project. What can be expected when an irrigation project is created in two to three years? In any case not a situation comparable with situations existing already for generations.

Comment of Mr. van der Molen (The Netherlands)

By going back in history it can be seen that very often these existing organizations were enforced by higher authorities. Smaller organizations were organized at some places with very strict rules and fines. As a consequence of this training during centuries farmers in the west of The Netherlands will obey the water-board.

Comment of Mr. Neefjes

Not only these strict rules and fines, but also the fact that the water-boards in the Netherlands are on the same level as the municipalities, has developed this rather democratic structure. In the water-boards farmers can influence the legislation, which is very important as mentioned by several participants of this Symposium. All the time I hear that the law has to be enforced, but if the law has developed from the actual need, then it is much easier to maintain it.

Comment of Mr. van der Molen

There are several examples in the world apart from The Netherlands and Indonesia where there are such types of organizations. In general age is needed for such organizations and also it needs maturity of the people to obey the rules, which is a difficult point. Law enforcement is quite different from making laws.

Question from Mr. Sevenhuysen (The Netherlands)

There is a tendency to make farmers associations (FA) responsible for all kinds of aspects of project operation and maintenance. To my experience, if funds are collected by them for maintenance there is a resistance to have these funds put into general accounts. Are there possibilities to have these funds managed by the FA themselves and does experience exist?

Answer of Mr. van Steekelenburg (The Netherlands)

Experience in this respect exists in projects along the Senegal river in Senegal and Mauretania. In these projects the water charges collected by the organizations were put into accounts of the irrigation organizations. There was a lot of resistance against it and also the farmers were not motivated to pay these charges. Later on it became a joint responsibility and the water charges were put into separate accounts. To withdraw money from these accounts two signatures, of the farmer and the irrigation organization, are needed. To spend these water charges for certain activities such as operation and maintenance, supply of spare parts, etc. both parties have to agree on it. It is important to put the money aside, and not to channel it to the treasury of the country and to have the votes of both parties involved for spending it.

Question from Mr. Bos (The Netherlands)

Is the cooperation among farmers considered to be a major problem and if so, how can this be improved? Is the cooperation and coordination between farmers organizations and state organizations felt as a problem? How can a better situation and functioning be promoted?

Answer of Mr. Bhuiyan (Philippines)
At present there is in the Philippines a development of better understanding between farmers groups and the National Irrigation Administration (NIA). For many years the NIA tried to promote the development of farmers organizations at the user level with very little success. The farmers always thought that they were getting the worst end of the deal, because they were asked to clean the channels and to do all the dirty work of the NIA, which should be the job of the NIA itself. So the development was very little. Recently the NIA has, on experimental basis, embarked on a plan to share the work between the NIA and the farmers organizations. This sharing does not concern only the work, but also the revenue that comes through the collection of water fees. So the NIA has given an incentive plan to the farmers organizations, which through their own channels go to the farmers, collect the fees from their members and can retain a percentage of the collection if it exceeds a given target within a certain time as an incentive payment. The farmers organizations come under contract with the NIA to maintain the irrigation and drainage channels. For each kilometre of maintenance of the channels the organization receives a lump sum payment, which creates jobs in the farmers society (a second job). By this process the NIA is also saving money, because if the same job had to be done through its own contractors than it would have spent more than twice the amount. Although this experiment is still at a pilot stage, it seems to be doing very well.

Question from Mr. Dahmen (The Netherlands)
Would the World Bank approve a project in which investment costs are higher, thus depressing the internal rate of return to just below 'acceptable' standards, but in which less maintenance, that probably will not be executed anyhow, will be needed?
Answer of Mr. Ochs (World Bank)
I do not think so. If the economic returns are that low, than it will become very difficult to get that project through.
Comment of Mr. van der Molen (The Netherlands)
In general maintenance is not financed by bankers, but if the internal rates are based on too optimistic views of the profits due to lack of maintenance, what happens then?
Comment of Mr. Ochs
In the past years the Bank financed five drainage projects in Egypt and recently also a project just for maintenance of canals and to get the organization developed. Sometimes to save the investment the Bank has to fund maintenance. Another project where maintenance is funded, is a pilot project in Mexico for the on-farm part and the village part of maintenance work and a kind of start-up fund is available for purchasing equipment, etc. necessary for maintenance work.

Question from Mr. Mihnea (Romania)
During winter and early spring the drainage canals in Romania are affected by snow backfilling. Is there experience with mechanical cleaning of blocked canals under these conditions?
Answer of Mr. Hamster (The Netherlands)
When the drains in the area of our water-board 'Veenmarken' are filled up with snow

and/or ice, a high water level is maintained in these drains and consequently the water can flow underneath the snow and ice. If the water level is too low, the snow or ice will block the water flow.

Comment of Mr. Ochs (World Bank)

These problems exist in drainage canals in the northern part of the USA where it is impossible to maintain water levels, because very often the canals are frozen from top to bottom. When the spring floods come, there are big problems at the bridges due to the drifting of ice blocks. Most of the time draglines are located at the bridges or are movable from bridge to bridge, e.g. rubber-tired truck-mounted draglines, in order to remove the ice chunks when these start to drift at the bridges, damming the canal and creating floods. In my opinion it is the only successful operation.

