"TOWARDS INTEGRATION OF IRRIGATION AND DRAINAGE MANAGEMENT"

Proceedings of the jubilee symposium (25-26 november 1996) at the occasion of the fortieth anniversary of ILRI and thirty-fifth anniversary of the ICLD

W.B. Snellen (editor)

ILRI
WAGENINGEN
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PREFACE

The Earth Summit held in Rio de Janeiro in 1992 emphasized the need for integrated irrigation development and management (United Nations Conference on Environment and Development/UNCED). The Jubilee Symposium at the occasion of the fortieth anniversary of ILRI and the thirty-fifth anniversary of our International Course on Land Drainage (ICLD) looked at the possibilities and potential benefits of better integration of irrigation and drainage management. ILRI selected this theme because of its belief that the integration of irrigation and drainage management represents an opportunity to alleviate many of the problem issues in irrigated agriculture. As irrigated agriculture is by far the largest consumer of freshwater, these issues are highly relevant for the water sector as a whole and for rural communities, particularly in developing countries of the arid and semi-arid regions where environment, employment and food security depend on irrigated agriculture.

For these reasons, the highlights and conclusions of the Jubilee Symposium were presented to an international audience of policy and decisionmakers in the water sector, on 28 November, 1996.

The proceedings before you provide a complete account of what was presented and discussed at the Jubilee Symposium.

I wish to thank all those who were active in planning, organizing and participating in the Jubilee Symposium and also those who assisted in preparing the proceedings.

Wageningen, April 1997

M.J.H.P. Pinkers
Director ILRI

ACKNOWLEDGEMENTS

The first meaning of **symposium** according to *The Concise Oxford Dictionary*, is '**1**. Ancient-Greek after-dinner drinking party with music, dancers, or conversation.' While our symposium involved a certain amount of 'wining and dining', this was not a primary objective. A more suitable description is given in *The Longman Dictionary of Contemporary English*: '**sym-po-si-um** / a meeting between scientists or other people experienced in a particular subject, in order to talk about a certain area of interest.' The names of the scientists and other interested people who took part in our symposium are listed in these proceedings, as a speaker, author, session chairman, rapporteur or participant. Their contribution is greatly appreciated. There are other persons who are not mentioned elsewhere in these proceedings, and without whom there would have been neither symposium nor proceedings. These are the ILRI support staff, whose contribution is hereby acknowledged. In particular, we wish to thank Mrs. Elizabeth Rijksen for handling most of the logistics, Mr. Joop van Dijk for doing all the artwork, and Mrs. Dorethé Kuijpers for processing and finalizing the text and lay-out of the proceedings.

Organizing Committee
Cor de Jong
W. Bart Snellen

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PROCEEDINGS OF ILRI SYMPOSIUM: TOWARDS INTEGRATION OF IRRIGATION AND DRAINAGE MANAGEMENT

Introduction by the editor

ILRI organized a symposium, entitled TOWARDS INTEGRATION OF IRRIGATION AND DRAINAGE MANAGEMENT, on 25 and 26 November 1996 on the occasion of its 40th anniversary and the 35th International Course on Land Drainage (ICLD).

The main objective of the symposium was to identify research needs that promote integration of irrigation and drainage management and contribute to a sustainable water, salt, and financial balance.

To achieve this objective, first a background paper was prepared which 1. Explains why this theme was selected, 2. Describes the organization of the symposium, and 3. Provides guidelines for presentations. The background paper is included in these proceedings as Annex A. It was sent to potential guestspeakers, who were asked to prepare a presentation, if they were interested in the topic. Fortunately, the response was adequate to prepare a programme with 15 speakers. Subsequently, this programme was considered interesting enough for some 100 participants who not only gave two days of their valuable time, but who also contributed examples from their own experience.

The symposium consisted of four sessions:
1. Examples of situations that call for integration of irrigation and drainage management;
2. Technical innovations towards integration of irrigation and drainage management;
3. Institutional innovations towards integration of irrigation and drainage management;
4. Identification of research needs.

In the first three sessions, 15 presentations were given by speakers representing FAO, IIMI, IPTRID, IWASRI (Pakistan), DRI (Egypt), Euroconsult, The Waterboard of Schieland (Netherlands) and ILRI. The contents of their presentations and a summary of the discussions are given in these proceedings.

In addition, 89 participants from 16 countries contributed examples from their own experience on standard forms. On the basis of these forms, participants were divided into 6 sub-groups, who in the fourth session discussed research needs in their specialized fields. The results of these discussions are also presented in these proceedings.

Wageningen, April 1997 W.B. Snellen

Session 1 Practical examples that call for integration of irrigation and drainage management

Dr.Ir. W. Wolters (ILRI) and Dr. M.N. Bhutta (IWASRI). *Need for integrated irrigation and drainage management, example of Pakistan*

Dr. J.M. Beltran (FAO). *The need for integration of irrigation and drainage management; some examples and proposals*

Dr. N.K. Tyagi (CSSRI). *Salinity management: the CSSRI experience and future research agenda*

Dr.Ir. L.K. Smedema (IPTRID) and W.J. Ochs (World Bank). *Integrated water management for the humid tropics*

Ir. H.W. Denecke (ILRI). *Towards integration of irrigation and drainage management in the Aral Sea basin*

Chairman:	Prof.Dr.Ir. R.A. Feddes (Wageningen Agricultural University)
ILRI rapporteur:	Ir. K.J. Lenselink

NEED FOR INTEGRATED IRRIGATION AND DRAINAGE MANAGEMENT, EXAMPLE OF PAKISTAN

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Abstract

Pakistan has the largest contiguous irrigation system in the world, 16 Million ha. Lack of well-defined natural drainage in the Indus Basin has caused a surface drainage problem that has been further aggravated by construction of roads, railways, flood embankments and the irrigation system, while the existing surface drainage system is inadequate. The agricultural sector of Pakistan suffers dearly from this drainage problem, which is among the causes leading to waterlogging and salinity. About 75% of the population is dependent on agriculture, and about half of the Gross National Product is related to the agricultural sector.

The irrigation system is simple in set-up, with continuous flow all the way down to the *mogha* (tertiary unit offtake), from where the farmers take over management of the water. Formally, operation and maintenance of drainage systems is to be taken care of by the Provincial Irrigation Departments, a few years after completion of the systems. However, these Departments do not receive additional funds when they are presented with the additional charge of O&M of the drainage systems, and therefore, the systems could not be operated and maintained as necessary. The administrative structure of the Provincial Irrigation Departments was established around the extensive canal irrigation system. With the installation of the drainage systems, separate sections were simply added to the administrative structure, but not integrated in the existing set-up. This resulted in diffused responsibilities for the operation and maintenance of the entire system. Integration of irrigation and drainage management is very necessary because the irrigation management and drainage problems are strongly inter-linked through: (i) irrigation as a cause of waterlogging; (ii) relationship between irrigation management and drainage effluent. Since irrigation and drainage are closely interrelated, research on these aspects should also be interrelated.

Introduction

Irrigation, waterlogging & salinity, and socio-economy

Pakistan has the largest contiguous irrigation system in the world: 16 Million ha. Irrigation in Pakistan is very old; the Indus Basin has witnessed one of the early 'hydraulic civilizations' about 5,000 years ago. Construction of the contemporary system started about a century ago, and the design of the system was based on the principle of thin spreading of available

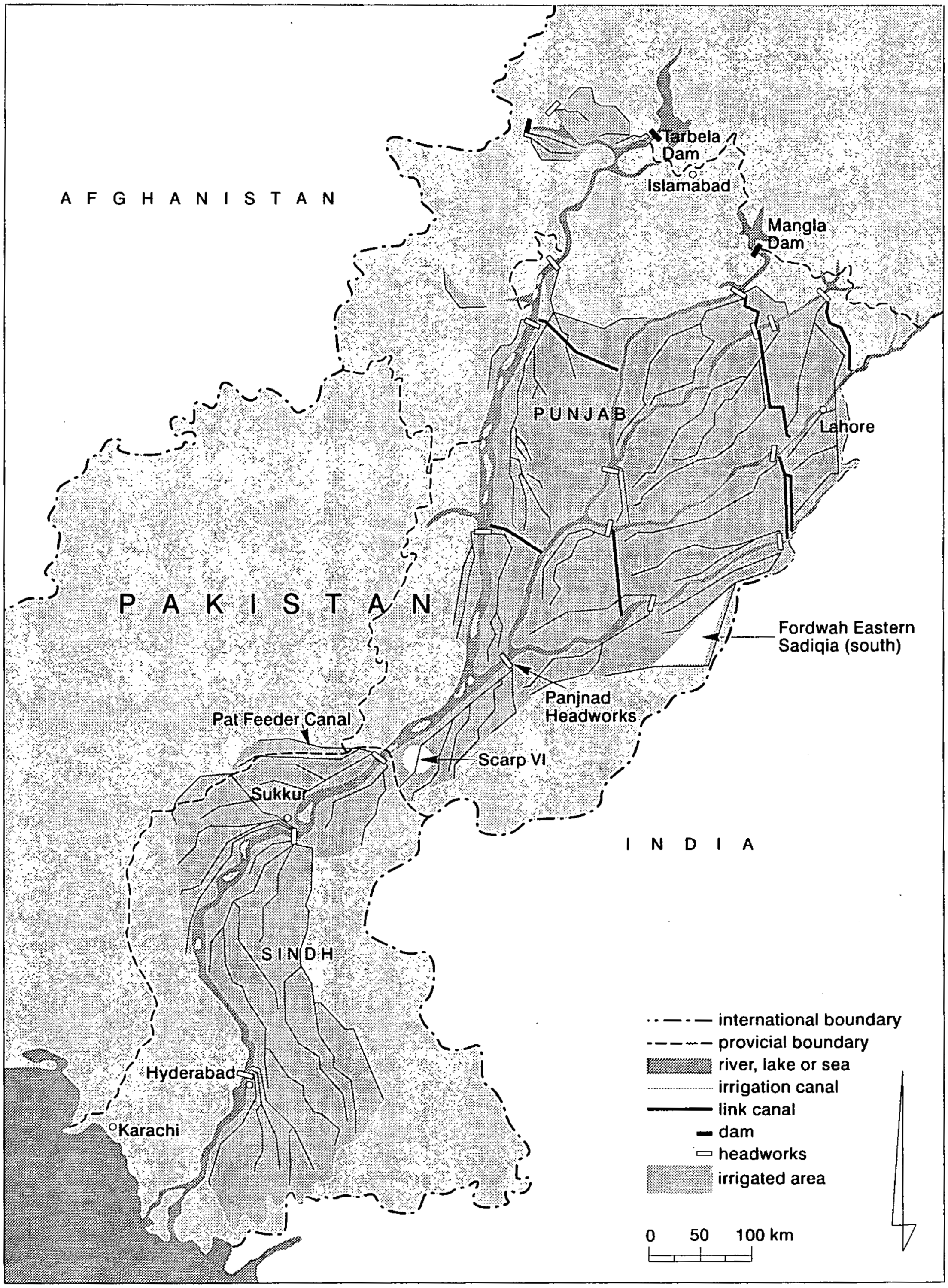

Figure 1. Pakistan and some features of its irrigation system

water over a large area. The main purpose of the system was to prevent crop failure in dry years, as there is not enough water to supply the full crop irrigation water requirements. Figure 1 shows Pakistan and some features of its irrigation system.

The introduction of irrigation has resulted in an impressive production capacity. Although the average yields are low in terms of production per area, they are among the highest yields per unit of water in the world (Bhatti et al., 1991). However, the introduction of irrigation has also resulted in widespread waterlogging and salinity. Figure 2 shows the rise of the watertable after introduction of irrigation in the Punjab. For Pakistan, the area of lands (Tarar, 1996) with a water table depth in April-June (pre-monsoon) within 5 ft (1.5 m) of the soil surface varies between 1.5 and 3 million ha, whereas Pakistan has almost 6 million ha salt affected lands, of which about half is found in the canal irrigated area. An estimated 2 million ha is abandoned due to severe salinity.

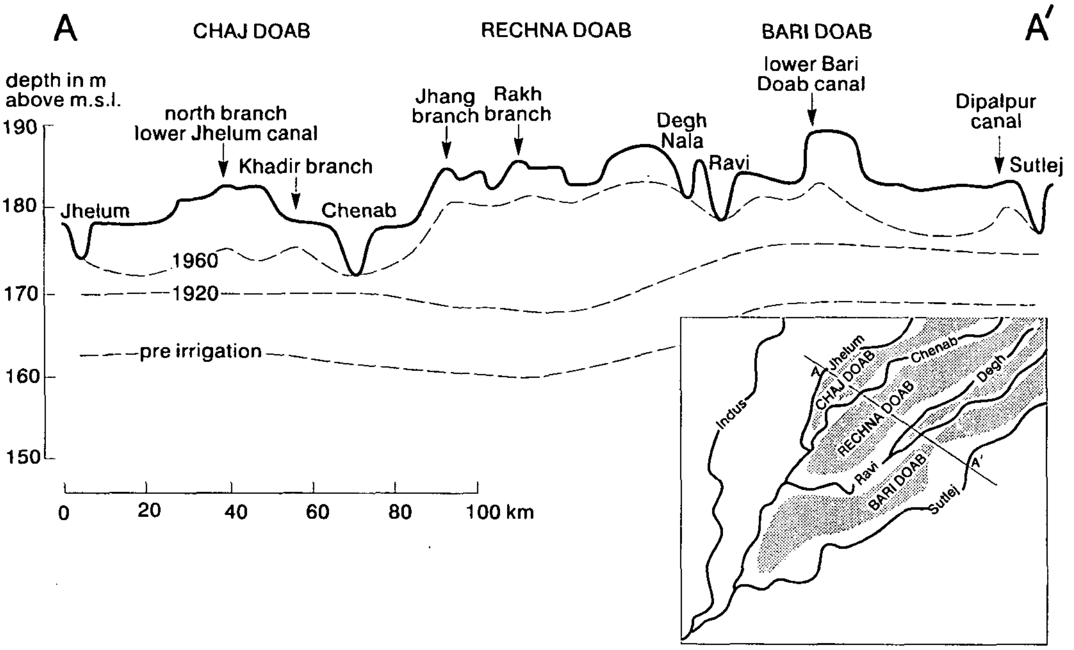

Figure 2. Rise of the water table after the introduction of irrigation

Editors note: This figure is based on Fig.14.4 in ILRI Publication 16 (Ritzema, H.P. 1994. Drainage Principles and Applications). By request of the author, the groundwater profiles for the year 1920 and the pre-irrigation period have been modified. In the earlier figure, these profiles connected with each of the riverbeds, which in the author's present view is not correct.

The salt balance of the Indus Basin is known in rough figures only, but an estimate can nevertheless be made. The salts are brought in by the rivers and their tributaries. The total salt load entering Punjab is about 15.8 Mton of which 2.2 Mton can be disposed of into evaporation ponds. Of the remaining 13.6 Mton, about 2.5 Mton goes below Panjnad mostly during high flow and the remaining 11.1 Mton is stored within the Punjab (NESPAK/MMI, 1993). This implies that, annually, an average of one ton of salt is added to each hectare of irrigated land.

The agricultural sector suffers dearly from the waterlogging and salinity. About 75% of the population is directly or indirectly dependent on agriculture, and about half of the Gross National Product is directly or indirectly related to the agricultural sector. These facts illustrate that problems of waterlogging and salinity are not just agricultural problems, but that they do affect the country as a whole and ultimately the social fabric of Pakistani society.

Waterlogging and salinity remain a hazard for the Indus Basin and threaten the livelihood of farmers, especially the smaller ones. Drainage rather than additional water continues to be priority number one for the sustainability of the system. While this may be understood by planners and researchers, the farmers individually and collectively often appear pre-occupied primarily in securing additional irrigation water.

Drainage in Pakistan

SCARP Tubewells

In the 1950s detailed surveys were made of groundwater tables and salinity in the Punjab with collaboration of the US Geological Survey. These surveys formed the basis for the SCARP (Salinity Control And Reclamation Project) program and for the decision to go ahead with the public tubewell program. About 14,000 such wells, producing approximately 80 l/s (3 cfs) average were constructed in the 1960s and 1970s. The main purpose of the public tubewells was to combat waterlogging and salinity, but where the water was not too saline, it was used for irrigation. This demonstration led to a proliferation of private tubewells of about 28 l/s (1 cfs) and less by the farmers in the 1970s and 1980s, and resulted in a reduction in plans for public tubewell installation particularly in fresh ground water (FGW) zones, where a SCARP transition program is attempting to hand over the pumping of ground water to the farmers. However, in saline ground water (SGW) areas, where tubewell effluent cannot be used for irrigation, the tubewells remain in the public sector but these are plagued with technical and institutional problems effecting O&M. Excessive private tubewell pumping, while increasing the cropping intensity in an environment of scarce canal water and lowering the water table, will deplete the FGW and result in encroachment of poor quality ground water.

Surface drainage

Lack of well-defined natural drainage in the Indus Basin has caused a surface drainage problem that has been further aggravated by construction of roads, railways, flood embankments and the irrigation system. The existing surface drainage system is inadequate, although over the years more than 9,000 miles have been constructed, but not well maintained.

Sub-surface drainage

The technical performance of operated sub-surface drainage systems is good, although the costs may be too high:

- IWASRI has reviewed the performance of drainage systems in Pakistan for a number of years now, and there is ample evidence that the variety of systems (tubewell drainage, pumped and gravity pipe drainage) is capable of controlling the water table at lower levels. Moreover, the soil salinity status, area cultivated, and cropping intensity has improved in many systems also (Bhutta et al., 1995, 1996a, 1996b);
- Costs of drainage. The Government of Pakistan (GoP) cannot continue to fund the operation and maintenance of the entire irrigation and drainage system, in conditions where, for instance, in the fiscal year 1992, the operation of tubewells in the Punjab absorbed more than 50% of the available O&M funding, even though the wells were operated on a very limited basis (SAR, 1992). Also in Sindh, cost of operation of the LBOD drainage system is more than the Government can budget: the annual cost for O&M Rs 600 million (1993 prices, equivalent to about US$ 20 M), with a construction cost of Rs 24,000 million (US$ 800 M).

Present irrigation and drainage management

Irrigation Management

The size of the Pakistan irrigation system becomes clear when realizing that water released from one of the main reservoirs Mangla or Tarbela in the North travels about 20 days to reach fields in the south of Punjab, and more than 20 days for Sindh. Fortunately, the system is simple in set-up, with continuous flow all the way down to the *mogha* (tertiary unit offtake), from where the farmers take over management of the water. In times of water shortage, the water has to be rotated between secondary canals: the minors and distributaries. Theoretically, there is a system of requesting for water also. A main or branch canal is called a Division, split up into Sub-divisions. The 'lowest' Sub-division submits its indent to its upstream Sub-division, and so-on. The accumulated indents will reach the Executive Engineer at the Head-works, and water will be supplied accordingly. Extra water allowance can even be requested for reclamation purposes.

However, actual practice differs considerably. Water, once released from the reservoirs, will flow and will continue to flow. Canals will usually not be allocated more than their design capacity, of which a typical value is equivalent to about 2 mm/d, in a climate with an ET_0 in May-June of about 15 mm/d. Moreover, many canals can even no longer convey their official design capacity, due to siltation and erosion of banks.

Drainage Management

Formally, operation and maintenance of drainage systems is to be taken care of by the Provincial Irrigation Departments, a few years after completion of the systems. However, these Departments do not receive additional funds when they are presented with the additional charge of O&M of the drainage systems, and therefore, the systems can not be operated and maintained as necessary. This is one of the main problems of drainage management in Pakistan.

The administrative structure of the Provincial Irrigation Departments was established around the extensive canal irrigation system. With the installation of deep tubewell-, surface- and sub-surface-drainage systems, separate sections were simply added to the administrative structure and not integrated in the existing set-up. This resulted in diffused responsibilities for the operation and maintenance of the entire system (Bandaragoda and Firdousi, 1992).

Need for integration of irrigation and drainage management

Integration of irrigation and drainage management is very necessary because the irrigation management and drainage problems are strongly inter-linked through: (i) irrigation as a cause of waterlogging, and (ii) relationship between irrigation management and drainage effluent.

Irrigation as a cause of waterlogging

There are several examples of where irrigation causes waterlogging, often unnecessary as it seems:

- By law, neither the Irrigation Department nor farmers are allowed to close a tertiary canal. Once farmers do not need water, it is diverted away from their fields, and collects in the lower areas. Field observations in the Fordwah Eastern Sadiqia system confirm that operational spills collect in depressions, in times of low water demand. The lack of a well-defined surface drainage system, furthermore impeded by infrastructure (as roads, railways, flood embankments, and the irrigation system) causes the water to stagnate, thereby making use of the lower-lying lands impossible. Prevention of spills would undoubtedly lead to less need for drainage;
- The *punchoo* (or *panchoo*) system of Sindh operates differently from the *warabandi* system. *Warabandi* means 'time-sharing'. The water is turned over from farmer to farmer. In the *punchoo* system, however, water is supplied to all farms at the same time. This results in very low application efficiency, as the aquifer is just allowed to fill up;
- By law, outlets for tertiary canals cannot be installed on a main or branch canal. In practice, however, many such off-takes exist, which gives the possibility to take any excess water, for an area for which already a share is included in the secondary canal. This excess does not help in reducing the drainage requirement.

Relationship between irrigation management and drainage effluent

The volume of drainage effluent can be reduced by:

- Increasing irrigation efficiency. Wolters (1992) presents a list of positive and negative effects of increased irrigation efficiencies. Among the negative effects: (i) increased soil salinity because of reduced leaching. The increase of soil salinity due to reduced leaching was studied for Pakistan by Smedema et al. (1992), who conducted rainfall/salinity simulations. The results agreed with the field experience that irrigation-induced soil salinization is not an acute hazard when the annual rainfall is more than 400-500 mm/year. Although there are claims of 'uneducated' farmers who over-irrigate, field observations also show that farmers use water sparingly. The canal supply is by far short of the crop irrigation water requirement, which forces many farmers to cultivate only a part of their lands; (ii) need for more sophisticated operation and more accurate monitoring, leading to more expensive infrastructure and management (if at all possible). The latter point is cost related, and, as the greater part of the farmers are without resources, government investment will be necessary to improve the efficiency of irrigation. Wolters (1992) also presents conditions that favour the efficient use of irrigation water, including: medium or heavier textured soils; control over water flow to the system and within it; sophisticated field application methods; and data availability. These conditions are not always encountered in the Indus basin irrigation system;

- Re-use of drainage water. The volume of drainage water available for potential reuse in Pakistan varies considerably in both space and time, and in addition to salts and trace elements leached from the soil, drainage may contain domestic sewage, industrial effluent and chemicals, such as fertilizers and pesticides. Data on trends and patterns in drainage quantity and quality is a prerequisite for any proposed re-use scheme. Although some limited spot sampling has been undertaken in this regard, no long-term, comprehensive data exist. Available data is scattered having been collected at different times by different organizations using a variety of methods at sometimes ill-defined locations. The direct use of untreated effluent for irrigation, which is being practiced by some farmers in Pakistan, frequently leads to damage to crops and could be a danger to public health.

Related to the desired reduction of drainage effluent are salt disposal problems. Evaporation ponds are a means of disposing of saline drainage water for a number of command areas in the middle reach of the Indus plain, Punjab. Evaporation ponds are already in operation in two commands (Pat Feeder on the Indus right bank and SCARP VI on the Indus left bank). Other ponds are in an advanced stage of planning for another command (Fordwah Eastern Sadiqia South). Evaporation ponds may eventually serve a total area of 1 to 2 million ha. Data on their performance and environmental impacts is scarce. Monitoring of the existing ponds has been limited. However, these ponds have created waterlogging of nearby agricultural lands through groundwater seepage.

Problems of salt disposal are experienced all over the world where there is no environmentally acceptable means of drainage waste disposal. Research is now yielding unconventional solutions to many of the traditional problems with re-use. Ochs et al. (1995) present an example of 'agro-forestry', where drainage water is re-used for increasingly salt-resistant crops and trees, with the drainage water becoming more concentrated in the process, but reduced in volume. Ultimately that water is disposed of into a solar evaporator, where the salt is converted into a crystalline form.

The future

To tackle the urgent problem of waterlogging and salinity - which is the result of a multitude of factors, including: human intervention in nature, financial neglect, mismanagement, decay of institutions, lack of planning and learning from research, exclusion of the end-users as active stake holders in the management of the system - a mid-term strategy emerges from the National Drainage Program. This strategy essentially relies on drainage, implemented along-side long-term measures, as the single most important operation to bring the Indus System back into balance that can then be maintained by the adoption and institutionalization of the measures of a long-term strategy. Environmental impact mitigation of the negative effects of drainage should form an essential part of the surface and subsurface drainage schemes, as well as of the small schemes to alleviate localized drainage and public health problems.

The Government cannot continue to inject huge amounts of money in drainage projects forever. The users will have to take their share as well. Preferably, and that seems to be a growing consensus now in Pakistan, the main systems of irrigation and of drainage should both be managed by the Government. Somewhere in between, the users of the system should become involved in the management. The GoP has plans and policies ready in this direction, outlined in the National Drainage Programme (NESPAK/MMI, 1995). In this programme, PIDA's, Provincial Irrigation and Drainage Authorities, will become autonomous bodies to manage the system. The conceptual framework of the National Drainage Programme mentions as three specific objectives to be achieved through the programme:

- Participation of farmer's organizations and private sector in construction, operation and maintenance of drainage facilities;
- Targeting government investment on areas in greatest need of drainage;
- Quicker returns by targeting drainage investments on smaller scale, quicker yielding interventions.

The NDP proposes to directly involve farmers in the planning, design, construction, operation and maintenance of on-farm drainage systems. It presents modes for setting-up and operating farmers organizations and stipulates that research should develop instruments to involve the farmers. NDP admits that there is limited experience with direct farmer participation in on-farm drainage in Pakistan and states that the technical capacity will initially be weak. During a transition stage farmers could learn, thereby assisted and guided by professionals, directly or through Non-Governmental Organizations (NGO's).

However, we should not expect too much of this 'social approach' in a short time, because:

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

Need for integration of irrigation and drainage research

Since irrigation and drainage are closely interrelated, research on these aspects should also be interrelated. For example, the recharge of the aquifer due to seepage from the (canals of the) irrigation system is considered as the main cause of drainage problems. Therefore, several recharge reducing measures are being studied. This includes: (i) improved field irrigation management; (ii) seepage interceptor drains along canals; and (iii) lining of distributaries.

The 'drainage' research will show the impact of installation of interceptor drains, and 'irrigation' research will show the impact of the lining work. But, these results cannot be seen on their own. Their impact has to be integrated for use in recommendations for final drainage plans for the area. For the Fordwah Eastern Sadiqia (South) area, IWASRI studies the combined impact of all proposed measures in a groundwater model.

Much data has been collected in Pakistan, by the SCARP Monitoring Organization, as well as many others. Also, a lot of research has been completed on problems of waterlogging, salinity, drainage and irrigation. However, it appears that the research results are either not extracted from the data, when data is not critically analyzed, or that research results just do not reach the users. For IWASRI, this last group includes: (i) farmers; (ii) planners and designers; (iii) policy makers; and (iv) construction industry.

It is here that the urgent requirement for mobilization and dissemination of research results meets with the task and mandate of ILRI. ILRI is unique in the world, is well-known through its publications as well as its other work, and there is enough scope for another 40 years!

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Discussion

The rapporteur for this session summarized the discussion as follows:

- Dr. Wolters stressed that the farmer orientation must not be considered a panacea: it will not lead to quick results for various reasons, such as the small resource base of the farmer, little experience with the process, and lack of understanding.
- Accepting that irrigation and drainage management should be integrated, research on irrigation and drainage should be integrated as well. The International Waterlogging and Salinity Research Institute (IWASRI) in Lahore follows this approach. The IWASRI also realizes that its research should yield practical results and offer 'value for money'. Potential benefits from a number of research items were calculated, showing that a multiple of the IWASRI budget could possibly be saved. In addition, IWASRI sees an urgent need for mobilizing the vast amount of data that have already been collected, e.g. by the SCARP Monitoring Organization, so that these data become available to the potential users, be they farmers, planners, policy makers, or the construction industry.
- In remarks from the audience, better application of known research results was stressed. Also, available technologies are not so easily accessible/adaptable. The point of groundwater management in relation to drainage problems was also stressed, although it is sometimes difficult to find data for groundwater models.

THE NEED FOR INTEGRATION OF IRRIGATION AND DRAINAGE MANAGEMENT; SOME EXAMPLES AND PROPOSALS

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In irrigated lands lacking or with insufficient natural drainage, artificial drainage systems are needed to capture irrigation water losses. The conveyance losses can be intercepted either by a subsurface drainage system of parallel drains or by interceptor drains. The operational losses are discharged into the main drainage system and the application losses at the field level are captured by the surface and subsurface drainage systems.

In many rehabilitation projects of areas currently under irrigation, waterlogging and salinization problems must be solved. To do that, a choice has to be made among possible options:
(i) Modernization of the irrigation system.
(ii) Improvement of the water management at the project level.
(iii) Improvement of the water management at the field level without changing the irrigation method.
(iv) Improvement of the water management at the field level by changing the irrigation method.
(v) Intensification of the drainage system.

The following goals can be achieved by investing in modernization of the irrigation network and by improving the irrigation water management:
(i) Water savings.
(ii) Diminishing the drainage recharge.
(iii) Diminishing the drainage requirements.
(iv) Reducing the volume of the drainage water to be disposed.

However, sometimes the costs of modernization of the irrigation systems are so high that a compromise must be reached between investments in irrigation and drainage.

In this paper two examples are described showing the need for integration of irrigation and drainage. The first example comes from the Lower Tunuyan Irrigation Scheme, Mendoza, Argentina. There, alluvial soils situated in a large alluvial fan are irrigated by means of unlined canals on a rotational basis. In the upper and middle parts of the fan vineyards are irrigated with surface water. The overall irrigation efficiency is low and water losses recharge the aquifer. Groundwater flows towards the lower part of the fan, where farmers pump groundwater to irrigate because surface water is insufficient. Soil salinization occurs locally because of the salt content of the groundwater. In the adjacent fan formed by the river Mendoza, the low-lying lands need subsurface drainage to avoid waterlogging. Therefore, the best solution from a technical, economic and environmental point of view calls for integration of irrigation and drainage management.

Similar cases are common in the irrigation districts of northwestern Mexico, such as the Carrizo district in Sinaloa. There, seepage from unlined irrigation canals and application losses due to surface irrigation recharge the water table, which is close to the soil surface in the low-lying areas. In developing a solution to these problem, a comparison must be made of the benefits and costs of modernization of the irrigation network, improvement of the irrigation water management at the field level, and drainage intensification.

A case study on the integration of irrigation and drainage management is the Bajo Guadalquivir irrigation project. It is situated in southern Spain, where heavy clay and saline soils were reclaimed by means of irrigation and drainage. At the very start of the project, irrigation water was poorly applied. To solve the waterlogging and salinization problems, farmers asked for intensification of the subsurface drainage system by installing a new drain between two consecutive laterals. From monitoring the drainage system and the water management, it was concluded that by improving the irrigation management without changing the irrigation model no new investments in drainage works were needed.

To achieve the integration of irrigation and drainage management some research needs are proposed:
(i) Development of simulation models.
(ii) Introduction of environmental effects in the cost-benefit analysis.
(iii) Evaluation of areas with integrated irrigation and drainage management.

The improvement of the productivity of the areas already under irrigation per unit of water used is an element of a strategy defined in the context of FAO's Special Programme on Food Production in Support of Food Security. To achieve this goal, there is a need for integration of irrigation and drainage in the currently irrigated lands.

In the Waterlogging and Salinity Control activity of the FAO-AGLW Regular Programme for 1997, a proposal has been submitted which include two objectives:
(i) Review the existing simulation model for integration of irrigation and drainage management.
(ii) Review recent experiences in drainage design factors for a revised edition of FAO Irrigation and Drainage Paper no. 38[1].

To achieve these objectives international cooperation is necessary.

Discussion

On the issue of more efficient water use, a question was raised on how to determine the amount of water which is just adequate. Fixing the right amounts of ET and leaching is indeed difficult, but experience will help. Another question addressed the integration of saturated regional models with unsaturated one-dimensional models as one of the difficulties in the development of appropriate simulation models. A final remark was made on the absence of water pricing in the Argentina case. It appeared that the Water Users Association is now being involved in making farmers aware of the cost of irrigation water.

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[1] Drainage design factors, 1980.

SALINITY MANAGEMENT: THE CSSRI EXPERIENCE AND FUTURE RESEARCH AGENDA[1]

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Abstract

Salt affected soils are an important ecological entity in the landscape in most arid and semi-arid regions. In India they occupy nearly 8.6 million hectares and represent a serious threat to its ability to increase food production to meet the expanding needs. The establishment of CSSRI in 1969 gave a real impetus to the reclamation of salt affected soils in the country. The main thrust of the Institute in the seventies was on development of technology for reclamation of alkali soils and its transfer to farmers, whereas in the eighties it was on reclamation of waterlogged saline soils. Of late, the focus is on utilization of poor quality waters and saline effluents. Attention to certain areas of research which were earlier not our priorities is now needed. Generation of excellent inventories on salt affected soils and poor quality waters development of alkali soil reclamation technology for areas underlain by brackish water or areas with limited access to irrigation water; development of alternative technology for situations where subsurface drainage is not feasible; researches on novel methods of utilizing saline water where fresh water is not available for mixing; diversification of existing cropping patterns into cash/horticultural crops; and increasing the pace of technology transfer efforts to marginal production environments needs urgent attention in coming years. Cost of present reclamation technology is rising. Therefore, development of cheaper options for reclamation of alkali soils through the biological route, development preventive strategies to check waterlogging, scientific water management practices, cheaper drainage technology, eco-friendly options for use of saline drainage waters etc., solutions for the problem of excess water in monsoon and deficit in winter in coastal saline soils have been identified as priority areas for research.

Looking ahead at the existing and new challenges in the coming 25 years and to develop a comprehensive strategy in order to fulfill the above-stated mandate, the CSSRI has prepared a perspective research plan for the coming decades addressing all the issues through an inter-disciplinary approach. The perspective plan analyses our strengths and weaknesses in various areas to tackle the challenges ahead and looks at a programme of 25 years, lays the cornerstones of policy within which we need to operate and broadly analyzes the issues which will come to the fore and need our research attention.

Salinity problems in India

In the arid and semi-arid regions, low rainfall coupled with uncertainty of its occurrence has been the major limiting factors in crop production. This is particularly true of India because

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[1] This paper has not been presented at the symposium, because Dr Tyagi was unable to attend.

most of the agriculturally productive regions lie in hyper-arid to sub-humid regions where evaporation far exceeds the rainfall (Figure 1). The introduction of irrigation in these areas has been considered as the most effective way of controlling the other production factors and therefore, the government took necessary steps to develop irrigated agriculture in the arid and semi-arid regions most extensively. Large scale irrigation development in association with high yielding varieties and inorganic fertilizers increased production and productivity and brought stability. However, introduction of irrigation has often been followed by salinity and India is no exception to it.

The salt affected soils are an important ecological entity in India and it is estimated that nearly 8.56 million ha are already afflicted with this menace. The estimates are based on information from secondary sources. The problem being dynamic in nature, the extent keeps on changing. The salt affected soils that occur in different climatic regions have been classified into alkali or sodic and saline categories. The distribution is given in Table 1.

Table 1. Extent and distribution of Salt Affected Soils in India (1,000 ha)

State	Waterlogged area			Salt affected area			
	Canal Command	Unclassified	Total	Canal Command	Outside Canal	Coastal	Total
Andhra Pradesh	266.4	72.6	339.2	139.4	390.6	283.3	813.3
Bihar	362.6	NA	362.6	224.0	176.0	Nil	400.0
Gujarat	172.6	311.4	484.0	540.0	327.1	302.3	1214.4
Haryana	229.8	45.4	275.2	455.0	NA	Nil	455.0
Karnataka	36.0	NA	36.0	51.4	266.6	86.0	404.0
Kerala	11.6	NA	11.6	NA	NA	26.0	26.0
Madhya Pradesh	57.0	NA	57.0	220.0	22.0	Nil	242.0
Maharastra & Goa	6.0	105.0	111.0	446.0	NA	88.0	534.0
Orissa	196.3	NA	196.3	NA	NA	400.0	400.0
Punjab	198.6	NA	198.6	392.6	126.9	Nil	519.5
Rajasthan	179.5	168.8	348.3	138.2	983.8	Nil	1122.0
Tamil Nadu	18.0	109.9	127.9	256.5	NA	83.5	340.0
Uttar Pradesh	455.0	1525.6	1980.0	606.0	689.0	Nil	1295.0
West Bengal	NA	NA	NA	Nil	NA	800.0	800.0
Total	2189.4	2338.1	4527.5	3469.1	3027.0	2069.1	8565.2

Note: NA refers to data not available

As a result of soil degradation, there have been serious negative effects at the farm level, such as: i) decrease in farm production due to abandoned crop lands, ii) decline in resource productivity and iii) cut back in resource use. Similarly at the regional level there has been: (i) displacement of labour from agriculture, (ii) widening of income disparities, and (iii) adverse effect on the sustainability of secondary and tertiary sectors.

CSSRI: mandate and programmes

During the Fourth Five-Year-Plan period (1967-72), the Govt. of India constituted an Indo - American team to assist the Indian Council of Agricultural Research (ICAR) in developing a comprehensive water management programme. This committee inter-alia recommended the establishment of a national centre for research on salinity and alkalinity and water management problems. As a result, one of the most important decision was the establishment of the CSSRI to provide research back-up to maintain sustainability of irrigated agriculture. The institute came into being in 1969. Besides the main institute at Karnal, there are two regional stations, one for dealing with the problem of coastal salinity at Canning Town in West Bengal and the other for black soils at Anand in Gujarat. There are four research divisions at main institute.

Mandate

The CSSRI has the mandate to:

- undertake basic and applied research for generating appropriate agro-chemical/biological/ hydraulic technologies for reclamation and management of salt affected soils and use of poor quality irrigation waters for sustainable production in different agro-ecological zones.
- evolve, evaluate and recommended strategies that promote adoption of preventive/ ameliorative technology.
- act as a repository of information on resource inventories and management of salt affected soils and waters.
- be a nucleus of research on salinity management and coordinate/support the network of research with universities, institutions and agencies in the country for generating and testing location-specific technologies.
- act as a centre for training in salinity research in the country and region and provide consultancy.
- collaborate with relevant national and international agencies in achieving the above goals.

Research programmes

The institute has organised its research in programme mode. The following are the major programmes:

- Generation of resource inventories on waterlogged salt affected soils and poor quality waters for land use planning
- Reclamation and management of alkali soils
- Management of waterlogged saline soils
- Management of poor quality waters, including domestic, drainage and agro-industrial effluents
- Alternate land use of salt affected soils
- Improvement crop tolerance for salinity, alkalinity and waterlogging stresses
- Coastal salinity management
- Management of salt effected vertisols
- Technology transfer, impact assessment and human resource development

Salient achievements

During 28 years of its existance the institute has made great scientific strides. The technologies developed by the institute have found favour with the policy makers and the farmers. The institute has also won recognition and appreciation from scientific organizations. Some of the achievements in important programme areas are given below.

Resource inventories

i) Legends for mapping salt affected soils using remotely sensed data were developed and using this methodology, maps of salt affected soils of Gujarat and selected districts in U.P. and Haryana have been completed. This will enable plan formulation for reclaiming salt affected soils.

ii) Water quality mapping for irrigation on 1:6 million scale for country has been published. This map gives useful indications on the extent of saline/sodic waters.

Alkali soil reclamation

i) A reclamation package for alkali soils in terms of application of 50% of gypsum requirement in the upper 15 cm soil only, and agronomic and cultural practices for a rice based cropping system have been developed. The technology has been adopted in about 7 *lakh*[2] ha area in Punjab, Haryana and U.P. and additional food grains to the extent of about 3 million tons are being produced.

ii) For the poor farmers, low input technology for reclamation of alkali soils by biological means through Karnal grass/rice (CSR-10) based cropping systems has been developed. This is finding applications in some areas of Uttar Pradesh.

iii) Salt tolerant tree species for sodic and saline/waterlogged soils have been identified. Also planting techniques (auger hole, pit-auger hole, ridge-furrow) have been developed. Biomass production, nodulation, nitrogen fixation and nutrient recycling studies in multi purpose tree species (MPTS) demonstrated the potential benefits. The technology is finding increasing application by the forest department.

Management of waterlogged saline alluvial lands

i) Design criteria for subsurface drainage in waterlogged saline lands of alluvial region has been developed. The performance in terms of crop production and salt removal has been evaluated. A number of large pilot projects have been initiated by state agencies which are based on the technology developed.

ii) Information on evapotranspiration and other factors for important crops of the region has been developed through electronically weighing lysimeters.

iii) Management models for evaluation of irrigation performance and system design for improved irrigation efficiency in irrigation commands have been developed. Adoption of the prescribed intervention would lead to reduction and delay in occurence of salinity.

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[2] 1 lakh = 100,000

iv) Disposal strategies for saline drainage effluent in closed basins have been tested and proposed to users.

