ILRI WORKSHOP: WATER AND FOOD SECURITY IN (SEMI-) ARID AREAS

Proceedings of the Wageningen Water Workshop 1998

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PREFACE

In October 1998, ILRI organized the second Wageningen Water Workshop, or WWW. WWW98, like WWW97, was a lively academic event. It brought together scholars and subject-matter specialists from The Netherlands and other parts of the world. During WWW98, they listened to presentations and debated issues. They agreed and disagreed on various matters, and they tried to advance the current knowledge by proposing solutions to problems. WWW98 took the full two days that were scheduled for it. The third day was for excursions. At times, the participants worked in small groups on selected issues. They formulated conclusions and presented them during the plenary sessions.

The title of WWW98 was 'Water for Food Security in Arid and Semi-Arid Areas.' This theme was chosen in preparation for the Second World Water Forum, an international conference that will be held in The Hague, The Netherlands, in March of the year 2000. Preparations for the Second World Water Forum started long ago. During the Forum proceedings, a 'global vision for water, life, and the environment' will be presented. One of the ways in which this global vision is being developed is by the formulation of sector visions. One of these sector visions is on water for food security and rural development.

Institutes in Wageningen are working together, and with institutes elsewhere in the world, to formulate the sector vision on water for food and rural development. For this purpose, a group of Wageningen-based institutes has set up a platform called the Wageningen Water Initiative, or WWI. WWW98 was one way in which the WWI institutes prepared themselves for their work on the sector vision. Scholars and subject-matter specialists, employed by the WWI institutes, or associated with one of them, exchanged research results and field experiences. In doing so, they improved their understanding of each other's work and of the practical implications of the relationship between water and food in arid and semi-arid countries. WWW98 was a *work*shop in the true sense of the word!

WWW98 could not have been the success it was without the support of all of the participants, not only those who presented papers, but also those who contributed their comments, observations, and questions during the discussions. I wish to thank all of them for their contributions.

A.W.H. van Weelderen
Director ILRI

ACKNOWLEDGEMENTS

Although a certain routine develops when you organise a workshop for the second year (actually for the third year, if you include the ILRI Jubilee Workshop of 1996), the amount of work involved does not become less. Preparations include the formulation of the workshop objective and programme, the selection of and correspondence with the speakers, the announcement of the workshop at various places and in various periodicals, the invitations to special guests, the organisation of the logistics, and, last but not least, the production of the Proceedings.

I am grateful to all those who contributed to the success of WWW98 in one way or another. Special mention goes to the colleagues who presented their papers during the plenary sessions on Days 1 and 2. With a few exceptions, their papers are in these Proceedings. I wish to thank all those participants who were willing to express their views in the working groups and during the plenary discussions that followed the group sessions. In particular, I wish to thank Professor R. Rabbinge, who did an excellent job as chairman of the workshop on Day 1.

The organisation of the workshop was the joint effort of colleagues from the WWI institutes and ILRI. I mention in particular Dr P. Bindraban (AB-DLO), Dr H. Diemont (IBN-DLO), Ir C. Roest (SC-DLO), Dr M. Oneka (Wetlands International), and Ir G. van Vuren (Irrigation and Water Engineering Group, Wageningen Agricultural University). I certainly enjoyed working with all of you! Those who did most of the work were two former ILRI colleagues: Ir J. Sluysmans and Ir E. Kloosterboer. It was always pleasant to work with them, too.

If an event that involves over seventy people and lasts for three days is called successful, then this is, in a large part, because those responsible for the logistics made certain that all was ready in time. Once again, Mrs E. Verschoor-Visser, Mrs E. Rijksen, Mr J. van Manen, and the staff of the WICC did an excellent job. The same is true for Ir A. van Keulen, who organised the excursion, for Mr J. Twente, who supervised the finances of the workshop, and for Mrs D. Huijssoon, who formatted the proceedings.