Comment of Mr. Kabat (Czechoslovakia)

In this respect I would like to make a comment concerning drain pipes. In Czechoslovakia the pipes are installed at a depth of 80 cm, but in my opinion the estimation of freezing depth in soils, e.g. loess, is not reliable. This can cause problems in the functioning of the pipes. Recently when digging up clay pipes it was found that they were damaged by ice, because the pipes were frozen and this damage will complicate maintenance operations.

Question from Mr. Mihnea (Romania)

Is there experience with chemical cleaning of channel sections?

Answer of Mr. Abdel-Dayem (Egypt)

In Egypt chemical weed control is practised due to aquatic weeds in the channels, which is a big problem. Research on aquatic weed control is the responsibility of the Ministry of Irrigation and specialized institutes. They are testing different types of chemicals, which are not harmful for the environment. Chemical weed control is limited to 10-15% of the total channel length in Egypt. Most weed control operations are done mechanically.

Comment of Mr. van der Molen (The Netherlands)

At present chemicals are hardly used anymore for cleaning channels and drains in The Netherlands, because one of the main problems is that the water is used by farmers and horticulturists downstream, e.g. chemical weed control in drains by a water-board caused complete loss of lettuce production in greenhouses. Later on nature preservation aspects were also taken into consideration.

Comment of Mr. Henkin (Israel)

In Israel chemicals, which quickly disintegrate, are used as spot treatment and not as general treatment. But chemicals are used anyway for malaria control, so there is a problem from that side. However, only rapidly disintegrating chemicals are allowed to be used and for aquatic weed control in channels mechanical means are developed and used.

Comment of Mr. Vermes (Hungary)

Using chemicals for weed control in channels is forbidden in Hungary and most control is done mechanically. In cooperation with Dutch firms floating machines are developed with good results. I like also to mention other research work on weed control with good results, namely weed control by using weed eating fishes, the Chinese grass carp, which is a cheap method. Due to certain limitations it can not be used everywhere.

Question from Mr. Bhatti (Pakistan)
The sloughing of side slopes of drainage channels under high watertable conditions is a serious maintenance problem. Could Mr. Ochs suggest an economical and feasible solution for side slope failures?
Answer of Mr. Ochs (World Bank)
Recently I visited a project in Inner-Mongolia where this was the primary concern. In arid climates soil salinity often occurs, causing dispersion in the soils and consequently problems with the side slope stability. In this project very expensive trials were done in the affected areas with different mechanical means, e.g. concrete lining, precast concrete sections, and concrete-grout filled mattress type arrangements. Some recommendations were to construct parabolic cross sections, to unload the banks of spoil, and to excavate a berm at the top of the water surface profile. Due to the availability of fairly coarse gravel in the nearby mountains, it was also recommended to use this gravel as a toe drain, about one third high as often is done in the USA, and to put in a cut-off. This method is the cheapest one if such material is in reasonable distance from the project. The ultimate solution is to put in a subsurface drain, an interceptor along the boundary of those areas with troubles.
Comment of Mr. van der Molen (The Netherlands)
I agree completely. But if an area where this problem exists will be tile drained, it is not very costly to put in an extra drain along the canal at a few metres distance with some outlets. In my opinion this is the solution for the side slopes failures in Pakistan.

Question from Mr. Henkin (Israel)
Several times in discussing environmental aspects I was informed that environmentalists were able to define their goals. I never really met environmentalists, who were able to define their goals so exactly that they could tell me very intangible aspects or quantitative data. An example from Tennessee: environmentalists delayed the construction of a multi-million dollar dam due to a certain snake type, which became an endangered species. Later on they found that this endangered species was located in five or six different places elsewhere, but in the meantime they stopped the work of the dam for years. How can I handle this?
Answer of Mr. Ochs (World Bank)
I agree. It is quite a severe problem, particularly in the early stages when environmental groups are so strong that they will not accept any change. Those groups are really difficult to work with. The way USA authorities tried to deal with it, after the Environmental Policy Act was passed, was to try to get other more realistic environmental groups also involved in helping with these environmental evaluations. The key is to find other groups that are reasonably well respected, more open-minded and more realistic about what can be done. If those groups are together with other environmental groups than the chances are a little better.

Question from Mr. Henkin (Israel)
Some recent constructed small dams in Israel became bird sanctuaries and environmentalists demand a say in its operation. Who should be responsible for an environmental evaluation?
Answer of Mr. Ochs (World Bank)
In my opinion the organization that will be responsible for implementing, is responsible for leading the environmental evaluation. Of course it should involve environmental organizations as well as other groups with different interests. Because whoever is making the plan and whoever will be responsible for the project, is responsible for the environmental evaluation as well.
Comment of Mr. Cavelaars (The Netherlands)
Although the word 'different interests' has been used, I do not think that there are so much different interests. How do I see it? The environmentalists are just an expression of concern, which we all have, against what has been happening in the recent past when mankind was bulldozering one sided all over this planet in whatever form, e.g. poor peasants going up hill to cut trees for their firewood or big firms chopping down forests by hundredth of hectares. Therefore I think it is quite normal that an expression of our own consciousness is coming-up, which takes the form of some environmentalists. So no bad words for the environmentalists.

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II Foreign participants

III Dutch participants

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