Use of poor quality waters

i) A procedure to assess damage by waterlogging and salinity in irrigation commands was developed and applied to several important irrigation command areas.
ii) Improved technology for using saline/sodic waters has been evolved. Pre-sowing irrigation with good quality waters, if available, allowing the use of high salinity waters at later stages of crop growth, is the general recommendation. Recommendations on the preferred mode of saline water use has been developed and tested through the network programme.
iii) ORP findings on saline water use and on *Dorouvu* (Skimming wells) technology for skimming fresh water floating over saline aquifers in coastal sandy soils (Andhra Pradesh) has been highly succesful.

Crop improvement

i) Breeding programme on development of salt tolerant crop varieties resulted in the release of CSR 10, CST 7-1 in rice and KRL 1-4 in wheat. Several varieties of other crops are at various stages of development.
ii) Indices for higher tolerance of some crop varieties have been established in terms of avoidance of excessive Na uptake and maintaining a low Na/K ratio in shoot.

Coastal salinity

i) An economically viable 'package' on rainwater harvesting in dugout farm ponds and its judicious use for multiple cropping was evaluated in coastal saline soil conditions.
ii) A crop calendar for Sunderbans (coastal area in West Bengal) which permits best utilization of rainwater and minimizes yield losses due to heavy storms, has been developed.
iii) The salinity/sodicity tolerance of crops has been established for monsoonal climate. the major efforts have been made in development of strategies for conjunctive use of saline and fresh water for different crops.

Human resource development

i) Through training and other human resource development programmes, over 1100 SMSs, working in State Departments were trained. This would strengthen land reclamation activities in the country.
ii) An advanced centre of post graduate education and research on 'Irrigation management' was established with UNDP support. 15 Ph.D. and 20 M.Techn. scholars completed their postgraduate programme. Advanced training was also provided through the Indo-Dutch project on Agricultural drainage. This trained manpower would, to some extent, meet the growing need for trained research personnel.

Salinity vision - 2020

Sustainable management of soils, water and crops - the basis resources of agriculture, calles for a holistic and visionary approach to plan for the future. The pace of technology introduction and its absorption in recent years has been so rapid that in the 21st century, agriculture in India will be practiced under quite different ecological, technical adn socio-economic conditions than in the decades before. Water and not land would be the major constraint in producing enough food at that time but soil management concerns such as physical, chemical and biological degradation would also become increasingly relevant. Agricultural development in the future would have to be sensitive to social needs but at the same time will have to take care of environmental issues.

The important unfinished agenda include development of:
- alkali soil reclamation technology for areas underlain with poor quality waters, and in areas with resource constraints.
- effective prevention strategies for arresting the further spread of soil salinity and waterlogging.
- low-cost drainage technology for saline and waterlogged soils for implementation in participatory mode.
- methods for eco-friendly use of saline effluents/waste waters, assess impacts on soil quality and human health.
- salt tolerant, high yielding varieties of crop plants and assess salinity effects on plant quality.
- technologies for salt and water management, and alternate cropping systems in coastal saline soils.

In early 1995 the CSSRI celebrated its silver jubilee, took stock of what had been accomplished in the past, discussed the likely future scenario and prepared a document titled **Salinity Vision-2020**, and set the agenda for identifying future needs in different thrust areas. The following are the brief outlines of the studies to be undertaken.

I. Resource inventories on waterlogged salt affected soils and poor quality waters for land use planning

- Preparation of legends for identifying salt affected soils through remote sensing for preparing reliable estimate of waterlogged salt affected soils in selected areas.
- Generation of dat base on poor quality waters
- Linking of the resource base of salt affected soils to their effective management options

II. Reclamation and management of alkali soils

- Sustenance of crop production in post-reclamation phase
- Refinement of existing technology to address emerging and anticipated issues
- Development of technology for soils underlain by RSC[3]/saline waters

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[3] RSC = Residual Sodium Carbonate

- Development of technology for areas with limited access to irrigation
- Development of agroforestry systems for salt affected soils
- Developing strategies for agroforestry interventions in waterlogged saline soils and for recycling saline drainage effluent
- Enhancement of biological nitrogen fixation in agroforestry systems in salt affected soils

III. Management of waterlogged saline soils

- Evolving strategies for reducing drainage volumes
- Development of drainage technology for various agro-climatic zones
- Studies on drainage water disposal alternatives
- Evaluation of socio-economic and institutional mechanisms for increasing adoption of drainage technology
- Studies on brackish water fish culture for disposal of saline drainage effluent

IV. Management of poor quality waters, domestic, drainage and agro-industrial effluent

- Investigation on regional surface and groundwater interaction and modelling water balance
- Development of strategies for conjunctive use of surface and groundwater to optimize their use
- Establishment of tolerance limits of crops to saline/sodic/toxic waters
- Development of appropriate strategies and technologies for utilizing poor quality waters in raising crops and forest species on sustainable basis
- Studies on impact of poor quality waters and effluent on crop and soil quality, groundwater pollution and human health.

V. Crop improvement for salinity, alkalinity and waterloggin stresses

- Generation of stress-tolerant and high yielding breeding lines/varieties in crops and physiological indices
- Field evaluation of suitable crop varieties for use in biological reclamation technology

VI. Coastal salinity management

- Management of water resources and agricultural drainage for sustainable crop production
- Development of improved crops and cropping systems and cultural practices
- Development of alternate farming systems

This programme will be undertaken by the regional centre of CSSRI at Canning Town, West Bengal.

VII. Management of salt affected vertisols

- Refinement of existing technology to address emergin and aticipatory issues
- Development of technology for soils underlain by RSC/saline waters
- Development of technology for areas with limited access to irrigation
- Management of soil physico-chemical environment in salt affected vertisols.

This programme will be undertaken by the regional centre of CSSRI at Anand, Gujarat.

VIII. Technology transfer and impact assessment

- Approaches to accelerate adoption of alkali soil reclamation technology
- Approaches to encourage adoption of subsurface drainage technology
- Implementation of first line transfer of technology programmes in different agro-ecological regions
- Assessment of impact of salinity and waterlogging on agricultural production, farm income and employment
- Evaluation of alternate economic activities for sustaining farm production and income in salt affected environments.

IX. Human resources development

- Organization of training programmes of various kinds for personnel involved in reclamation work at various levels in states and SAU's
- Degree-related and post-doctoral training programmes
- International training for developing countries
- Faculty improvement programmes.

Linkages

Keeping in view the nature, dimension and geographical spread of the problem of soil salinity, CSSRI has already developed very effective linkages with several national and international organizations for effective implementation of its research programmes. These have proved very rewarding and helped to fulfill our mandate. In future programmes, these linkages will assume more significance because of a perceptible shift in the role of CSSRI. In the past we were busy in developing technology and the scientific aspects underpinning it. Now, with enormous experience, expertise and management, we see ourselves in the future as playing the role of a catalyst and driver of change through our linkages with state agencies involved in reclamation. Whatever research is needed for that purpose will be conducted in the location specific context and will be executed by scientists of CSSRI in collaboration with national and international organizations.

The generation and testing of technology for different agro-climatic regions will be done by the regional centres of CSSRI as well as state agricultural universities (SAU) collaborating with AICRIP[4] on saline water as well as in Indo-Dutch network project. For adaptive researches to be carried out in collaboration with state agencies, forest departments, CSSRI will be actively involved at planning as well as implementation stages and will provide regular scientific and technical backup for monitoring, but the projects will be executed and maintained by the user agency itself. SAUs' and other organizations will develop expertise while working in association with CSSRI and be able to attend to the future problems. Some other projects will be executed by CSSRI scientists providing consultancy only as required. We have linkages for research, education and extension activities with SAUs and state agencies. Several programmes are being implemented with inter-institutional (ICAR) collaboration. We have also international collaboration in various thrust areas of research (Table 2). In addition we have several inter-departmental programmes wherein specified collaborative activities are planned and implemented. We are actively pursuing to improve upon these linkages and establish new relationship with several national and international organizations.

Table 2. Linkages* with international organizations

Programme	Collaborating Organizations
Drainage and water management in irrigation commands	CSSRI - ILRI, Netherlands
Breeding for salt tolerance	CSSRI - Univ. of Sussex, UK
Breeding for salt tolerance in rice	CSSRI - IRRI, Philippines
Breeding for salt tolerance in wheat	CSSRI - Univ. of N. Wales, Bangor, UK
Irrigation management	CSSRI - EU
Nutrient management	CSSRI - IRRI
Socio-economic issues	CSSRI - CIDA

* Programme implemented through bilateral agreements approved by DOE and ICAR

Summary

The institute has been in the service of the farming community for more than 28 years. During this period, the institute has developed technologies that have been accepted by the farmers and the research achievements have been hailed by the scientific community. The major contributions have been the development of appropriate technology for reclamation of alkali lands underlain by good quality ground waters, agroforestry systems both for saline/sodic lands, and water management practices for efficient use of fresh and saline sodic waters/subsurface drainage technology for waterlogged saline lands/breeding of salt tolerant varieties of rice and wheat.

Establishment of strong linkages with state line departments and other development agencies has been a strong point which helped in faster dissemination of knowledge. However, there are several problems and areas that are looking for solutions. The important problems to be attended include: crop production technology in alkali soils underlain by sodic waters with and without fresh waters, horticultural crops for sodic soils, use of industrial waste waters, testing of appropriate drainage effluent disposal options etc. Also,

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[4] AICRIP = All India Coordinated Research Project

there is shortage of trained man power for conducting salinity research. CSSRI will therefore have to strengthen its programme of human resource development to provide research support at national level.

INTEGRATED WATER MANAGEMENT FOR THE HUMID TROPICS[1]

L.K. Smedema[a] and W.J. Ochs[b]

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Introduction: Difficult hydrological characteristics of the humid tropics

The humid tropical zone has some very distinct hydrological characteristics, which makes it almost mandatory to integrate irrigation and drainage. It is a very difficult climatic situation. This is illustrated by the fact that the agronomists distinguish for this zone between lowland and upland crops; in no other climatic zone such a distinction for cropping is based on hydrology.

The following graphs from the Mekong delta present some of the difficult hydrological characteristics which are typical of the humid tropical zone. There is a pronounced rainy season and also a pronounced dry season (Figure 1). During the dry season the water table drops. It starts rising at the beginning of the rainy season and almost immediately there are severe waterlogging problems and in many cases even flooding. During the dry period obviously the emphasis should be on irrigation, and during the wet period it should be on drainage. But much of the water for the irrigation needs to come from the wet season. This implies the need for storage or at least transfer of some of the water and also the need for integrated water management. Most of my presentation will be on hydrological integration. Obviously, institutional integration is required as well.

During the wet season river levels are high. This makes it difficult to discharge drainage water by gravity. Pumping could be a solution. That is something I'll come back to later.

In addition to the difficult hydrological context of the humid tropics, there is also the agricultural context which further complicates water management. This is the desire for crop diversification and intensified agriculture. In the old days, very often there was only cropping during the wet season. Most countries now desire year-round cropping, with intensities of 200% or more. Most countries in the humid tropical zone now want to diversify and eliminate this distinction between upland and lowland cropping. I think water management is a very important tool towards such diversified cropping.

I will illustrate the need for integration and also the problems of integration with two cases. One case is from the conventional large canal irrigation schemes of Eastern India and Bangladesh. The other case is the swamp development schemes of the Mekong and also Indonesia, which both have the feature of the multi-functional canal system.

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[1] Text below is based on a tape recording of Dr. Smedema's presentation.

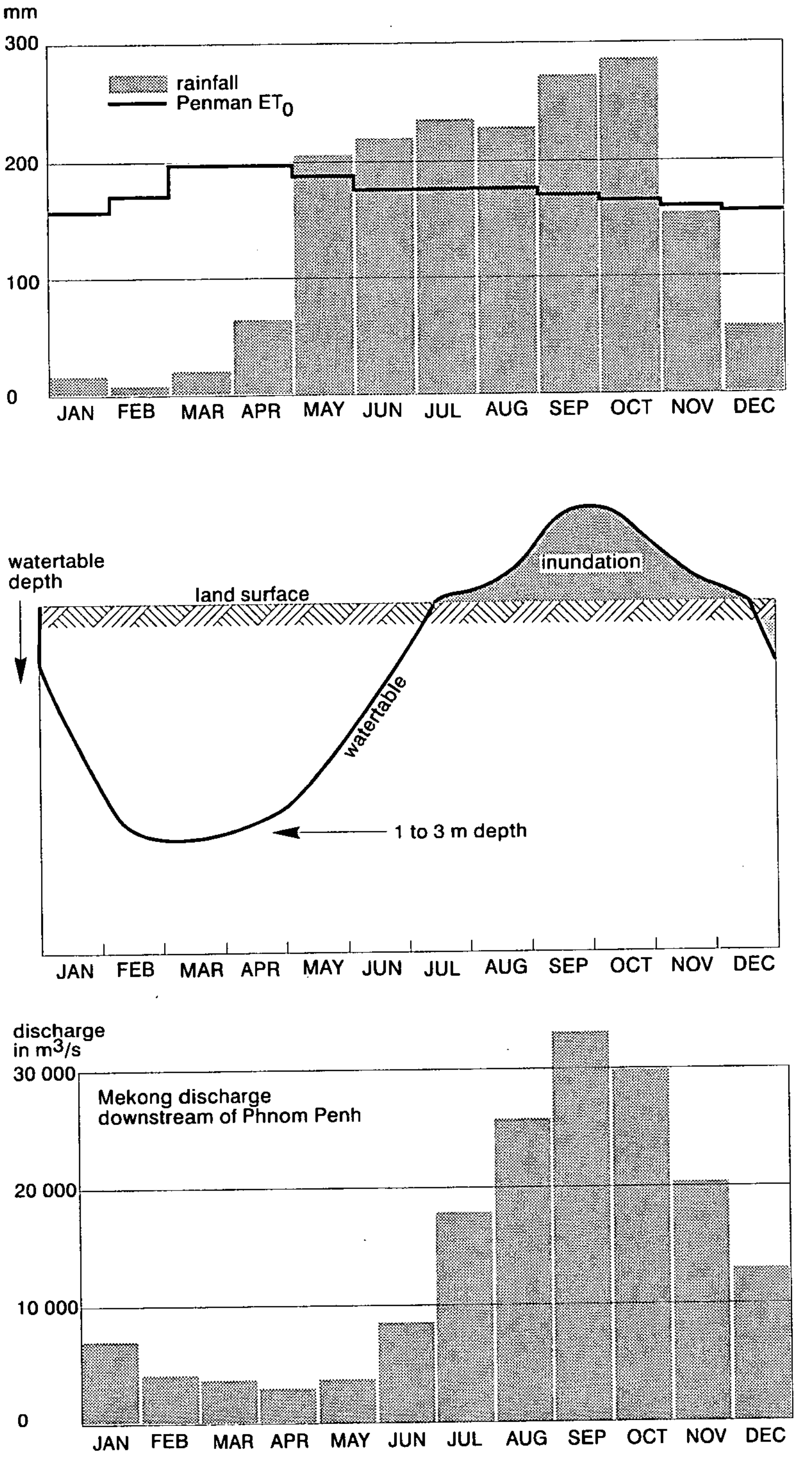

Figure 1. Natural water regimes in the Mekong Delta

Case 1 Canal irrigation schemes of Eastern India

Let us first consider the canal irrigation schemes of Eastern India and Bangladesh. An example is the canal irrigation scheme in the Krishna delta. It was developed around 1900 and during that period the conventional way to develop these deltas was by constructing a barrage and then cover the delta or the coastal lowland areas with an extensive canal irrigation system basically to use the dry season river flow, to spread the water over the land, so that during the dry season there could be cropping. One of the problems created by spreading that water over the land and not having a very good drainage system was the problem of waterlogging. No salinity, because we have about 1,200 mm of rain and my experience is that with more than 600-700 mm of rain there is no salinity problem. There is, of course, some coastal salinity here, but that is a different type.

This kind of irrigation development is very common in Eastern India. Most of it started early in the 19th century, but until recently the same type of schemes still continued to be developed (e.g. the Sharda-Sahayek scheme in eastern Uttar Pradesh, India, and the Ganges Gobadah scheme in Bangladesh, which were developed in the 1960's and 1970's).

I think the rationale of these schemes is sound enough: you have that river flow, so you use it and spread it over the land so that you can have some dry season cropping. There are also considerable problems related with this kind of schemes. The first is related to scale. These large systems require long development periods of 30-40 years. People establish practices which are based on the availability of a lot of water during the initial period. It is difficult to correct those practices later.

Also, these schemes are typical examples of public schemes, with public funding and public management. Nowadays we like to have a more private type of development. I am not going to say more about this issue, because I want to concentrate on the hydrological aspects.

Developing these schemes to spread water over the land requires building a lot of infrastructure. The infrastructure that has been built - not only the irrigation infrastructure, but also roads and railways - block whatever natural drainage systems there are. This has created a lot of waterlogging and flooding during the monsoon season.

Another feature is that under natural conditions, during the dry season the water table would drop, but with irrigation during this season this does not occur, so at the beginning of the rainy season there is much less storage capacity available. With irrigation , the water table remains high, so that part of the storage is not available. This leads to additional drainage problems, which can be avoided through cautious irrigation management.

In the case of Eastern India and Bangladesh, one should avoid the temptation to irrigate during dry spells in the rainy season, because in many cases this does more harm than good. Whatever is gained in yield by preventing drought, is lost by creating waterlogging problems. Of course, it is expensive as well to irrigate. There has been a High Level Commission in Uttar Pradesh which has looked into these problems. One of the recommendations this commission has made is to close the irrigation canals during the wet season. Another recommendation made by this High Level Commission is to irrigate with tubewells, not with canals. There is this groundwater which is a resource but can also be harmful. So why not exploit that groundwater, use the water for irrigation and at the same time have the advantage of lowering the water table. I think that this is a very good example of integrated irrigation and drainage management.

Intermezzo: An example of a management intervention from Tanzania

The benefits of cautious irrigation management can be illustrated with an example from Kilombero Sugar Estate in Tanzania, which has basically the same climate as East India. Whenever there was a short dry spell during the wet season, the estate managers would start to irrigate. When shortly after they had irrigated and filled up the storage the next rain would come, this rainfall could not be accomodated; so they had created their own waterlogging problems. One of the recommendations I made - and of which I'm still proud - was not a physical intervention but a management intervention: I convinced the managers to risk some drought. So we did not irrigate some fields during that period and then we noticed that if the wet periods and the dry periods fell in a certain pattern, we could manage and maintain the water table at a reasonable level. So we solved the drainage problem by a management intervention.

Case 2 The multifunctional canal systems in the Mekong Delta

The second case which I would like to discuss is what I call the multifunctional canal systems [combined irrigation and drainage functions]. An example is the Mekong delta, where during the French period the entire delta was completely covered by canals. The French did it, I am told, for defense and strategic reasons to improve the accessibility, but now it is used as infrastructure for water management. The canal system is completely open and hydraulically connected. There are no structures in the canals. The system serves three water management functions.

The first function is flood control. The primary canal is just for conveyance. At the secondary canal the spoil is used to build low embankments. These low embankments are only meant to stop the flood at the beginning of the season. During the full flood season they are overflowing.

The second function is irrigation. The irrigation water is pumped from the secondary canal into the tertiary canals and then sometimes again from the tertiary canals on to the fields. In some cases near the sea there is also tidal irrigation. During high tide the water comes high enough to let the water in the field.

These tides, of course, can also be used for drainage, which is the third water management function. The pumps used in the Mekong are a reversible type. They can be used for pumping the water from the tertiary canals onto the field, but also for draining the fields by pumping into the tertiary canals.

What is important from this development - which is completely different from the conventional schemes that were discussed earlier - is that here pumping has become a very important tool for water management. Instead of relying on elevated [= above field level] systems for irrigation by gravity, the canal system is only used for conveyance and storage.

Once you have the water near the fields, you manage it by pumping. That is a development which has spread after World War II. It has revolutionized the water management in these lowlands, as shown in Figure 2. Traditionally, there was only a deep water rice crop during the wet season. Now, with low dikes to prevent early flooding, one can have a crop that starts with the early rains preceding the rainy season. With lowlift pumps and bunds around the fields, one can dispose of drainage water, get an early crop and then on the residual moisture a second crop after the rainy season. With complete flood protection - this is still far away and there are many environmental problems related to it - and good surface drainage, it is possible obtain three crops a year. For rice-growing in the humid tropics a surface drainage system alone is adequate, but cultivation of upland and perennial crops in these lowlands requires subsurface drainage as well.

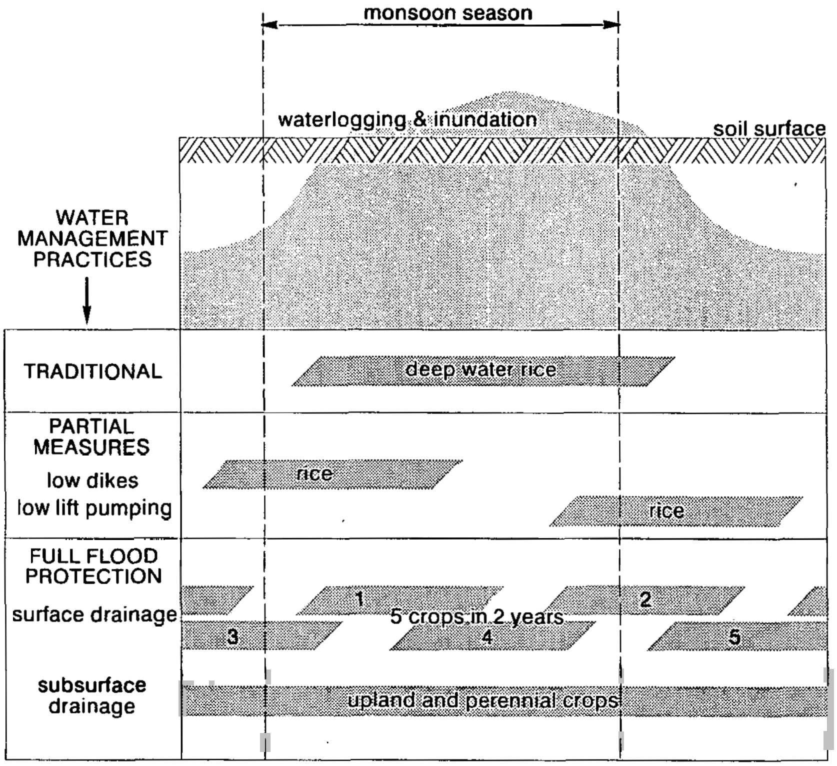

Figure 2. Water management and agricultural development stages in humid tropical lowlands

Time does not allow to present the Indonesian swamp development case, but basically it is the same. An open canal system, no structures, except in some cases a few flapgates. I noticed, both in Indonesia and also in the Mekong, that most flapgates are not functioning properly. There seems to be a need for more attention to the design of flapgates, because they are very useful in this kind of multi-functional canal system.

Discussion

A remark from the audience indicated that tubewells in coastal areas may be dangerous, as they will pump saline water at a certain moment. Another point was made that rice growing in deltaic areas is not normally the problem, but the second crop is the problem. Moreover, it was mentioned that general conclusions from average rainfall/evaporation data may be misleading. It was also mentioned that canal irrigation cannot be left out completely in many areas, especially not in situations where aquifer conditions are not favourable for tubewells.

TOWARDS INTEGRATION OF IRRIGATION AND DRAINAGE MANAGEMENT IN THE ARAL SEA BASIN

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Introduction

Integration of irrigation and drainage management in this presentation will be linked to and based on the different management levels in a water control system of the Aral Sea Basin.

This topic is based on on-going studies in the Aral Sea Basin in Central-Asia. In the context of Central Asia, the theme of this symposium is mostly identical with integrating water quantity with water quality management. Water quality includes the non-point source pollution, mainly caused by irrigated agriculture, and the point source pollution mainly caused by industries, cities and municipalities. The non-point source pollution consists of salt and residues from agro-chemicals.

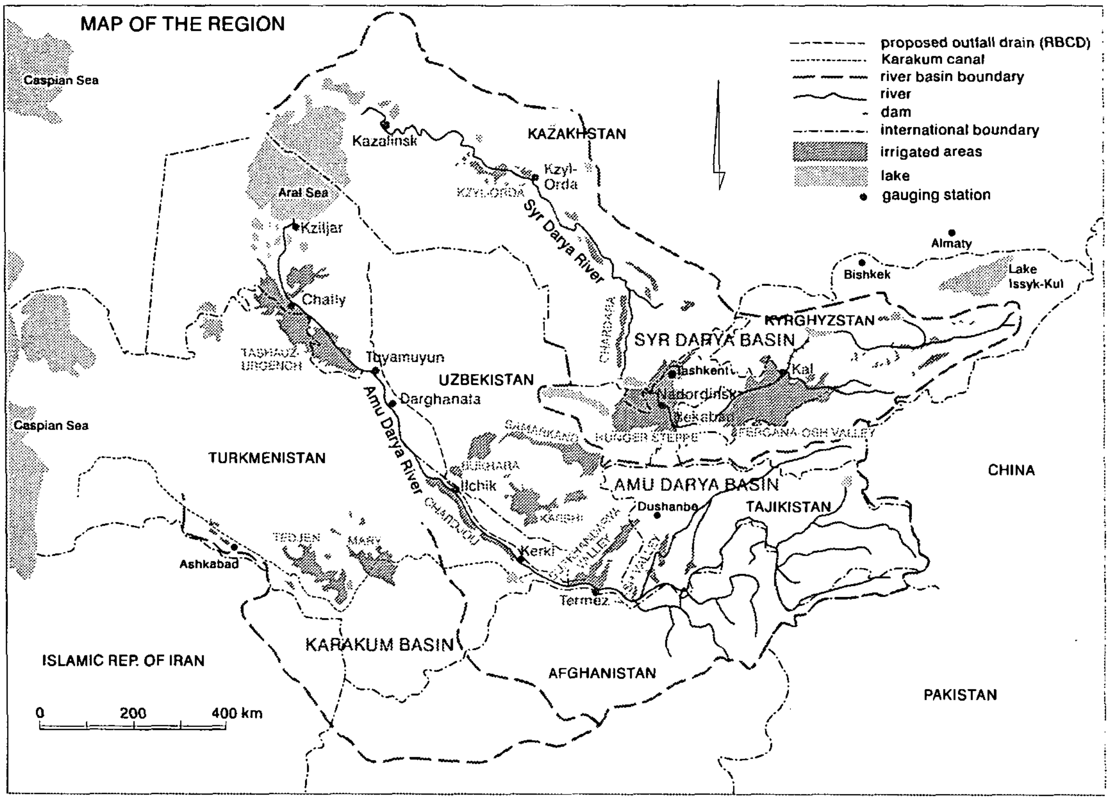


Figure 1. Regional map

The regional map (Figure 1) shows the principal river basins feeding the Aral Sea. The two main rivers, Amu Darya and Syr Darya, are now mainly being used for irrigating some 8 million ha in five nations: Uzbekistan, Kazakhstan, Kyrghyzstan, Tajikistan, and Turkmenistan. A major off-take is the Karakum canal conveying flow from the Amu Darya to irrigate areas in Turkmenistan.

The following management levels are distinguished:
1. River Level
2. Regional Level, Major Irrigation Schemes (*Oblast*)
3. District Level (Rayon)
4. Tertiary Unit/Farm
5. Effluent management (Drainage Disposal Schemes)

The options for integration of irrigation and drainage management are discussed for each of these levels.

1. River level

The options for the management of river flows as controlled by the Basin Valley Authority, are determined by the following factors or conditions:

- *regional (transboundary) limitations: or the individual republic's water rights*: every republic has a certain right to delivery of water for mostly historical reasons, related to the capacity of off-take structures and irrigated area; as the now independent states were formerly one nation, the water rights were not based on individual state's interests but on goals set by the Central Government in Moscow for irrigated agricultural production with a correction for local political realities. The choices made were to promote the production of cotton and some other crops largely at the expense of the economic value (fisheries) of the Aral Sea. This inner lake rapidly shrunk as a result of the two major rivers being tapped almost entirely for irrigation.
- *per republic: the individual scheme's water rights*: the agreed schedule of water delivery is related to a predetermined area to be irrigated, and this is related to a targeted crop yield output in the concerning major irrigation scheme. (This major irrigation scheme is the so-called *Oblast*-level, see par. 2.)
- *forcible return of effluent*: the drainage effluent is partially evacuated to disposal schemes, as evaporation ponds, etc. However, part of this effluent is returned to the rivers and must then be accepted by river water management and included in its operation of irrigation water delivery schedules. This factor is of extreme importance for users downstream of the point where the return flows occur.
- *adequate information system*: the monitoring of river water levels, of river water quality and the scheme's inlet and outlet quantities needs an accurate measuring and communications system to allow the river water management to adjust delivery schedules for optimum water use.
- *scenario's for river discharges deviating from average flows*: as river flows fluctuate daily, mostly depending on rainfall in the upper reaches and on scheme's intake volumes deviating from previously agreed amounts, an alternative water delivery schedule prepared for differing conditions is to be set in operation again aiming for optimum use of available river water.

2. Major irrigation schemes (Oblast)

Figure 2 gives the typical layout of a major irrigation scheme. The management options for the scheme management to integrate irrigation and drainage management include the following:

- *at head water intake: assess water quality (salinity and point-source pollution):* decisions on intake moments and volume depend on agreed schedules, but may be adapted for different circumstances, e.g. when a slug of dirt passes, then the water intake may be suspended temporarily, or whenever the salinity content is judged as too high the same decision may be taken.
- *at the level of the main and secondary canals*: an accurate information system on water intakes by the different main and secondary canal command areas, or districts (Rayons), together with water level and water quality data, provide the necessary tools for the scheme's water management to optimize the water use given their water rights. The collected data are transmitted to the Oblast's Water Control Operation Center and are fed into a decision support system that allows the management to operate the scheme's water delivery system at the highest efficiencies possible and truly integrate irrigation and drainage management. For the integration of irrigation and drainage management this is a very relevant management level as much reuse occurs, with effluent from districts and the large collective farms partially being returned to the irrigation system. This requires careful water quality management to be integrated with the agreed flow delivery schedules.

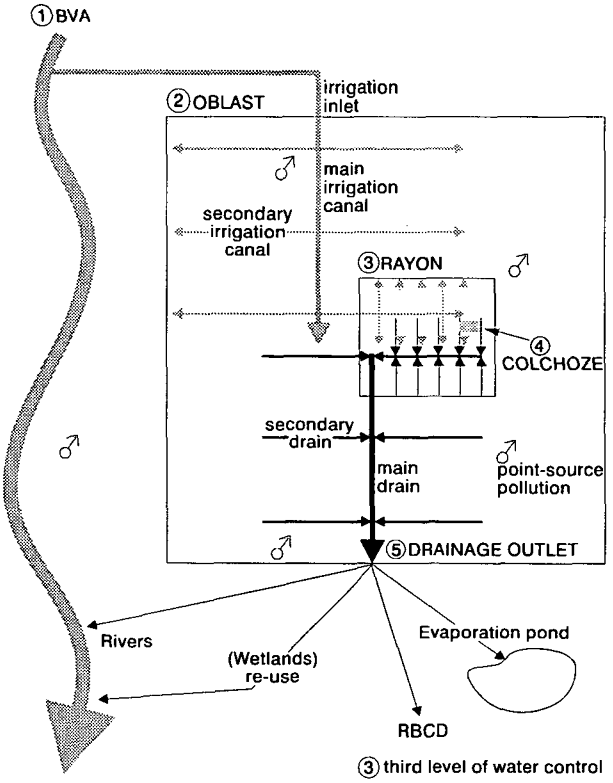


Figure 2. Typical lay-out of irrigation scheme

- *attunement of demand and supply*: the regular and peak water requirements (leaching doses) and the evacuation of effluent will not exactly coincide with water supply offered and drainage disposal available. This requires temporary storage facilities and emphasizes even more the need to integrate irrigation and drainage management.

3. District level (Rayon)

The options for integrating irrigation and drainage management at this level must focus especially on the following issue:

- *reuse and equity*: as the value of water for irrigated agriculture depends on its quality, especially the salinity content, the distribution of flow in the districts over the farms (collective farms or colchozes) requires an in-seasonal and multi-annual assessment and adjustment so that the farms are delivered water of equal average quality to avoid unequal treatment and injustice and to promote equity. There are consequences for the design of the water conveyance system, as flow directions may be seasonally reversed, and for the water pricing in case water charges are levied. Figure 3 shows a typical reuse case, where effluent is blended with water of better quality for subsequent use on more downstream located land.

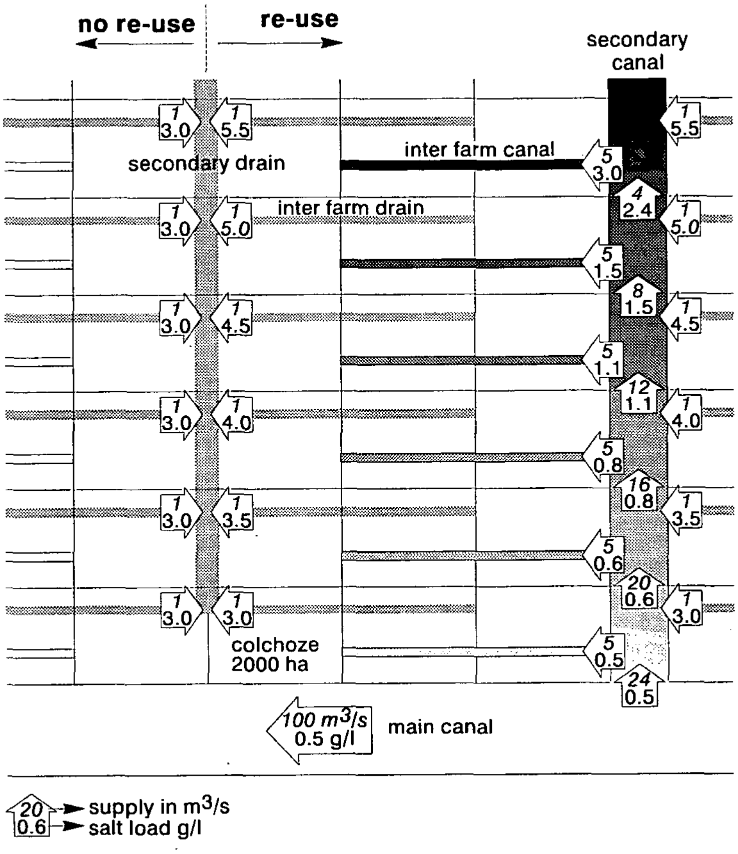


Figure 3. Typical reuse case

- *effluent disposal*: the remaining drain effluent may be disposed of into wetland water purification schemes, evacuated to evaporation ponds, used in saline agro-forestry systems, or returned back into the river. The options for the management of the major irrigation schemes is dependent on the alternatives possible and allowed for by the river flow management, i.e. the Basin Valley Authority.

4. Tertiary unit/farm level (Colchoze)

The management option for integrating irrigation and drainage at the prevailing farms in Central Asia, predominantly the collective farms (colchozes) of a size of 1000-2000 ha, is limited to:

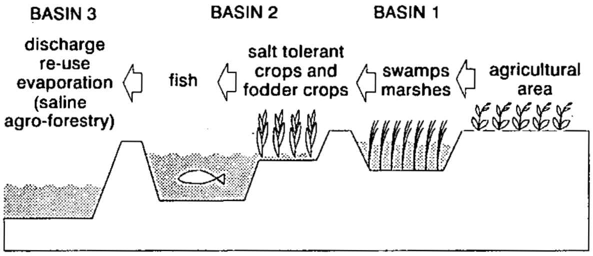
- *internal reuse of internally produced effluent*: as crops cultivated may allow this, to a small degree reuse may be practiced, after blending effluent with water of a better quality

Further it is at this level that efficient irrigation, efficient leaching schedules, and minimization of the local salt mobilization, through the optimum design of the water conveyance systems and the sub-surface drainage systems, should contribute to the efficient operation of the scheme's water control system.

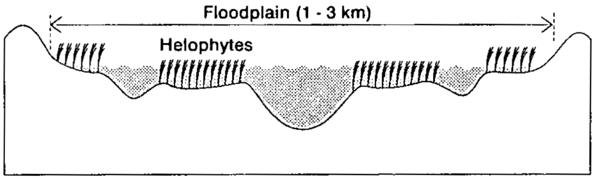
5. Effluent management

The water control over the drain effluent must decide over when and where to evacuate this effluent to. The various options are:

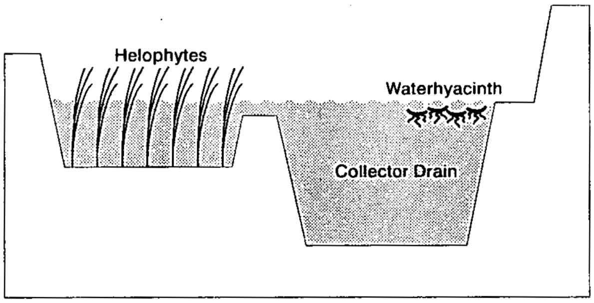
- *evaporation ponds*: in the vicinity of the schemes in low lying areas or desert depressions, the effluent is disposed of by evaporation; also by deep percolation to deep aquifers some disposal is done. They could also be used as temporary storage facilities and be included in the overall effluent management at the national and transboundary level.
- *wetland water purification systems (WWPS)*: effluent of the schemes may pass through WWPS to effectuate a certain purification. Several systems are possible: polder system, flooding system, bank and floating system, see Figure 4. This purification is effective for most of the non-point and some point source pollution, except for the salt content, which may be reduced only slightly or could even increase. More investigation is required to assess the relevance for drainage disposal. After purification reuse of the water may be considered, e.g. after blending with water of better quality.
- *saline agro-forestry systems (SAFS):* this system is aiming at using the effluent directly for mainly irrigated agricultural production with a sequence of crops that are increasingly salt tolerant. Experience is available from other countries, but not yet in Central Asia. Especially the tree component in the SAFS needs more research on location as it is very climate dependent. The principals of the SAFS are outlined in Figure 5.
- *return to rivers*: direct return to the main rivers is possible, but significant downstream effects may be present in case downstream users experience too high salinity levels. This also could become gradually worse over the next decennia. It must be integrated with the salt and water management for the whole of the Aral Sea basin.
- *main outfall drains*: the most expensive but probably most effective alternative is to evacuate the effluent through especially for this purpose constructed large outfall drains that take this effluent to the final destination: the only natural sink with sufficient capacity



Poldersystem



Flooding system



Bank and floating system

Figure 4. Wetland water purification systems

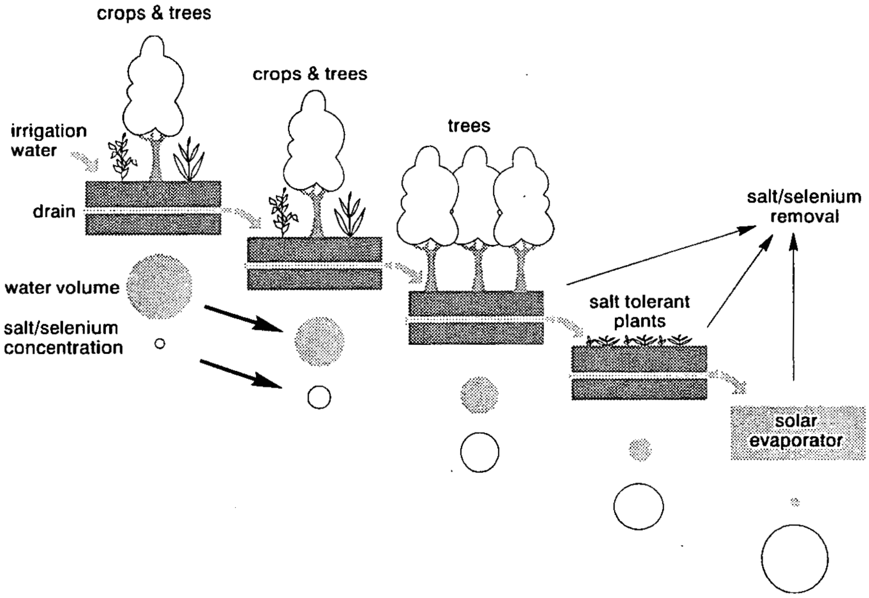


Figure 5. Salt/selenium removal by means of a saline agro-forestry system

in the region viz. the Aral Sea. (Under consideration is the construction of the so-called RBCD, or Right Bank Collector Drain, located along the right bank of the Amu Darya).

Conclusion

The integration of irrigation and drainage management should be linked to the various levels of management in a water control system. The responsibility of integration is then clearly linked to the levels where the decisions are taken on water delivery to the water users. Moreover the linkage to investment is then also made very clear as this responsibility should be connected to the same institutions or persons in charge at the respective levels.

Integration of irrigation and drainage management is at the same time integrating water quality with water quantity management. Adequate information on water levels (flow) and water quality monitoring is required for the needed integration of the water management.