Aart Schrevel
Editor and Member of the Organising Committee

EDITOR'S NOTE

The papers printed in these proceedings are copies of the original papers, exactly as the authors presented them to the editor. They have not been subjected to technical or language editing. No attempt has been made to adjust the original papers to standard criteria for length, sector divisions, and so on. This explains their variety of form.

Due to circumstances beyond our control, not all of the papers presented at the workshop could be offered here in their entirety. In three cases, only the abstracts of the papers were available. Yet even these abstracts contain interesting information on their authors' work and views, and so we have decided to include them.

TABLE OF CONTENTS PAGE

STRUGGLE AGAINST WATER LOGGING AND SALINITY: THE CASE OF PAKISTAN[1]

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Foreword

It is with feelings of deep gratitude that I accepted the invitation to be present at this Wageningen Water Workshop. I wish to share with you the story of a nation that is fighting its number one enemy; the story of Pakistan fighting the twin problem of water logging and salinity. We, the people of Pakistan, believe this to be a most serious threat to our national food security.

Introduction

The seriousness of Pakistan's water logging and salinity problem can hardly be underestimated. A few statistics will make this clear.
By far the major share (97%) of all water use in Pakistan is used to irrigate agricultural land. And not less than 80% of the total area under cultivation in Pakistan is under the command of an irrigation system. In figures this is 16 million hectares (some 40 million acres). Of this irrigated land, not less than 14% is seriously affected by water logging and/or salinity, or just over 2 million ha (more than 5 million acres).

The existing irrigation system is vastly deteriorating. Among others this is explained by the fact that in Pakistan the management of irrigation systems is the task of government officials, and not of the people who ultimately are to benefit from effective water management: the farmers whose lands are being irrigated. It is estimated that as much as US$ 300 billion would be required in case the existing irrigation and drainage systems were to be replaced. It would be far beyond Pakistan's capacity to generate this amount of money; it is even beyond the capacity of the major international donors. Pakistan is faced with the situation that, although it is blessed with sufficient water, a favourable climate, and fertile soils, it nevertheless has an annual food import bill in the order of US$ 2 billion. This is a great burden to the national economy. It is also a threat to the country's future food security situation.

In this paper, I will discuss how Pakistan is fighting this 'war against water logging and salinity', as it was termed in the fifties when the problem first started to manifest itself, was called. I will do so by first outlining the problem, then by explaining the lessons that

[1] The text of the paper was written by A. Schrevel, on the basis of the recorded presentation and of figures made available by Ahmad Khan Bhatti.

we have learned during the first decades of combating water logging and salinity, and finally by explaining to you our latest initiative: the National Drainage Program (hereinafter NDP).

The problem

Extensive development of irrigation infrastructure in the Indus Plain in the 19th and 20th century has brought large tracts of land under year-round cultivation. The irrigation systems were constructed without supplementary drainage systems; the negative impact of the irrigation development is water logging and salinity.

Figure 1 is a cross section of the north-eastern part of the Punjab plain. It shows how groundwater tables in different parts of the plain rose after the introduction of irrigation.

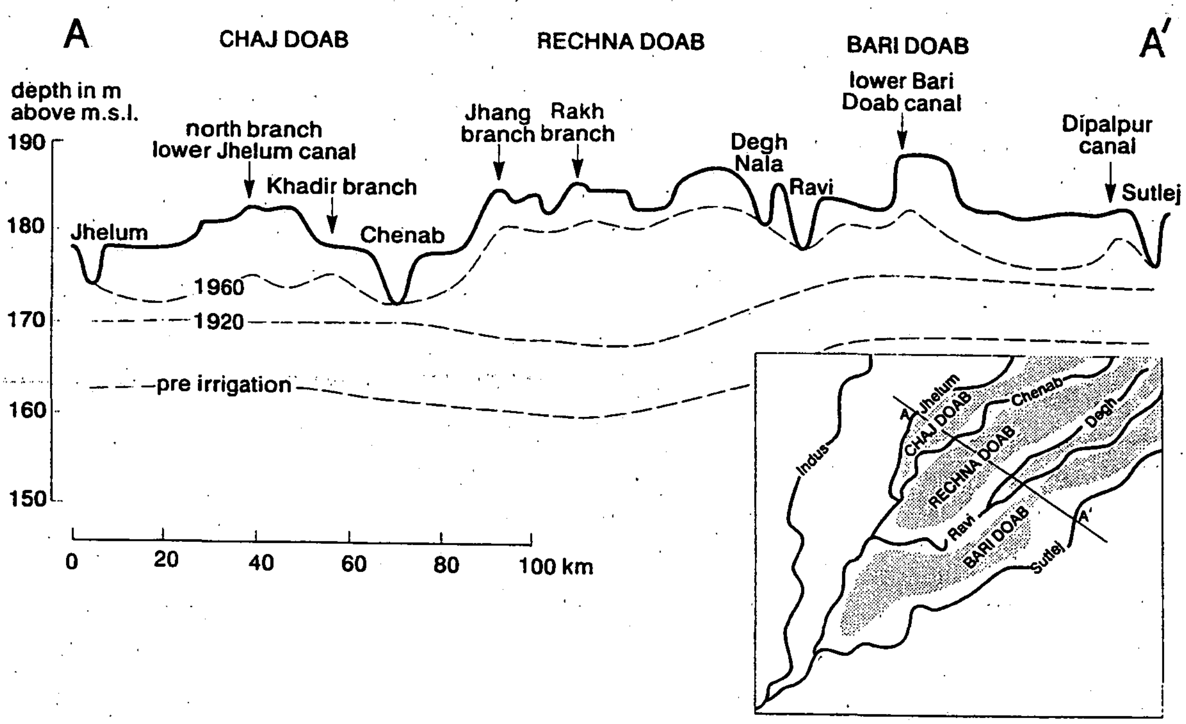

Figure 1: Rise of the water table after the introduction of irrigation in Pakistan
Source: ILRI, 1997[2]

Before the general rise of groundwater tables because of irrigation water infiltration, groundwater tables were typically at 10-20 meters deep. The figure shows general groundwater tables at pre-irrigation times, in 1910, in 1920, and in 1960. The steady increase in apparent. Waterlogging and the associated problem of salinity became

[2] ILRI, 1997, Towards integration of irrigation and drainage management: proceedings of the jubilee symposium at the occasion of the fortieth anniversary of ILRI and thirty-fifth anniversary of the ICLD, ILRI, Wageningen

manifest for the first time in the fifties. Its seriousness was well understood and prompted the then-government to declare water logging and salinity Pakistan's number one problem. Today Pakistan is loosing as much as 100,000 acres per year, or as much as one acre every five minutes.

The first attempts to deal with the problem consisted of the construction of subsurface drainage systems; they were followed by the construction of surface drainage systems. Still large tracks of land are in need of drainage.
Figure 2 shows the areas with drainage systems in place and areas still in need of drainage.