Drains are not only used by irrigated agriculture to dispose of the polluted effluent from irrigated agriculture, causing mainly the non-point source pollution, but also by industries, cities and municipalities who add the so-called point source pollution. The non-point source pollution consists mainly of residues from used agro-chemicals and of leached salts as evacuated by the sub-surface drainage systems. This justifies the conclusion that the effluent management, especially in case of reuse requires an integrated water management that is alert on the water quality situation.

Design and the sustainable long-term operation of water control systems must take into account long-term trends of water quality development. The planning of irrigated agriculture and of industrial development cannot be done separately but requires an integrated approach.

Only when the above conclusions are given due consideration in actual management and in future planning, the maximum benefits may be derived from the available water supplies.

Discussion

In reponse to a question from the audience about evaporation ponds, Ir. Denecke replied that these are only a temporary solution on a local scale. It was emphasized that the self-purification of rivers does not represent a solution for removal from the system of common salts. The agro-forestry option and the creation of wetlands were considered questionable, because of the severe winters in the area. It was also mentioned that the *loess* soils (high capillary rise) in the area and the artesian pressure in the rolling landscape are making the drainage situation more complex.

Session 2 Technical innovations towards integration of irrigation and drainage management

Ir. R.J. Oosterbaan (ILRI). *SALTMOD: A tool for the interweaving of irrigation and drainage for salinity control*

Dr. Safwat Abdel-Dayem (DRI). *DRAINMOD-S as an integrated irrigation and drainage management tool*

Dr.Ir. J. Boonstra (ILRI). *Constraints and opportunities for integrated water management tools*

Dr. M. Bakr Abdel Ghanya (DRI), I. Lashin (DRI), Dr.Ing. W. F. Vlotman (ILRI) and A. El Salahy (DRI). *Farmers participation in the operation of modified drainage system*

Ir. F.W. Croon (Euroconsult). *The choice of crop rotation: An important parameter for creating an acceptable salt balance under minimum water use*

Chairman:	Prof.Dr.Ir. W.H. van der Molen (Wageningen Agricultural University, emiritus)
ILRI rapporteur:	Dr.Ir. Th.M. Boers

SALTMOD: A TOOL FOR THE INTERWEAVING OF IRRIGATION AND DRAINAGE FOR SALINITY CONTROL

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Hitherto, SALTMOD[1] was used to analyse data from pilot areas (Egypt, India, Portugal) where data were available for calibration. For this ILRI symposium it is used to demonstrate the complex inter-actions between irrigation, watertable, salinity and agriculture.

A scenario is presented for an area with a watertable at 10 m depth when irrigation starts. There are two seasons, an irrigation season and a non-irrigation season, when agriculture is rainfed. Initially, during the irrigation season, 100% of the area is irrigated. There is no natural or artificial drainage and no use of groundwater for irrigation.For this scenario, SALTMOD is run in 'automatic gear': the program runs for 15 years without changes in external boundary conditions (e.g. rainfall) but it generates automatic internal responses to changing internal conditions, such as the farmers' responses, which are simulated through in-built mechanisms. For example:

- reduction of irrigated area when irrigation water is scarce,
- reduction in irrigation supply per ha when the watertable becomes shallow,
- abandoning land upon salinization.

In this scenario, the option to change conditions annually and manually ('manual gear') by interactive intervention is not used.

Figure 1 shows that the irrigated area decreases in the first 4 years from 100% to about 80% and in the years 8 to 12 it again decreases to less then 70%. These reductions have different causes.

Figure 1 also shows the reason for the first reduction. It presents the irrigation sufficiency, defined here as the ratio between actual evapotranspiration (ETa) and the potential evapotranspiration (ETp) of the irrigated crops. In the first 4 years, the sufficiency increases from less than 70% to over 80%. Apparently there is not enough irrigation water available to irrigate all crops to full sufficiency and the farmers leave some of the land fallow so that more water can be applied to the remaining irrigated land. The fallow land is not permanent but in crop rotation. Figure 1 shows that the sufficiency increases sharply during the years 4 to 6. To understand the reason of this increase, we look at the behaviour of the watertable.

Figure 2 shows that the depth of the watertable decreases steadily during the first four years, i.e. the watertable is rising. Especially during the fourth year there is a sharp rise, due to a smaller porosity of the soil. From the fifth year onwards, the depth of the watertable becomes less than 1 m, and deep percolation losses can no longer occur. As a result, the irrigation sufficiency increases to almost 100%.

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[1] SALTMOD is an agro-hydro-salinity model developed by Ir. Oosterbaan.

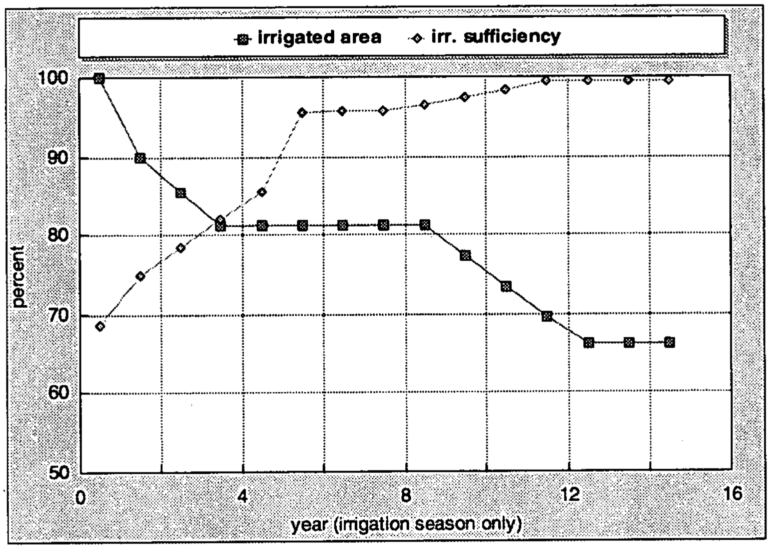

Figure 1. Effects of size of irrigated area on irrigation sufficiency

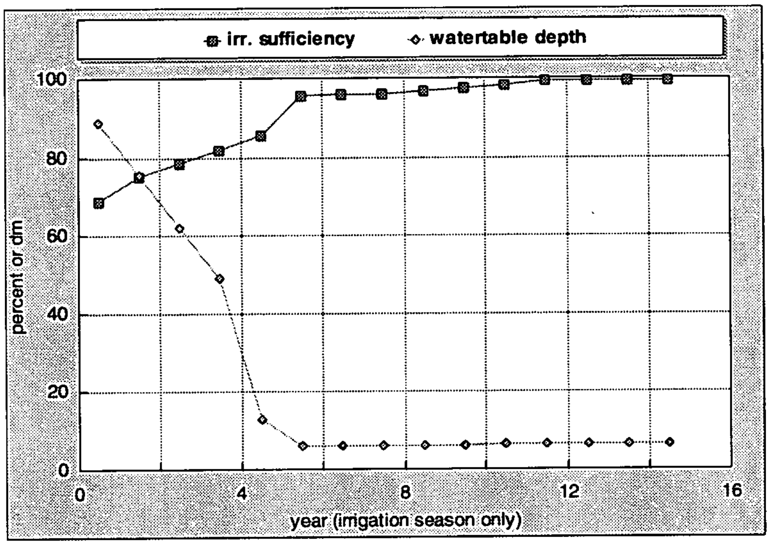

Figure 2. Effects of watertable depth on irrigation sufficiency

The irrigation effectiveness is not only determined by sufficiency but also by efficiency. This is defined here as the ratio between the amount of irrigation water used by the crop (ETi) and the amount of irrigation water applied (Irr). Figure 3 shows that the irrigation efficiency decreases slightly during the first 4 years as the irrigated area decreases and more water can be applied to the irrigated land, so that also the irrigation losses increase. In the years 4 to 6 the efficiency increases sharply from less than 70 to about 80%, although the irrigation application remains stable. After year 8, the irrigation application increases again while the efficiency goes down. An explanation of both features is partly offered in Figure 5 and more fully in the later figures.

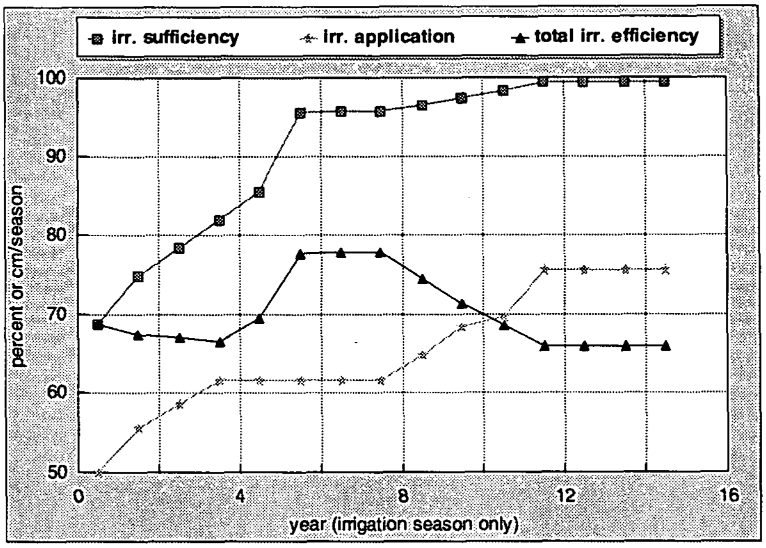

Figure 3. Changes in irrigation sufficiency, irrigation application and total irrigation efficiency

Figure 4 shows that the soil salinity hardly increases during the first four years, as it is checked by the reduction of the irrigated area, higher irrigation applications and more leaching of salts. Hence, the initially low irrigation sufficiency was not the only reason for fallowing the land. Salinity control is a second reason. When, towards year 6, the watertable comes close to the soil surface, deep percolation losses of irrigation water are restricted. Hence the increase in irrigation efficiency. Due to the reduction in percolation, salt leaching is less and the input of salts by the irrigation water begins to build up the soil salinity. The salinity reaches a maximum in year 9. Thereafter, it decreases again while simultaneously the irrigation application goes up and the efficiency down. Figure 5, which shows the non-irrigated area, may shed some light on this phenomenon.

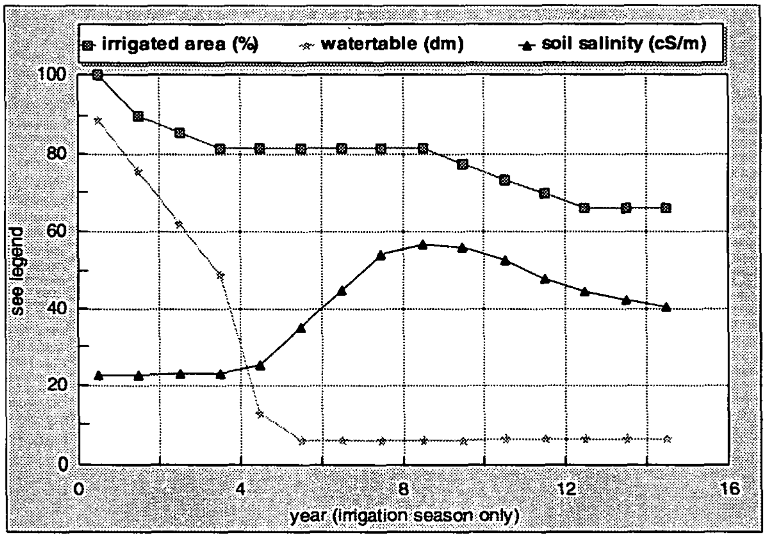

Figure 4. Interrelations between irrigated area, watertable depth and soil salinity

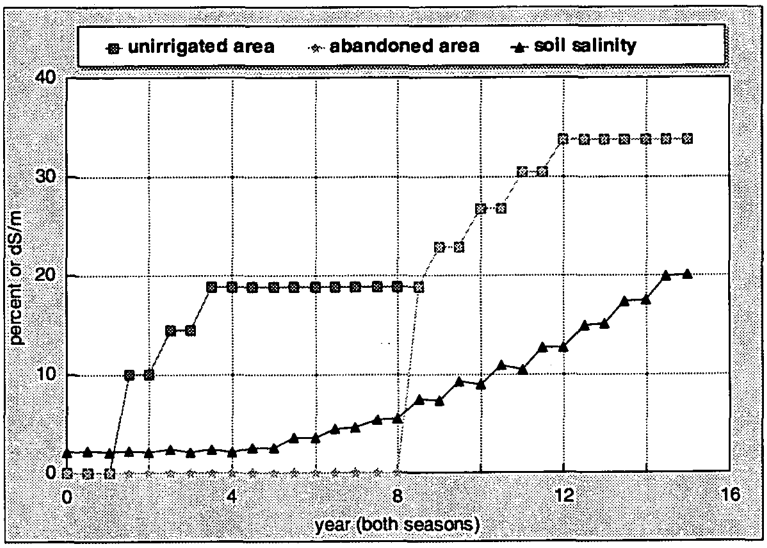

Figure 5. Changes in size of unirrigated area, abandoned area and soil salinity

The unirrigated (rotational fallow) area in Figure 5 increases from 0 to about 20% in the first four years. After this, the area remains constant until year 8. Thereafter, the fallow land increases again to more than 30%. This land becomes permanently fallow because it is abandoned. Its soil salinity reaches high values (20 dS/m). The abandoned area has a dry topsoil and groundwater is evaporated through capillary rise from the watertable. The area serves as a natural 'drain'. The salts brought in by the irrigation water accumulate here. The abandoned land permits drainage of the irrigated land. This explains why, in Figure 2, the irrigation application is increased after year 8, while the efficiency diminishes, and with it, the salinity (see Figure 4).

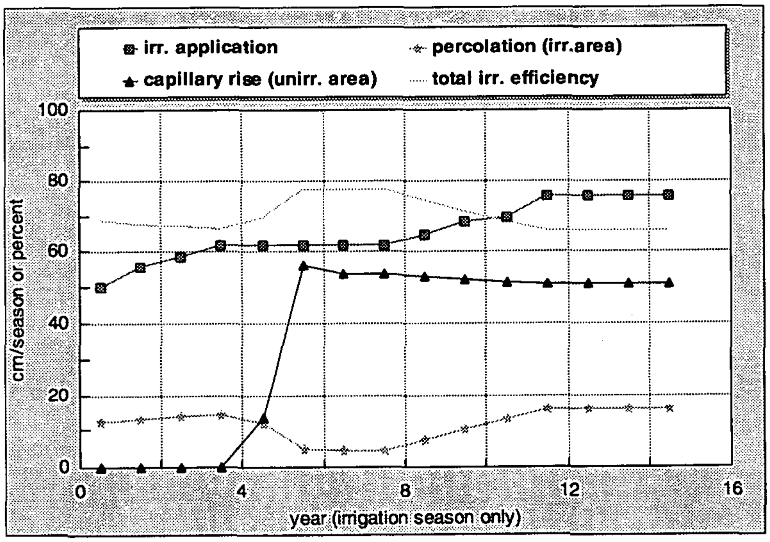

Figure 6. Changes in irrigation application, capillary rise, percolation and total irrigation efficiency

A summary of the variation of some hydrologic factors in time is given in Figure 6, showing stabilization at the end.

Conclusions

1. Irrigation and agricultural practices both determine the water and salt balance, which in turn determine these practices. There is a boomerang effect. All contributing factors are interwoven into a coherently knitted tissue.

2. Isolated drainage measures to combat problems of waterlogging and salinity run the risk of failure.

3. Hydro-agro-salinity models such as SALTMOD are a useful tool to understand the the intricate interrelations.

ILRI is developing a model that combines the SALTMOD program in different polygons with the SGMP[2] model for the flow of groundwater between the polygons: a Regional Salinity Model (RSM).

Discussion

The author explained that the graphs shown during the presentation (and reproduced in this paper (ed.)) were produced with a commercially available spreadsheet program, on the basis of output data from SALTMOD. The model produces a number of standard graphics, but they are not ideal for presentation. Results from the model were checked with field results, e.g. in Egypt, India, Pakistan and Portugal. Asked about farmers responses the author answered that SALTMOD can give three farmers responses. In practice when the watertable below a field rises, the farmer will reduce the irrigation application on that field. When the soil in a field becomes too saline, the farmer will abandon that field and concentrate available water on other fields. When water is scarce and the farmer does not have enough water available to irrigate all his fields, he will introduce fallow periods. If a user of SALTMOD selects the option *farmers response*, then the model (1) reduces applications on fields where the watertable rises too high, (2) abandons salinized fields and (3) introduces fallow periods when water is scarce. In answer to the last question, the author explained that SALTMOD was also applied on pilot areas in Mexico.

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[2] SGMP is a numerical groundwater model developed by ILRI. It is discussed further in Dr. Boonstra's contribution to these proceedings.

DRAINMOD-S AS AN INTEGRATED IRRIGATION AND DRAINAGE MANAGEMENT TOOL

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Introduction

FAO (1990) estimated the gross area of the world's irrigated land at 270 million hectares. During the past four decades, development of irrigated agriculture provided a major part of the increase in production necessary to meet population demands. About 36% of the total crop production came from less than 15% of the arable land that was irrigated. The FAO projections of expansion of irrigated land to the year 2000, based on previous trends modified by land, capital and inputs required to meet future needs, was 2.52% per year from 1984 to 2000. However, these projections are not likely to be met due to several reasons. Existing irrigation projects in several parts of the developing world are poorly performing due to poor operation and maintenance. Meanwhile about 20-30 million hectares are severely affected by salinity and an additional 60-80 million hectares are affected to some extent. Moreover, water resources in arid and semi-arid regions, where irrigation is necessary for crop production, are facing rapid decrease in the per capita share with increasing competition on water from other sectors (Engleman and LeRoy, 1993). The total area currently irrigated is about 235 million hectares.

Traditionally, irrigation and drainage systems were designed, constructed and managed separately. More often, irrigation systems were introduced without thinking about the drainage needs. Moreover, the classic design and management concepts depend on hypotheses that seldom exist in practices. Performance of such irrigation and drainage systems is often below expectation due to many unforeseen inter-relationships that were overlooked in the design or cannot be understood during the management stage. Because of the complexity of the soil-water-crop relationships, it was practically impossible to define their exact physical state and behavior. Therefore, in dealing with any particular problem, no other way was possible except simplifying the system by concentrating upon the factors which appear to have the greatest and most direct bearing upon the problem at hand. With more understanding of the state and movement of water in the soil, plant and atmosphere and with the concurrent development of experimental and computational techniques allowing more exact measurements and more complicated computation, a more holistic approach for addressing the problem became possible (Hillel, 1980a; Hillel, 1983).

In recent years computer simulation models that describe the performance of field scale water management systems have been developed. They are important and useful in simulating the mechanisms and processes governing movement of water and solutes in soils, handling a large number of variables and predicting actions and interactions of multiple processes over long periods of time. A good review of models based on different approaches is given by Skaggs (1992).

Water management in irrigated land

The objective of water management in irrigated agriculture is to maintain an adequate quantity of soil moisture available for plants at all times, and to leach salts out of the root zone before they build up to levels that might affect yield. In both cases, soil being the media for water and solute movement and crop yield being the target of irrigation, makes both plant and soil determinant factors in water management. Drainage is equally important for sustainable crop production otherwise salinity control will not be possible. The quality of irrigation water also is a major factor in management. Increasingly, more saline water is used in irrigation due to scarcity of fresh water resources.

Irrigation water supply and movement

Under arid and semi-arid climatic conditions, irrigation is necessary to provide the evaporative demands of field crops. The rate of water applied to the irrigated fields depends on many factors, among them are climatic conditions, water supply, crop type and growth stage; irrigation method and economics (Hansen et al., 1980 and Hillel, 1983). The quantity and frequency of irrigation are determined on the basis of these factors but in all cases they have to satisfy the crop water requirements at any given time through the different growing stages. Crop growth depends on the availability of moderate quantities of soil moisture in the root zone. However, excessive or deficient quantities of soil moisture cause reduction or even loss of the crop yield (Hiler, 1969). Therefore, the soil moisture content in the root zone should be maintained between an upper limit that ensures an adequate diffusion rate of oxygen to the roots and a lower limit which does not cause the plant to spend extra energy to meet its water requirements.

Generally, irrigation water is abstracted from a conveyance system, pipe or channel, and discharged onto a field sloping away from the point of supply. At the time of initiation of flow the soil is normally at a uniformly low soil moisture content. In surface irrigation, water moves down the slope as an advancing wave and infiltrates into the soil. As the wave progresses down the field, its magnitude is reduced by the water infiltrating into the soil until a point is reached where infiltration has accounted for the whole discharge, and there the advance terminates. In case the irrigation supply is more than adequate water may build-up on the field causing ponding conditions. If more water is still provided spills or surface runoff occurs.

The water infiltrating into the soil moves downward and laterally forming a wetting front. Infiltration is affected by soil factors such as hydraulic conductivity, initial soil moisture content, surface compaction, depth of profile and groundwater table depth. It also depends on climatic factors such as intensity, duration and time distribution of rainfall and temperature. Finally, plant factors such as extent of cover and depth of root zone also influence the infiltration of water into the soil. The amount of water infiltrating into a unit surface area of soil may be computed from a water balance at the soil surface during certain time increment Δt. The balance equation may be written as:

$$F = I - RO - \Delta W \tag{1}$$

where F is infiltration (cm), I is irrigation (cm), RO is surface runoff (cm) and ΔW is the change of water stored on the surface during the time interval Δt. Approximate equations such as the Green-Ampt equation (Hillel, 1980) can be used for estimating the infiltration rate. Until all irrigation water on the soil surface infiltrates into the soil, the direction of water movement is essentially downwards. While water is moving downward, it fills the soil pores of the unsaturated zones until the soil moisture content increases up to its field capacity. Excess water continues moving downwards repeating this process until the remaining volume reaches the groundwater table causing a rise in its levels.

Water is removed from the soil by the plant roots or by direct evaporation from the soil surface. Shallow-rooted crops will require more frequent irrigation than deep-rooted crops. Similarly, the same crop requires more frequent irrigation in the early stages than when its roots develop to its full depth. The combined effect of plant transpiration of water to the atmosphere through their leaves and the water evaporation directly from the soil is the evapotranspiration (*ET*) of the crop cover. A plant in wet soil will extract more water than the same plant growing in dryer soil. The evapotranspiration reaches its full potential rate for a given set of climatic conditions when the soil is well-watered and the crop completely shades the soil surface (Walker and Skogerboe, 1987). Potential *ET* depends on climatological factors which include net radiation, temperature, humidity and wind velocity. However, the actual field evapotranspiration is often limited by soil moisture conditions and is less than the potential evapotranspiration. When the available soil moisture in the root zone is depleted, the *ET* can not exceed the upward flux from the groundwater table. After the end of infiltration and between two successive irrigation the water movement above the watertable remains in upward direction. The upward flux by capillary water movement increases with a shallower watertable than from a deeper one. Hence, a shallow groundwater table can effectively contribute in meeting the crop evaporative demands through upward capillary flow.

Water that percolates below the root zone has no direct value for the crop. When it reaches the groundwater table, the later rises proportionally to the quantity of water entering the watertable: in general the watertable should not rise and remain in the root zone. The soil in the root zone should be well aerated by the continuous exchange of oxygen and carbon dioxide between the air-filled pores and the external atmosphere. Most terrestrial plants cannot transfer oxygen from their aerial parts to their roots at a rate sufficient for root respiration. Thus, an excessive wet soil will stifle the crop roots. In many irrigated lands, natural drainage is not sufficient to lower the groundwater table at an adequate rate for optimal crop cultivation. In this case drains should be constructed to provide the required rate of groundwater table drawdown. The rate of subsurface water movement into drain tubes or ditches depends on the hydraulic conductivity of the soil, drain spacing and depth, drain capacity, profile depth and groundwater table height above the drain. The change in air volume in a thin section of soil of unit surface area which extends from the soil surface to the impermeable layer and is located midway between adjacent drains (Fig. 1) is given by the following balance equation (Skaggs, 1978):

$$\Delta V_a = D + ET + DS - F \qquad (2)$$

where ΔV_a is the change in the air volume (cm), D is the artificial lateral drainage from the section, ET is the evapotranspiration (cm), DS is the deep seepage, if any (cm) and F is the infiltration (cm) entering the section during the time increment Δt.

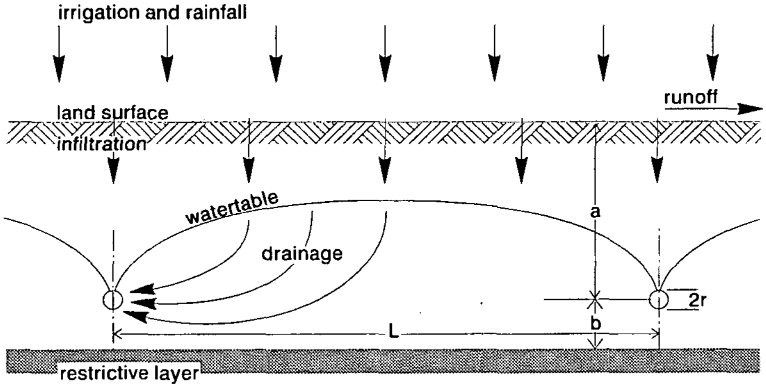

Figure 1. Schematic diagram of water management system with subsurface drains

Salt movement and salinity control

Irrigation water from streams, rivers and groundwater contains significant quantities of dissolved salts. Applying 100 cm of water which is a normal quantity in a season, with salt content of 300 mg/liter means adding 3 tons of salt per hectare to the irrigated land. Irrigation water during its residence in the soil tends to dissolve additional salts. As it moves through the profile, soil moisture carries its solute load in its convective stream, leaving some of it which is adsorbed, taken up by plants, or precipitated whenever their concentration exceeds their solubility (Hillel, 1980). Solutes move not only with soil moisture, but also within it in response to concentration gradients. At the same time, solutes react among themselves and interact with the solid matrix of the soil in a continuous cyclic succession of interrelated physical and chemical processes.

While upward flow from a groundwater table is an important source of water for transpiring plants, it is also a cause of salt accumulation in the root zone. Although the rate of upward movement of water from a groundwater table may not be sufficient for plant growth, it may be rapid enough to present a serious salinity hazard especially when the groundwater is saline (Gardner, 1960). The salinization hazard may still exist even when the groundwater table is several meters below the soil surface. In many irrigation projects, under-irrigation with the consequent salinization of the soil profile due to capillary rise is almost inevitable if preventive measures are not taken. Salinization may be aggravated by over-irrigation which causes a rise of the groundwater table and hence accelerates the upward flow.

The salt balance is a summary of the quantities of salt inputs and outputs for a defined volume or depth of soil during a specified period of time. If salts are neither generated nor decomposed chemically during the movement of the soil solute, then the difference between the total input and output must equal the change in salt content of the soil zone considered. The salt balance can be used as an indicator of salinity trends and the need for salinity control measures in irrigation schemes. The salt balance equation for a thin soil section extending from the soil surface to the bottom of the root zone and of unit surface area during a time increment Δt is given by the following equation (van der Molen, 1983):

$$\Delta S = F.C_i - R.C_d \tag{3}$$

where ΔS is the change in salt content of the root zone in meq/m^2, F is the net volume of water infiltrated into the soil as a result of irrigation and rainfall (cm) during the time interval Δt, R is the net volume of water moving across the lower boundary of the root zone (cm) as a result of deep percolation and upward flux during the time interval Δt; C_i is the salt concentration (meq/liter) in the irrigation water and C_d is the salt concentration (meq/liter) of the soil moisture below the root zone. Equation 3 can be expressed in terms of the electric conductivity of the saturated paste, EC_e which is roughly proportional to the concentration C. Equation 3 implies that a net downward movement, i.e. deep percolation below the root zone more than upward flow, is required to reduce the salt accumulation in the root zone. At a state of salt equilibrium (i.e. $\Delta S=0$) the salt added equals the salt removed.

An excessive accumulation of salts in the soil profile causes a decline in productivity. Soil salinity affects plants directly by reducing the osmotic potential of the soil solution and by the toxicity of specific ions such as boron, chloride and sodium. Some plants can survive in salt affected soil but many are affected to varying extent depending on their tolerance to salinity. Even, the same crop has different tolerance levels to salinity for its different growing stages. Mass and Hoffman (1977) indicate that each increase in soil salinity (electric conductivity of the saturated paste) in excess of the concentrations that initially begin to affect yield will cause a proportional decrease in yield. They have proposed the following equation to express this effect:

$$RY = 100 - b\,(EC_e - a) \qquad (4)$$

where RY is the relative crop yield (%), EC_e is the salinity of the soil saturated extract (dS/m), a is the salinity threshold value for the crop representing the maximum EC_e at which a 100% yield can be obtained (dS/m) and b is the yield decrement per unit of salinity, or % yield loss per unit of salinity (EC_e) between the threshold value (a) and the EC_e value representing the 100% yield decrement. The threshold value depends on the crop tolerance to salinity. The relative salt tolerance of most agricultural crops is well known. General salt tolerance guidelines are given by most of the irrigation text books (FAO, 1985; Hansen et al., 1980).

The leaching of excess salts from the root zone is an essential aspect of salinity control. Without leaching, salt will accumulate in direct proportion to the amount of water applied and its salt content. Salt residues can be prevented from accumulating during repeated irrigation-evapotranspiration cycles by applying water in an amount greater than evapotranspiration. This practice will cause a significant fraction of applied water to flow through - and past - the root zone and leach away the excess salts. However, unless the groundwater table is very deep or subsurface drainage is sufficiently rapid, the excess irrigation causes a progressive rise of the watertable. Once, the watertable comes closer to the soil surface between irrigations the groundwater tends to flow upwards into the root zone by capillary action.

The leaching requirement depends on the irrigation water salinity and the crop tolerance to soil salinity. FAO (1985) recommends the equation proposed by Rhoades and Merrill in 1976 to calculate the leaching requirements for ordinary surface irrigation methods. The equation reads:

$$LR = \frac{EC_i}{5EC_e - EC_i} \qquad (5)$$

where LR is the minimum leaching requirement (dimensionless fraction) needed to control salts within the salinity tolerance level of a certain crop which is EC_e (dS/m) and EC_i is the salinity of the applied irrigation water (dS/m). The total depth of water that needs to be applied to meet both the crop demand and the leaching required can be estimated from the following equation:

$$I = \frac{ET}{1-LR} \tag{6}$$

where I is the irrigation water depth (cm), ET is the crop evapotranspiration (cm), and LR is the leaching fraction (ratio).

Theoritically speaking, the timing of leaching is of no significance provided crop tolerance is not exceeded for extended or critical periods of time. Salt takes time to accumulate in the root zone of initially non-saline soils, to a concentration that reduces yield. Leaching can be done at each irrigation, every second irrigation or less frequently such as seasonally or at even longer intervals. In many instances, the usual inefficiencies of irrigation water application satisfy the leaching requirement, particularly with good quality irrigation. water. In the case of irrigation with more saline water, larger amounts of water will be needed to meet the leaching requirement. When the leaching fraction exceeds 0.25 -0.3, it may be more efficient from a water saving point of view to change to a more tolerant crop or to accept a relative yield less than 100% of the potential.

Water management modeling

Background

The field scale water management simulation model DRAINMOD is developed and field tested under varying conditions (Skaggs, 1978; Skaggs, 1982). It uses functional algorithms to approximate the hydrologic components of shallow watertable soils. Approximate methods are used to simulate surface runoff, infiltration, drainage, upward flow, evapotranspiration, and seepage processes on hour-by-hour, day-by-day basis. Input data include soil properties, crop parameters, drainage system parameters, climatological and irrigation data. DRAINMOD is based on solving water balances similar to those described by Equations 1 and 2. The basic time increment used in both equations is 1 hour. However, when rainfall does not occur and drainage and ET rates are so low that the groundwater table position moves slowly with time, a Δt of 1 day is used in Equation 2. Conversely, time increments of 0.05h are used to compute the infiltration when rainfall rates exceed the infiltration capacity.

The basic water balance equation for the soil profile (Eq. 2) does not require knowledge of the distribution of the soil moisture content within the profile. However, the methods used to evaluate the individual components such as drainage and ET depend on the position of the watertable and the soil moisture distribution in the unsaturated zone. Groundwater table depth is determined in DRAINMOD at the end of every water balance calculation. The pressure head distribution above the groundwater table during drainage is assumed nearly hydrostatic. The soil moisture distribution under these conditions is the same as in a column of soil drained to equilibrium with a static watertable. These assumptions will generally hold for conditions in which the Dupuit-Forchheimer assumptions are valid, i.e. for situations where the ratio of the drain spacing to profile depth is large. The maximum groundwater table depth for which the approximation of a drained to equilibrium soil moisture content distribution will hold depends on the hydraulic conductivity functions of the profile layers and the *ET* rate.

The determination of *ET* is a two-step process in the model. In the first step, the daily potential evapotranspiration (*PET*) is calculated in terms of atmospheric data and is distributed on an hourly basis for 12 hours representing the day time (6 am to 6 pm). In case of rainfall, hourly *PET* is set equal to zero for any hour in which rainfall occurs. In the second step, a check is made to determine whether *ET* is limited by soil moisture conditions. If the soil moisture conditions are not limiting, *ET* is set equal to *PET*. This water can be supplied by soil moisture stored in the root zone if it has not already been used, down to a lower limit (wilting point or a higher water content if desired). This deficit will be compensated fully or partly by upward flow from the groundwater table depending on its depth at the beginning of the time step. The watertable will accordingly drop to a new position as a result of the upward flow. When the soil moisture content in the root zone is depleted to the set lower limit, *ET* is limited by soil moisture conditions and is set equal to the upward water movement.

The effective root depth is used in DRAINMOD to define the zone from which water can be removed as necessary to supply *ET* demands. An effective root depth is defined for all periods considered in the simulation process. When the soil is fallow, the effective root depth is defined as the depth of the thin layer that will dry out at the surface. The rooting depth function for each crop included in the simulation is read in as a table of effective root depth versus Julian date. Among many other factors influencing root growth and distribution, soil moisture is the most important. This includes both depth and fluctuation of the groundwater table as well as the distribution of soil moisture during dry periods.

Procedures used in DRAINMOD to calculate drainage rates assume that lateral water movement occurs mainly in the saturated zone below the groundwater table. The lateral flux is evaluated in terms of the watertable elevation midway between drains and the water level in the drain. The model uses the Hooghoudt steady state equation to calculate the drainage rates. Although this equation was derived for steady state conditions, it compares well with transient methods for predicting drainage flux when applied sequentially for short time increments or for small changes in the groundwater table position. Thus the new position of the watertable at the end of each time increment is determined on the basis of the upward flux and the lateral drainage during this particular time increment.

The overall objective of agricultural water management systems is mostly to eliminate water related factors that limit crop production or to reduce those factors to acceptable levels. The objective functions considered by DRAINMOD are the number of working days which characterize the ability of the water management system to insure trafficable conditions during specified periods, the sum of excess water at depths less than 30 cm that provides a measure of excessive soil moisture conditions during the growing season, sum of dry days during a growing season which quantifies the length of time when deficient soil moisture conditions exist. Groundwater table position and factors such as the *ET* deficit are used to quantify stresses due to excessive and deficient soil moisture conditions. Stress-day-index methods (Hiler, 1969) are used to predict relative yields as affected by excessive soil moisture, deficit or drought conditions and planting date delay. The following algorithms are examples used for corn:

$$RY_w = 100 - 0.71\, SDI_w \tag{7}$$

$$RY_d = 100 - 1.22\, SDI_d \tag{8}$$

where RY_w and RY_d are the relative yields if wet stress and dry stress occurred, and SDI_w and SDI_d are the stress-day-index for excessively wet conditions and the stress-day-index for drought conditions, respectively. The overall response of the crop to delayed planting date, excessive wet and dry conditions can be determined as follows:

$$RY = RY_p \times RY_w \times RY_d \tag{9}$$

where RY is the overall relative yield, RY_p the relative yield for delayed planting and RY_w and RY_d are as defined above.

The simulation model DRAINMOD as briefly presented above, is best suited to humid regions although it may also be applied to irrigated conditions where irrigation applications may be introduced in a similar way as rainfall. However, the model can not simulate the solute movement nor it can predict the salt distribution and its changes in the soil profile.

The reliability of DRAINMOD for irrigated crop land in a semi-arid climate was tested by Chang et al. (1983) with field data from California. Groundwater table elevations predicted by the model reasonbly agreed with measurements for five experimental locations differing in soil texture. The first successful attempt made to test the reliability of the model to simulate water management in irrigated arid land was made by Abdel-Dayem and Skaggs (1990). Outputs of the DRAINMOD simulation were used in a spread-sheet analysis of the corresponding salt balance computed on daily basis. The results agreed well with field data about soil salinity changes measured at the beginning and the end of the crop season in the Nile Delta. This encouraged research to proceed for developing a new version of DRAINMOD that combines simulation of both soil moisture and solute movement in the soil profile in irrigated land with a shallow groundwater table and provided with horizontal drains.

Model development

The development of a salinity version of DRAINMOD (= DRAINMOD-S) started by modifying the model DRAINMOD to provide daily average fluxes as a function of depth in the unsaturated zone above the groundwater table (Kandil et al., 1992; Kandil, 1992). The average flux over time step Δt at any distance Z below the soil surface is determined by breaking the profile into depth increments, Δz (Fig. 2) and calculating the volume of water removed or added to each increment. In the saturated zone, the vertical fluxes are linearly decreased from the net recharge at the watertable level to zero at the impermeable layer depth. In addition, a profile of soil moisture content is also generated using soil moisture characteristic data based on the drained to equilibrium assumption. This method proved to give reliable results for flux computation (Skaggs et al., 1991) and solute transport (Kandil et al., 1992) when compared to fluxes predicted with a finite element solution of the Richards equation.

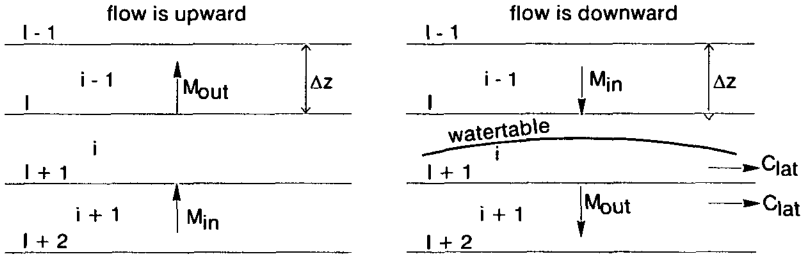

Figure 2. Schematic diagram of flow field in the soil profile considered in DRAINMOD-S

Kandil (1991) used a mass balance approach to solve the advective-dispersive-reactive equation for total dissolved salt concentrations in the soil profile at each time step. The basic differential equation reads:

$$\frac{\partial \theta C}{\partial t} = \nabla \,.\, (\theta D_h \,.\, \nabla C - qC) + R(C) + \Gamma_c \tag{10}$$

where C is the volume-average solute concentration (mg/liter), θ is the volumetric soil moisture content (cm^3/cm^3), t is the time (day), D_h is the second-rank hydrodynamic dispersion coefficient (cm^2/day), q is a flux vector (cm/day), $R(C)$ is a general solute reaction term (mg/liter.day) and Γ_c represents the solute sources (mg/liter.day). For one-dimensional systems composed of non-reactive solutes, Equation 10 reads:

$$\frac{\partial \theta C}{\partial t} = \frac{\partial}{\partial z}\left(\theta D_{hz}\frac{\partial C}{\partial z}\right) - q_z\frac{\partial C}{\partial z} + \Gamma_c \tag{11}$$

where D_{hz} is the hydrodynamic dispersion coefficient in the vertical direction, and q_z is the flux. The equation can be approximated for downward flow as:

$$C_{ini} = \frac{C_{io}\,\theta_{io}}{\theta_{ini}} + \frac{M_o - M_i}{\Delta Z\,\theta_{ini}} + \frac{\Gamma\,\Delta t}{\theta_{ini}} \tag{12}$$

where C_{io} and C_{in} are the salt concentrations at the end of the pervious and the new time steps (mg/liter); θ_{io} and θ_{in} are the soil moisture contents of layer i at the end of the previous and the new time steps; M_i and M_o are the mass of salt (mg) entering and leaving the soil layer i in time Δt; Γ is a source/sink term (mg/liter.day); ΔZ is the vertical distance increment (cm); and Δt is the time increment (day).

For upward flow with no drainage and no lateral water movement, the advective-dispersive-reactive equation is approximated by changing the sign of the second term on the left side of Equation 12 to a negative sign and the expressions for calculating M_o and M_i will be adjusted for the flow conditions accordingly. During periods where evapotranspiration exceeds the infiltration rate, the salt was assumed to leave the soil with a net flux at soil surface and added as a source term to the root zone. A source-sink term is used in terms of total salinity rather than individual salt species. Precipitation and dissolution of salts are considered by defining a concentration level of the soil solution at which there is no precipitation and no dissolution. Site specific values of this concentration levels can be determined using the geochemical assessment model for environmental systems MINTEQA2 (USEPA, 1991).