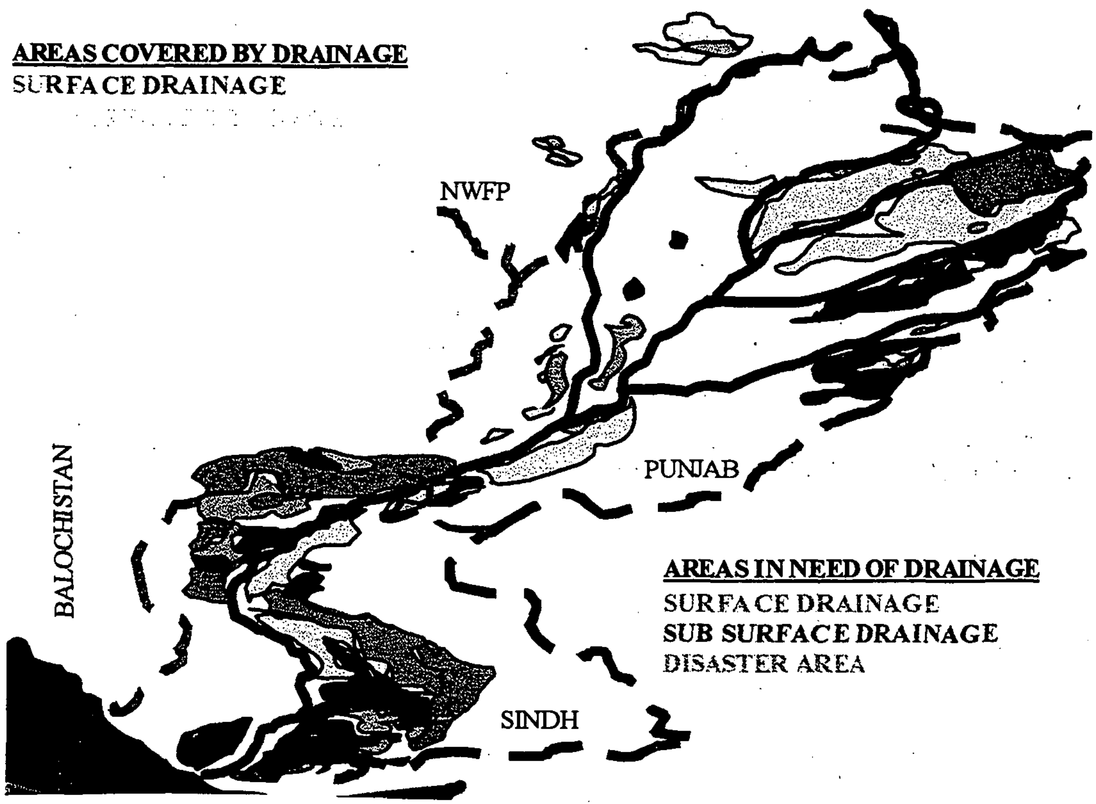

Figure 2: Drainage conditions in Pakistan

Altogether some 16 million acres are already served by a drainage project of one kind or another. At present 13 projects are under construction; they cover some 7 million acres. The latest of the drainage projects is NDP (National Drainage Project). NDP is actually a conglomeration of individual projects.

Despite all these efforts and investments, the available information leads to a firm conclusion: Pakistan is neither winning nor loosing the war against water logging and salinity. During the last 18 years, always 5 million acres of agricultural land were affected. Pakistan is successful in reclaiming land at one place; it looses about the same area of land elsewhere. It is a constant fight. Yet, the fight is not without purpose: If we had not constructed projects the area affected by waterlogging and salinity would be as much as 9.5 million acre.

Two other problems were not yet mentioned. Drainage water is usually of bad quality. Because of the flatness of large parts of Pakistan and the absence in many parts of natural drainage systems, disposing drainage water is difficult. The northern parts of Pakistan do not have an outlet to sea for disposal of excess water. Poor quality water is disposed of in a river whenever possible. This water is used for irrigation again further downstream. In fact, the problem - salts - are just being transported from one area to another.

This is not only a problem causing water tables to rise and groundwater resources to become polluted; it is as much a problem with serious political and social implications. Downstream areas protest against being supplied with polluted water.

Lessons learnt

We have to ask ourselves the question: what went wrong, why were we not able to control water and salinity problems from aggravating? Why could we not win the war? Several lessons contain answers to these questions.

For one thing, earlier projects exclusively focused on the construction of infrastructure and neglected other aspects. We were just building works. The projects did not at the same time improve capacities of institutions to manage the works that were constructed. By and large, operation and maintenance, in general and of the newly constructed works in particular, faltered.

Research into the most appropriate techniques and approaches also was neglected. This is different now and ILRI is a partner in this research.

It is now being acknowledged that unless the beneficiaries participate, chances to successfully manage drainage systems are minimal.

Further, in the past we addressed local problems with local interventions. Groundwater systems cover entire basins; this implies that waterlogging problems cannot be solved locally. We have now come to realise that drainage problems require site specific solutions that are not immune to influencing factors elsewhere in the system. We must have site specific designs, but at the same time should not forget the overall interplay of the basin.

Strict environmental design and control standards were never applied. Thus it could happen that highly polluted drainage effluent was disposed of in river systems (see also above). This is not desirable.

Further, attempts to make the public at large aware of the problems was never taken at hand seriously. Whereas if the public is involved, in planning and concept development, chances of failure are reduced.

Below, the major lessons learned are summarised:

- undertaking major projects without at the same time developing institutions capabilities is an investment risk,
- high priority must be given to research in cost-effective and sustainable solutions,
- to achieve sustainability of results beneficiaries should be involved at all stages,
- entire basins should be accepted as drainage units when assessing drainage needs,
- the salts problem cannot be effectively managed at 'project level' (it is a macro problem),
- drainage effluent needs to be minimised at the source,
- the need for drainage will be for <u>ever</u>.

NDP

The NDP project is the latest of the initiatives taken to combat waterlogging and salinity. It is a mega project. WAPDA (Pakistan Water and Power Development Authority) is the implementing agency, alongside the Provincial Irrigation and Drainage Authorities.
Figure 3 shows the main components. These are Drainage Sector Planning and Research, Institutional Reforms, Investments, and Programme Co-ordination and Supervision.

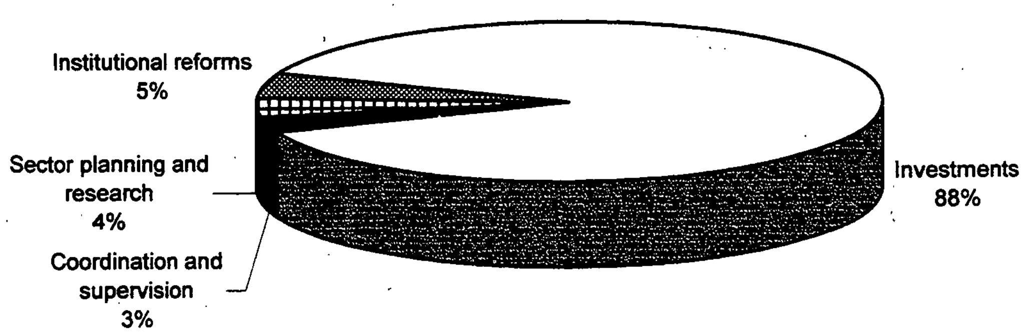

Figure 3. Costs of NDP components in percentage of total costs

As can be seen, in terms of costs research is not the most important component. But in terms of position we attach great value to this component. 3.7% Of the total budget is allocated to drainage research and studies (sector planning and research in the figure).

Studies focus among others on the improvement of technical planning, the enhancement of the technical foundations for drainage, and on the facilitation of long term sector and project planning.
Construction is the most costly project component; it is 88% of the total project costs.

NDP also has an important institutional reform component. Traditionally the Provincial Irrigation Departments (PIDs) of each of the four Provinces of Pakistan were responsible for irrigation and drainage in their respective areas. Under NDP this has changed. The PIDs have been transformed in PIDAs: Provincial Irrigation and Drainage Authorities. PIDAs are autonomous bodies under statutory arrangements, with autonomous revenue collection and spending authority. They are accountable to those to whom they supply their services: the farmers.
The transformation has been far from easy. It took one full year to convince politicians and government agencies of the need to make the shift. Not less than 5 high level meetings, in which even the highest authority of the state - the President - participated, were necessary to reach agreement. This transfer, which radically altered the position of 110,000 employees in one blow, is probably unique. The employees have now become corporate employees, whereas they were government employees.
Part of the institutional reform implies also the transfer of responsibilities for system operation and management to farmers. We experienced, however, that even farmers appeared at times reluctant to assume new responsibilities.