The solute transport model is coupled with DRAINMOD through independent or alternate solution methods. The combined model is called DRAINMOD-S. The additional inputs are the salinity of the irrigation water and the initial solute concentration in the soil profile. For independent flow and transport models the flow model is first solved for the entire duration of the simulation and results are stored. The results are then used to solve the transport model. For an alternate solution method, the flow and transport models are solved alternately over a series of time steps that together constitute the simulation period. In both cases, DRAINMOD is used to predict groundwater table depth, drainage rate, soil moisture fluxes and soil moisture contents. Then concentrations are predicted by the transport model. Computational requirements are similar for both approaches. Additional outputs other than those computed by DRAINMOD are predictions for solute concentration as a function of profile depth and time and drainage water salinity as a function of time.

The above approximate solution for solute transport based on mass balance was compared with a more accurate approach based on finite element solution developed by the same author (Kandil et al., 1992). The comparison was made for two soils, namely clay and sandy loam. The results of both methods were reasonably in agreement with a correlation coefficient $R^2 = 0.82$. However, the mass balance-based approach was two orders of magnitude faster than the finite element based approach. The mass balance approach is therefore considered reliable, simple, significantly saving simulation running time and will not deal with convergence and stability problems that sometimes arise with numerical solutions to nonlinear differential equations.

The response of crop yield to soil salinity is determined by Equation 4. The overall crop response model for DRAINMOD-S is modified to read:

$$RY = RY_p \times RY_w \times RY_d \times RY_s \quad (13)$$

where Equation 13 is similar to Equation 9 but with the right side multiplied by the relative yield due to salinity stress, RY_s. To compare predicted yields to field measured yields, relative yield may be expressed as:

$$RY_{measured} = \frac{Y}{Y_o} \quad (14)$$

where Y is the measured or observed yield in a given year and Y_o is the long-term average yield that would result from a combination of abundant irrigation, good drainage, root zone salinity below the threshold value and favorable crop production inputs.

Model testing

The reliability of the DRAINMOD-S for simulating water management in irrigated lands under actual field conditions was tested against data sets from the Zankalon Experimental Field (ZEF) in the Nile Delta (Kandil et al., 1992b). The soil profile consists of alluvial clay extending to a considerable depth below surface. The ZEF is provided with covered drains at a spacing of 20 meters and depth of 1.2 m approximately. Soil properties are represented by the saturated hydraulic conductivity and soil moisture characteristics. The later were used for determining the drained volume, unsaturated hydraulic conductivity, coefficients of Green-Ampt infiltration equation and rate of upward movement as a function of groundwater table depth using the SOILPREP program developed for preparing soil input data sets for DRAIMOD (Workman et al., 1990). Climate, groundwater table depth, drain discharges and irrigation water quantities and their salinities, crop data and soil salinities for 15 cm increments of the soil profile down to 150 cm below the soil surface are available for the cropping seasons 1989 - 1991.

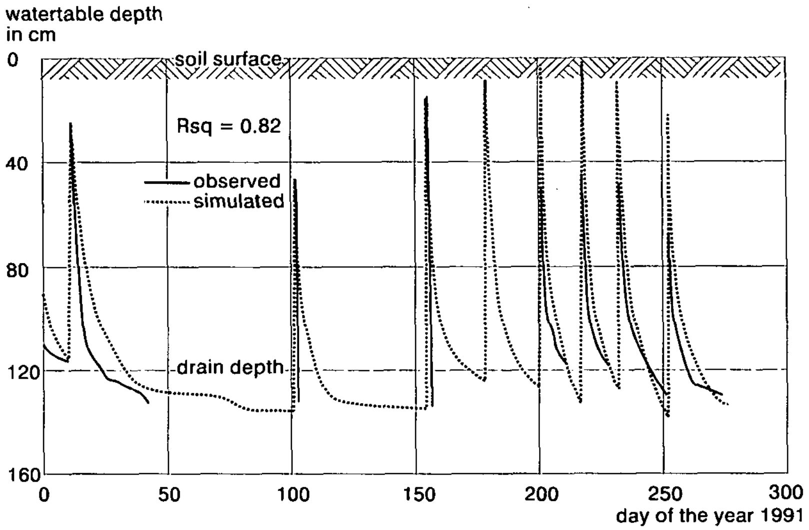

Figure 3. Comparison between the simulated measured daily groundwater table depths midway between laterals for the Zankalon Pilot Area

A sample of measured and predicted groundwater table depths midway between two lateral drains is shown in Figure 3. The agreement between predicted and measured values was quantified by conducting a regression analysis. The correlation coefficient (R^2) was in the range of 0.80 - 0.88 for all the tested data sets. There was also good agreement between the simulated and the measured drainage rates. The average of measured salt concentrations in three layers versus simulated values, as a function of time, are shown in Figure 4. The trend

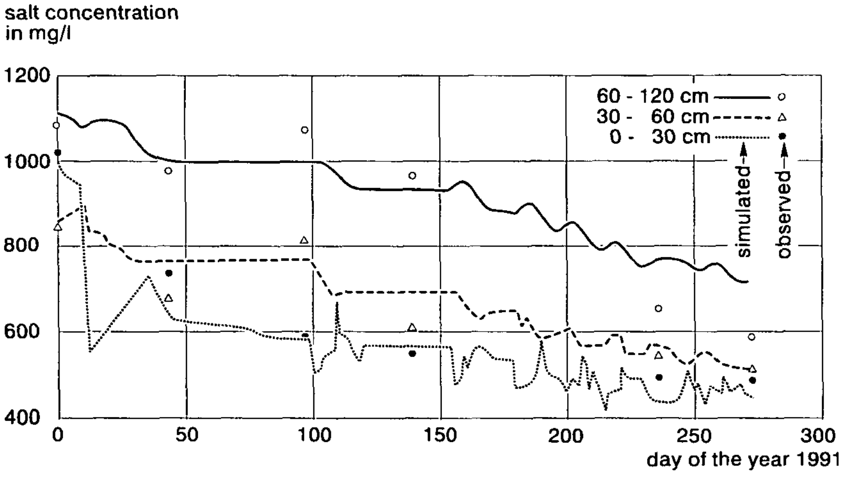

Figure 4. Comparison between the average measured and the simulated soil salinity at different depths as function of Julian days

of the simulated salt concentrations in Figure 4 mirrors the net infiltration, buffered by depth below soil surface. The results indicate that the effect of irrigation salt concentration on the soil salinity is more pronounced in the surface layer than in the deeper layers. The differences become less as time progresses, until the soil salinity is reduced to almost the same level as the irrigation water salinity irrespective of its initial salinity. A good agreement was also observed between the simulated and the measured drain effluent salinity.

DRAINMOD-S was also tested under semi-arid conditions in India (Merz, 1996). The study was carried out using data from the RAJAD Project in the Chamball Command Area near Kota, Rajasthan. Simulated water management in wheat and soybean fields showed that predicted and measured groundwater table depths were in reasonable agreement. The same was also noticed with the seasonal long term salinity trends.

Model applications

DRAINMOD-S as described above can be used either for the design of a new drainage system that should fulfill certain objectives or for evaluating the performance of existing drainage systems and their short and long term impacts on the groundwater table, soil salinity and crop yield. It can also be used for testing different water management strategies involving water quality and economic issues.

For design purposes, drain depth and drain spacing can be determined for a given set of conditions in an irrigated area. These conditions are represented by irrigation practices, quality of irrigation water, soil physical properties, initial salinity distribution in the soil profile, climatic data, crop rotation and other general information such as the drain radius and depth to impermeable layer. Overall relative crop yield is then computed for a range of drain spacings. A graph showing the relationship between the drain spacing and relative yield will give the drain spacing corresponding to the maximum crop yield (Figure 5). It is the drain

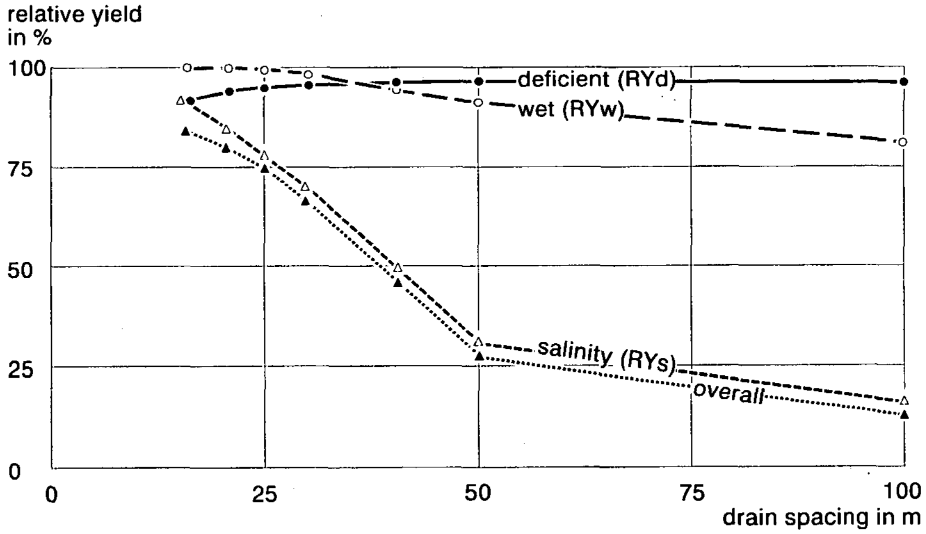

Figure 5. Relative crop yield as a function of drain spacing

spacing that, for the given set of input data, results into minimum stresses due to excessive wetting, drought, and soil salinity. Where there is more than one crop in the crop rotation, it is possible to have different drain spacings that produce the maximum yield of each crop. In this case, the designer has to assess the performance through either adjusting the irrigation practices of some crops in the rotation to eliminate stresses caused by the irrigation inputs (if possible) or selecting the spacing on the basis of economic analysis (costs and benefits). Market prices of crops and interest rates play an important role in the latter case.

Kandil et al. (1993) compared the performance of several drainage and irrigation strategies in an area, where a crop rotation consisting of bean, maize, wheat, cotton and soybean was proposed. In this study, different drain depths and drain spacings were considered as well as different timing of irrigation water applications and different leaching fractions. The timing of adding leaching water was also considered. DRAINMOD-S was used to simulate the water management for each individual case over a 19 year-period. The relative yield was predicted for each crop which was grown several times during this period. Beans, which is a salt sensitive crop, responded well to additional leaching water applied before the beginning and at the middle of the growing season. It gave maximum yield with closer drain spacing and less frequent irrigation. On the other hand, maize yield was maximum at wider drain spacing and more frequent irrigations. Wheat and soybean are less sensitive to salinity in the soil and therefore high yields were obtained at wider spacings. All crops responded well to pre-cropping leaching rather than to an uniformly distributed leaching fraction with each irrigation. Deeper drains were generally more effective in reducing salinity stresses and in increasing crop yields.

El-Hawary (1995) presented an approach for the determination of the most economic design of subsurface drainage projects based on the results of water management simulation using DRAINMOD-S. The calculated crop yields over the project life time for different drain depths and spacings were used for economic analysis based on the net present worth of each design. An interesting conclusion was that the most economic design is not necessarily the one producing maximum yield. The analysis showed that it is most sensitive to the interest rate rather than to initial project costs or crop price changes.

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Discussion

During the discussion the author explained that hydrological parameters such as hydraulic conductivity vary in space and the applied drain spacing also varies. The maximum yield is obtained at a spacing of 20 m, but the most economic system is obtained at spacing 35 m. A participant asked about a sensitivity analysis and different production functions and the author explained that verification on crop yields had been done in the United States but not in Egypt.

CONSTRAINTS AND OPPORTUNITIES FOR INTEGRATED WATER MANAGEMENT TOOLS

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Introduction

The water management problems in semi-arid regions can be summarized as follows. Due to an overall shortage of water to irrigate all the agricultural lands, the farmers in the fresh-water zones use groundwater as a supplementary source of irrigation water, quite often resulting in a groundwater decline as a consequence of the mining of this resource. On the other hand, the irrigation losses from the conveyance system and in the fields are resulting in a rapid rise of the watertables in the saline groundwater belt. The poor quality of the groundwater in those areas reduces the possibilities of its beneficial use and pollution problems may be created when the excess saline groundwater is drained to the river systems or is disposed in another way. It is clear that there is not a single simple way to solve these problems. A combination of measures has to be taken to attain technically and economically feasible solutions.

Optimal management of the available surface and subsurface water resources with respect to quantity and quality will be urgently needed in view of increasing demands, limited resources, rising watertables, and salinization. The complexity of the groundwater-surface water system is caused by the multiple interactions of the various components of the system. For managing this system, integrated water management tools are a prerequisite. In this paper, applications of this type of tools are presented with field examples from Pakistan and India and their constraints and opportunities discussed. To avoid duplication, relevant aspects of the application of this type of tools are spread over the three presented case studies.

Integrated water management models

The water balance is defined by the general hydrological equation, which is basically a statement of the law of conservation of mass as applied to the hydrological cycle. In its simplest form, this equation reads:

Inflow - Outflow = Change in Storage

Irrigation areas and areas in need of drainage usually cover only part of a river catchment or a physical groundwater reservoir. We therefore have to take into account any surface and subsurface inflow and outflow across the vertical planes of the boundaries of these areas. If we determine all their inflow, outflow, and water-storage components, we can assess the overall water balance. This is how water-balance studies are usually done (de Ridder and Boonstra 1994).

In overall water balances, we consider the flow domain vertically - from the soil surface to the impermeable base of the groundwater reservoir. The impermeable base may consist of massive hard rock or of a clay layer whose permeability for vertical flow is so low that it can be regarded as impermeable. Three reservoirs occur in this flow domain: at the surface itself, in the zone between the surface and the watertable, and in the zone between the watertable and the impermeable base. Because the reservoirs are hydraulically connected, partial water balances often have to be assessed for each of them in order to specify the drainable surplus. These water balances are referred to here as: the surface water balance, the water balance of the unsaturated zone, and the groundwater balance.

In the first two presented studies, ILRI's numerical groundwater simulation model SGMP (Boonstra and de Ridder 1990) was linked with different water distribution/unsaturated zone models. For the Schedule I-B of the Fourth Drainage Project in Pakistan, SGMP was linked with a spread-sheet model which calculates the flow components at the land surface and in the unsaturated zone. At a later stage, SGMP was linked with ILRI's SALTMOD model which calculates the flow components in the unsaturated zone. This integrated model, also known as the Regional-Agro-Hydro-Salinity Model (Rao et al. 1996) was also applied to the same area. For the Sirsa District Project in Haryana in India, SGMP was linked with the Winand Staring Centre's SIWARE model which is a combination of a surface-water distribution simulation model and an unsaturated-zone model. All the above unsaturated-zone models are based on a volume-balance approach. For the Fordwah Eastern Sadiqia (South) Project in Pakistan, SGMP version 2.8 was used as a stand-alone model. Here, an inverse-modelling approach was applied.

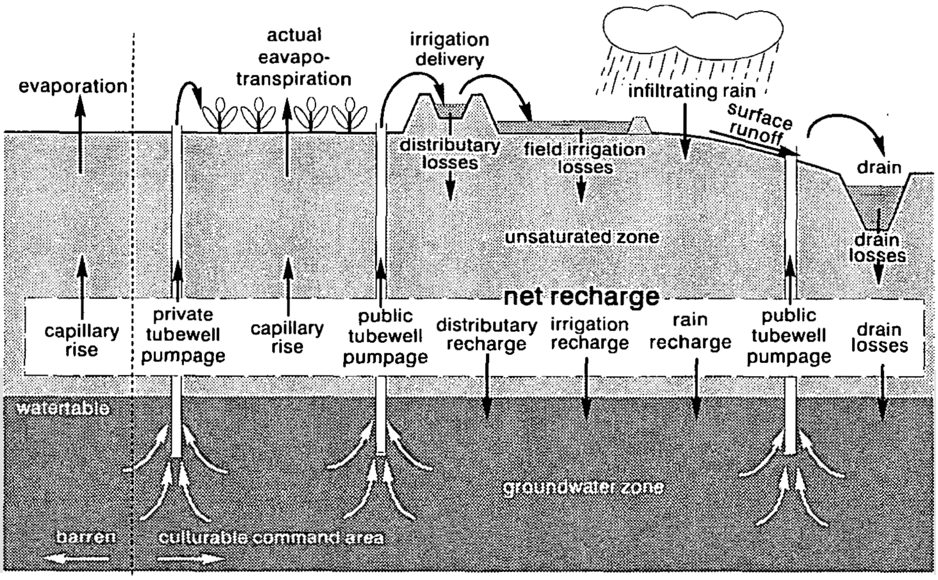

Figure 1. Water balance components resulting in net recharge to the aquifer

The linking mechanism between saturated and unsaturated flow in the above integrated water management models is the net recharge (Figure 1). This net recharge to the groundwater system is the algebraic sum of the following recharge and discharge components: rainfall; seepage from main canals, distributaries, minors, and water courses; field irrigation losses; capillary rise from watertables; and pumping by tubewells. Based on values of reported rainfall, irrigation water supplies, irrigation efficiencies, land use data, crop water requirements, capillary rise and evaporation data, and pumping by tubewells, the various unsaturated-zone models calculate the corresponding net recharge rates to the underlying aquifer system. Based on these net recharge values, the numerical groundwater simulation model SGMP then calculates the corresponding watertables; SGMP then returns its calculated watertables to the particular unsaturated zone model. When watertables are within critical depth, an iterative procedure follows till all the partial water balances are stabilized, before the calculations are continued for the next time step.

Schedule I-B of Fourth Drainage Project

To improve drainage design criteria, the Netherlands Research Assistance Project/NRAP, in collaboration with the International Waterlogging and Salinity Research Institute/IWASRI in Lahore, Pakistan, executed field research at the Fourth Drainage Project near Faisalabad in Pakistan. The Fourth Drainage Project is located in the south-western part of the Rechna Doab. The Rechna Doab consists of the area between the Rivers Ravi and Chenab and comprises about 28,000 km^2. The Fourth Drainage Project includes two separate areas, Schedule I and II, covering a total of 55,000 ha. In an area of 31,000 ha, horizontal subsurface drainage systems have been installed. Various research activities were initiated to provide answers to problems occurring during the pre- and post-periods of installing the various subsurface drainage systems. One of the objectives of the research in this Project was to use a groundwater approach to refine the calculation of the drainable surplus of an irrigated area.

Schedule I-B was selected as the study area; Table 1 summarizes the relevant information on this area. Schedule I-B belongs to the Samundri Unit II. It borders on the Lower Gugera Branch Canal in the north, on the Burala Branch Canal in the south, on the town of Satiana in the east, and on the Maduana Branch Drain in the west. To alleviate waterlogging and salinity in this area, eleven sump units with collectors and field drains have been installed (see Figure 2); their design capacity, also called drainable surplus, was calculated by the USBR as 2.44 mm/d.

Table 1. General project area information

area	:	9,000 ha
altitude	:	175 m a.m.s.l.
mean annual rainfall	:	250 - 400 mm
mean annual evaporation	:	1500 mm
irrigation water delivery	:	2 mm/d
transmissivity aquifer	:	6000 - 8500 m^2/d
specific yield aquifer	:	5 - 15 %

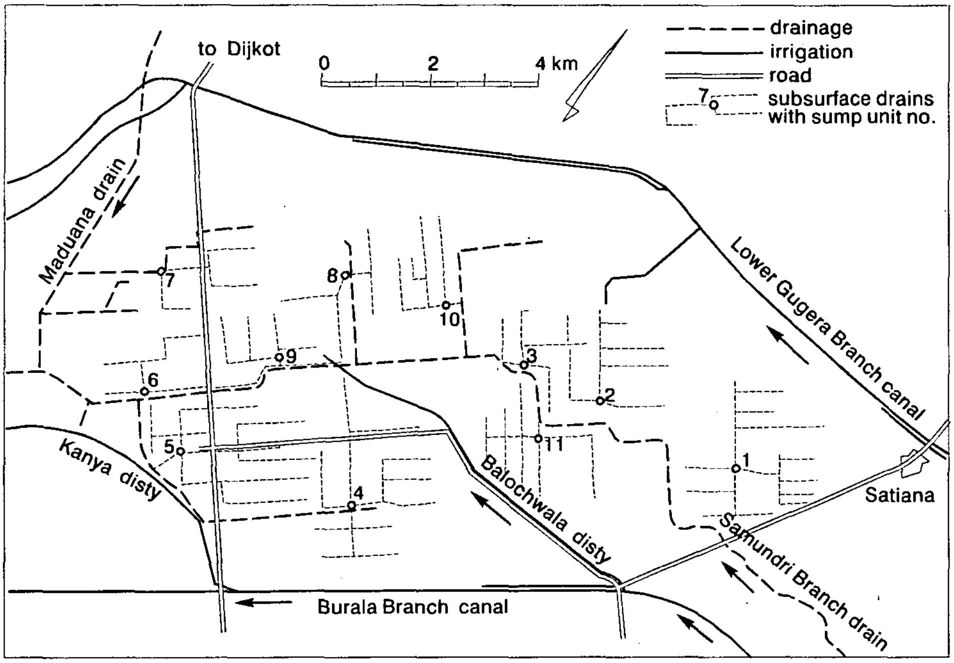

Figure 2. Schedule I-B of the Fourth Drainage Project with the location of the 11 sump units

In Pakistan, the depth-to-watertable has been monitored twice a year from the beginning of this century onwards. To this end, a primary observation network covers all of Pakistan. The spacing of these wells in the Rechna Doab area is some 15 km. In 1985, to be able to study the watertable behaviour in the Fourth Drainage Project in more detail, the SCARP Monitoring Organization/SMO installed about 300 observation wells throughout the area. Some 40 wells were installed in Schedule I-B; since that time, they have been monitored twice a year, in June and in October. These data were regarded as being representative of the pre-monsoon and post-monsoon conditions.

The model was run for the period June 1985 - June 1990 with a variable time step of 4 and 8 months, respectively. This yielded ten sets of seasonal net recharges: five sets for monsoon periods and five for non-monsoon periods. After calibration of the model, the five-year average contributions of the various water-balance components to groundwater recharge were assessed (Table 2).

Table 2. Water-balance components contributing to net recharge (in mm/d)

Water-balance components	five-year average
rainfall	0.28
distributaries	0.05
water courses & fields	0.29
capillary rise	0.38
private tubewells	0.03
Net recharge	0.21

In drainage design in Pakistan it is common to take a one-in-5-year wet monsoon to represent the design rainfall. A frequency analysis of the rainfall records of Faisalabad for the period 1930 to 1989 showed that the total rainfall in such a design monsoon would equal 347 mm (Boonstra et al. 1991). The historical monsoon season of 1975 yielded the value closest to the design rainfall of 342 mm. This historical monsoon of 1975 was taken as being representative of a design monsoon. The wettest monsoon in the study period occurred in 1986, with 282 mm of rainfall and a return period of 2.8 years; its rainfall data were replaced by those of 1975. The model was rerun with the design monsoon data and Table 3, Column 2 shows the corresponding water balance components and the resulting design net recharge.

Table 3. Water-balance components contributing to net recharge (in mm/d)

Water-balance components	Design Monsoon	Design Month
(1)	(2)	(3)
rainfall	0.93	2.30
distributaries	0.07	0.05
water courses & fields	0.39	0.42
capillary rise	0.55	0.46
private tubewells	0.04	0.14
Design net recharge	0.8	2.17

Comparison of Columns 2 of Tables 2 and 3 shows that the contribution of rainfall to the overall net recharge significantly increased as was to be expected. The reason that the contribution of the irrigation components also increased, can be explained by the canal closure period which was only accounted for in the five-year average values. The increase in capillary rise can be explained by the shallower depth-to-watertables during a design monsoon.

The same model was applied to the same area, but now on a monthly basis with more consistent field data. The objective was to study the effect of monthly rainfall compared to that of monsoon rainfall and to verify the previous results. The model was run for the period June 1994 - October 1994 with a fixed time step of one month. This yielded four sets of monthly net recharges. After calibration, the model was rerun with the design monsoon data of 1975 and Table 3, Column 3 shows the corresponding water balance components and the resulting design net recharge. Table 3 shows that the increase in design net recharge is mainly due to the higher design rainfall.

The above assessments of the design net recharge are very similar to what is usually done in traditional drainage design. The relevant components are considered and appropriate values are adopted. Such a drainable surplus is actually the design net recharge to the aquifer system. It is often assumed that its value is representative of the drainage coefficient, i.e. the discharge capacity of a subsurface drainage system. The model was used to test the validity of this assumption. In SGMP, there is a provision to prescribe upper levels of the water table, which may not be exceeded in a simulation run. If during a particular period the calculated watertable elevations exceed an upper level, SGMP introduces an artificial drainage component to keep the calculated watertable elevation just below that level. These upper levels represent the minimum permissible depth to watertable to be controlled by a subsurface drainage system, and the artificial drainage rate represents the drainage coefficient. In reality, the watertable depth between two drains will be less than the actual drain depth. This can be accounted for by taking the average of the minimum permissible watertable depth midway between the drains and the actual drain depth.

The areas where the 11 sump units in Schedule I-B are located were selected as potential areas in need of drainage. In other words, the drainage strategy of USBR was again adopted in this study. To these areas, upper levels of the watertable were assigned. The levels were calculated as follows: Average natural surface elevation in the area in question minus average permissible depth to watertable (being 1.5 m below land surface). With these data, the groundwater model was run for the period June 1985 to June 1990 and for the monsoon 1994 data with various permissible depths to watertable. The model introduced artificial drainage rates whenever the calculated watertable exceeded the prescribed upper limit in a certain area. Figure 3 shows the areas in need of drainage when the permissible depth to watertable was taken as 1.5 m below land surface. This critical depth was also used in the original design of the 11 sump units.

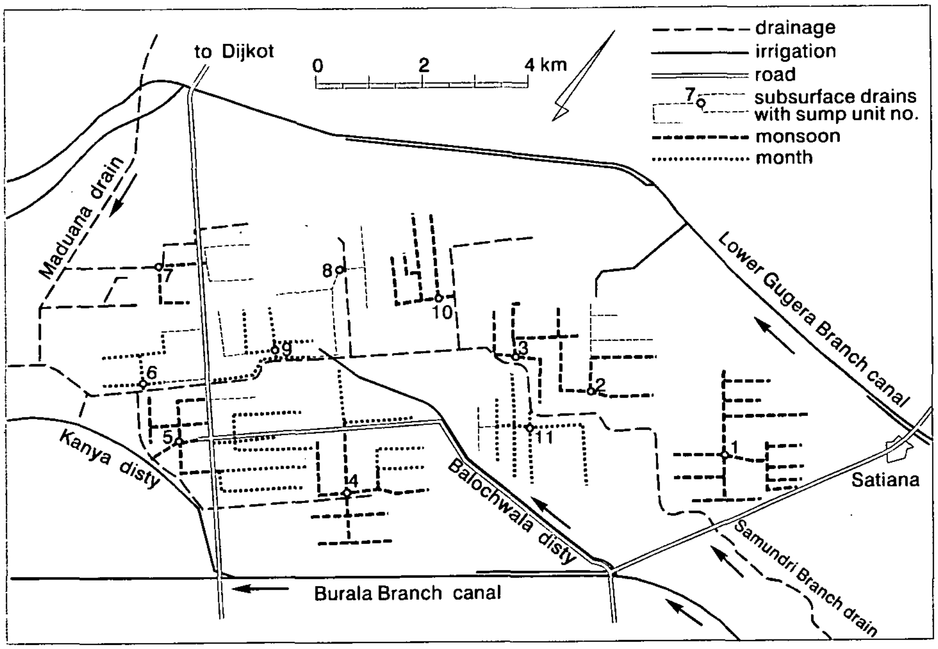

Figure 3. Results of the model study with respect to the areas in need of drainage in Schedule I-B (bold dashed lines based on monsoon period and bold dotted lines based on monthly period)

For a design monsoon rainfall, the results can be summarized as follows: (1) of the 11 sump units, only half of them are actually needed, and (2) an average value of 1.3 $mm.d^{-1}$ for the drainage rate was found whereas, in the original USBR design, it was taken as 2.4 $mm.d^{-1}$. For a design monthly rainfall, Figure 3 shows that all the sump units except sump unit 8 are needed; their average drainage rate was calculated by SGMP as 1.7 mm/d. From the results of both studies, it is clear that, although the introduction of large scale irrigation in Pakistan in the beginning of this century is the main cause of the rise of the regional watertable close to the land surface at present, drainage is now required to cope with the monsoon rainstorms. The watertable is at present so shallow that a few high intensity rainfall results in a rise of the watertable within the so-called critical depth. A field drainage system should not be designed on these short-duration high intensity rainfalls; the costs would simply be prohibitive. It is therefore proposed that a design monsoon rainfall is used for the design of field drainage systems. Such an approach was also followed by the USBR in their design; the contributing rainfall was representative for a period of approximately 2.5 months. It should be noted that taking the average design monsoon rainfall as component in the drainage coefficient will result in watertables within critical depth during monsoon periods.

Finally, this study clearly demonstrated the dynamic relationship between the drainable surplus, i.e. design net recharge, the permissible depth-to-watertable, the areas in actual need of drainage, and their required drainage rate. Such relationships can only be studied when this type of models are used.

Sirsa District Project

The application of an integrated water management model was one aspect of the research carried out within the framework of the Operational Research Project for Hydrological Studies. This project was implemented at the CCS Haryana Agricultural University in Hisar in collaboration with ILRI and the Winand Staring Centre for Integrated Land, Soil and Water Research from The Netherlands. The main objective of the research in this Project was to make forecasts of the effects of alternative water management scenario's on both the regional rising and falling watertables using this type of models. Sirsa District was selected as the study area; Table 4 summarizes the relevant information on this area.

Table 4. General project area information

area	:	420,000 ha
altitude	:	175 - 210 m.a.m.s.l.
mean annual rainfall	:	300 - 550 mm
mean annual evaporation	:	1600 mm
irrigation water delivery	:	1.6 mm/d
transmissivity aquifer	:	100 - 1300 m^2/d
specific yield aquifer	:	8 - 16 %

Sirsa district is situated in the north-west of Haryana State (see Figure 4); it borders on the state of Punjab in the north and Rajasthan in the west and south. Here, the same phenomena are encountered as can be found in the whole state of Haryana, i.e. rising watertables in the saline belt and falling watertables in the fresh groundwater zone along the Ghaggar river.

The depth-to-watertable are also monitored in India twice a year: in June and October. In Sirsa district a network of 91 observation wells is located. These data were obtained from the

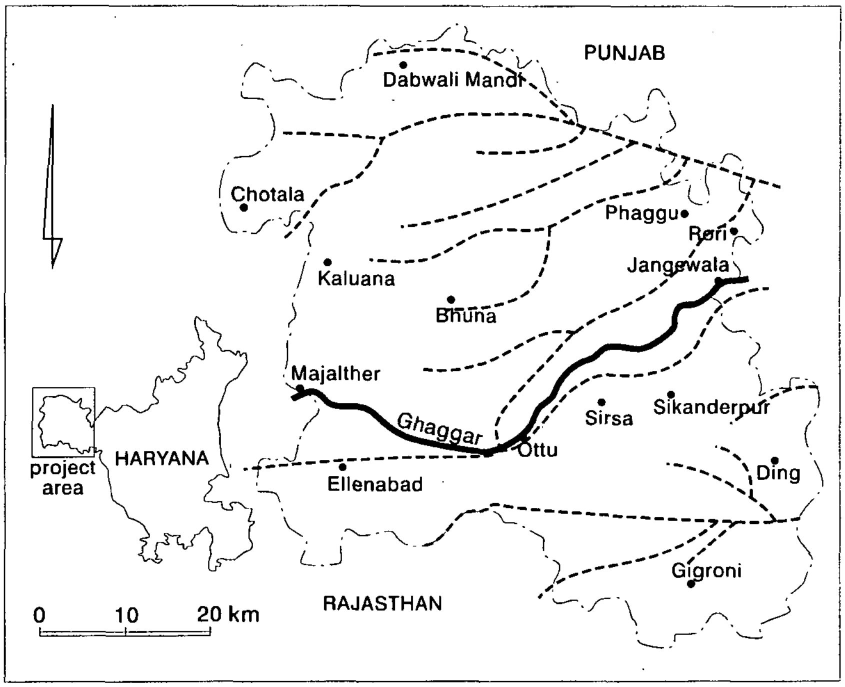

Figure 4. Sirsa District showing the location of the primary irrigation network

Haryana State Minor Irrigation Tubewell Corporation for the period 1976 to 1992, together with the reduced levels of the observation sites.

The model was run for the period January 1977 - January 1992. The time interval within a calendar year was dictated by the irrigation interval, irrigation being the major component in the overall net recharge. A calendar year was therefore subdivided in 15 intervals of 24 days - the common irrigation interval in Sirsa district - and one interval of 5 days to have exactly a calendar year. So, the complete simulation period of 15 years comprised 240 different time intervals and resulted in 15 yearly water budgets.

The period for which historical records are available, is usually split up in two parts. The first part is used to make certain adjustments in the uncertain model input parameters to obtain a good agreement between the calculated and observed watertable behaviour (calibration). The second part is used to check the accuracy of the calibration results; in this period the calibrated input parameters remain unchanged (validation). The model was calibrated using the data of the first five years and subsequently validated using the remaining ten-year period. Figure 5 shows the comparison between calculated and observed watertables in the north-western part of Sirsa district, where the watertables were rising monotonously during the period 1977-1991; here the validation results were very successful. In the central part of Sirsa district the watertable behaviour was quite different. Close to the Ghaggar river, the tendency of rising watertables was reversed after the first two years due to increased tubewell pumping by farmers. Further away from the river, the watertable stabilized either after an initial rise or after an initial rise followed by a decline. In this central part, the validation results were less successful. Figure 6 shows the comparison between calculated and observed watertables for two nodes in this area. Finally, in the south-eastern part of

Sirsa district, where the watertables were also rising monotonously during the period 1977-1991, the validation results were again successful.

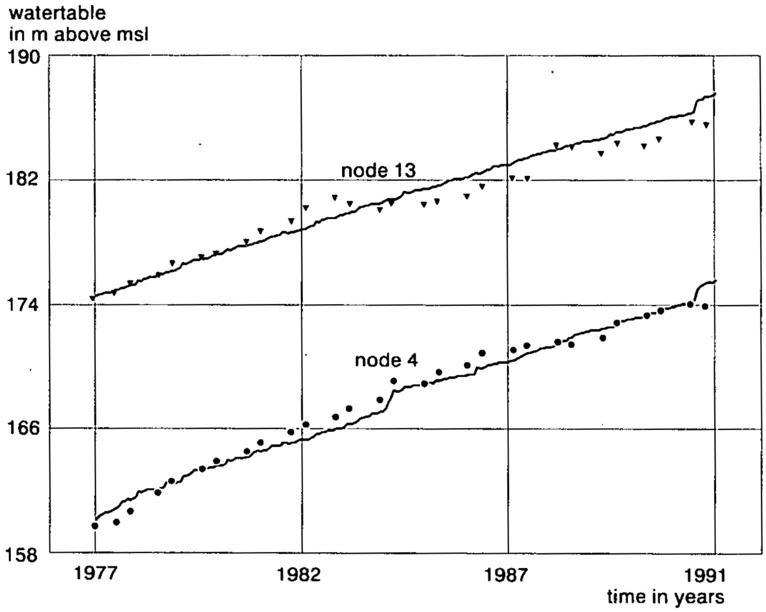

Figure 5. Comparison between simulated (continuous lines) and observed (discrete points) watertable elevations in the north-western part of Sirsa district

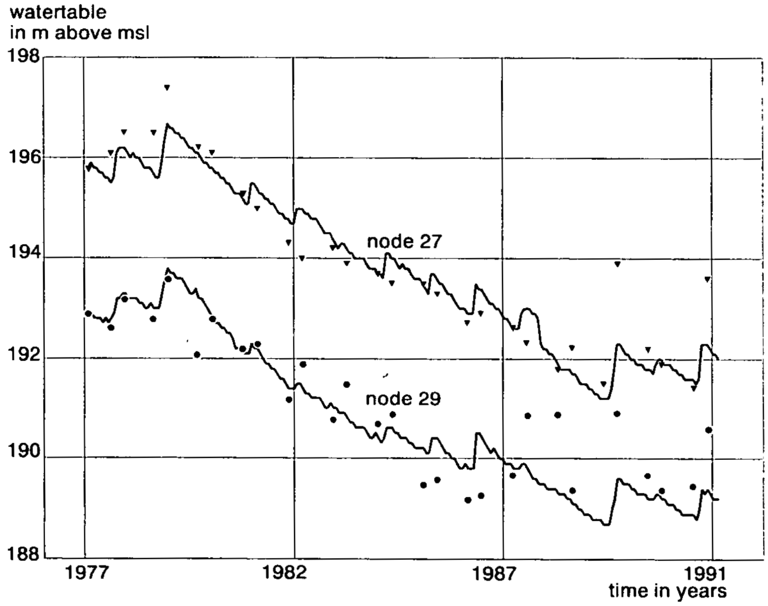

Figure 6. Comparison between simulated (continuous lines) and observed (discrete points) watertable elevations in the central part of Sirsa district around the river Ghaggar

It is standard procedure to make predictions on future watertable behaviour on the assumption that the present water management practices remain unchanged. In these prediction runs, two issues generally need to be addressed: (1) which recharge rates need to be prescribed to the model and (2) how to deal with the boundary conditions. In the calibration and validation periods, the various recharge and discharge components to the overall net recharge were more or less constant, except for rainfall, Ghaggar river recharge, and tubewell pumping; the latter increased significantly over the period 1977-1991. Instead of extrapolating this tendency in tubewell pumping, the overall net recharge was assumed to be constant in the prediction run, being the average of the historical recharges in the period 1982-1991.

The boundary conditions to the groundwater model were treated in the calibration and validation phases as head-controlled boundaries. In stead of extrapolating the tendencies in watertable elevations at the boundary nodes, the average flux over these boundaries of the groundwater model was determined over the period 1982-1991 and assumed to be constant in the prediction run. The groundwater model was subsequently run for the period 1985-2010. Figure 7 shows the results of this prediction run in terms of waterlogging conditions, i.e watertable depths less than 3 m below land surface. It can be seen from Figure 7 that waterlogging conditions will develop in the year 2000 in the central-eastern part and in the south-eastern part of Sirsa district and that especially in the central part north of the Ghaggar river, these waterlogging conditions will expand rapidly in the succeeding ten-year period. Although these predictions should be treated with some caution due to the above-mentioned assumptions, it will be clear that a considerable part of Sirsa district will face serious problems in the near future unless changes will be made in the present water management practices.

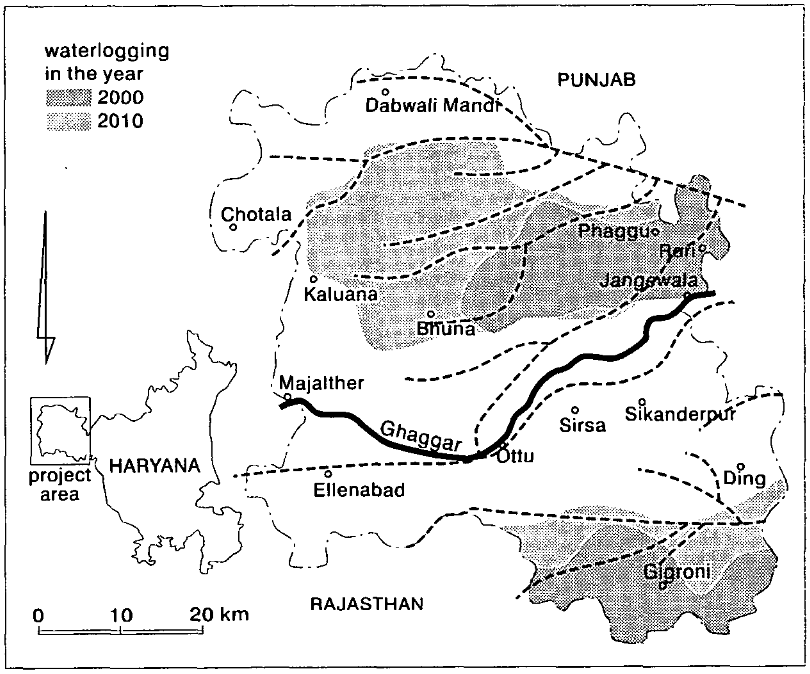

***Figure 7.* Results of the model study with respect to predicted waterlogging conditions (depth-to-watertable less than 3 m below land surface) in Sirsa district**

Finally, two different water management scenario's were simulated with the integrated model: scenario 1 was based on water pricing, i.e. water charges to the farmers are based on the amount of water rather than on the irrigated area, and scenario 2 was based on water supply according to demand (Boels et al. 1996). Table 5 shows the results of future waterlogging conditions for scenario b compared to that with the without case, i.e. present water management will remain unchanged in the future.

Table 5. Predicted waterlogging conditions as percentage of total area

Period	Without case	Scenario 2
1995 - 2000	10 %	5 %
2000 - 2010	45 %	20 %
2010 - 2040	50 %	45 %

For both scenario's, the tendency of rising watertables in the northern and southern part of the Sirsa district could only be attenuated, but not stabilized. This attenuation will be only prominent in the first coming 15 years as can be seen from Table 5.