A top down approach was followed to create an enabling environment for the institutional transforms. It was a deliberate choice not to work from bottom upwards. The process did not start with the installation of Farmers' Organisations, of Area Water Boards, and finally with the reorganisation of the provincial authorities. It was thought that first new corporate organisations at provincial level were necessary before it could be expected that reforms at a lower level would have any chance of success.

Under NDP different policy issues are being worked out. To be mentioned are a policy to regulate the transport of drainage effluent to the sea; a policy on groundwater abstraction; a policy to protect wetlands; and a policy to price water and to introduce a drainage fee. The introduction of a drainage fee raises questions regarding who should pay it, as not only farmers, but also industrialists and road users profit from improved drainage. In Balochistan groundwater tables are falling and for this province a policy will be developed to recharge groundwater. Finally, a policy is to be formulated to deal with hill torrents, which always cause a lot of damage.

The construction component of NDP involves rehabilitation and improving existing drainage systems and the construction of new facilities to evacuate water and salts from the Indus Basin. Schemes eligible for financing under this component fall in the following broad categories:

I. restoration and remodelling of existing surface drainage systems (10,000 km);
II. new drainage facilities on need basis (400 km);
III. rehabilitation and replacement of deteriorated saline groundwater SCARP (Salinity Control and Reclamation Project) tubewells (where feasible these are

to be replaced with on-farm tile drainage, to minimize the negative environmental impacts), (1150 units);

IV. expeditious completion of on-going projects, through supplementary financing to close the funding gap;

V. construction of on-farm tile drains and surface drains (on 85,000 ha);

VI. multi-year performance contracts for improved operation and maintenance of the off-farm drainage facilities (310 units);

VII. improvement and lining of distributaries, minors and watercourses in saline groundwater areas and installation of interceptor drains along selected canals to reduce drainable surplus (1050 units);

VIII. control of water tables through biological drainage by encourging beneficiaries' participation (on 40,000 ha);

IX. rehabilitation, improvement and modernisation of selected canal systems for enhanced operational efficiency and improving communication (4 pilot areas).

The costs of these works are massive: US$ 785 million. The bulk of the finance comes from the World Bank (US$285 million); the Government of Pakistan and the Provinces invest a lion's share as well: US$233 million. The remainder comes from the Asian Development Bank (US$140 million), the OECF (US$100 million) and the beneficiaries themselves (US$27 million). This is also shown in figure 4.

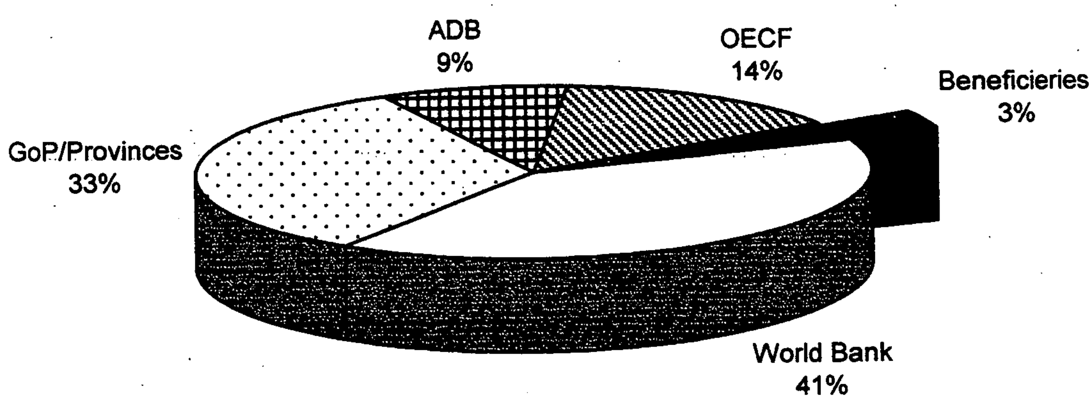

Figure 4. Contribution to total costs NDP by main investors

Epilogue

We do hope that with the combined attention for hard ware, and institutional and policy development we will be able to effectively control the waterlogging and salinity problems that we are confronted with. This cannot be realised overnight . NDP is a long-term project as ever there was one: NDP is foreseen to last 25 years. We have just started the first phase.