Fordwah Eastern Sadiqia (South) Project

The main objectives of the FESS project can be summarized as follows: (i) increase agricultural productivity and income; (ii) reduce the need for expensive subsurface drainage and avert environmentally harmful effects; and (iii) improve the equity of water distribution. Within this project, it is the intention to install interceptor drains along unlined branch canals and distributaries, to line 180 km of minors and distributaries with a geomembrane covered with soil and then concrete slabs, to improve another 340 water courses, and to construct another 159 km of surface drains giving a total length of 352 km of surface drains.

One of the objectives of the research in this Project was to use a groundwater model to study the effects of the above anti-seepage measures on the regional watertable and to what extent these measures would reduce the areas in need of drainage. Table 6 summarizes the relevant information on the FESS area.

Table 6. General project area information

area	:	120,000 ha
altitude	:	140 - 160 m.a.m.s.l.
mean annual rainfall	:	170 - 190 mm
mean annual evaporation	:	> 2000 mm
irrigation water delivery	:	2 mm/d
transmissivity aquifer	:	800 - 1600 m^2/d
specific yield aquifer	:	10 %

In 1993/1994, to be able to study the watertable behaviour in the FESS Project in sufficient detail, the SCARP Monitoring Organization/SMO installed about 125 observation wells throughout the area (see Figure 8); since June 1994, they have been monitored on a monthly basis.

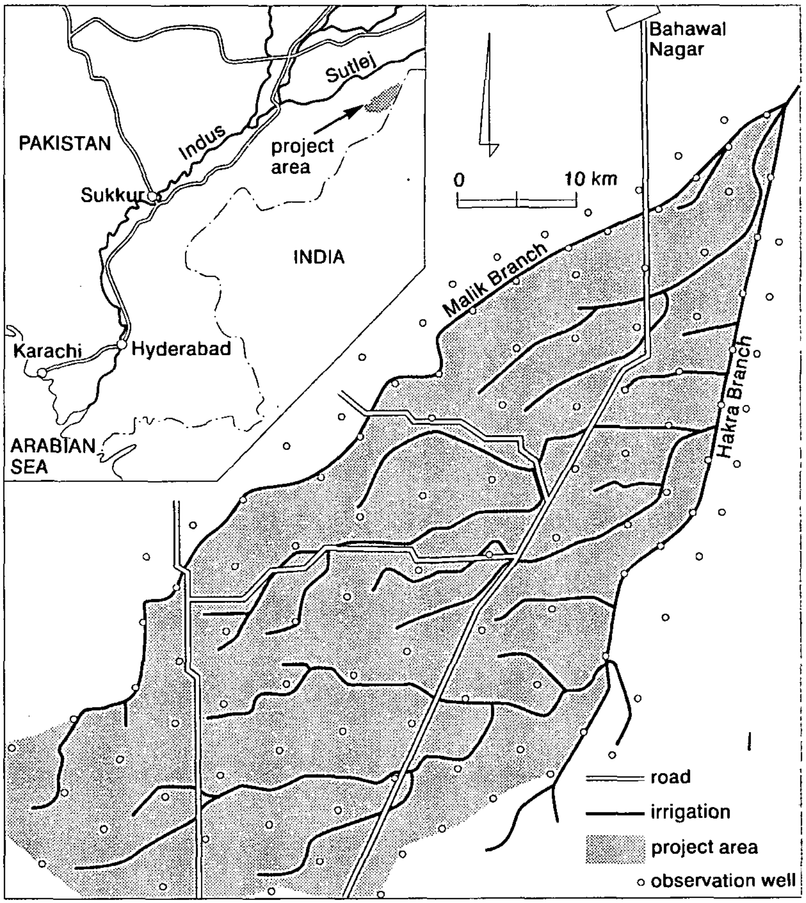

Figure 8. Fordwah Eastern Sadiqia (South) Project with the location of the 125 observation wells for depth-to-watertable measurements

The data base of the collected watertable data presently consists of monthly absolute watertable elevations for the period June 1994 up to August 1996; groundwater hydrographs and watertable contour maps were prepared to analyze the regional watertable behaviour. At present, five additional aquifer tests are made which will be analyzed with software (Boonstra 1989). The model will initially be run in the inverse mode; its principles were discussed by Boonstra and Bhutta (1996).

The advantage of assessing the net recharge with SGMP in inverse mode is that far fewer data are required. For instance, to assess the same net recharge by integrating the water balance for the unsaturated zone with the water balance at the land surface would require considerably more data (e.g. data on rainfall, irrigation, seepage from open water bodies, cropping pattern, crop-water requirements, soils, and tubewells).

The historical net recharges thus obtained will be prescribed to SGMP to make forecasts for future depth-to-watertables. Figure 9 shows the expansion of areas with depth-to-watertable less than 1.5 m (critical depth) between now and the next five to ten years. This figure clearly shows that the area in need of drainage will significantly expand unless changes will be made in the present water management practices.

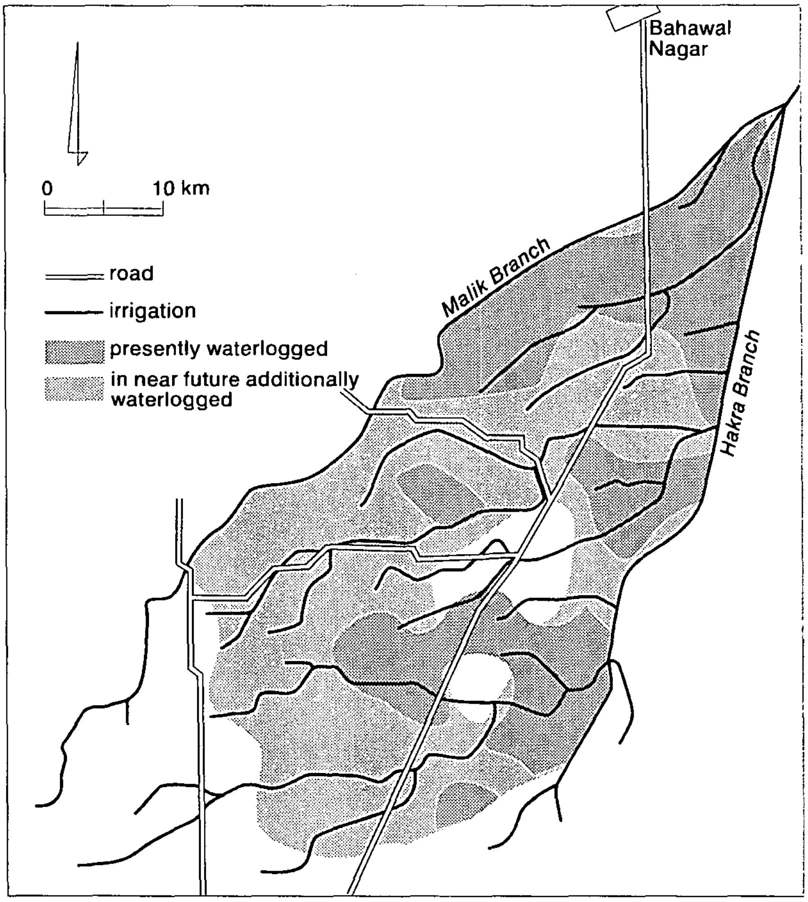

Figure 9. Results of the model study with respect to present and predicted waterlogging conditions (depth-to-watertable less than 1.5 m below land surface) in FESS area

At present, IWASRI is doing considerable field research; it comprises (i) field measurements to determine how much surface water is being lost in distributaries to the groundwater; (ii) the construction of test sites with interceptor drainage along the two main branch canals to study to what extent these interceptor drains will reduce the seepage losses to the groundwater; and (iii) the installation of subsurface drainage systems at three sites to test design specifications. Once these data are available, prediction runs will be made with the numerical groundwater model to make forecasts to what extent the anti-seepage measures will reduce the actual areas in need of drainage.

Concluding Remarks

With integrated management models, the magnitude of the various recharge and discharge components contributing to the overall net recharge to the underlying aquifer system can be systematically accounted for and evaluated. This is an important aspect of this type of tools because it significantly contributes to a proper understanding of past and present water management practices. Another aspect of these tools is that the effects of alternative water management scenario's can be tested on the regional watertable behaviour before they are implemented.

A major constraint of these models is that they require many input data that are often not readily available. This implies that a good monitoring network is necessary, with proper screening procedures to minimize field measurement errors. Finally, it is stressed that GIS pre-processors are a prerequisite when this type of models is applied on a provincial or state level, due to the inherent large spatial variability of the relevant data.

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Discussion

Asked whether the model gave consistent results, the author replied that the approach in this model application was based on unsteady-state conditions and that results were consistent. Another participant asked about the surface drainage system in Fordwah Eastern Sadiqia South and whether the effect of surface drainage was incorporated in the model. The author replied that surface drains were not included in the model and that in Fordwah Eastern Sadiqia South construction of the surface drainage system had not yet been completed. At this point in time it was not yet possible to calculate the effects of surface drainage on the model output, but the author offered the following observations on the effect of a functioning surface drainage system: (1) During monsoon surface drains would evacuate overland flow from the project area, thus reducing the groundwater recharge. (2) Although on the upstream side surface drains would be shallow and may not cut into the watertable, this would not be the case at the downstream end where large surface drains, like the Harunabad Drain, would not only remove overland flow but would also remove groundwater and so lower the watertable. (3) During harvesting periods, when irrigation supplies continue but farmers cannot use this water, it can be expected that this excess irrigation water will be discharged in the surface drains and leave the project area towards the evaporation ponds. This would also reduce groundwater recharge in the project area. The above three effects indicate that surface drains would reduce groundwater recharge and lower the watertable, provided these drains would be properly maintained. In case maintenance would not be good, this would mean more water would remain in the area, would recharge groundwater and result in more shallow watertables.

From the audience the remark was made that maintenance of surface drains is a government responsibility. Even if privatization programs would be introduced and become effective and the farmers themselves would accept responsibility for drainage, maintenance of main drains would always remain with the government.

FARMERS PARTICIPATION IN THE OPERATION OF MODIFIED DRAINAGE SYSTEM

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Abstract

Egypt is implementing a large scale programme of land drainage. About 150,000 feddans[1] are provided with subsurface drainage systems yearly. Among the drained areas there are areas planted with rice and provided with a subsurface drainage system. The presence of rice as wet-foot crop in the crop rotation requires that the farmer closes the subsurface drain during the summer season. This creates a problem of groundwater table rise in the neighboring areas cultivated with maize and cotton (dry-foot crops) if served by the same collector. The modified drainage system was proposed for rice areas to prevent this problem by consolidating rice areas on selected (sub)collectors. Pilot area research and monitoring activities revealed that there is considerable water saving when the modified system principles are applied.

Before 1992 farmers were required to apply consolidated cropping, meaning summer crops are concentrated in blocks of 24 - 48 fed, which made the modified system principle possible. Since then cropping was liberalized and the farmers are free to plant any crop. This created difficulties in operating and managing the modified drainage system, unless farmers can be made to appreciate the importance of collective efforts to operate the system according the modified drainage system principle.

A study was conducted in the Balaktar area, Behaira Governorate, to involve farmers in operating the drainage system during the rice season according the modified drainage system principle. Along five collectors farmers were organized on voluntary basis to consolidate the rice areas and the collectors were provided with closing devices. Observations were also made along two other collectors where farmers did not consolidate rice areas. Results after the first season are reported. Future work in organizing Collector User Groups is indicated.

Introduction

Egypt has a total area of one million km^2, of which about 3% (6.5 million fed, 2.69 Mha) is agricultural productive. The climate is warm and arid with a short and mild winter. The soils

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[1] 1 feddan = 4200 m^2. fed = feddan.

in the Nile Delta are fine textured, medium heavy to heavy clays, becoming heavier towards the sea. The River Nile is the main source of irrigation water for the agricultural lands. Since the completion of the Aswan High Dam in 1970 and the introduction of a perennial water supply to all the irrigated areas, the cropping intensities and water use in each irrigation unit increased sharply and all agricultural lands are now double cropped with crop intensities of up to 200%. The natural drainage system could no longer cope with the increased percolation from irrigation water and much of the land became waterlogged and/or salinized. To overcome these problems the Government of Egypt has initiated an intensive land drainage programme which includes, among others, the installation of subsurface drainage systems.

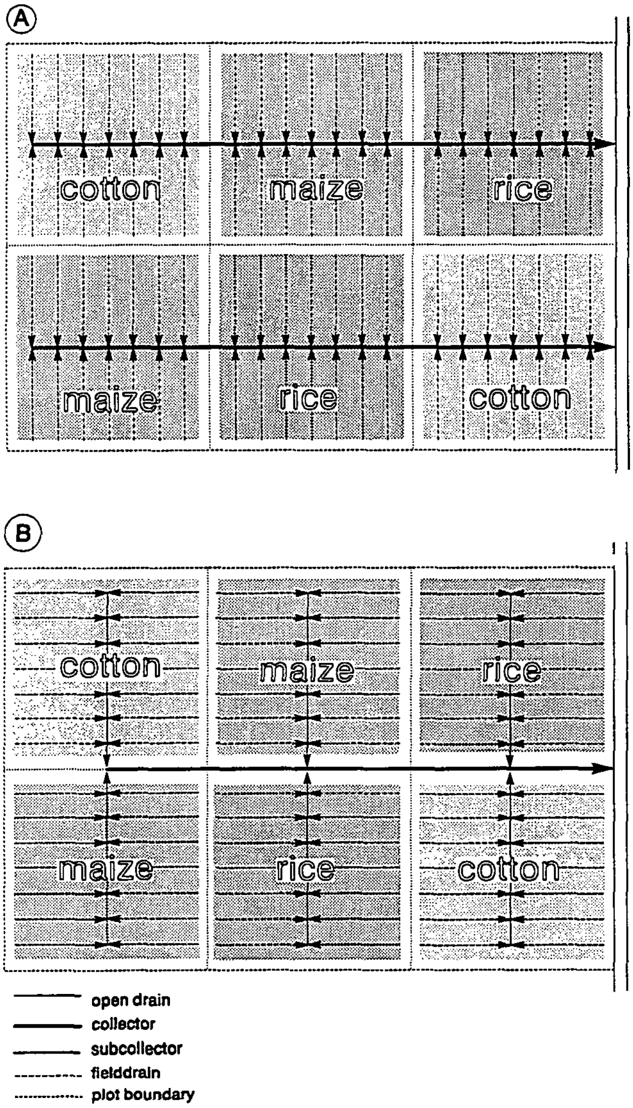

Figure 1. ***Layout of conventional and modified drainage systems (Cavelaars et al., 1994).***
A: Conventional layout, not adapted to the cropping units
B: Modified layout, adapted to the cropping units

The subsurface drainage systems installed in Egypt are generally of the composite type, which means that they consist of lateral and collector drains (Figure 1A). The laterals are on average 200 m long. The collectors, which transport the water to open drains, vary in their length from a few hundred meters to more than two kilometers depending on the topography and the layout of the main irrigation and drainage systems.

The problem of implementing a drainage system in rice areas was realized soon after the start of the World Bank supported large scale drainage programme in the Nile Delta in 1970 (Abdel Dayem, 1995). The problem occurred as a result of the mixed cropping pattern in the Nile Delta where rice is cultivated with cotton and maize in the area served by the same collector drain. The water requirements of rice and other crops are distinctly different. Rice is a wet-foot crop requiring continuous standing water in the field, while the other crops need good control of the groundwater table below the root zone.

As the implementation of the conventional drainage system causes rapid drainage of the rice fields to an extent that the standing water cannot be compensated by fresh irrigation water, the farmers plugged the drain pipes using plant leaves and mud. The problems which were created are:

1. drainage water is backing-up in the subsurface drainage system and causing a poor growing environment for the other crops sharing the same collector drain with rice;
2 the dirt used for plugging the pipes often slipped into the pipes causing serious maintenance problems.

Several studies to develop more appropriate drainage techniques for rice growing areas were started. The major objective was to minimize the drainage flow from the rice field (controlled drainage) and at the same time to allow free drainage flow from the other crop fields (conventional drainage). A modified drainage system layout was developed (Figure 1B). An investigation programme was conducted from 1977 until 1979, while, during the period 1980-1988, the concept of the modified drainage system was developed and tested both in experimental fields and in pilot areas. A total of 5400 ha was constructed according the modified drainage system principle[2]. By the mid 90's there were two developments in Egypt which affected the implementation of the modified drainage systems:

1. The abandonment of mandatory crop consolidation in 1992, leaving the farmers free to choose the crops they like. Hence, the block system of land use could not be imposed any more;
2. The government plans to involve farmers in the on-farm water management and make them more responsible for operation and maintenance of the irrigation and drainage systems.

The aspect of free non-consolidated cropping patterns decreases the chances for implementing modified drainage systems. However at the same time, the move to stimulate farmer's participation in on-farm water management may help to introduce these systems. The Egyptian Public Authority for Drainage Projects (EPADP) is moving towards farmer's participation in the operation and maintenance of the (sub-)surface drains. This is one of the requirements for successfully operating the modified system. DRI therefore, followed up on a suggestion of the Advisory Panel on Land Drainage, to investigate the possibility of applying the modified drainage system design and principle of operation under the new conditions.

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[2] These 5400 ha were constructed as "Modified Drainage System", however, EPADP has since then constructed many hectares with the collector-subcollector idea, but did not install gates to control drainage

The main objectives of this paper are :
- To present results of the water management studies of rice fields in areas provided with sub-surface drainage systems since 1977-1979;
- To present results of applying the concept of modified and conventional drainage systems in rice field since 1980-1988;
- To present the experiences with farmer's participation in voluntary crop consolidation and application of controlled drainage during the 1996 rice season;
- To present future plans for the introduction of voluntary crop consolidation by farmers and to recommend on modifications in traditional drainage system design which will give farmers more flexibility in operating the subsurface drainage system.

Previous work

In arid climates such as Egypt, the high groundwater table causes salinization of the root zone. Without adequate drainage facilities, the accumulated salts cannot be leached from the root zone. To overcome these problems, a widespread system of open main drains and pumping stations was constructed. The installation of subsurface drainage systems began on a large scale in the 70's as the existing drainage system could no longer handle the rising groundwater table. About 1.76 million ha of agricultural lands have been provided with subsurface drains. The installation of subsurface drainage systems is primarily meant to improve the growing conditions of dry foot crops such as cotton, maize, berseem, wheat, etc. In Egypt, rice is grown along with dry foot crops. Rice cultivation is concentrated in the Nile Delta, with the main rice belt in the northern part.

In rice areas provided with subsurface drainage some farmers were obliged to close the drain outlets using straw and need to keep standing surface water in the field as long as possible. These methods of field water management from the farmers point of view caused many problems on system maintenance. Therefore DRI and EPADP started to study and implement modified drainage systems in rice areas.

Drainage of rice should be based on the following principles (Abdel Dayem and Ritzema, 1987):
- To operate the covered drains in the rice fields independently from the rest of the drainage system. This can be achieved by using a subcollector drain for each crop area;
- To reduce the outflow from a field cultivated with rice a closing device should be installed in the downstream part of the (sub)collector. If other crops than rice are cultivated the closing device should be left open, enabling unrestricted outflow conditions;
- The design criteria for pipe drain capacity of a modified layout can be the same as those applied for non-rice areas. In the conventional design, a drainage duty of 4 mm/day is applied for the calculation of drain capacities for areas with rice in the crop rotation versus 2 mm/day for non-rice areas. With the modified layout this increase in capacity is not necessary. Even on occasions when rapid drainage is required, e.g. for renewal of the standing water in a field or at the end of the rice season, which can be achieved by accepting temporary over pressure for short periods.

The studies executed by DRI included those described in the next two sections.

Water management observations

From 1977-1979 DRI carried out a field study on the water management in rice fields during three successive summer seasons (1977, 1978 and 1979) in the North West of the Delta near Damanhour (Figure 2). It was found that although yields remained the same or slightly increased with subsurface drainage, there was a continuous loss of irrigation water standing in the rice fields through percolation to the subsurface drains. The amount of water removed by drains from the rice fields was estimated at 5-10 mm/day. In order to compensate these continuous subsurface drainage discharge, an increase in irrigation water is required. In areas with a shortage of irrigation water supply, specially during and for some time after the nursery bed stage, the lack of water may cause an adverse effect on the crop. A temporary closure of the drainage system was therefore recommended.

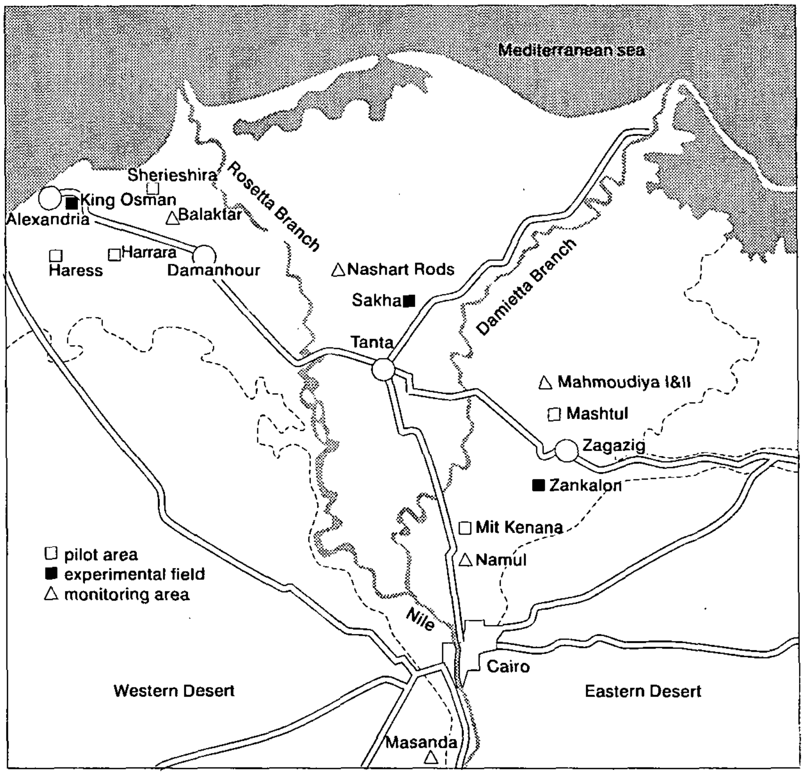

Figure 2. Location of experimental fields, monitoring and pilot areas of DRI

Testing of modified drainage system

The modified layout of the drainage system was introduced in 1980 at the Mahmoudiya-I drainage project in the Bahr Saf area in the Eastern Nile Delta (Amer and De Ridder, 1989). It consists of covered main collector drains with subcollector branches. Each subcollector serves an area coinciding with a "one crop block" of the crop consolidation system (Figure 1B). The junction of the subcollector to the main collector consists of a manhole with a suitable device for regulating the subcollector outflow. In this way, there will not be a need for unauthorized blocking of the system and regulation will be carried out without any conflict for the drainage requirements of the various crops.

The most important feature of the design criteria for a modified drainage system in areas with rice in the crop rotation, is the design drainage rate which is the same as for non-rice crops. This implies a reduction in the pipe size as compared to the current design norms and consequently a saving in construction costs. In addition the introduction of the modified system indirectly helps in saving precious fresh irrigation water.

After comparing the results of the study it was concluded that the results obtained in the experimental fields (King Osman, Sakha, Zankalon) in 1984 are in agreement with those of the detailed studies carried out in farmers fields in respectively Mahmoudiya, Mashtul (1986) and Nashart Rods (1986). The conclusions are summarized as follows (DRI staff 1988).

The introduction of a modified drainage layout in the rice growing areas in the Nile Delta will:
- Save between one and three billions cubic meter of irrigation water which would otherwise be lost through the subsurface drainage system in a total area of 1 million feddans in the Nile Delta (being the difference in drainage rate between the conventional and modified system 1-3 mm/day over a growing season of 100 days);
- Save the drainage system from unauthorized and improper interference of farmers to stop irrigation water losses from rice fields through the subsurface drainage system;
- Save other crops than rice from the damaging effects of the improperly blocked conventional collector drains.

These benefits are obtained without causing any negative effects on either the soil salinity levels in the blocked subcollectors of the modified system or on the yield of cotton, maize or rice.

Since the detailed research by DRI, seemingly little was done about the modified drainage system. However, EPAPD experienced problems with the O&M of long collectors in, amongst others, rice areas. When farmers blocked long collectors large areas were affected. Hence EPADP adjusted their designs to short collectors, or long ones, but with subcollectors. If farmers then would block the collector only a small part would be affected. EPADP did not install gates at the end of the subcollectors but left the decision on how to close/block to the farmers. EPADP did not call the system 'Modified Drainage', but in fact they are. The main objections to the gates were the costs and the more difficult maintenance and operation of systems with gates. Therefore since 1988 very little has been done with the modified drainage system principle.

Reasons to look more into the application of the modified drainage system are:
1. the increased interest in creating more water for new irrigation areas and the increased awareness of the limited supplies of the Nile River;
2. the world wide attention given to controlled drainage, not only from water savings point of view, but also to control the environmental impact of drainage systems;
3. the attention to involving farmers in O&M of irrigation and drainage systems in Egypt, which is actively taken up by EPADP for management of its drainage systems.

The objective this time is to first interest the farmers in the idea and then see if further changes are necessary in the collector-subcollector design as presently used by EPAPD. At the same time the legal option to formalize the organisation of farmers needs to be looked into, although at present it would seem an option to continue on voluntary basis for quite some time to come.

Legal aspects of water user associations (WUA) in Egypt

It is commonly accepted that for water user associations to be able to operate effectively they need to have a legal basis which allows them to levy fees and execute penalties. Following is a brief description of the laws that affect the operation of water user associations in Egypt. Most of these pertain to irrigation improvement and none of them thus far mentions drainage.

To date many attempts have been undertaken in Egypt through numerous projects to increase the benefits and minimize the losses of water resources. The concept that maximum benefits from technical solutions can only be attained through full collaboration with the intended beneficiaries is still rather new in Egypt.

Major efforts aiming at greater farmer involvement are undertaken in the Irrigation Improvement Project (IIP) and the Fayoum Water Management Project (FWMP staff, 1995).

The IIP concentrated at *mesqa* (tertiary canal) level: technical improvements accompanied by organizational development. It is the latter which has proved to be the most difficult. *Mesqa*s are considered private property and therefore Water Users Associations to be established at this level and notably to acquire a legal status, would not have been in accordance with the law on Irrigation and Drainage (Law12/1984). Modifications to the Law were prepared and proposed to Parliament. The ensuing Law 213/1994, stipulating modifications to Law 12/1984, makes a distinction between old and new lands. In new lands it is now possible to establish Water Users Associations, albeit at the *mesqa* level only. In old lands, Water Users Associations, according to Bylaws to this Law as issued recently by the Minister of Public Works and Water Resources Resolution (FWMP 1995), have to be established in those areas where the irrigation system is improved. For the remaining areas of old lands, Law 12/1984 remains basically as it was, implying that the creation of Water Users Associations, let alone granting them a legal personality, is not permitted. Although above Bylaws have primarily been geared to the requirements of the second phase of the IIP, the interpretation of what is an improved irrigation system, appears to leave some leeway for further experiments in the old lands as well.

Apart from Law 12/1984 and Law 213/1994 the following laws could also pertain to the organization of Water User Associations:

- Law No.43/1979 and it's modifications concern the organization of the Local Administration. According to this Law the management of irrigation is a national, and not a local, service. It is a task carried out by and under supervision of the central government. The only local participation is realized through the people's council at the Governorate's level. Still, this council can only exercise its authority within the general policy and rules set by the Ministry of Public Works and Water Resources;
- Law No.32/1964. This law concerns private and non-government organizations. Membership of such an organization is voluntary and decisions are applicable to members only. A regional union of associations at Governorate level may be formed. The decisions of the associations and unions with respect to water management can only be consultative, not binding to local and central authorities.

From the foregoing it may be clear that there is little at present that would legalize the organization of farmers in Collector User Groups (CU Groups). Nevertheless, the organization of CU Groups seems legal under Law 32/1964. DRI therefore decided to organize on voluntary basis a number of farmers in CU Groups with the aim to investigate the potential for voluntary crop consolidation along selected collectors or subcollectors. Because of the implied legal connotation of the word 'Association', the word 'Group' is used to avoid implying more than is intended.

Controlled drainage with collector user groups

DRI approached the farmers in the area of interest indirectly: they first identified which organization had the trust of the farmers. It was decided that the "Cooperatives" of the Ministry of Agriculture were the best focal point for DRI's intentions. The Cooperatives provide farmers on a day to day basis with advice, provide fertilizer, seeds and assists with resolving any problem that might occur in the field. Over time they have built up a good reputation amongst the farmers. The staff of EPADP's Maintenance Centres in the area (which are responsible for the O&M of the drainage system) were also involved right from the start, but as their interactions with the farmers are less intensive, they were not selected as the main go-between DRI and the farmers. DRI then arranged a meeting at EPADP's Damanhour office with EPADP, the Cooperative, the EPADP Maintenance Centre staff, and EPADP's Regional Headquarters staff, and introduced the plans as well as arranged which areas to perform the tests. The Cooperatives then talked with the farmers and introduced DRI staff. Video tapes were made of these meetings. During subsequent meetings with the farmers (always under guidance of the Cooperative and at the Cooperatives quarters in the area or in the field) a memorandum of understanding was drafted which primarily assured cooperation between farmers and DRI to install the necessary equipment for the experiment. For each of the subcollectors selected the farmers elected a leader of the CU Group with concurrence of the Cooperative. All parties involved, the leader of the farmers and the representatives of the Cooperative, DRI and EPAPD's Maintenance Centre signed the MOU. The leaders became the direct contact point for the DRI staff in the field, and assisted with installing the gates, arranged field observers, performed measurements, etc.

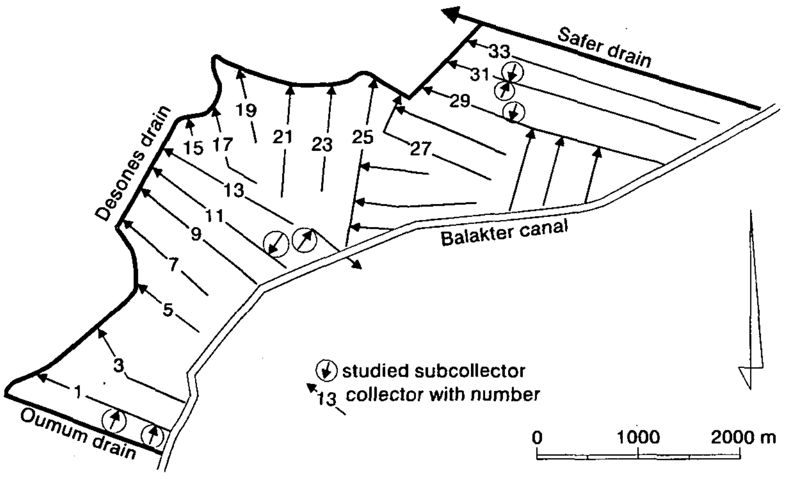

Figure 3. Location of collectors selected for the study

Finally seven collectors were selected, five subcollectors along which farmers agreed to consolidate rice, and two conventional collectors in areas close to the subcollectors where rice consolidation was not practiced. Table 1 gives some of the characteristics of each of the (sub)collector areas. The study was conducted at Balaktar area (Figure 3) which is situated in the Western Delta, 20 km east of Damanhour in Beharia Governorate (Figure 2).

Table 1. Characteristics of collectors with collector user groups

Collector number	type	area feddan	number of rice fields out of total fields	number of farmers	farmers with schooling %	farmers with no schooling %
Agreed to rice crop consolidation						
1	subcollector	12.33	9/9	9	44	56
11	subcollector	20	24/24	22	17	83
12	subcollector	27	30/30	26	19	81
29	subcollector	29.5	25/25	30	0	100
31	subcollector	22.3	26/26	26	0	100
No rice crop consolidation						
Ext.1	collector	5.5	1/2	3	0	100
3	collector	9.25	1/6	7	14	86

Special closing gates designed by DRI (DRI, 1987) were supplied to the five subcollector CU Groups and DRI assisted with the installation of the gates. Operation and maintenance of the gates were fully the responsibility of the CU Groups. The gates were left open till rice plants were transplanted from the nursery beds to the main fields; then they were closed.

In order to monitor what was going on in the fields the following observations were made:

- the groundwater table depth under the rice fields;
- the groundwater level in the rice fields from installed staff gauges to check the amount of water applied;
- the discharge of a number of diesel pumps were determined;
- the rice yield of 1994 was determined through interviews with farmers;
- the 1996 rice yield was determined from crop sampling;
- the costs of fuel and rental of irrigation pumps were determined;
- soil samples were taken before and after the season to determine soil salinity levels;
- periodic meetings were held with the farmers to solve any problem during the study period.

Results first season (1996)

The Collector User Groups (CUG) which are formed for the first time for field drainage do not have a formal structure, but are a voluntary group of farmers. After one month since the starting of the study, the farmers of modified collectors noticed that the closing of the collectors prevent drainage and reduced the frequency of irrigation applications to the rice fields. Consequently, this helps in saving money for the farmers. For the modified drainage system, the response of accepting the idea of farmer participation in CUG are quicker in the collectors with a higher percentage of educated farmers. Table 1 shows the modified collectors under study and the educational level of the farmers. It is observed that collector no.1 has the highest percentage of educated farmers followed by collectors no. 12 and 11 respectively. The results obtained from these collectors showed that these collectors do not need more time to accept the CUG. During the study period religious people in mosques and churches were informed about the study by DRI engineers and consequently they invited the farmers to participate in this study. Many farmers have accepted the idea and meet with DRI staff to apply the study for the next year. Figure 4 presents the yields of 1994 and 1996, without and with modified drainage, respectively.

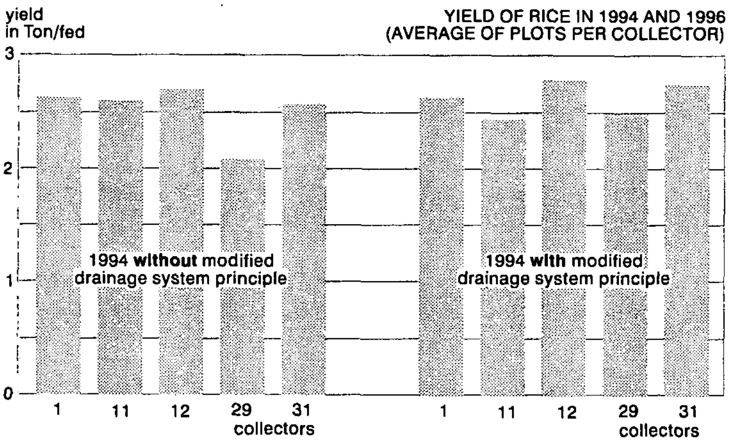

Figure 4. ***Yields of rice with and without modified system management application.***

Saving irrigation water and operational costs

Figure 5 shows the total irrigation water amounts during the rice season for the modified and the conventional collectors. It is observed that the amount of irrigation water used for modified system are less than the amounts used for conventional system. The average amount of irrigation water used for the modified system is 4298 m^3/fed and 7545 m^3/fed for conventional collectors. This means that the modified drainage system saves about 43 % of the irrigation water comparing with the conventional one.

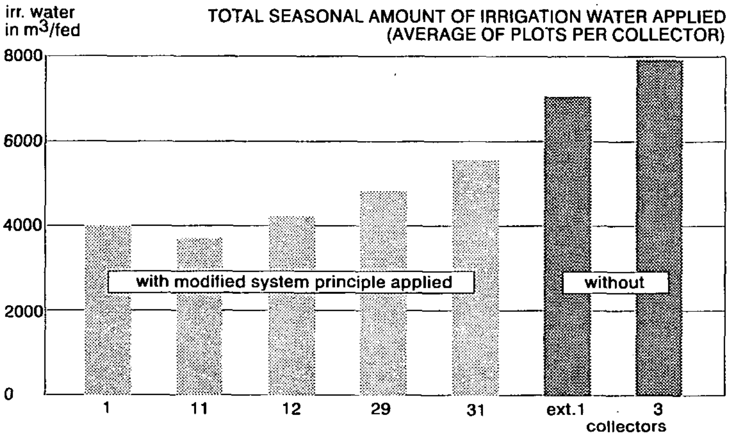

Figure 5. ***Irrigation water applied with and without modified system principle.***

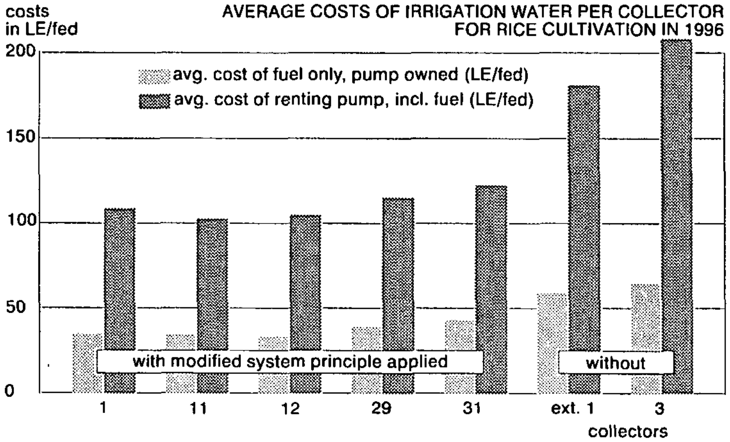

Figure 6. Comparison of some of the costs of irrigation water.

Figure 6 shows the costs of fuel for pumps owned by farmers and the cost of renting irrigation pumps including fuel. Although these two amounts cannot be compared with each other in a strict sense, they reflect the actual expenditures of the farmers during the season. Further details will be worked out at a later stage.

The total costs of renting the pump was 113 LE/fed/season[3] for farmers using controlled drainage and 197 LE/fed/season for the conventional drainage.

The costs of fuel for privately owned pumps ranged between 30-37.5 LE/fed/season with an average of 33.75 LE/fed/season for rice cultivation with controlled drainage and ranged between 56-62.5 LE/fed./season (average 59.25 LE/fed/season) for rice cultivation with the conventional drainage system.

The difference in expenditure to obtain irrigation water to achieve a satisfactory rice crop was approx. 43% lower than with controlled drainage.

Table 2. 1994 and 1996 yields and water use in 1996.

Collector number	average 1994 rice yield by farmers recall in kg/fed	avg.1996 rice yield kg/fed (**)	avg. total m^3/fed/season irrigated in 1996
Agreed to rice crop consolidation			
1	2640	2611 (6)	4104
11	2630	2441 (5)	3617
12	2710	2756 (5)	4103
29	2100	2544 (5)	4424
31	2600	2731 (3)	4762
No rice crop consolidation			
Ext.1	-	2016 (1)	7140
3	-	2348 (1)	7956

** in brackets is number of fields from which samples were taken.

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[3] 1 LE (= 1 Egyptian pound) is equal to US$ 0.30 (July 1996)

Conclusions and recommendations

The results of the first season of using controlled drainage with the modified drainage system principle (collector-subcollector design) are very positive. Farmers were organized on voluntary basis in groups along small subcollectors to consolidate crop cultivation to rice only in the catchment of the subcollector. Farmers clearly observed the savings in expenditures to the reduced amount of irrigation water applied. No significant major difference was observed in yield in areas with and without controlled drainage, nor were other detrimental effects observed. This confirms the findings of work done during the period 1980-1988.

A major achievement was the methodology followed in establishing the Collector User Groups. An existing organisation that had the trust of the farmers already, essentially organized the CU Groups.

Farmers of adjacent areas have expressed interest in performing similar experiments in their areas. As rice is grown in a two year crop rotation, new areas for the experiment will be selected for the 1997 rice season. During 1998 we hope to return to the same collectors to see if the farmers are willing to consolidate again.

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Discussion

Asked about observations on other fields, the author replied that on other fields no effects were observed. Most farmers had a rice-cotton-maize cropping pattern. A question about discussion with the farmers was answered by the author explaining, that the impact on water saving and on neighbouring fields and the slight yield increase of cotton and maize was communicated to the farmers through video presentations. The report of the study was also presented to the farmers. A participant was interested in the timings of the different crops rice, cotton and wheat. The author explained that a group of farmers volunteered in the crop rotation. In Egypt the planting dates of various crops coincide, so that this was no problem. The farmers agreed to close subcollectors during rice cultivation.

THE CHOICE OF CROP ROTATION: AN IMPORTANT PARAMETER FOR CREATING AN ACCEPTABLE SALT BALANCE UNDER MINIMUM WATER USE[1]

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Introduction

The parameters for determining the optimum water management are the available water supply as compared to the crop water requirements, which in turn depend on the crop rotation. The drainage criteria also depend on the crop rotation, the irrigation supply, the irrigation water quality and the leaching fraction. This means that the choice of crop rotation has important implications for both irrigation and drainage management. This will be illustrated with an example from a project in Western China.

Drainage Project in Western China

The Xinjiang Pipe Drainage Project in Western China (Figure 1) has a continental climate; it is arid with an average rainfall of only 56 mm/year in summer. Due to the high number of sunshine hours in summer, the potential for crop production is high. The potential evapotranspiration is 1590 mm/year, of which the major part (1272 mm) is in summer in the growing season. In winter, everthing is frozen. The soil texture is sandy-loam to loamy-clay. Below 1.5 m -2 m , the subsoil is completely unstable.

The main problems encountered in the area include:

- **High ground water levels**, varying between 0.25- 2 m below field level. Irrigation in the area started somewhere in the 1950's and by the end of the 1980's the ground water level had already risen about 10 m;
- **Very saline groundwater** in places, with an electrical conductivity (*ECe*) of 5-100 dS/m, with the higher ranges being much more prevalent than the lower;
- **Secondary salinization** in the hot summer is considerable, especially after the harvest of the main crops in September/October before the frost sets in.
- **Water scarcity**. It is in a desert area so people want to irrigate the largest possible area.
- **Low quality irrigation water** with an *ECe* of 1.2-2 dS/m;

The above problems resulted in low crop yields and high water consumption. In solving these problems, we faced a number of constraints:

- Existing irrigation practices had to be maintained. Changing of these practices would have required adjustment of the irrigation infrastructure, which was not acceptable to our client;

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[1] Text and figures are taken from the summary provided by Ir. Croon, a tape recording of his presentation, and some of the overheads used therein.

- There was no additional water available;
- It was practically impossible to construct deep open drains, basically because of the unstable subsoils.

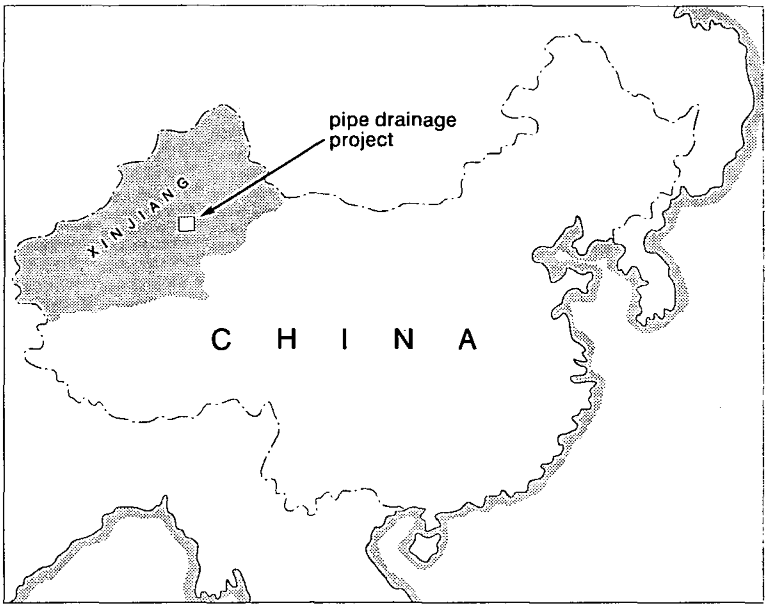

Figure 1. The Xinjiang Pipe Drainage Project in Western China

The only available option was the construction of a pipe drainage system, which could be installed, although with some difficulties, in the unstable soil at a depth of about 2 m. The design of the drainage system had to take into account the drainage water flow through the system as a design parameter. For determining this parameter, alternative salt and water balances were calculated for various crop rotations.

The traditional crop rotation was rice-cotton. Due to high water use by the rice crop (1800 mm net) this rotation resulted in scarcity of water and under-irrigation of the cotton crop (354 mm). The overall result is that salt accumulates in the top soil during the cotton crop and leaches out during the rice crop. Figure 2 presents the seasonal variation of the *ECe* under the traditional rice-cotton rotation. Please note that this is the situation **before** the installation of the drainage system.

Figure 2 shows a very high soil salinity during the cotton season, with the *ECe* going down during the rice season, and up again during the cotton season. The dip occurs when they started irrigating the cotton. Then, the *ECe* went somewhat down but after the harvest it went up again. Most of the secondary salinization took place in the months just before the frost sets in.

The installation of a pipe drainage system gave some scope for improvement:
- A possibility for leaching and lowering of the ground water table;
- Salinity control through drainage;
- Possibility to try out alternative cropping patterns;

- Reduced water use, because of less leaching requirements and less secondary salinization.

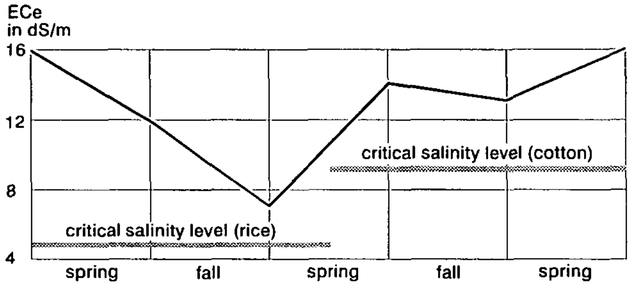

Figure 2. The seasonal variation of the ECe under the traditional rice-cotton rotation

Rice was - and this was mandatory by our client - to remain in the cropping pattern for economical reasons. We started, therefore, to evaluate the possibilities to vary the crop rotation with the existing infrastructure and irrigation practices. We considered about 13 crop rotations initially, and in the end did all the calculations for 7 rotations. The criteria we used for the selection of the crop rotations were:

- The highest possible income per ha and per m^3 of irrigation water;
- The lowest possible water use;
- The highest possible yield.

These are, of course, rather self-evident criteria, but it was quite difficult to match them. We arrived at the following solution. A six year rotation of one year rice, then one year wheat followed by sunflower as a green manure, then one year cotton. Then the salinity went up so much that we had to include a year with rice. After the rice, we had again cotton, for two years. With this rotation, we now have 33% of rice instead of 50%. This means a reduction of the crop with the highest water consumption.

The selected rotation gave the following results:

- The average water use was reduced to 93%. We had to grow sunflower as a green manure, which consumes quite a lot of water, but at a time when there is more water available;
- The average income per ha increased by 26%;
- The average income per m^3 of water increased by 40%;
- The average yield increased only 3%.

The salt balance with the chosen rotation (Figure 3) shows that during the growing seasons, one would have more or less acceptable *ECe* levels, with the exception of the wheat crop. The reason why the salinity level goes down after the wheat crop, is mainly because of the sunflower, which uses massive amounts of irrigation water.

During the first cotton season the *ECe* is quite good, during the rice season it is at acceptable levels, aterwards it rises again. But during the cotton seasons, during the critical stages of the crop, the soil salinity remains within acceptable levels.

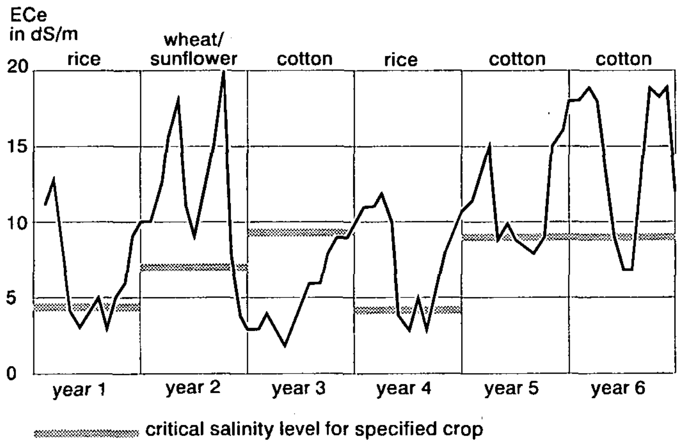

Figure 3.

This was the outcome obtained with the constraints mentioned earlier. In case the constraint of the irrigation infrastructure could be eliminated, irrigation for the dry-foot crops could be modified and increased, a crop rotation without rice is well feasible. In case of a rotation of cotton-wheat, water savings of 30-40% are attainable, while maintaining the *ECe* in the rootzone below 6-9 dS/m. Since the leaching is less dependent on peak flows during the rice growing period, the capacity of the drainage system could then also be reduced somewhat.

Conclusions

1. The introduction of a sub-surface drainage system (spacing 50 m, depth 2m) for salinity control in arid Western China created the potential for more effective water management and salinity control.
2. The crop rotation is an essential factor in determining the design and operation parameters for irrigation and drainage management as well as the overall water requirement for maintaining an acceptable salt balance.
3. Success depends on your ability to influence farmers to grow what you want them to grow. Under the conditions of a state farm in Western China, however, this was hardly a problem.

Discussion

Taking questions from the audience on crop rotations, the author discussed the problem of how to remove salts from the profile. In the applied crop rotation, extra water to remove salts was given to the cotton crop. A second point of discussion was the salt balance of the area. The author explained about the total salt load entering the area at the upstream side and the salts removed from the area, which were evacuated to desert evaporation ponds. Another question dealt with model simulations of this problem. The author mentioned that five year data was availale, which could be used for model calibration. On aspects of yields and income, the answer was that if farmers could grow more cotton their income would rise. The last question dealt with leaching of salts. The author explained that in between the cotton and wheat crops, salinization occurred, which was leached with extra water.

Session 3 Institutional innovations towards integration of irrigation and drainage management

Ir. J.A.C. Knops (ILRI), Dr. M.N. Bhutta (IWASRI), H. Malik (ACTIONAID) and Dr.Ir. W. Wolters (ILRI). *Towards improved drainage performance in Pakistan*

Dr. S.A. Prathapar (IIMI), J.C. Madden (CSIRO) and G. McLeod (Murray Irrigation). *Modeling salt, water and financial balances of typical irrigated farms in the Murray Valley, Australia*

Ir. J.J. de Graeff (Water Board of Schieland). *Water Boards in the Netherlands*

Dr. F. van Steenbergen (Euroconsult). *International experiences with the drainage water board concept*

Dr. O.P. Singh (CSSRI). *Integration of irrigation and drainage management in a monsoonic climate*

Chairman:	Prof. L. Vincent (Wageningen Agricultural University)
ILRI rapporteur:	Ir. J. Vos

TOWARDS IMPROVED DRAINAGE PERFORMANCE IN PAKISTAN[1]

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Abstract

Review of the performance of drainage systems in Pakistan shows that the installed tubewell and pipe drainage systems are capable of controlling the water table. Moreover, the soil salinity status has improved in many systems also. Nevertheless, there have been problems, e.g. with the choice of technology, and the operation and maintenance of the systems. Current practice is that the Government funds operation and maintenance, within its limitations. This cannot continue forever, and the users will have to take their share as well.

The Government of Pakistan and the World Bank have prepared a National Drainage Program, NDP, with objectives to: (i) Improve the management of public expenditure in drainage; (ii) Strengthen key drainage institutions; (iii) Initiate changes in the legal and regulatory framework to facilitate implementation of a new strategy. This strategy includes surface and pipe drainage schemes, small schemes to alleviate drainage and public health problems, mitigatory measures to protect the environment and increase the drainage efficiency.

A development concurrent to the NDP is the participatory approach to drainage, as started by IWASRI, in cooperation with NRAP. After a Workshop on Options to Involve Farmers, a pilot area study was started, in a waterlogged and saline area, where the research team was the first serious contact with the population to address the drainage problem. That is considered the best possibility to move forward as partners in the planning, design and construction of a drainage unit in a participatory way.

The research results have made clear that: (i) the social and economic framework in which the users of (future) drainage systems live, determines their capacity to cooperate towards solutions to the drainage problem; (ii) They should be involved in (future) drainage systems, from the planning stages onward.

Introduction

In Pakistan 75% of the population depends, directly or indirectly, on agriculture. This sector contributes 50% to the gross national product. Today the Indus Basin has a vast contiguous

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[1] This is a slightly modified version of a paper that was presented at the sixteenth congress of the International Commission on Irrigation and Drainage (ICID), held in September 1996 in Cairo, Egypt

irrigation system, developed over the past 150 years and commanding a net area of 14 million hectares. The climate in the basin is semi-arid to arid, hence the necessity of irrigation to support agriculture. The rapid expansion of the system and the increase in cropping intensities, to cope with the ever increasing population, combined with the flat topography and the lack of well defined natural drainage in the Indus basin has caused serious waterlogging and salinity problems. Since the early sixties the Government of Pakistan has made huge investments to control these problems and to cope with water shortages. By mid-1994, surface and subsurface drainage facilities had been installed in 6 million hectares at a cost of Rs. 21 billion. Ongoing constructions, covering over 2 million hectare require another Rs. 20 billion (NESPAK-MMI, 1995). In spite of these measures, salinity, sodicity and waterlogging problems persist in the Indus basin and threaten the sustainability of irrigated agriculture and, hence, the livelihood of future generations. Monitoring the performance of the completed drainage projects revealed that some had been reasonably successful, whilst others failed to deliver the expected results. Causes for failure are related to: (i) deficiencies in policy and institutional matters; and (ii) low priority given to allocation of resources for the operation and maintenance (O&M) of drainage facilities in favor of initiating new projects (World Bank, 1994).

The O&M of irrigation, drainage and flood protection facilities is the primary responsibility of the Provincial Irrigation Departments. The administrative structure of these departments was primarily established around the extensive canal irrigation systems. With the establishment of deep tubewell-, surface- and sub-surface- drainage systems, separate sections were simply added to the administrative structure and not integrated in the existing set-up. This resulted in an extremely diffusive situation as to the responsibilities for the operation and maintenance of the deep tubewells, the surface drainage system and the horizontal subsurface drainage system (Bandaragoda and Firdousi, 1992). This was further exacerbated by problems concerning the safe disposal of saline drainage effluent. Funds for the operation and maintenance of these various systems kept decreasing in real financial terms; with 63% of the annual budget allocation going to the establishment, and 21% to flood protection embankment maintenance, only 16% remains for the operation and maintenance of the surface drainage system (NESPAK-MMI, June 1993). Hence the deplorable state of this surface drainage system and the far below design capacity operating deep tubewells. In the fresh groundwater zones the public tubewells have been superseded by private shallow tubewells, intentionally to supply additional water for irrigation but at the same time controlling the groundwater table. Given the failure of the Government to mobilize sufficient funds for an appropriate O&M of the various systems to control waterlogging and salinity, the National Drainage Program strongly advocates private sector participation in drainage. This though, would not be a policy that can be implemented easily for the following three reasons. The first reason is that farmers rank water shortage as the major production constraint (63%), while waterlogging comes far second (15%) (Ahmad M. and G.P. Kutcher, 1992). The second reason is that drainage problems are often caused by practices in adjacent areas, hence creating a feeling of unjustness with the farmers if they would have to bear the costs for the system. A third reason is the lack of goal-oriented motivation in the public sector. Henceforth, enormous changes need to be initiated to: (i) convince the farming community that investments in (on-farm) drainage measures will strongly improve agricultural productivity, and (ii) provide incentives to the public sector staff to introduce the enormous changes that increased private participation implies. Anyhow, the government is no longer able to carry the burden of the total costs of operation and maintenance of the systems. For this reason drastic institutional changes, including the participation and direct involvement of the producers are inevitable.

This paper describes participatory action research on working with farmers to implement on-farm measures to solve waterlogging and salinity problems in a pilot area in Bahawalnagar Tehsil in South-East Punjab (Figure 1).

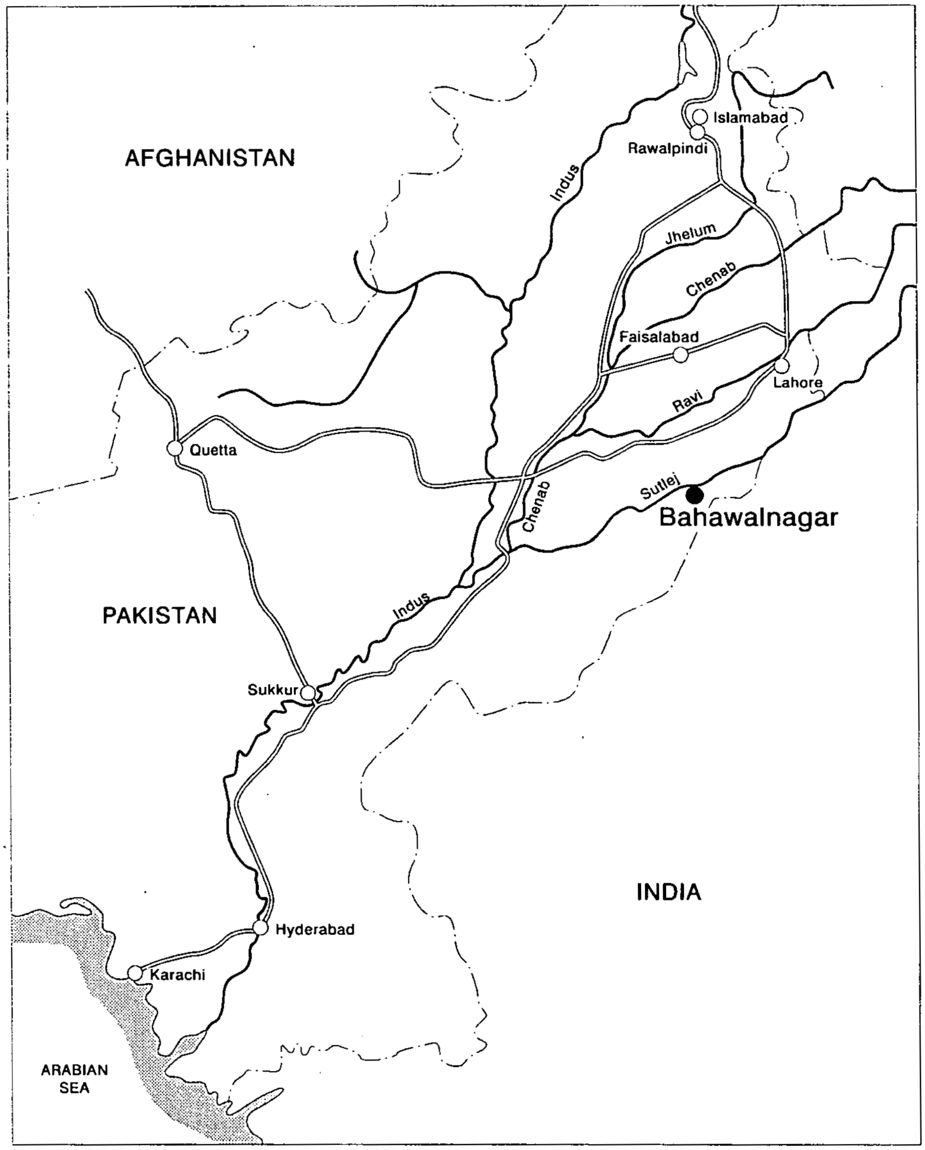

Figure 1. Location of the Bahawalnagar Pilot Area

Towards participatory drainage research

In addressing the O&M issue, the National Drainage Programme (NESPAK-MMI, 1995) focusses on the sustainability of the irrigation and drainage system. The conceptual framework of the National Drainage Programme mentions three specific objectives: (a) participation of farmers' organizations and the private sector in construction, operation and maintenance of drainage facilities; (b) targeting government investment on areas in greatest need of drainage; and (c) quicker returns by targeting drainage investments on smaller scale, quicker yielding interventions. The NDP proposes to directly involve farmers in the planning, design, construction, operation and maintenance of on-farm drainage systems. It presents modes for setting up and operating farmers' organizations and stipulates that research should develop instruments to involve the farmers. NDP admits that there is limited experience with direct farmer participation in on-farm drainage in Pakistan and states that initially the technical capacity will be weak. During a transition stage farmers could learn, with assistance and guidance from professionals, either directly or through Non-Governmental Organizations (NGO's).

The International Waterlogging and Salinity Research Institute (IWASRI) embarked, concurrent to the NDP, on participatory action research in drainage, waterlogging and salinity. One of its activities concerns the transfer of research results directly to the end-users, through the Joint Satiana Pilot Project. This project, which is also supported by UNDP, aims at the introduction of salt tolerant trees and shrubs on abandoned saline lands. Another activity, supported by the Netherlands Research Assistance Project, aims at the introduction of non-technical issues in the mainstream research on waterlogging, salinity and drainage. One of the NRAP supported activities is the result of a workshop held at IWASRI on ways and means to start participatory action research in drainage (IWASRI-NRAP, 1995). The favored option, conceived in the workshop, was to start a pilot study in a waterlogged and saline area and implement measures to overcome these problems with full participation of the farmers.

Participatory implemented drainage system

How to involve farmers

Against the background of the gradually decreased capabilities of the government to take effective and efficient responsibility for the operation and maintenance of the system, privatization is advocated as the only way out. The 'aloofness' of the civil service concerning the 'know-how' of the farmers and their belief of farmers' incapability to identify and handle their real problems, has created the so-called credibility and confidence gap. To regain the trust and confidence of the farmers in the government service, the general feeling is that NGO's should be involved to: (1) assist farmers in organizing themselves; in analyzing their real problems and in regaining confidence with the government service, and 2) work on drastically changing the attitude of the service staff towards the farming community, from 'aloofness' and 'depreciation' into appreciation and esteem for farmers' insight in their productive environment and their know-how about its potentials for improvement and development. This idea is based on experience in different countries in the region which has shown that NGO's do understand the social, cultural, economic and political conditions of government and local communities, which enables them to devise modes for building understanding of common interests. Hereto IWASRI/NRAP called-in the assistance of ACTIONAID-Pakistan (AAPk), to involve, communicate with, mobilize and organize the farmers. The NGO had expertise in working with rural communities towards social development and had an interest, in compliance with IWASRI, to start a new programme in a poverty stricken area in the Punjab. One of the attractive points for IWASRI to collaborate with AAPk is their objective to improve demand-based delivery and coordination of services by government agencies to communities, and a fairer allocation of resources by the government, in response to the real felt needs of rural communities. To build confidence and raise awareness with the community, the NGO required a starter activity around an acute problem threatening the livelihood and well-being of the rural community. The area selected suffers greatly from waterlogging and salinity, large tracts of lands being abandoned, and still cultivated lands suffering from salinity.

IWASRI and AAPk may be convinced though, that waterlogging and salinity are the foremost threat to a sustained livelihood for the rural community, with whom they plan to work towards improvement of their socio-economic conditions, but does the rural community also conceive it that way? If so, will the farmers be prepared to invest in solving the problem? If so, what assistance would the farmers need to get organized, and to mobilize their resources and know-how? To get answers to these questions, and to explore the willingness of the communities to work with the NGO towards development, the technique of Participatory Rural Appraisal (PRA) was applied.

Participatory rural appraisal

Participatory development can only be achieved if the rural communities are willing to: (i) organize themselves in community based organizations; (ii) work together as a group in identifying their real needs, developing solutions to the identified problems, be prepared to discuss the various possible solutions to the problem openly and freely with agency staff, come to an acceptable solution and are committed and willing to work together towards its implementation; and (iii) clarify and agree on their contribution towards the full-fledged implementation and their acceptance of their own responsibilities towards the operation and maintenance activities.

At this point it is important to note that AAPk's objective is to build capacity in communities to become fully involved in planning and implementing their own development that is sustainable in social, economic and environmental dimensions. Its strategy consists of three components: (i) long-term involvement; (ii) developing community organizations for participation: a viable Community Management Structure will be central in identifying needs, selecting the type of program and its design, implementation, and monitoring and evaluation, as well as detailing the different responsibilities of the different actors involved; (iii) enhancing community capacity through entry point activities: the program content would be based on the communities' assessment of their needs and priorities. An essential entry activity could be based on the principal activities of IWASRI in the selected pilot areas.

The need-assessment analysis with the community through the PRA investigation process would not necessarily yield waterlogging and salinity as the primary problem conceived by the community. One of the drawbacks of a first and open contact of outsiders with rural people, not accustomed to being listened to and their opinion asked, will definitely raise their expectations. But with the long-term interest of AAPk in working with the communities, this was not considered a problem. AAPk, in consultation with IWASRI, decided to hold a first exploratory PRA in 6 villages of two Union Councils in Bahawalnagar District. The team members, who would conduct the ten days field work, received first a two day training in PRA-techniques and held a one day brainstorming session to determine key questions, main and sub topics, sources of information and tools to be applied to acquire the information. The field work was carried out in ten days by three teams of 4 people each, in a mixed composition of NGO and IWASRI staff, and 2 specialist moderators. The PRA was exploratory as AAPk itself was only recently introduced to the people in the area. It requires time to build confidence with the people. The PRA attempted to explore the perspective of the community on the waterlogging and salinity problems as caused by the irrigation system. The community was involved as: (i) providers of relevant knowledge and information based on several PRA tools (map, trend lines, cropping calendars and water need periods, ranking, pie charts); (ii) analyze the problems related to irrigated agriculture with help of cards and flow charts which visualized causes, effects and possible solutions; and (iii) cross-checking of information received through triangulation. Some conclusions of special interest to IWASRI/NRAP in their aim to develop on-farm drainage measures with the farmers are: (i) organizational: dominance by certain feudal families is a major issue in the area as this impedes the introduction and evolution of democratic norms and collective decision making and action; (ii) gender imbalances: women in the area are an unrecognized, though vital, human resource and have little say in decisions taken, many of which have a direct impact on them; (iii) environmental degradation: the irrigation system put into place in the early sixties, has brought the evils of waterlogging, salinity and sodicity, rendering large tracts of land unproductive, threatening the livelihood of the rural people.

The NGO will continue its contacts with the people and in doing so will build trust and confidence, which is a necessary prerequisite for participatory development. These regular interactions with the people will further contribute to clarifying the picture on the socio-economic conditions and the organizational setting of the local communities.

The increasing loss of agricultural lands due to waterlogging, sodicity and salinity is considered by the communities as one of their biggest problems. People are of the opinion that once this problem would be solved, many related problems - such as health and rural water supply - could then easily be overcome.

Selection of pilot area

Given the limited financial resources to both organizations it was decided that the pilot area to start the participatory action research should not be larger than 100-150 ha. Criteria agreed upon for the final selection of the pilot site were: (i) community should be poverty stricken; (ii) area severely degraded by waterlogging and salinity; (iii) area with many small holdings and no feudal dominance; (iv) area easily accessible for demonstration impact; and (v) land ownership. Field visits and a walk-through were conducted before a final choice for the pilot area could be made. These visits were carried out initially by NRAP/IWASRI and AAPk staff. Later, staff of the Irrigation and Agricultural Departments joined in the site selection. Criteria for site-selection were defined during the learning process of getting to grips with: (i) the general topography and hydrology of the area; (ii) the possibilities of temporary evacuation of the drainage water; (iii) the land tenure situation; (iv) the potential solutions to the problem, manageable and operable by the beneficiaries; and (v) the willingness to cooperate of representatives of the community and local Government Agencies.

When the potential site was selected, meetings were held with the farmers of those lands. In these meetings, attended by all actors involved, the possibilities of solving the waterlogging and salinity problem were discussed with the farmers. Farmers explicitly made clear that they were willing to work with the NGO and Government Agencies in solving these problems. The area was also selected because, according to the land tenure survey, these lands are cultivated by many small landholders (114) all residing in one village. According to the PRA, there ara no feudal families dominating this village, which under the prevailing social and cultural conditions in the Punjab would make the formation of a farmers organization extremely difficult (Merrey, 1986).

Development of working relations with government agencies

One of the objectives of both the NGO and IWASRI is to draw upon the services of the Government Agencies present in the area and in doing so, create an awareness among their field staff on the need for attitudinal changes in dealing with the farmers. Hereto contacts were made with the On-Farm Water Management Directorate in the Fordwah Eastern Sadiqia (South) Irrigation and Drainage Project, Agricultural Extension of the Punjab Department of Agriculture, and the Sadiqia Division of the Punjab Irrigation Department, all at Bahawalnagar. All organizations expressed their willingness and interest to work with the NGO and IWASRI on the Pilot project and assist with the technical surveys. From each organization a staff member participated in the walk-through and in the meetings with the farmers.

Development of community management structures

To enhance the capacities of communities to identify and exploit resources for development, the NGO is to develop and strengthen accountable and equitable community management structures, which can sustain development initiatives and redress societal discrimination. This will be done by strengthening the community based organization or by developing new community management structures taking into account existing social structures.

Technical survey of the pilot area

The technical survey could not start before final selection of the pilot site and farmers expressed willingness to work together towards a solution to their waterlogging and salinity problems. A detailed proposal was prepared for the technical survey, based on a rapid appraisal of potential solutions to the waterlogging and salinity problem in the selected area, and discussed with the NGO and farmers representatives of the village concerned. Farmers expressed their willingness to assist in the field survey. But a disadvantage was the timing of the field surveys, at a time that farmers were busy with their regular farming activities, like harvesting of wheat and land preparation and sowing of the successive cotton crop. Nevertheless, farmers showed an interest in what was going on in their fields by sending some representatives to assist whenever possible. In the long run it is felt to be extremely important that farmers do not feel overruled or cut-out from any step taken along the long road leading towards a participatory implemented drainage system. In the end they should really consider it their own system, created by themselves, only assisted and guided therein by the governmental agencies.

Formation of a farmers organization.

Formation of a Farmers Organization (FO), as a sub-unit of the CBO (community based organization), for the anticipated drainage unit. This may require communally developed and accepted solutions to such questions as: (i) need for cooperation between different classes (land owners, tenants, share-croppers); (ii) need for cooperation between different kinship groups; (iii) need for cooperation between members of different villages; and (iv) need for cooperation between farmers of different water courses.

Still there remains another set of questions to be resolved: (i) from experience on FO's it has been proven that the social group cohesion is more sustainable if based on kinship relations (Merrey, 1986). But will this imply the complexities of more than one FO-responsible for one drainage unit?; (ii) it has been proven in irrigation management that FO's based on hydraulic units function more efficiently than social based FO's. But will this complicate the social cohesion sustainability of the group?; and (iii) how do or do not watercourse command areas coincide with the hydraulic boundaries of drainage units? If not, will it further complicate matters as to one FO for both functions? If an area has strong village councils (community based organizations); they may be able to take-up drainage, alongside other activities such as roads, health, education. Probably it is wise to have only one set of community (village) based organizations.

Experience in organizing farmers in Pakistan have shown that (NESPAK & MMI, 1995): a) successful farmers' organizations are best based on social structures of kinship relations; b) authoritarian views are not conducive with farmers' participation. Relevant local knowledge and skills should be drawn upon; and c) success in participation often stems from input of NGO's, who work in close collaboration with the people in the project area.

Experience in other countries with farmers' participation has shown that the following attributes are desirable: (i) Felt Need: the farmers must be convinced that there will be a definite and tangible gain for them by cooperating and taking responsibilities for irrigation and drainage activities and investments; (ii) Accountability: the farmers' organization should be solely and fully accountable and transparent to their farmers; (iii) Sustainability: there must be a certain degree of social cohesion within the farmers' organization to be able to survive the reliance on outsiders during the initial formation and establishment period; and (iv) Accessibility: the farmers' organization must have easy and ample access to the technical advice and expertise related to the tasks to be performed, either among its own members or by employing or hiring technical staff (Coward, 1986 and Uphoff, 1986).

As these questions of a socio-cultural nature and the more pragmatic ones cannot be resolved beforehand, the process of establishing farmers' organizations, around one or more beneficial activities, will require a gradual approach, needing research and pilot studies to lead the way!

Design and action plan

The next step to be undertaken is the development of different design proposals, which then have to be discussed with the farmers as to which one can be implemented together, within the resources available to the community and IWASRI. An action plan needs to be drawn-up when agreement has been reached on the preferred technical solutions. This plan should specify the responsibilities and resource contributions of all stakeholders involved in the implementation of the technical solutions. The final design choices to be implemented have to be agreed upon, fully understood and accepted by the farmers; construction works have to be implemented (when, where, how and by whom); the system has to be operated (why, what and by whom); the system has to be maintained (why, how frequent and by whom). It must be ensured that each different issue is fully understood by the farmers and the plan in all its details will have farmers' consent. Technical staff of the government agencies seriously need to consider any suggestions and comments made by the farmers and modify the plans and planning accordingly, whenever realistic and possible. If suggestions cannot be taken into account on technical-physical grounds, this should be clearly and convincingly be explained to the farmers in such a way that farmers do not feel overruled.

Formal agreement of action plan.

Formal agreements have to be drawn-up between the farmers organization, the NGO and the government agencies before undertaking any implementation activities. These agreement should spell-out the responsibilities, contributions (resources and finances), rights and obligations of each party. The NGO-support organization should ensure that the farmers organization fully understands and accepts the agreement; if this is not the case it needs to be modified until all parties find it acceptable.

Financial contributions

Collection of the financial contributions from the farmers will be the responsibility of the farmers organization. These funds together with the contributions of IWASRI are to be deposited in a FO's Bank Account.

System construction

Construction works can only be started if full consent is reached on proposed works; its layout; right of way has been secured; funds and materials have been secured; pending issues have been dealt with; an implementation plan has been worked out and is accepted by all parties concerned; and their is clear understanding of each party's role and contribution during the implementation process.

At this stage it cannot be stipulated how and by whom the different works will be implemented. It is for example conceivable that part of the works (a shallow surface drain) will be constructed by the farmers with advice and technical guidance of the government agencies. It needs to be looked into, whether horizontal pipe drainage systems can be installed by the farmers or will have to be contracted out. If works have to be contracted out, it is still too early to decide on whether the work-contracts can be made-up by the farmers organization or whether the government agencies still have to take charge of it. If the latter will be the case, the government agency must ensure that a construction supervision committee (of FO representatives) is established and that the government agency only provides advice and technical guidance to the committee.

Training in operation and maintenance of the system

When all construction works have been completed to the full satisfaction of all parties concerned, the operation and maintenance of the system will be handled independently by the farmers' organization. Beforehand the government agency, with assistance and guidance of the NGO-support organization, ensures that relevant members of the farmers organization or their staff will have received the proper training in all aspects of the operation and maintenance of the system and operations and maintenance manuals have been compiled.

Follow-up services

The government agency commits itself to remain responsible for assisting the farmers in solving any technical design flaws which may surface during the normal operation and maintenance of the system. The government agency though, cannot take any responsibility for problems arising from gross neglect by the farmers organization or caused by malfunctioning of the farmers organization. The duration of this follow-up period, that should include monitoring as well, needs further consideration and will also depend on the technical complexity of the solutions chosen.

It should be realized that the above course of actions is by no means a blue-print that has to be followed exactly. Each step will provide new insight in the situation, circumstances and conditions one has to deal with. Hence, based on the experience acquired, the next step in the process can be determined more precisely. These steps merely provide a rough guidance for what will have to be done and can be expected in the process of developing drainage measures to combat waterlogging and salinity in participation with the farmers.

With this research approach IWASRI aims at developing guidelines for the replication of this pilot study at a much wider scale. Therefore, it is of the utmost importance that all field level activities are properly documented. The focus of this documentation should not only concern the project-related activities of the farmers, but also those of the Government Agencies Drainage Service Staff and the field support staff of the NGO.

Conclusions and summary

The direct involvement of small farmers in solving their waterlogging and salinity problem is a totally new concept in Pakistan. It is the politically accepted view that there is an urgent need to involve the private sector in the operation and maintenance of not only the irrigation but also the drainage system. The Government is no longer in a position to carry the whole burden. The National Drainage Programme I advocates a widespread privatization of the irrigation and drainage infrastructure. But the Government Agencies are bureaucratically entrenched in a system developed over the last 150 years. The recurrent expenditure for the establishment puts a large drain on the governmental resources, such that little is remaining for an appropriate operation and maintenance of the facilities implemented over the last 35 years.

IWASRI has embarked on a study to find ways and means to overcome the serious waterlogging and salinity problems in full participation with the farming community. It is too early to draw conclusions and come-up with recommendations, as this research approach in drainage has been taken-up only recently. The PRA revealed that: (i) the social and economic framework in which the users of (future) drainage systems live, determines their capacity to cooperate towards solutions to the drainage problem; and (ii) farmers should be involved right from the planning stage in any future drainage implementation activities.

This new approach may contribute to improved efficiency and effectiveness of the huge investments made in Pakistan to combat waterlogging and salinity, and may have a great impact on the sustainability of agriculture.

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Discussion

A summary of the discussion following Ir. Knop's presentation is given below:

Question: In organizing farmers for irrigation management, it is sometimes advocated to organize farmers at the distributory level, rather than at the water course level. The reason to organize farmers at this higher level is to obtain an organization that is more capable and powerful in dealing with government institutions. Would you recommend the same practice for organizing farmers for drainage?

Answer: Yes, I would.

Question: You are currently working in an area where farmers have identified drainage as a major problem. However, in many other locations famers do not yet perceive drainage as a priority problem. What do you intend to do in these areas?

Answer: Our work is a very first start. Once we have some results to show, we can use them in making farmers elsewhere aware of drainage problems and solutions. We could think about making a popular type of movie as a way to increase this awareness.

MODELING SALT, WATER AND FINANCIAL BALANCES OF TYPICAL IRRIGATED FARMS IN THE MURRAY VALLEY, AUSTRALIA

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Abstract

The viability of irrigated agriculture in the Murray Valley is threatened by waterlogging and salinisation induced by rising watertables. By limiting net recharge to the watertable to zero or below, watertable rise can be prevented and the risk of watertable-induced environmental damage can be minimized.

Primary factors affecting the rate of net recharge to the watertable on a farm include: the as determined by soil type and farmer preferences, intensity of irrigation, depth to the watertable, leakage to deeper aquifers. Among these variables, the depth to the watertable and leakage rates are difficult to alter, whereas the landuse and intensity of irrigation can be managed such that net recharge is maintained at or below zero. Such changes to land use and irrigation management must give maximum profits if the farm is to remain a viable enterprise.

To determine the optional land use which give maximum financial returns to the farmer while maintaining net recharge and soil salinisation at zero, we have developed a non-linear programming model - SWAGMAN Farm. SWAGMAN Farm was used to study the effect of leakage, initial depth to the watertable, and landuse restrictions on total gross margin received and optimal intensity of irrigation.

Introduction

In irrigation areas and districts of the Murray Valley of Australia, agricultural enterprises vary from farm to farm. However, nearly all farms face two environmental problems: waterlogging and salinisation. The primary factor controlling these two environmental concerns is the depth to watertable below the soil surface. Depth to watertable is governed by the net recharge to the watertable and lateral groundwater movements. Therefore by managing net recharge to the watertable, the hazards of waterlogging and salinisation can be minimized. Such a strategy should also result in maximum economic return to the farmer.

In order to determine on-farm land use practices and intensities of irrigation which produce an optimum result (maximum economic returns, zero net recharge, and zero gain of salt in the rootzone), an optimization model, SWAGMAN Farm, was developed. The model takes into account distribution of soils within the farm, potential land uses, crop evaporative requirements, current irrigation practices, leaching requirement, annual rainfall, rainfall runoff, leakage to deeper aquifers, depth to watertable, capillary upflow from shallow watertable, salt concentration of irrigation water, groundwater, and rainwater, and the economic returns from potential land uses.

Model description

The objective of SWAGMAN Farm, subject to recharge and salinity constraints is to maximize total gross margin per farm, i.e.,

$$TGM = \sum_{3}\sum_{s} GMLW_{c} - IRN_{c,s} *WATPRICE \qquad (1)$$

where,

TGM	Total gross margin ($)
GMLW	Gross margin of a land use less cost of irrigation water ($ ha^{-1})
IRRN	Irrigation in use (ML ha^{-1})
C	Land uses considered in a farm
S	Soil types in a farm

Soil types considered in the model were: clay (CLAY), loam (LOAM), and sandy loam (SLOAM). Land uses (C) considered in the model were: rice (RICE), soybeans (SOYB), maize (MAIZE), lucerne (LUCERNE), hay lucerne (HLUCERNE), fababeans (FABA), canola with 4 ML irrigation (CANOLA1), canola with 1.5 ML irrigation (CANOLA2), wheat with 4 ML irrigation (WHEAT1), wheat with 1.5 ML irrigation (WHEAT2), barley with 3 ML irrigation (BARLEY1), barley with 1.5 ML irrigation (BARLEY2), annual pasture (APASTURE), perennial pasture (PPASTURE), dry land wheat (DWHEAT), dry land canola (DCANOLA), and dry land annual pasture (DAPASTURE).

The objective function was solved using a non-linear programming solver, GAMS-MINOS (Brooke et al., 1988), subject to the following constraints.

Area constraints within the model

- SOYB, MAIZE, LUCERNE, CANOLA1, WHEAT1, BARLEY1, and PPASTURE were not to be grown on clay soils.
- Land uses on a particular soil type cannot exceed total area of the soil type.
- Area of a land use cannot exceed maximum allowable area (PMXA). The maximum limit was set to reflect real world considerations such as enterprise diversification, crop rotations, market demand, and restrictions set by natural resource managers.
- Area of a land use must be greater than minimum required area (PMNA).
- Minimum area of any land use (other than FALLOW) selected by the model must be greater than 10 ha to avoid inclusion of an inefficient area of a land use.

Salinity constraints within the model

- Salt was assumed to be brought into the rootzone by irrigation (0.12 dS m^{-1}), rain (0.0001 dS m^{-1}), and minimum rates of capillary upflow from the static watertable (concentration of groundwater).
- The total mass of salt brought into the rootzone by irrigation and rainfall, and salt brought to the soil surface by capillary upflow, was required to be removed by leaching and runoff, resulting in zero salt gain on the farm.
- The model required that salt brought into the root zone by irrigation water be removed by leaching. Therefore, part of the irrigation water was required to leach the irrigation borne salts. This leaching requirement was determined from the equation below. The leaching water will recharge the watertable, which ought to dissipate by leakage or capillary upflow. We assumed that the concentration of salt in leaching water was 2 dSm^{-1}.

$$LREQ = CIRRN * IRRN/CDWATER \tag{2}$$

where,

LREQ	Leaching requirement, ML
CIRRN	Salt concentration in irrigation water, dS m^{-1}
IRRN	Irrigation amount, ML
CDWATER	Salt concentration of leached water, dS m^{-1}.

- Salt brought to the soil surface due to capillary upflow was required to be removed by rainfall runoff. Salt at the surface was assumed to be the product of capillary upflow and groundwater salinity. The upper concentration limit of salt in runoff water was set at 15 dS m^{-1}. This is consistent with data collected in northern Victoria.

Net recharge constraints within the model

- Net recharge to the watertable depends on recharge mechanisms (irrigation and rainfall in excess of actual evapotranspiration) and discharge mechanisms (capillary upflow and leakage to deeper aquifers). The net recharge was required to be equal to zero. It was determined using the equations below.

$$RECHARGE = \sum_{c,s} AREA_{c,s} * IRRN_{c,s} + AREA_{c}*GRAIN_{c}-AREA_{c,s} * AET_{c,s} \tag{3}$$

$$DISCHARGE = \sum_{c,s} AREA_{c,s}* BRAIN_{c}+ AREA_{c,s}.CUFLOW_{s}-TAREA*LEAKAGE \tag{4}$$

$$NET\ RECHARGE = RECHARGE - DISCHARGE$$

where,

GRAIN	Rainfall during growing season of land use C(ML ha^{-1})
AET	Actual evaporation use by land use C (ML ha^{-1})
BRAIN	Rainfall during bare season of land use C (ML ha^{-1})
TAREA	Total area of farm (ha)
$AREA_{c,s}$	Area of land use C on soil S (ha)

LEAKAGE	Leakage from watertable to deeper aquifers (ML ha^{-1})
CUFLOW	Capillary upflow (ML ha^{-1})

Model parameters

Estimating minimum capillary upflow from a static watertable

Minimum rates of capillary upflow from a static watertable at 1 and 1.5 m depths under a bare soil (CUFLOW) were determined using a numerical model, HYDRUS (Kool and van Genuchten, 1991). Capillary upflow rates for depths in excess of 1.5m were estimates only. Minimum capillary upflow rates determined for Riverina clay, Mundiwa clay loam, and Hanwood loam were considered as the capillary upflow rates for clay, loam and sandy loam (Prathapar and Madden, 1995).

Estimating actual evaporation (AET)

Initially, monthly reference evaporation (RET) values were used to estimate RET during the growing season of individual crops (Meyer, 1995). The RET value of each crop was multiplied by a seasonally weighted crop factor to obtain seasonal crop evaporative demand (CET). The assumed 'crop factor' for a bare period during average rainfall years was 0.11. This 'crop factor' is considered adequate for summer months but may be too low for the winter period. A better estimate is required to reflect the winter bare-period crop factor.

Actual evapotranspiration (AET) was determined by multiplying the CET by a correction factor (PDFACT). This was to account for irrigation management as well as soil water deficit, and was determined with the equation:

$$\text{PDFACT} = 0.8-0.7*(\text{CET}-\text{WAVAIL})/\text{CET} \tag{6}$$

where WAVAIL is the sum of irrigation and infiltrating rainfall during the growing season.

The actual evapotranspiration values and estimates of recharge for the land uses are presented in Table 1. Negative values of recharge imply water moving from the watertable to met evaporative requirements of the land use.

Representative farms

Six representative farms in the Murray Valley were considered for investigation. Characteristics of the six farms are summarized in Table 2.

Table 1. Estimated AET and recharge for land uses during an average year (mm)

Land use	AET	Recharge
Rice Clay	1203	293
Rice Loam	1203	493
Rice Sloam	1203	893
Soyb	689	385
Maize	581	486
Lucerne	1188	259
Hlucerne	1188	259
Faba	404	80
Canola1	461	115
Canola2	287	40
Wheat1	474	110
Wheat2	287	40
Barley1	392	85
Barley2	277	38
Apasture	416	187
Ppasture	1115	356
Dwheat	172	-7
Dcanola	172	-7
Dapasture	158	7
Fallow	210	-110

Table 2. Characteristics of representative farms

Farm ID[1]	Farm Number	Area (ha)	Clay (ha)	Loam (ha)	Sloam (ha)	GW Salinity[2]	DWT (m)
WKD	1	200	50	100	50	5	1
WKR	2	550	500	50	-	40	4
WKP	3	500	350	100	50	15	3
DNE	4	460	92	368	-	10	4
DNW	5	1000	750	250	-	20	7
BQR	6	284	160	124	-	3	3

[1] WKD: Wakool dairy farm; WKR: Wakool rice farm; WKP: Wakool mixed-pasture farm; DNE: Denemein East mixed farm; DNW: Denemein West mixed farm; BQR: Beriquin rice farm.

[2] Groundwater salinity in dSm^{-1}.

Major determinants of the model

Since the objective of the model is to maximize gross margins while constraining net recharge to zero, the model will initially choose that land use which gives maximum gross margin per unit of recharge. Therefore the primary determinant will be the recharge efficiency ratio (PER). We define recharge efficiency ratio as the ratio between gross margin and recharge for a land use. In general CANOLA, DWHEAT, CANOLA2, and DAPASTURE-D result in higher gross margins per ML of recharge than the other land uses.

Another important controlling factor is the ratio of gross margin to actual evaporation, which will identify land uses that result in maximum gross margin per unit of water used by the crop. Therefore, the secondary determinant will be the evapotranspiration efficiency ratio (ERR). In general, DCANOLA, CANOLA2, MAIZE, and APASTURE-D result in the highest gross margins per ML of recharge.

Table 3. The recharge efficiency ratio (PER) and evapotranspiration efficiency ratio (EER) of land uses during an average year.

LAND USE	PER ($\$\mathrm{ML}^{-1}$)	Land Use	EER ($\$\mathrm{mm}^{-1}$)
DCANOLA	-2759[1]	DCANOLA	115
DWHEAT	-1218	APASTURE-D	101
DAPASTURE-D	1173	MAIZE	97
CANOLA2	673	CANOLA2	93
DAPASTURE-M	461	SOYB	81
FABA	339	CANOLA1	70
LUCERNE-D	308	LUCERNE-D	67
HLUCERNE	288	FABA	67
CANOLA1	283	HLUCERNE	63
WHEAT2	282	PPASTURE-D	54
APASTURE-D	226	DPASTURE-D	53
BARLEY1	194	DWHEAT	51
RICE-Clay	175	RICE-Clay	43
PPASTURE-D	171	BARLEY1	42
SOYBEAN	146	RICE-Loam	41
WHEAT1	136	WHEAT2	39
BARLEY2	118	RICE-SLoam	37
MAIZE	117	WHEAT1	31
LUCERNE-M	114	APASTURE-M	30
RICE-Loam	100	LUCERNE-M	25
APASTURE-M	68	DAPASTURE-M	21
RICE-SLoam	51	BARLEY2	16
PPASTURE-M	36	PPASTURE-M	12
FALLOW	0	FALLOW	0

[1] A negative value indicates discharge

These two sets of coefficients are the major determinants of the model. However, the final results of individual runs will also depend on specific features and constraints attributed to individual farms. Generally, irrigated crops have higher evapotranspiration efficiency ratios and higher gross margins than dryland crops. This will result in the selection of irrigated crops over dryland crops, provided recharge is not limiting.

Sensitivity analysis

The model was used to determine the sensitivity of leakage to deeper aquifers, depth to the watertable and minimum rice areas on selected farms.

Leakage

The model was used to evaluate the sensitivity of leakage rates on gross margins and optimal intensity of irrigation on Farms 1, 2, and 3. The leakage rates used are -0.1, 0, 1, 0.2.25 and 0.4 ML ha^{-1} yr^{-1}. The following observations were made.

For farm 1, all five runs gave feasible solutions. Optimal irrigation intensity increased from 1.39 ML ha^{-1} (leakage = -0.1 ML ha^{-1} yr^{-1}) to 2.46 ML ha^{-1} (leakage = 0.4 ML ha^{-1} yr^{-1}). The upper bounds set for lucerne and hay lucerne were reached in all runs. This reflects high returns obtainable for lucerne on dairy farms. As the leakage increased, dry land annual pasture substituted irrigated pasture.

For farm 2, when there was upward leakage it was not feasible to meet salinity and recharge constraints. This farm had a deep water table (DWT = 4), and so the opportunity to discharge water in the form of capillary upflow was not available. Four other scenarios (leakage greater than or equal to zero) gave feasible solutions. Optimal irrigation intensity increased from 0.00 ML ha^{-1} (leakage = 0 ML ha^{-1} yr^{-1}). With an increase in leakage, dryland crops decreased and irrigated crops increased; notably FABA was introduced and DCANOLA was replaced by CANOLA2.

Depth to the watertable

The effect of shallow water tables was studied by raising the watertable to 3 m below the soil surface in Farms 2,4, and 5. This enables capillary upflow to occur.

For farm 2, when upward leakage was 10 mm it was not feasible to meet recharge and salinity constraints, i.e., the capillary upflow rates are still inadequate to offset upward leakage. Recall that the soil type in farm 2 is predominantly clay, which precludes a number of high-value irrigated crops. The optimum intensities of irrigation, without resetting the watertable at 3 m, were 0.0, 0.33, 0.98 and 1.7 ML ha^{-1}. In contrast, when the watertable was reset at 3 m, the optimum intensities of irrigation estimated for comparable runs were: 0.09, 0.53, 1.10 and 1.83 ML ha^{-1}.

For farm 4, when upward leakage was 10 mm, it was not feasible to meet recharge and salinity constraints. However, feasible solutions were obtained when leakage was zero. Recall that, for such a condition, and without resetting the watertable at 3 m, feasible solutions were not obtained. The optimum intensities of irrigation, without resetting the watertable at 3 m, for runs with positive leakage were 0.33, 0.98 and 1.55 ML ha^{-1}. In contrast, when the watertable was reset at 3 m, the optimum intensities of irrigation estimated for comparable runs were: 0.55, 1.14 and 1.62 ML ha^{-1}.

Minimum rice area requirement

For this set of runs, minimum area of RICE was set at 40 ha for farms 2,5, and 6. Runs were made with five leakage rates (-0.1, 0, 0.1, 0.25 and 0.4). For farm 2, feasible solutions were obtained when the leakage was 0.4. For farm 5, feasible solutions were obtained when the leakage was greater than 0.25 and the rainfall was average or wet. Farm 6 had no feasible solutions.

Although it is unfeasible to maintain zero net recharge in these farms if rice is grown on 40 Ha, rice remains the preferred crop for most farmers. Watertable rise in these farms may be avoided if groundwater pumping is adopted. For example, in farm 6, where the initial watertable depth is 3 m, growing 40 ha of rice will result in the watertable at a depth of 2.73 m in an average rainfall year. This watertable rise can be avoided if 1.68 ML ha^{-1} yr^{-1} of groundwater pumping is implemented.

Areas for further development

We believe that the model has performed in a logical manner for the runs carried out. However, some of the assumptions made in the model could be refined which would improve the model. This section outlines perceived weaknesses in the assumptions.

Estimating gross margins

The model uses gross margins as an indicator of profitability. Gross margins are simply income derived from an enterprise minus the variable costs directly associated with this income. The gross margin is not a profit figure and ideally should only be used to compared activities with similar resource use. As the model recommends optimal land uses, any major changes in a farm plan should be evaluated. This could be done externally to the model.

At present, the yield of a crop does not change as the level of water deficit changes. A crop-specific function need to be developed to account for this problem.

Salt and water balance of the farm

We assumed that the farms had reticulation systems, so that, irrigation runoff (drainage) was assumed to be zero. This may not be the case in some farms. Further, the levels of irrigation were not changed with changes in weather conditions. For example, RICE was assumed to use 20 ML ha^{-1} on a sandy loam, irrespective of weather.

Soil hydraulic properties

The optimal intensity of irrigation depends on minimum capillary upflow rates (CUFLOW) of soil types within a farm. Additional work is required to determine these rates under bare surface conditions and varying depths to the watertable.

Role of SWAGMAN Farm in the development and implementation of L&WMPs

Currently in NSW, Victoria and South Australia there is a move towards privately run irrigation systems, managed by irrigation boards. "For the privatization process to take effect, irrigation boards are required to develop Land and Water Management Plans (L&WMP) which are acceptable to Governments. We believe that SWAGMAN Farm has the following roles to play in the development and implementation of such L&WMPs.

SWAGMAN Farm could be used for educational purposes. Since SWAGMAN Farm accounts for aspects of agronomy, irrigation, salinity, soils, hydrogeology, and economics it can be used to evaluate the impact of a change in any one of the above variables. Therefore, agency personnel, members of irrigation boards, and the farming community at large will be in a position to understand the net effect of a potential change in farming practices.

Irrigation boards are required to identify and promote best management practices which will contribute to overall enhancement of the irrigated environment. We believe that SWAGMAN Farm could be used to determine guidelines for best management practices. Although SWAGMAN Farm is not comprehensive enough to be a farm management model, it can also be used by farmers to aid planning and management.

Conclusions

The following general conclusions can be made from this study:

1. The recharge efficiency ratio is the critical controlling factor. As the discharge capacity increased selection of a land use depended on the evapotranspiration efficiency ratio. However, the final solution depended on farm-specific characteristics and constraints.
2. As the leakage increased, total gross margin per farm increased.
3. The optimal intensity of irrigation (ML ha^{-1}) was low when the watertable was at depths below 3 m, the groundwater salinity was high, and the soil type in the farm was predominantly clay.
4. Considering the results of the study we believe that the optimal intensity of irrigation in the Murray Valley is approximately 2.5 ML ha^{-1} yr^{-1}, conditional on farm type, soil types and depth to the watertable. This compares with a current average rate of 4-5 ML ha^{-1} yr^{-1}.
5. When the watertable is deep and highly saline and the soil type is clay, it is advisable to avoid irrigation to prevent watertable rise and salinisation.
6. For a loam soil, when the watertable is deep and moderately saline, irrigation must be combined with groundwater pumping in order to maintain zero net recharge.
7. If area restrictions are not imposed as constraints, total gross margins per hectare received by the farm were high. This was primarily due to the cultivation of crops that had higher recharge and evapotranspiration efficiency ratios.
8. For the farm considered it is not feasible to maintain net recharge at zero and maintain rice area at 40 ha per farm, unless the level of leakage is high.

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Discussion

Dr. Prathapar's responses to questions from the audience were summarized as follows:

- Information on leakage is indeed essential for sustainable agriculture in this region. This information can be obtained, due to a well developed piezometer network in the area.
- Evaporation ponds in this region do not need to be lined, because they leak into an acquifer which is already saline.
- Agriculture in this region is sustainable, in spite of shallow and saline groundwater. This is possible due to high frequency of irrigation applications (every ten days), which remove the salt.
- Farmers accept the restrictions imposed on them to make irrigated agriculture environmentally sustainble, because they are consulted in the decision-making process through workshops. The model shows them the financial implications of various management practices. Acceptance is easier when farmers see that they can still make money.

WATER BOARDS IN THE NETHERLANDS[1]

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Introduction

In this presentation on "Water Boards in the Netherlands" , I intend to tell you something about the way Water Boards started in our country, something about their tasks, something about their organisational framework and finally something about integrated water management, which is being accomplished in the Water Boards.

Our country is an artificial one, because 25 percent of the area was reclaimed from the sea and is below sea level . About 50 percent would be inundated in times of high floods, if we had no dikes. That means that our country, and especially the western and north-western parts, could be quite dangerous to live in if we would not protect it from high floods both from the sea and from the large rivers entering our country, mainly the Rhine, the Meuse and the Scheldt.

Therefore, it is not surprising that from very old times - from the eleventh and twelfth century - Water Boards were formed, originally mainly to protect our country against floods. They were formed when land was reclaimed from the sea. Farmers put a dike around a piece of land and formed one of the oldest organisational governmental structures in our country. Water Boards existed even before villages and cities were formed. It is a form of local government, not a private institution. It is a governmental institution which has existed now for about eight to nine hundred years.

It all started with flood control, protection against the sea and high floods of the rivers. Later on, as the land started to sink and the sea level started to rise, it was also necessary to have a drainage system to pump surplus rainfall and sometimes also to let water in, in dry periods. So, later on, the task of water management was added to the task of flood control.

Water Boards are very old. The Water Board where I work started in the year 1273 and I am the seventieth chairman in a row. During the centuries we have added land to our country and in that process about two to three thousand Water Boards were formed. Around 1940 we had about three thousand Water Boards in the Netherlands. Some larger ones, but most of them very small.

After the large flood of 1953 in the Province of Zealand, people started to realise that perhaps many of these Water Boards were too small to have the capacity - also financially - to upkeep and improve our dikes. As a result, smaller Water Boards were merged into larger ones. Instead of the three thousand Water Boards in 1940, we now have about 70 altogether. I expect there will be about 50 by the year 2000.

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[1] The text below is prepared on the basis of a tape recording of Ir. de Graeff's presentation.

Tasks of Water Boards

Next, I would like to tell you something about the tasks which are entrusted to us.

We have three tasks. The first and oldest one is flood control. The second is water management, especially quantitative water management. The third task is qualitative water management.

Flood control. Since 1200 we have had about 20 large floods that inundated parts of our country. After the disasterous flood of 1953, a very intensive program to strenghten our dikes was launched. This program has been going on for almost half a century. It has been completed for all the dikes which protect us from the sea and it has almost been completed for the dikes which protect us from the high floods from rivers. Many of you will remember the spring of 1995, when heavy floods were almost inundating the country, also here in Wageningen. This event provided a strong incentive to complete our dike program for the rivers around the year 2000 as well.

In the western part of our country we are now protected against a peak flood which occurs once in every ten thousand years. In the inland areas - where you are staying now - the return period varies between fifteen hundred years and three thousand years. In the western part of our country we still have the problem of the sinking of the land and the rising of the sea level, so that we may have to strengthen our dikes again in twenty or thirty years. The frequency of high floods from the rivers seems to increase, so in due time we may have to strengthen our river dikes as well.

Altogether about three thousand kilometres of dikes have been strenghtened. Of course, these dikes have to be maintained every year.

The second task of the Water Boards involves **water quantity control**, which simply means to avoid too much or too little water occurring in the areas where the Water Boards perform their tasks. Especially in the western part of the Netherlands excess water has to be pumped out. This is not only surplus rainfall, but also seepage water which comes up from the subsoil, due to the fact that the water level in the sea or the river is higher than the groundwater level in the polders. We have to pump out this water because otherwise it would suffocate our water management systems. In some polders of the Water Board of Schieland, one has to pump during four to five months a year - for four to five hours every day, even if it doesn't rain - to prevent inundating the whole area within about two weeks time.

In dry periods we sometimes have to let fresh water in, both in the lower lying parts and in the upper parts of the Netherlands. Therefore, one has to provide for a water management infrastructure which can be used for supplying water, or for removing it, according to the needs. This infrastructure has to be maintained too, which is another task of the Water Boards.

The third main task is **water quality control**. This task was entrusted to the water boards from 1970 onwards. Water quality control involves in particular the purification of waste water from cities and towns, and from industry. At the moment, about 95% of our households and small industries are connected to the sewerage system. All of them are served by sewage treatment plants operated by the Water Boards.

The task of water quality control has given an enormous boost to the Water Boards. Sewage treatment involves a lot of money, which required strengthening of the organisations. As a result, the Water Boards were able to employ more people, with a higher level of education.

Organizational structure and financing

Besides the extension of the tasks of the Water Boards, another development took place in the sphere of organizational structure and financing. It is an essential principle that the people who benefit from the work performed by the Water Boards, are financing them, and are represented in the Board. There are four groups of people who benefit in different ways from the work of the Water Boards. Those are:

- the owners of agricultural land;
- the owners of buildings;
- the industry;
- the households.

In our Water Board of Schieland there is an important green house industry, which has become the fifth group.

From these groups, representatives are elected every four years in the general assembly of the Water Board. The representatives in the general assembly elect an executive board of five to six persons. The chairman, however, is appointed by the Crown. The five groups pay a fixed amount of taxes to the Water Board, in such a way that 100% of the costs of the organizations is borne by the various groups of beneficiaries.

The Water Boards also have an executive body for the performance of the various tasks, including administrative and technical staff, which may vary from 20 persons for a small Water Board to 400 for a large one.

To finance all operations there are two kind of taxes. One tax is for water pollution control. This tax is levied from both industry and households on the basis of the amount of pollution that has been discharged. The second tax is for flood control and quantitative water management. This tax is levied on the basis of, either the value of property, or the area of land. The latter tax is especially important for farmers.

Interrelationships of tasks

In the past, one could find two or three different Water Boards active in the same spot: one for water quality control, another for water quantity control, and sometimes still another one for flood control. This is gradually disappearing, and nowadays in most places one only has one -all-in- Water Board that performs the tasks of pollution control, quantitative water management and flood control. This is a very favourable development because the three tasks are very closely related, as shown by the following examples:

- **The relationship between flood control and river management.** Controlling the floods by building dikes may narrow the river bed. In periods when the river carries much water, the water level may rise so high that one would have to strengthen the dikes once more, in order to offset this effect. We have become very much aware of this feature after the floods of spring 1995. Therefore, nowadays much care is taken not to narrow the river bed, when the dikes are strengthened, in order to avoid this particular effect.

- **The relationship between river management and nature conservation.** From the point of view of water quantity control it may be desirable to canalise meandering rivers, or to strengthen their embankments to prevent erosion. On the other hand, such interventions may destroy plants which are growing on the river banks. Therefore, one is trying to design and operate the whole water management system in such a way that it can serve its purpose, without disturbing nature too much.
- **The relation between ground water and surface water management.** If one removes water from the drainage system, one may lower the level of ground water, and if one lets water in, the opposite effect will occur. Ground water control is, of course, one of the main purposes of the drainage systems. Also urbanization could affect surface and ground water management. The relationship between ground water and surface water management is presently being studied intensively, with a view to the question whether it is useful to extend the tasks of the Water Boards also to ground water control.
- **The relation between the dredging of canals and pollution control.** Regular dredging of canals is necessary to maintain their capacity. Sludge may be contaminated by polluted water. If sludge is contaminated, one can no longer simply deposit it on the embankments as was the usual custom for centuries. Nowadays, one would have to deposit the contaminated sludge elsewhere. Of course, this poses great difficulties in terms of finding space and in terms of money.
- **The relation between drainage and water quality management.** If necessary, one may use the drainage system to flush out salts or other harmful substances.

Tools for integrated water management

During the last 10 - 20 years, one has come to the conclusion that the above-mentioned management tasks are very closely related. To achieve integrated management, one needs to have the proper instruments.

First of all, an appropriate organisational framework is required. Merging of single purpose Water Boards for flood control, quantitative and qualitative water management, thus integrating their tasks in one all-in Water Board is the answer.

A second instrument is the planning procedure, which has been developed during the last ten years. At the national level, the Ministry of Transport and Public Works will regularly publish a document which outlines the general policy for the next four years. This strategic plan is elaborated at provincial level where it is more or less made operational, and where it is integrated with plans in the field of physical planning and the environment.

Thirdly, at the level of the Water Boards one has to work out operational plans which indicate how one intends to accomplish the assigned tasks in the coming four years.

This planning system is very useful for integrating the tasks assigned to the Water Boards, but also for connecting these tasks with goals that will be pursued in the field of physical planning.

Finally, at the moment a discussion is going on about integrating the financial instruments which the Water Boards have at their disposal. These are the water pollution tax, and the levies on land and other property. If this will be achieved, one may have only one or two taxes from which all expenditure will have to be paid.

Discussion

Ir. de Graeff's responses to questions from the audience were summarized as follows:

- Water Boards are set-up by the Provinces, on the basis of hydrological boundaries.
- Water Boards are in principle financially autonomous.
- In some parts of the country (Eastern and Southern parts) Water Boards are also responsible for groundwater control.
- Water Boards are not directly involved in domestic water supply.
- Although strategic planning is the responsibility of the national government, Water Boards are consulted in the planning process.
- Due to the increased size and the water quality tasks, there is a gradual decrease of the relative importance of agriculture in the objectives and activities of the Water Boards.
- Cooperation between Water Boards is coordinated through legislation, planning and mutual agreements.
- Water Boards do not decide on standards for fines, etc. This is done by the national government through legislation and policy documents.
- Practices and principles of Water Boards may be applied in other countries, but need to be adapted to suit local conditions.

INTERNATIONAL EXPERIENCES WITH THE DRAINAGE WATER BOARD CONCEPT

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Introduction

'Upward behind the onstreaming it mooned'

I would like to start this presentation with a quote from the language of Tlon, as described in a short story by Borges. In this fictional essay Borges talks about the people of Tlon, who thought in distinct acts, rather than in objects in space. Nouns did not exist in the language of Tlon. In a language of nouns 'Upward behind the onstreaming it mooned' would translate as 'The moon rose above the river'.

The point I want to make is that there is an alternative to thinking in structures and organizations as given, which is the thinking in processes: in local institutional change and organizational development. This reflects on the theme of this presentation: 'International experiences in applying the water board concept'. The danger with this theme (particularly if we mean with 'the water board concept' the Dutch water board concept) is that it encourages us to think in terms of organizational solutions and make a subsequent step of proposing a blueprint. The problem is unfortunately less amenable to generalizations, because:

- water management organizations evolve out of a path dependent history and a context; the hydraulic system is a very important part of that context.
- one has to look for more than organizations, while looking at institutions; in water management the rules with respect to water use and disposal are particularly important; as are on a different level the relationships between the different organizations

This is not to say that a number of the elements of Dutch water boards are very relevant for a number of developing countries. In the wake of institutional reforms in the water sector, there is now much attention for:

- user democracy;
- financial autonomy and;
- representation of (divergent) interests in the water management organizations.

It is with examples of these elements in a number of countries that this presentation is concerned.

Drainage as a collective good

Increasingly, it is argued that drainage is not necessarily a public good (or collective liability), but may be looked upon as a collective good as well. This requires that one reformulates the objective of drainage from a negative state, i.e. removing excess water and salt, to a positive state, i.e. the ability to control salt and water levels. In other words, in integrated water resource systems drainage provides the means to control the outflow of water.

Thinking of drainage as a collective good raises the question of drainage management by users. In recent years there has been considerable change in the field of irrigation management. There are a number of factors that distinguish drainage management by users from user irrigation management; factors that make user drainage management more difficult as well as more easy (see table below).

Complicating factors:	Facilitating factors:
• Quality problem: in some systems no immediate impact (of inadequate drainage)	• Local drainage units can be operated relatively independent of main system
• Variance of interests related to different land levels	• No conflict between head and tail
• Some existing drainage systems technically difficult to manage for users	• Fresh starts can be made: often no drainage infrastructure in place

In general, the viability of user management in drainage is a variable of the utility of drainage to the users. Users may be others than farmers, as the next section argues they may for instance be fishermen too, as in Bangladesh. The utility of user drainage management is in essence a function of:

- the utility of drainage within the management of land and water resources in a specific place;
- the degree of local autonomy and control within the hydraulic system.

When utility is very high, such as where drainage is required to reclaim land, special purpose farmer-managed drainage systems may develop spontaneously. The polders and water boards in The Netherlands, Germany, England, are examples. The *koliparam* in coastal Kerala (India), draining land in the dry season, is another example of a farmer-managed drainage system. In other systems the inducements are less, but may still be rewarding enough to sustain local management. In Pakistan a number of successful experiments were undertaken with small local farmer-managed drainage systems, that served to avoid high groundwater tables and concomitant salinity problems. In other systems the benefits of drainage may not be enough to sustain a special organization, yet drainage could be a useful additional function of irrigator groups or other local organizations.

The utility of user drainage management is also related to the degree of local autonomy. User management makes no sense when drainage and other water management issues cannot be controlled locally. In publicly developed hydraulic systems, the degree of local autonomy is closely related to drainage system design.

The SCARP deep drainage programme in Pakistan may serve as an example: the deep tubewells addressed problems of waterlogging at a regional level. Clearly, therefore the deep drainage systems were not amenable to local management - as a drainage facility that is.

Farmer organizations for drainage management

Below we present experiences with water boards/ user control in drainage, based on the experiences of projects in which Euroconsult is involved. We concentrate on Pakistan, Egypt, India and Bangladesh. In all four countries user control over water management organizations is limited - not just in drainage, but in irrigation as well. The experiences below therefore concern pilot activities rather than consolidated policies.

In this respect the term the 'Asian model' of transfer of responsibility in water resource management has been used (Gorriz et al., 1996). The Asian model of irrigation management transfer typically relies on direct participation of all water users in system management. Basic units are smaller and user-management in public systems (if at all) gravitates towards tertiary level. Bearing a few exceptions, above the tertiary level responsibilities are - at the most - mixed: for managing supplies at canal level 'joint management' arrangements have evolved. Because of their 'local' nature farmer organizations are not specialized in water management, but are multi-purpose.

The antipode of the Asian model is the 'American model'. The recent institutional changes in water management transfer in Latin America have been more far-reaching than anything that happened in India, Pakistan or Egypt. In this paper Mexico is discussed as an exponent of this American model. In Mexico in a short-time span a large part of the responsibility for water management at secondary level (irrigation and drainage) has been handed over to WUOs. This example has been followed in a number of other Latin American countries. Unlike the Asian model, the American model of irrigation management transfer relies more on specialized farmer organization with role differentiation (only water management related) and of larger organizational sizes. User management is not direct, but delegated to user organizations, who collect the requisite fees from their members.

The difference between the two models has a bearing on the theme of this symposium, i.e. the integration of irrigation and drainage management. The question is whether these two functions of integrated water resource management should be combined in one organization.

In as much as drainage problems can be mitigated by the management of water supplies (in semi-arid regions), the linkage between the two does not take place at tertiary level as much as it does on secondary level and above. Drainage problems at local level do not originate from leakages from local tertiary channels. Moreover, constraints in local fresh water supplies - important to regulate salinity levels - are also not determined at tertiary level. Integrating both functions at tertiary levels will resolve little.

This has two implications:

- in the Asian model integrated water resource management (at secondary level and above) will take place in a polycentric setting with different organizations (farmers and public sector). At tertiary level one can imagine a separate organization for irrigation and drainage to exist side by side;
- in the American model integrated water resource management can take place within one organizational shelter. Since water management functions are not delegated to separate organizations at tertiary level, there is no question of local level irrigation and drainage organizations.

In the following the different experiences with water boards under the Asian model (Pakistan, Egypt, India, Bangladesh) and the American model (Mexico) are discussed.

Pakistan

Reforms in the water sector in Pakistan are currently the topic of much debate and controversy. By cabinet decision in 1995 it was decided that the Provincial Irrigation Departments would have to be transformed into financially autonomous Provincial Irrigation and Drainage Authorities. On each command Area Water Boards would have to be formed, that would be governed with farmer representation. On secondary canals water users federations would come into being, composed of representatives of water course level water users associations.

These plans are still concepts. However, the establishment of distributary federations is being tried out, since 1995, whereas the first pilot Area Water Board is to be floated in 1997. So far in the pilot distributary federations the emphasis has been on the management of canal water. Drainage has not (yet) been incorporated as a task for the pilot distributary level federations and the responsibility for the management of drainage facilities is still be settled.

At the same time the entire concept of how to drainage is being rethought. The SCARP deep drainage programme has run its course. In fresh groundwater areas the explosive growth in private shallow tubewells numbers has made the drainage by SCARP tubewells unnecessary and in fact the increased pressure on ground water increases the need for integrated water resource management: surface water supplies, drainage and ground water.

SCARP tubewells will continue to be operated in saline groundwater areas. Yet their mode of management is being reconsidered, because of the high number of non-functioning deep tubewells under public management. In the National Drainage Programme a clear choice has been made to have local drainage systems managed by user groups.

As frontrunners, a number of experiments in farmer-managed drainage systems are being tried out. Under the On-Farm Drainage projects (with the Department of Agriculture) a number of local surface drainage systems are being developed. Special purpose drainage beneficiary groups are to manage these systems. The lay-out of the drainage systems is the outcome of close consultation between engineers and farmers, whereby the latter decide on the size of the system and within given parameters the location of the surface drains. Interestingly, the drainage units, that evolved out of this discussion process, were larger than expected originally, as farmers felt it would be problematic to exclude certain areas from drainage. Another experiment is on-going in the Fordwah Eastern Sadiqia South Project, where a trial has just started to develop farmer-managed subsurface systems. One important finding of this trial is to downsize and adjust the design of the system, so as to make it more manageable. Two common lessons from both projects are the importance of functioning main drains to dispose of the effluent of the local drainage systems and the fact that local drainage systems do not work in each place.

India

Public investment in drainage in India has been significantly less than in Egypt or Pakistan and has been predominantly in surface drains. Both the Union Government and several State Governments have adopted a policy of participatory water management in official documents. On the ground, however, particularly in the field of user management of drainage systems, not much is happening.

Under the Operational Pilot Project Haryana a model for the development of subsurface drainage is being developed. The ultimate goal is to develop a service organization, that will be able to construct subsurface systems on farmers lands against full or subsidized charges.

The most likely option is that of a semi-public corporation under the Department of Agriculture. These local drainage systems are to be managed by farmer groups.

Egypt

In the past decades substantial investments have been made by the Egyptian Government in surface and subsurface drains. With its increasing age the management of drainage systems has become an issue.

To date the management of irrigation and drainage systems is very much in the hands of the Government. A number of initiatives are being implemented to improve the performance monitoring of drainage facilities in order to prioritize rehabilitation activities (Drainage Research Institute, 1996). A second track that is being explored in a number of pilot activities is to investigate possibilities and mode of farmer management of irrigation and drainage infrastructure.

In the Fayoum Water Management Project two pilot activities have started to establish farmer organizations on secondary irrigation channels. Towards this end key persons of informal farmer groups have been asked to form a farmer organization at secondary channels. In the first years maintenance activities were prioritized by the farmer organizations. They have also agreed to undertake weed control in the canals and supervise the water distribution, including the resetting of intakes.

The next step in the farmer management pilot activities in Fayoum is to increase farmer management of drainage facilities. So far, there is little experience with this. Although in Egypt farmers contribute to costs of the drainage improvements in their land (repaying the investment interest-free over twenty years), the operation and maintenance of the works has been with the Egyptian Public Authority for Drainage Projects (EPADP).

Early indications show that the establishment of a farmer organization for the management of drainage only receives a lukewarm response. One may recall the hypothesis of the first paragraph: the urgency and importance of drainage may not be enough to sustain a special organization. Another point to be made is that in Egypt the systems are already in place, hence it is management transfer rather than new establishment. In addition farmer management of subsurface systems in generally is more difficult: because of the need for flushing and its invisibility. The latter would allow the drainage facilities to be more tuned to local wishes and capabilities of management.

Bangladesh

In Bangladesh drainage is of a different nature than it is in Egypt, India or Pakistan. Drainage serves to reclaim lands for cultivation that would otherwise be (seasonally) waterlogged. This brings drainage potentially in conflict with water management for fisheries. In construction and operation of drainage and other water management infrastructure compromises have to be found to serve agriculture and fisheries both. On the other hand, salinity management is of no importance in Bangladesh.

Unlike the countries discussed earlier, in Bangladesh, efforts are in place to systematically consult land and water users in drainage improvement projects. Official guidelines have even been issued to undertake extensive 'needs assessments' in water development projects. In line with these guidelines in a number of recent projects consultation meetings were held both at village-level with various population groups (land-owners, landless, women, fishermen) and in local elected bodies. In the Khulna Jessore drainage rehabilitation project for instance the following methodology was used to discuss the concepts for drainage improvement in an area covering 100,000 ha:

- pre-announced consultation meetings in hydraulic units (size 500-1000 ha), affected most by the proposed rehabilation works using participatory appraisal techniques;
- simultaneously: group interviews at the local elected bodies, including special interviews with women groups;
- synthesis by interdisciplinary project teams and reconstitution to the local groups that were consulted.

The result of the consultation process was a redefinition of the work and the identification of important additional activities to serve drainage rehabilitation (in the realm of agro-support services). In the consultation process a number of divergences in interests were identified too with respect to the proposed works, that could not be easily resolved without jeopardising the entire project.

The needs assessment preceded the establishment of farmer groups for water management. The establishment of these groups is left to the implementation stage. At present in Bangladesh the discussion on whether and which status such groups should get has not yet been completed. In the Compartmentalization Pilot Project and in the Khulna Jessore Project, which both have an exploratory nature, multi-tier farmer organizations have been proposed.

In the Compartmentalization Pilot Project/CPP three levels have been envisaged:

- at village/*chawk* level water user groups (*Chawk* Committees) are formed in which various groups of farmers are represented; at the same time special water user groups are formed for fishermen, women and landless;
- at subcompartment level water management committees are established, in which representatives of the various water user groups take a seat as well as two representatives from local NGO's, government organizations (extension workers) and the local government;

- at compartment level a project council is envisaged. This council has representatives of the subcompartment level water management committees, representatives of adjacent areas, as well as representatives from technical government departments, local elected bodies and non-government organizations.

Similarly in Khulna Jessore farmer organizations at three levels (village; catchment of primary or secondary drainage channel; entire drainage unit) are proposed, composed of representatives of various affected groups. Initially these groups would be informal in nature, but ultimately they would be transformed in multi-purpose cooperative societies. In Khulna Jessore the groups would never include representatives from government organizations, NGO's and local elected bodies.

The farmer organizations in CPP are all very new. An evaluation of the first year (when no compartment level organization was established) showed that the village/chawk committees played a strong role in the management of the various water control structures. Several chawk committees also took care of structures that were to be managed by the subcompartment level water management associations. Another interesting result was that several conflicts between fishermen and farmers were resolved locally. Another observation was that the type of water management in CPP (controlled flooding and drainage) was new in the area, resulting in a number of avoidable conflicts.

Mexico

In all of the four countries, discussed so far, the American model is promoted as an example of how irrigation and drainage system should be managed. In Mexico the irrigation management at subsystem level (units varying in command from 5,000 to 20,000 ha) of 2.5 million hectares was transferred from government irrigation districts to *Asociaciones Civiles* (water user organizations). These WUOs are responsible for the management of secondary irrigation channels as well as drainage facilities. In some cases a supra-level WUOs (called Society of Limited Responsibility) has also taken over the remaining responsibility of the irrigation districts. Unlike what is being tried in Pakistan, India and Bangladesh, there is no separate farmers organization below the WUO.

Farmers, who wish to form a user organization, must establish a *Asociacion Civil*. Without this legal status they will not be entitled to a Title of Concession for the use and management of irrigation infrastructure at subsystem level and for the collection of irrigation service fees. The system of representation in the General Assembly differs between WUOs. In some WUOs representation is by category of farmers (*ejido* and small landowner). In other WUOs representation is made per section of the irrigation system.

Prior to the dramatic move operation and maintenance of the facilities was largely paid for by the government, and collected water fees of farmers covering only 18% of the budget costs. At the same time many of the irrigation and drainage systems were in disrepair.

With the transition the WUOs take care of the operation of the secondary irrigation and drainage facilities and raise the budget for this from the water users. In addition, the WUO pays a charge to the Irrigation Districts for its services in delivering water. Farmers pay their WUO either prior to the irrigation season (which ensures a steady income to the WUO) or prior to the irrigation turns. Fees are hence related to irrigation supplies rather than drainage services. Interestingly, in several irrigation subsystems the WUOs after the transition have made changes in the water distribution system and have introduced arranged demand systems (Gorriz et al., 1995).

Concluding remarks

With the exception of Mexico, the management of drainage facilities still is very much a public affair as discussed in this paper. Yet several experiments and pilot activities have started in the past three years to explore models of users management and joint management of drainage facilities. In several countries it is at the moment not clear where responsibilities for integrated water resource management will be.

The important difference seems to be between the American model, whereby the responsibility of irrigation and drainage at the level of secondary and main system is transferred to farmer organizations; and the Asian model, whereby at secondary level joint management arrangements are explored. In the latter case, which in most countries was the dominant arrangement, water management will be the responsibility of several organizations. In line with what was mentioned in the first para, such a polycentric setting requires the formulation of rules that regulate the interaction between the various players.

Another point is the close interrelationship between drainage organization and drainage design. Particularly, if an important role is given to a local user organization with a degree of autonomy, this should be reflected in the design of the system. Substantial work is still to be done in the interface between drainage design and user management:

- at system design level: to create more local autonomy and control and facilitate integrated uses, particularly in the Asian model;
- at structure design level: to have systems that are manageable, easy to inspect and control and in general have low exploitation costs;
- to reconsider the design process and make it more consultative and farmer-driven, along the lines of the 'needs assessment' applied in Bangladesh, so that the design process does not only yield inputs for system and structure design, but also helps in formulating water management rules.

One of the purposes of this symposium is to give inputs to ILRI's research agenda. In this respect I want to conclude with two remarks:

1. User management of drainage facilities is still unexplored territory in many countries and as mentioned the design of drainage infrastructure plays an important role. It is my belief that in this interface of design and organization, working at user manageable systems institutes such as ILRI have an important function;
2. If one wants to experiment with different models of user organizations a very different type of research is required from the ones that institutes like ILRI are used to. One moves into a domain of policy experiments rather than technical research and this has implications for the way one operates. Research will be less academic and more political, and will include lobbying, policy advocacy and process management. *'Upward behind the onstreaming it mooned'*. Often this is a domain, where research institutes feel ill at ease.

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Discussion

Dr. Van Steenbergen's responses to questions from the audience were summarized as follows:

- Users organizations are more difficult to establish when stakeholders have very different interests. Water boards in the Netherlands were established centuries ago when the priority was flood protection, which was a common interest for all stakeholders. Once established, the Water Boards managed to take on more complex responsibilities, involving stakeholders with different interests.
- The example from Bangladesh indicates that stakeholders with different interests - farmers and fishermen - were more capable of resolving their conflicts than had been anticipated. This was due to the fact that these stakeholders were organized at the local level, which meant that they knew one another well.
- It is correct to say that another main reason for the transfer of management of irrigation and drainage facilities to the users is that governments want to reduce costs.
- To date, there is too limited experience to advise on the merits of a combined irrigation and drainage fee versus separate fees. In general, the cost of irrigation water is too low to have an effect on the volume of drainage water produced by the farm.

INTEGRATION OF IRRIGATION AND DRAINAGE MANAGEMENT IN A MONSOONIC CLIMATE[1]

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Abstract

The present paper describes the nature a of monsoonic climate affecting the irrigation and drainage activities. It has been established that in a monsoonic climate both irrigation and drainage are needed for potential agricultural crop production. In the past the irrigation and drainage systems have been designed, installed and managed independently by different agencies. But, for the efficient performance of irrigation and drainage systems their integration is necessary. Four different aspects (1) Land development for receiving irrigation water and releasing drainage water; (2) Design of irrigation and drainage system components; (3) Operational aspects of irrigation and drainage systems and (4) Institutional aspects of irrigation and drainage management were identified for the integration of irrigation and drainage systems.

Introduction

Irrigation and drainage are the practices which were initially adopted for water deficit and excess water regions for increasing agricultural production. The development of irrigation projects in arid and semi-arid regions invariably led to waterlogging and soil salinity problems in irrigation command areas. This has created the necessity of agricultural drainage to control excess surface water and/or sub-surface water for salinity control in those regions besides the already felt needs in humid regions. Similarly in regions with a monsoonic climate due to the seasonal variability of rainfall irrigation is required for a multi-cropping system adopted to the various seasons of the year. Therefore, both irrigation and drainage are required for arid as well as humid regions with a monsoonic climate. In the past the irrigation and drainage systems were planned, designed and implemented separately and are being managed by different agencies. However, the optimal and sustainable use of irrigated agricultural lands require irrigation and drainage systems to be designed, constructed and managed as an integral unit.

In a monsoonic climate the variability of rainfall is of relatively higher magnitude. To overcome this situation the development of irrigation and drainage projects have taken place at enormous cost for increasing the agricultural production. Irrigation projects provide water for crops in water deficit regions and also maintain the water supply for the crops during dry spells frequently observed in a monsoonic climate. The excess use of irrigation water or rainfall in excess of agricultural water requirements create the situation under which

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[1] Due to unforeseen circumstances, the author was not able to present his paper at the symposium

drainage also become an unavoidable proposition. In arid and semi-arid regions with low monsoonic annual rainfall the irrigation may cause worse environmental degradation of valuable soil resources affected by waterlogging and soil salinity problems. The potential gains of irrigation may be offset or reduced if the above mentioned problems are not taken care by providing land drainage along with irrigation. The irrigation and drainage management activities in a combined manner should attempt to narrow down the gaps between the water supply and water requirements of the crops in the project areas without causing environmental problems. The combined performance of irrigation and drainage systems is influenced by many factors which are of an engineering, hydrological, agricultural, or organizational nature. For the best performance and returns it is essential to integrate the management of irrigation and drainage systems in order to function in a harmonious inter-action.

Characteristics of the monsoonic climate

The monsoon rainfall is the primary source of water and dominating single weather parameter affecting salinity and waterlogging problems. There are periods when excess water occurs on the land surface due to surface ponding often combined with waterlogging of the top soil. Since the distribution is not uniform throughout the year, the canal irrigation water used during dry period also contributes towards the development of waterlogging because of the deep percolation losses. The monsoon rainfall always has a seasonal rhythm in which the rainfall exceeds the evapotranspiration only for 2-3 months of rainy season. During this period the groundwater table tends to be high and critical for the crops. During this period some control is desirable to prevent continuous flooding and severe waterlogging of the crop root zone. The rainfall distribution characteristics of varying magnitude and duration of rainfall storms are such that the amount of rainfall in a consecutive period of several days can be too heavy (Rao et al., 1994) for the watertable to be controlled below the soil root zone (Table 1). In such a situation, much of the rain which is unable to infiltrate into the soil needs to be discharged over the surface, requiring the provision of surface drainage in addition to the installation of a sub-surface drainage system.

Table 1. Rainfall intensity and dry spells of different return periods

Particulars	Return period, years					
	1.01	2.33	5	10	25	100
Maximum one day rainfall, cm	4.1	12.0	15.2	16.3	22.1	28.9
Maximum two days rainfall, cm	5.1	15.5	20.1	23.8	28.5	35.5
Maximum three days rainfall, cm	6.1	17.1	21.9	25.8	30.7	38.1
Maximum four days rainfall, cm	6.7	17.9	22.8	26.8	31.8	39.4
Maximum dry spells in monsoon season, days	15	28	34	39	45	54

In a monsoonic climate and in an area with severe waterlogging, the watertable remains very close to the surface during rainy season. The observations from several places have indicated that during driest period the watertable may recede beyond 2 m. The lowest watertable depths reached were not affected by subsurface drainage installation at about 1.5 m depth whereas the subsurface drainage influenced the position of shallow watertable depth during rainy season (Singh and Maraviya,1988). For the monsoonic climate, the design drainage rates are to be selected in such a way that the drainage aims are fulfilled for all the seasons. These aims are to obtain and preserve favourable conditions for plant growth and farm management by (a) avoiding too wet conditions during the rainy season, (b) obtaining workable conditions shortly after a rainy period, (c) maintaining the watertable at a proper depth during the *rabi* season between irrigation cycles, and (d) controlling salinity during dry off season after the *rabi* harvest.

Integration of irrigation and drainage management

The concept of integration of irrigation and drainage management can be applied with respect to four different aspects (1) Land development for receiving and releasing drainage water (2) Design of irrigation and drainage system components (3) Operational aspect of irrigation and drainage systems and (4) Institutional aspect of irrigation and drainage management.

Land development for receiving and releasing drainage water

The ultimate impact of integration of irrigation and drainage management is to be seen on the efficient utilization of irrigation water in order to reduce drainage loads or quick removal of the excess water from the agricultural fields. To fulfill this objective the land development and shaping are the most important activities. The land development and reshaping activities can be planned in such a way that on one side they are helpful for uniform and efficient application of irrigation water in desired quantity (Tyagi and Joshi, 1995) and on the other hand it is helpful for quick removal of surplus surface water at the time of excessive rainfall without causing high waterlevel built up which is very common in a monsoonic climate. The activities which can be helpful for integration of irrigation and drainage system management include reshaping of the fields, grading, bunding, layout of irrigation and drainage channels with their proper linkage.

The uniform and efficient application of water achieved in a well-graded field having proper border length and width according to available stream size of the water supply can be helpful in reducing the drain outflow and in effective leaching of the salts from the root zone. The location and layout of the irrigation and drainage channels along with their discharge carrying capacity is important in order to bypass the excess irrigation water during rain storms when it is not possible to close down the canal irrigation water supply all of a sudden. Bunding of the agricultural field is helpful for reducing the peak surface runoff rate and increasing the ground water recharge which can be utilized during lean monsoon months in the form of groundwater resource.

Design of irrigation and drainage system components

Drainage is required in many irrigated, arid lands to prevent rise of the watertable, waterlogging, and salinity build-up in the soil. The history of irrigated agriculture is replete with failures caused by the lack of adequate drainage to prevent salinization of the soils. Drainage to control salinity is, by definition, intended to remove salt, and will usually have a negative impact on the quality of receiving waters. The amount of salt removed depends on irrigation methods and management as much as on the drainage system. Hence the design of irrigation and drainage system should be considered as a unit rather than as individual systems.

Irrigation practices have direct effects on the watertable and the drain spacing is dependent on excess water applied and rainfall. Thus on-farm irrigation and drainage practices are mutually inter-dependent. For the integration of the drainage and irrigation system, it is necessary that the components of both the systems are designed and installed in the field keeping in view their inter-dependency. The aspects which are to be considered to fulfil these objectives are as follows:

Controlled drainage design to act as sub-irrigation

The soil moisture management by watertable control is popular in humid regions where ground water quality is generally good. But in arid irrigated regions also it is observed that after a few years of installation of subsurface drainage, the quality of shallow groundwater table is improved and the shallow watertable maintained by controlled subsurface drainage can contribute towards irrigation requirement of the crops. Because of the characteristics of the monsoonic climate with considerable variability in rainfall during long as well as short periods of time, their is need for drainage during excess rainfall and for irrigation during periods of drought. For soils with a shallow watertable depth this can be achieved using gravitational drainage cum sub-irrigation systems.

The controlled drainage at different watertable depths to fulfil the irrigation requirement of different crops can be managed by providing waterflow controlling devices in the drainage channels which can be operated as and when required. To reduce the cost of system, the depth of the drainage pipe can be designed to control the shallow watertable in the desired range of watertable depth.

During the design of the sub-surface drainage cum sub-irrigation system provision can be made for:

Controlled drainage

Controlled drainage technique is applicable in small areas with very limited water resource. The main advantages of such a technique are the low cost because only one control structure in the drainage ditch needs to be constructed and this kind of water management technique is easy to perform in the field. The main disadvantage is that during very dry periods it is not possible to maintain the groundwater level at the desired position (Brandyk et al., 1993).

Sub-irrigation with a constant waterlevel

Sub-irrigation with a constant waterlevel is based on keeping the groundwater level at a position which is close to its optimum value, by the proper maintenance of the open waterlevels in the ditch network using control structure. This practice can be used for such soils where it is possible to assess the optimal groundwater level which guarantees both the required air content in the root zone during periods of excess rainfalls as well as sufficient capillary rise during periods of drought. For removal of the annual salt build up some amount of leaching and drainage is also required.

Sub-irrigation with a regulated waterlevel
Sub-irrigation with a regulated waterlevel assumes the groundwater level changes according to weather conditions by rapid open waterlevel changes in the ditch-drain network. It is possible to implement this technique and is recommended for soils which require groundwater level changes under changing weather conditions. In a monsoonic climate changes in waterlevel in the drain network are very common.

Irrigation methods and drainage

The irrigation methods have a definite influence on the subsurface and surface drainage. The flood irrigation affects the drainage effluent in terms of discharge rate and water quality.

From a water quantity aspect, the flood irrigation event triggers a considerable jump in the discharge rates of the drains not only underlying the land receiving the flood irrigation but also adjacent drains.

The shallow groundwater is likely the primary determinant of drainage effluent quality. The ratios of drainage effluent and irrigation water show a relatively large increase in the concentrations of Na, HCO_3, SO_4, NO_3 and a decrease of the cations Ca, Mg and K.

The modern methods of irrigation water application like sprinkler and drip, have been proved to be effective in reducing the drainage outflow to a considerable extent. Their use in a saline environment is favoured where there is a problem of disposal of drainage effluent. The drip irrigation method has an added advantage of enabling the use of poor quality water and of reducing the drainage effluent load. The design of the system can be made in such a way that part of the drainage water can be recycled for irrigation application. An in-built monitoring system of the salinity development is required to control the fraction of drainage water reuse, so that salinity may not increase beyond a critical limit. In arid regions with a monsoonic climate, particularly during the months of summer, a situation rises where salinity and waterlogging and shortage of water for irrigation is very common. This situation can be tackled only by proper integration of irrigation and drainage system management.

The degree of drainage and irrigation needs

The drainage degree by surface and subsurface drainage methods have an important bearing on the irrigation system. In surface drainage system it is generally used for managing surface run-off generated by heavy rain storms. It can be influenced by rain water management in the agricultural fields. The storage of rain water in the agricultural field to the extent that it does not create any harm to the crops is beneficial for reducing the irrigation requirement. It is also helpful for improving the ground water recharge in the areas with deep groundwater table depths, thus helping in the better discharge from tubewells for irrigation purposes. The surplus water from the areas where deep aquifers have the potential to receive the excess water can be made available for groundwater recharge, thus reducing the surface drainage load. Design of drainage system can be made compatible to irrigation needs of the region.

Skimming wells for drainage and irrigation

Skimming wells serve the purpose of controlling shallow watertables in the regions where the quality of shallow water is fit for irrigation. In the coastal regions where deep waters are saline and fresh water is available only in upper thin layers, the skimming wells serve as very effective means of controlling subsoil water and at the same time making available good quality water for irrigation purposes. The design of skimming wells can be made to fulfil both above requirements.

Operational Aspects of Irrigation and Drainage Systems

Controlled-drainage is an important operational mode of the "total" water management system. Proper and timely control of subsurface drainage effluent can: (1) reduce the duration of excess soil-water conditions in the root zone caused by rainfall, (2) prevent over-drainage of the soil profile for more efficient use of naturally occurring rainfall, and (3) reduce the need for pumping sub-irrigation water. In geographic areas where a water source for sub-irrigation is not readily available, and for specific soils, properly designed and managed controlled-drainage systems can optimize crop production by efficient utilization of available rainfall. Controlled-drainage also has the potential to reduce the accumulative losses of plant nutrients carried in drainage effluent, and reduce the potential for ochre formation in the drainlines since they are submerged much of the time. Controlled-drainage can be used in humid regions rather than conventional subsurface drainage with "free" gravity flow or continuously pumped outlets.

In regions where drainage outlets are not available, the salt concentration is increased by evaporation. Such detrimental effect can often be avoided by making sure the reliable drainage outlet exists or is developed prior to construction of irrigation projects.

Leaching of salts

The leaching of salts from the rootzone is directly affected by irrigation and sub-surface drainage. For the reclamation of saline and waterlogged soil during the initial stage excess irrigation is needed for initial leaching of salts. This leads to additional drainage load for the sub-surface drainage system. After initial removal of the salts the leaching is needed only for removing the salts added each year during crop production by irrigation water or by the capillary movement of the ground water. The capacity of an integrated irrigation and drainage system should be such that they can be operated for handling the different water discharges.

Reuse of drainage water

With limited availability of water resources during certain months of the year in the monsoonic climate or in areas where drainage outlets are not available or have limited capacity, the reuse of drainage water is considered as one of the solutions. The design of drainage system has to be integrated with the irrigation system so that different fractions of drainage water can be used for irrigation purposes in a mixing mode or cycling mode. The fraction of drainage water to be used for irrigation will depend upon the assessment of the water quality in relation to crop tolerance limit for saline water and relative quantities of irrigation and drainage water to be used for irrigation..

Institutional aspects of irrigation and drainage management

In many countries, the irrigation and drainage activities are handled by two or more different agencies. Under such situations, the management decisions sometimes become contradictory to each other, resulting in a conflicting situation. The activities related with design, installation, management and operation of irrigation and drainage systems should be controlled by a single agency in order to get the advantage of integrated irrigation and drainage management.

Conclusion

In a monsoonic climate with short and long term variability and cyclic nature of rainfall, both the irrigation and drainage are needed for optimum crop production and sustainability. During different months of the year the irrigation and drainage needs are highly variable. In such a situation the integration of irrigation and drainage systems management becomes absolutely necessary. The concept of integration of irrigation and drainage management can be applied on four different aspects (1) Land development for receiving and releasing water (2) Design of irrigation and drainage system components (3) Operational aspect of irrigation and drainage systems and (4) Institutional aspect of irrigation and drainage management. The management either of irrigation or drainage directly or indirectly affect each other. The land development activities need to be carried out in such a way that they meet out the optimum performance requirement of both irrigation and drainage systems. Similarly, the design of irrigation and drainage system components are to be made with their mutual compatibility. The operation of irrigation and drainage system are to be managed for maintaining optimum conditions in the agricultural fields for optimum crop production. It is advocated that irrigation and drainage activities should be handled by a single agency for efficient management of irrigation and drainage systems.

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Session 4 Formulation of research needs in irrigation and drainage that promote integration of irrigation and drainage management and contribute to a sustainable water, salt, and financial balance

Chairman:	Ir. E.H. Kloosterboer (ILRI)
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Formulation of research needs in irrigation and drainage that promote integration of irrigation and drainage management and contribute to a sustainable water, salt, and financial balance

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Research needs for arid areas

1. Research on the physical and economic **effects of waterlogging and soil salinity** in order to sustain appropriate drainage development

2. The need is great for research on **minimization of irrigation losses**. The following topics should be investigated carefully:
   - possible water savings from **integrated management of irrigation and drainage**
   - the economic effects of **canal lining** to reduce water losses
   - the extent of water saving, and the agronomic and economic effects of **re-use of drainage water** of varying salt concentrations
   - the effects of various **drainage designs** on irrigation efficiency
   - the effects of various **water pricing** systems on irrigation (and drainage) efficiencies
   - the effects of various degrees of **autonomy and accountability of the organizations** involved in operating and maintaining water management systems on the quality and the cost-effectiveness of scheme **operation and maintenance** and, consequently, on irrigation efficiency and the reduction of drainage effluent.

3. Research on the sustainability of **large-scale irrigation systems** under various conditions, with the use of predictive models.

4. Research on the role of integrated irrigation and drainage management in maintaining **water and salt balances**.

5. Research on the role that **drainage management** can play in improving the unequal distribution of irrigation water.

6. Research on the conditions necessary for the successful implementation of **service-oriented** (integrated) irrigation and drainage management.

7. Research on **farmers' perceptions** of irrigation and drainage, to improve **communication** between suppliers and users of irrigation water, and to facilitate the introduction of **farmers' participation** into project management.

8. Research on **appropriate project designs** (and unit sizes), to facilitate farmers' participation in project operation and maintenance.

9. Research on possible improvements in the **conjunctive use** of surface water and groundwater, to provide irrigation water efficiently while controlling groundwater levels.

10. Research on **groundwater use** is urgently required. This research should include the following topics: the interaction between streams and aquifers; water quality; the possibility of artificially recharging the aquifer; sustainable rates of withdrawal. To improve **protection of available groundwater resources**, and to facilitate the introduction of adequate legislation on water resources, predictive models should be developed of the long-term impact of the unbridled exploitation of groundwater, and of the on-going pollution of the aquifers.

11. Research on the reduction and eventual **disposal of drainage effluent**, with special emphasis on:
    - simultaneous improvement of irrigation and drainage management
    - the possible contribution of the re-use of drainage water
    - the technical and economic feasibility of evaporators and evaporation ponds
    - the technical and economic feasibility of cultivating salt-tolerant crops and trees.

12. Research on the **incorporation of environmental costs and benefits** into the evaluation of water management projects.

Research needs for humid areas

1. Research on the technical and economic **feasibility of dual-purpose canal** systems for evacuating excess drainage water in the wet season, and for (supplementary) irrigation in the dry season.

2. Research on technical solutions to the problem of **storing excess water** in the wet season for use in the dry season. (Examples: cascade irrigation in Sri Lanka; horizontal drainage of sandy soils in India.)

3. Research on the benefits of introducing **service-oriented management** into (dual-purpose) irrigation and drainage systems.

4. Research on **broadening the criteria** for **designing irrigation and drainage systems** in problem soils (peat; acid sulphate soils; sodic soils), with a view to the specific characteristics of such soils.

Finally, the approximately one hundred participating experts from all over the world were urged to **continue rethinking their concepts** of irrigation and drainage development and management, taking into account the **interests and 'perceptions' of the various groups of farmers**.

To ensure that ILRI's future research activities will target generally accepted research needs and will not overlap the activities of other organizations, due attention will be given to the research needs that have been formulated already in recent international fora for related issues.

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"TOWARDS INTEGRATION OF IRRIGATION AND DRAINAGE MANAGEMENT"
held in Wageningen, The Netherlands, from 25 to 26 November 1996 on the occasion of the 40th anniversary of the International Institute for Land Reclamation and Improvement/ILRI and the 35th International Course on Land Drainage/ICLD

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Annex A Background Paper

FORTIETH ANNIVERSARY OF ILRI
THIRTY-FIFTH ANNIVERSARY OF THE ICLD

JUBILEE SYMPOSIUM
"TOWARDS INTEGRATION OF IRRIGATION AND DRAINAGE MANAGEMENT"

Information on symposium background, objectives, and procedures

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Background

On 1 February 1953, a raging northwesterly storm caused the North Sea to breach the sea dikes along the Dutch coast. It was one of the worst flood disasters in the country's history. Nearly two thousand people drowned in the devastating rush of seawater. The damage to agricultural land and the loss of property were staggering. Soon after, when the sea dikes were repaired, the Netherlands Government launched a large-scale flood defence plan in the province of Zeeland. Entire river arms were closed off and reclamation works were begun on the lands that had been saturated with seawater. Research and field trials were begun as well.

When reconstruction was well underway, it was decided to put the remaining international help to another purpose. Accordingly, with a generous donation from the American Kellogg Foundation, the International Institute for Land Reclamation and Improvement/ILRI was created in 1955 with a threefold mandate: to collect data on land reclamation and improvement from all over the world; to disseminate this knowledge through publications, courses, and consultancies; and to contribute, through supplementary research, toward a better understanding of land and water problems in developing countries. ILRI was established at Wageningen, and operations were begun in 1956. Since then, ILRI has concentrated on improving land and water use for better agriculture in developing countries. A particular field of activity is the drainage of irrigated land in arid zones.

Since 1962, ILRI has conducted the International Course on Land Drainage/ ICLD. This is a three-months', post-graduate, mid-career course for professionals engaged in research, planning, design, and management of agricultural land drainage. The celebration of ILRI's fortieth anniversary coincides with the Thirty-Fifth International Course on Land Drainage.

Aim of the jubilee symposium

To mark four decades of ILRI's existence, we are inviting a small group of experts to attend a special Jubilee Symposium. The theme of the Symposium is: "Towards Integration of Irrigation and Drainage Management." The main objective is to establish an agenda for irrigation and drainage research that will lead to a sustainable water, salt, and financial balance.

Why we chose this theme

The importance of management in irrigation and drainage

According to the historian and political scientist Karl Wittfogel, large-scale irrigation was the main cause for the development of ancient civilizations. Wittfogel believed that the development of irrigation works in areas like Mesopotamia and Egypt created a society that was capable of planning, coordinating, and directing the activities of many people. (Box 1)

Box 1 Irrigation and ancient civilization

"**Theories of civilization's development**. The first general theory advanced to explain the development of ancient civilizations with systematic organization of large-scale work, the emergence of social classes, and widespread specialization was elaborated in the United States by a historian and political scientist, Karl Wittfogel, in his seminal book *Oriental Despotism* (1957). Wittfogel believed that the development of irrigation works in such areas as Mesopotamia and Egypt led to the use of mass labour and to organizational hierarchy for coordinating and directing its activities. Though tribal societies had some form of government, this was usually personal in nature, exercised by a patriarch over a tribal group related by various degrees of kinship. Now, for the first time, an impersonal government as a distinct and permanent institution was established." (*The New Encyclopaedia Britannica*, 1980)

Although Wittfogel's theory has been modified by other scholars, who point to the emergence of civilizations in some areas without the presence of large-scale irrigation works, it underscores the importance of **management** in irrigation. The same point is illustrated by the publication, in the same year, of the first book on irrigation management (Newell, **1916**; Box 2) and the first book ever on general management (Fayol, **1916**).

Apart from technical matters, Newell's book contains chapters on: The Human Element; The Legal Side; Operation Organization; Water Economy; Maintenance; Expenditures; Receipts; The Irrigator and His Associations. In the concluding chapter, Newell addresses issues such as: financial conditions of irrigation systems; transfer of control; arousing a social conscience.

Irrigation professionals will acknowledge that many of these issues are still very much alive today!

Box 2 From the Preface of the first book on Irrigation Management

"The irrigation manager and his assistants are coming to be appreciated more and more as important factors in the successful growth of agriculture in the western part of the United States. Within the past few years, innumerable irrigating canals have been built, bringing water to many millions of acres. In planning these enterprises, the chief thought and effort was to build works to bring water to more lands. It was assumed that when this was done, the areas thus reclaimed would be quickly utilized and that there would rapidly grow up a prosperous and contented population. This happy condition has not followed; *we are beginning to see that the planning and building of irrigation works is only the beginning; possibly it is the easiest part. The really difficult and at times discouraging work is that of properly utilizing the irrigation systems after they are built and of getting fair returns from the irrigated lands.*" (Newell 1916)

In the drainage literature, there is much less evidence of an interest in management. There is an International Programme on Irrigation and Drainage *Technology* (IPTRID) and an International Institute for Irrigation *Management* (IIMI), but there is no equivalent institute for drainage management. Drainage research tends to focus on issues of design. Evaluation of drainage interventions tends to deal with performance of the installed infrastructure rather than with the activities of people. Although human activities are considered when it comes to maintenance of drainage systems, the emphasis is on the activities needed to keep the infrastructure in working order.

Why have drainage management issues been neglected?

Operating an irrigation scheme requires farmers and scheme managers to make daily decisions on timing, rates, and volumes of applications. Drainage, once the infrastructure is installed, usually does not require anyone to make decisions on operation. There are, however, some notable exceptions.

Drainage management in the Netherlands

A "*polder*" is an area with artificially controlled water levels that is cut off from outside water by dams and sluices (Bakker & Kooistra 1982). Excess rainfall in the polder needs to be collected and evacuated to prevent yield reductions due to high watertables and flooding. For this purpose, polders have an intricate network of farm ditches and collector drains in combination with several pumping stations. All of this drainage infrastructure needs to be managed! Polders cover about 965 000 ha in the Netherlands. Drainage management is done by water boards (Box 3). The oldest water boards were established in the Middle Ages.

Water boards today have taken on other tasks (e.g. waste water management), but drainage management remains their primary function.

Box 3 New Institutional Arrangements for the Water Boards

In 1953 the Netherlands had some 2500 water boards. Only some of the older water boards had a large territory and powerfully exercised their competencies. Consequently, the executive body of most of the water boards was not powerful. The knowledge of the technical and administrative staff was low. The small scale has contributed to the extent of the disaster of 1953. In the sixties and the seventies heated discussions about the water boards took place. Some political parties wanted to abolish this form of functional Government, others were in favour of reform.

In the middle of the seventies Government and Parliament decided to reform the institution by scaling up their activities and governing power. The responsibility for waste water treatment and for the water quality in local and regional waters became the duty of the water boards. The process of integration of flood protection, quantitative and qualitative water management tasks is still going on. Finally some sixty water boards will remain. The lesson from this development is that the reform of an old institution, once the democratic backbone of flood protection and water management, is better than its abolishment because of its deep rooting in society.

Drainage management in rice cultivation

The traditional rice field is a bunded basin. By adjusting the elevation of the sill at the drainage outlet, the farmer controls the water depth in the field. By storing rainfall in the basin, the farmer is able to reduce irrigation requirements and peak drainage discharge. If there is little or no drainage discharge after the application of agrochemicals, the quality of the drainage effluent in general will improve. Drainage management practices of individual rice farmers may have important implications for water management in the area as a whole.

Drainage management for salinity control in arid regions

An annual application of 500 mm of irrigation water that contains 200 ppm of salts (low to moderate salinity hazard) means an annual deposit of 1 ton of salts on every hectare. For sustainable agriculture, these salts must be leached from the rootzone, and the effluent containing the salts must be exported from the area, preferably to the sea. Operational decisions are required to establish the leaching requirement, organize and monitor the leaching, and dispose safely of the effluent.

Drainage management has been practised for centuries to sustain agriculture in environments as diverse as Dutch polders, riceland-based agro-ecosystems, and arid-zone irrigated agriculture. Wittfogel speculated that irrigated agriculture was at the origin of civilization's development. There is historic evidence that because of waterlogging and salinity due to poor drainage management, these civilizations experienced considerable setbacks. And we know that water boards established for drainage management were one of the earliest forms of government administration in The Netherlands.

Performance of irrigated agriculture

Despite the greater emphasis on irrigation management in comparison to drainage management, the performance record of irrigation is blotted. The main criticisms of the irrigation (sub-)sector, as expressed at the Earth Summit in Rio de Janeiro (United Nations Conference on Environment and Development/UNCED 1992), include:

- irrigation uses too much water: 70-80 per cent of global fresh water use;
- irrigation leads to waterlogging and salinity: some estimates indicate that half or more of the world's irrigated land has developed drainage problems, and some 24 per cent is subject to yield reduction from salinization;
- irrigation pollutes freshwater resources: through release of insecticides, pesticides and other agrochemicals, and saline drainage effluent;
- irrigation affects human health: by creating habitats for vectors of water-related diseases.

In addition to these issues, there is concern about the financial sustainability of irrigation. Investment costs for developing public irrigation schemes are almost always fully subsidized. Also, the recurrent costs of operation and maintenance are hardly ever fully recovered from the users. This means that irrigation often represents a permanent drain of government funds. Despite subsidies, maintenance of irrigation schemes has been generally poor: schemes covering an estimated 150 million hectares, or some 60 per cent of the world's irrigated area, need to be upgraded to remain in good working order.

Towards more integration of irrigation and drainage management

The 1992 Earth Summit emphasized the need for integrated irrigation development and management (see Box 4). At the Jubilee Symposium, we shall look at the possibilities and potential benefits of better integration of irrigation and drainage management. Some examples of such integration are given below.

Managing the water balance

Drainage management in rice cultivation is a good example of how the traditional rice farmer deals with the conflict inherent in the drainage of irrigated land. He, or she, stops draining by raising the sill when there is a need for water (either irrigation or rainfall), and stops irrigating while draining. With this kind of integrated irrigation and drainage management, it is possible to realize a considerable reduction in irrigation volumes. In addition, controlling drainage after fertilizers or other agrochemicals have been applied, prevents release of polluted drainage effluent. Finally, periodical drainage could be used to dispose of larvae of the vectors of malaria and other diseases.

Obtaining the benefits of drainage management requires flexible and reliable operation of the irrigation system: the farmer must be able to irrigate as required. Many irrigation schemes do not provide this flexibility.

Box 4 *Agenda 21 on Integrated Water Resources Development and Management*

"The extent to which water resources development contributes to economic productivity and social well-being is not usually appreciated, although all social and economic activities rely heavily on the supply and quality of freshwater. As populations and economic activities grow, many countries are rapidly reaching conditions of water scarcity or facing limits to economic development. Water resources are increasing rapidly, with 70-80 per cent required for irrigation, less than 20 per cent for industry and a mere 6 per cent for domestic consumption. The holistic management of freshwater as a finite and vulnerable resource, and the integration of sectoral water plans and programmes within the framework of national economic and social policy, are of paramount importance for action in the 1990's and beyond. The fragmentation of responsibilities for water resources development among sectoral agencies is proving, however, to be an even greater impediment to promoting integrated water management than had been anticipated. Effective implementation and coordination mechanisms are required." (UNCED 1992)

Staff of ILRI and the Drainage Research Institute/DRI, Cairo, while installing subsurface drains in Egypt, were confronted with farmers who blocked drainpipes during the rice-growing season. These farmers did not like the idea of letting good irrigation water run down the drain. But the blocked drains caused a salinity problem in the next cropping season, when the same fields were used to grow cotton. To cope with this problem, staff of DRI developed and installed a closing device at the junction of the subcollector (serving a crop unit of 30 to 150 ha) and collector drain, so that the subsurface drains could be closed in the rice fields during the growing season. This restricts the "managing" of the drain to one operation per growing season and helps to reduce irrigation requirements (El-Afty et al 1991).

A more dynamic type of controlled subsurface drainage is practised at the individual farm level in North America and Europe. Controlled drainage permits the farmer to vary the amount of water stored in the soil profile by using an adjustable overflow pipe or a float-controlled valve to raise the water level in a control chamber near the outlet. The function of the control chamber is basically the same as the adjustable sill at the drainage outlet of a rice field: it allows the farmer to manage the water storage. The main difference is that water storage in rice fields occurs above the surface and is therefore clearly visible, whereas in controlled subsurface drainage, as the name implies, water is stored below the soil surface. Subsurface storage permits integrated irrigation and drainage management aimed at:

- minimizing occurrences of excess or deficit soil moisture conditions;
- minimizing the need for supplementary irrigation, by making efficient use of rainfall;

- improving the quality of drainage effluent[1].

The most challenging aspect of designing and operating subsurface drainage systems in humid climates is to prevent randomly occurring periods of wet weather from causing crop injury due to excessive soil moisture, when the water level at the outlet is being kept high to minimize the need for irrigation.

Because field experiments take up much time and money, researchers use computer simulation models to test the performance of system designs for specific soil, crop, and climatological conditions (Fouss et al 1990).

The integration of irrigation and drainage management has the potential to reduce water requirements for irrigated agriculture. To realize this potential will require designers and engineers to adapt the current irrigation and drainage designs and practices, and expand their knowledge through research.

Managing the salt balance

Staff of ILRI and DRI, working in Egypt's Nile Delta, found that average seasonal depths of the watertable in the range of 1.0 to 1.2 m are sufficient for effective salinity control. Maintaining the watertable at a deeper level can have a negative affect on irrigation efficiency. Hence, drainage for salinity control is concerned primarily with the *discharge effect* rather than with lowering the watertable (Oosterbaan 1994).

To calculate the required discharge effect for a particular location, one must know the order of magnitude of the main components affecting the salt balance. These components, in turn, vary with the designs and management practices of the irrigation and drainage facilities. ILRI is collaborating with the International Waterlogging and Salinity Research Institute/IWASRI, Lahore, Pakistan, and the Central Soil Salinity Research Institute/CSSRI, Karnal, India, to develope and test numerical simulation models in which the various water and salt balances are fully integrated. Such models can be used as a tool for decision making in irrigation water management, to maintain the watertables at safe depths and minimize the areas that need artificial drainage (e.g. Boonstra & Bhutta 1996).

Maintaining the discharge effect calls for integrated irrigation and drainage management throughout the lifetime of an irrigation project, as opposed to the one-time installation of a drainage system aimed at lowering the watertable. Long-term management calls for appropriate organization and institutional arrangements (Box 5).

Managing the financial balance

To reduce the subsidies on the operation of public irrigation schemes, many countries are now trying (encouraged by financing agencies) to transfer management responsibilities to local irrigation organizations, and increase cost-recovery from users.

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[1] Please note that all three management objectives are also relevant for the water boards in the Netherlands!

Although the benefits of drainage are usually far less obvious than those of irrigation, the effects of poor drainage management can have dramatic long-term effects, both inside and outside the project area. As a result, the recovery of operational costs and the transfer of responsibilities tends to be more difficult for drainage projects than for irrigation projects. Research should be done on how to improve this situation.

Box 5 Institutional arrangements for conjunctive water use

"The introduction of tubewells in the Indus Basin was motivated by a concern over waterlogging and salinization that occurred when canal irrigation caused the watertable to rise. The demonstration effect of public drainage wells set off a boom in tubewell investment by individual farmers in South Asia. In Pakistan, the number of tubewells increased from less than 5,000 in 1960 to more than 200,000 by 1980. In the Indian states of Punjab and Haryana, there were more than 400,000 wells by 1980. It is estimated that more than 2 million shallow, small-capacity tubewells have been installed in the Gangetic Plain of India. These massive investments in tubewells have completely transformed the use of water resources in these regions and raise problems of resource management that are beyond the grasp of existing irrigation bureaucracies. For example, in the Indus Basin of Pakistan tubewells now supply more than half of the water actually available for crop consumption in the fresh groundwater areas, but of course supply none of the water for crop consumption in the saline areas, which account for about one-third of the total irrigated land of the basin. However, the bureaucracies concerned with the distribution of water do not attempt to achieve an efficient allocation of surface and groundwater supplies. In fact, the legal basis for doing so is unclear and open to challenge." (O'Mara 1988)

Organization of the jubilee symposium

To establish an agenda on *irrigation and drainage research towards a sustainable water, salt, and financial balance*, the Jubilee Symposium will have four sessions:

(1) Presentations of *field situations* which call for integration of irrigation and drainage management;

(2) Presentation and discussions of *technical innovations* towards integrated irrigation and drainage management;

(3) Presentations and discussions of *institutional innovations* towards integrated irrigation and drainage management;

(4) Discussions on research needs and the establishment of a research agenda.

SESSIONS 1, 2 AND 3

For the first session, all participants will be asked to formulate examples of situations which call for integration of irrigation and drainage management. For sessions 2 and 3, examples of technical and institutional innovations towards this integrated management will be requested. These examples should be based on problems participants have encountered during their professional career. Standard forms will be distributed during the session, on which the participant can write his/her example and, on the same form, categorize the example using the following checklist (see enclosed examples):

- Is the example/innovation mainly technical or institutional?
- At which level does this problem/innovation occur: farm/field - tertiary/secondary (group of farmers) - regional/basin?
- Which climate: (semi-)arid - (sub-) humid - temperate?

Presentations

The presentations of the invited guestspeakers should help the other participants in writing up their own experience on the standard forms.

GUIDELINES FOR PRESENTATIONS

Session 1: Practical example of a situation that calls for integration of irrigation and drainage management

The presentation, with a maximum duration of 20 minutes, should explain:
- The reason for irrigation and for drainage;
- The need for integration of irrigation and drainage management;
- The benefits expected from such integration;
- The innovations (technical and/or institutional) needed to achieve these benefits;
- (If applicable), the relevance of the example for other regions.

The presentation should be concluded with a completed form no. 1.

Session 2: Technical innovation towards integrated irrigation and drainage management

The presentation, with a maximum duration of 20 minutes, should explain:
- The background and reason for the technical innovation;
- The working principle of the technical innovation;
- The experience and results obtained (or expected);
- (If applicable), the relevance of the innovation for other regions.

The presentation should be concluded with a completed form no. 2.

Session 3: Institutional innovation towards integrated irrigation and drainage management

The presentation, with a maximum duration of 20 minutes, should explain:
- The background and reason for the institutional innovation;
- The main characteristics of the institutional innovation;
- The experience and results obtained (or expected);
- (If applicable), the relevance of the innovation for other regions.

The presentations should be concluded with a completed form no. 3.

SESSION 4

In the fourth and last session all examples will be used to identify research needs. Before the start of the fourth session, the Organizing Committee will arrange the examples (X problems, Y technical and Z institutional innovations) in six research fields. The symposium will be divided in six groups, one for each field. Based on the examples and proposed technical and institutional innovations, each group will formulate research items and present those to the other participants in a plenary session.

Form No. 1

ILRI'S JUBILEE SYMPOSIUM
"TOWARDS INTEGRATION OF IRRIGATION AND DRAINAGE MANAGEMENT"

Session 1: Practical example of a situation that calls for integration of irrigation and drainage management

Please describe a ***situation*** *which you have encountered that calls for integration of irrigation and drainage management.*

Country:

Classification: *Please try to classify this example by marking the appropriate boxes.*

Climate:

○ (Semi-) Arid ○ (Sub-) Humid Tropics ○ Temperate

At which level does the problem occur:

○ Farm/Field ○ Tertiary/secondary ○ Regional/Basin

This problem calls for a ○ technical ○ institutional *innovation*

Form No. 2

ILRI'S JUBILEE SYMPOSIUM
"TOWARDS INTEGRATION OF IRRIGATION AND DRAINAGE MANAGEMENT"

Session 2: Technical innovation towards integrated irrigation and drainage management

Please give an example of a ***technical innovation*** *towards integration of irrigation and drainage management.*

Country:

Classification: *Please try to classify this example by marking the appropriate boxes.*

Climate:

○ (Semi-) Arid ○ (Sub-) Humid Tropics ○ Temperate

At which level does the problem occur:

○ Farm/Field ○ Tertiary/secondary ○ Regional/Basin

This innovation results in a sustainable ○ water ○ salt ○ financial *balance.*

Form No. 3

ILRI'S JUBILEE SYMPOSIUM
"TOWARDS INTEGRATION OF IRRIGATION AND DRAINAGE MANAGEMENT"

Session 3: Institutional innovation towards integrated irrigation and drainage management

Please give an example of a institutional innovation towards integration of irrigation and drainage management.

Country:

Classification: *Please try to classify this example by marking the appropriate boxes.*

Climate:

○ (Semi-) Arid ○ (Sub-) Humid Tropics ○ Temperate

At which level does the problem occur:

○ Farm/Field ○ Tertiary/secondary ○ Regional/Basin

This innovation results in a sustainable ○ water ○ salt ○ financial *balance.*

Date and venue

The Jubilee Symposium will take place from Monday 25 to Wednesday 27 November 1996. Presentations will be held on Monday 25 and Tuesday 26, and there will be an excursion on Wednesday 27. The venue is the Wageningen International Congress Centre/WICC, located next to the ILRI offices.

Presentation of symposium results

The results of the symposium will be presented to an audience of policy and decision makers in the water sector, on 28 November, 1996. On this occasion, other presentations will be given by the leadership of international forums dealing with global water issues. Symposium participants are also welcome to attend.

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