This is the story of our struggle. We learned lessons in the past; we hope others will learn from us

OPTIONS FOR IMPROVEMENT OF WATER USE EFFICIENCY IN CROP PRODUCTION AT VARIOUS SCALES

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Abstract

The limited possibility for area expansion worldwide and even the loss of agricultural land in many countries implies that food production increase should be realised through productivity increase. This will place a heavy burden to the soil and the reliance of food production on external inputs, like nutrients and water is bound to grow. Sustainable food supply, therefore, compels judicious use of the natural resource base, with water being one of the most crucial production factor.

In order to facilitate optimal use of water resources, comprehensive analyses are needed that give quantitative insight in the current and future production possibilities of land and the associated specific water requirements and environmental load for target production levels. Agronomic research should therefore extend its study area from the field to higher geographical scales, such as farm, toposequences, watersheds, river basins, continents and even the entire globe, over longer time horizons to be able to seriously address sustainability. Methodologies developed at lower scale levels, like soil- and crop-models, can, however, not always be simply aggregated to higher scales. Large amounts of data needed at lower scale levels are generally not available for application at higher spatial scales. Moreover, while consideration of biophysical factors only at the field level may suffice to identify solutions to practical problems, socio-economic factors need to be considered also at higher, farm to global scale levels. Planning tools need therefore to be developed that indicate feasible paths from the present situation towards desired situations in the future, considering socio-economic and bio-physical processes at various tempo-geographical scales.

Examples of studies addressing water use in relation to sustainable agricultural production systems at global, and crop(ping) scale are presented and an integrating methodology to analyse feasible options to improve food production at the regional scale is described.

FOOD SECURITY AND FOREST CONSERVATION IN THE TROPICS

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Abstract

Over 40 million hectares of tropical forest and wetlands are claimed for food production in the next decade 2000-2010. It is suggested in this paper that conversion of these forests and wetlands may even decrease food security in the tropics.

Introduction

Global land available for crop production accounts some 1.5 billion hectares. The potential reserve of land which is physical suitable for cropland is 1,8 billion hectares including grassland, forests and wetlands. It is claimed that at least some 40 million ha of closed forests in the tropics and an unknown area of wetlands is needed for conversion to cropland in order to meet food demands in the coming decade (Alexandratos 1995). The main issue addressed in this paper is whether conversion of forest land/ wetlands will improve food security in the world? It is suggested below that conversion of tropical forests and wetland probably negatively effect incomes of poor people, decreasing food security.

Food security and income

The world can produce sufficient food and the reason that about one billion poor people are deficient in food is that these people lack the income to buy food. This figure of 1 poor billion people deficient in food , include some 500 million people in the agricultural sector. Thus, for these people there is a link between food production and poor people and it has been stated that " so long as this dependence (*of people for their income on agriculture*) continues to be high , the growth of food production and of agricultural productivity in the countries with high concentrations of rural poverty will continue to be among the principal means for alleviating poverty and improving nutrition:" (Alexandratos 1995) . At a first glance one might be willing to accept this statement . Giving the statement some thought it appears that the statement is only relevant with respect to growth of agricultural productivity not growth of production. Growth of food production without an increase of productivity may even increase poverty in the rural area. Accepting this view implies that from a point of view of income security, conversion of forest or wetlands is only justified if the productivity of the land increases such that farmers are able to escape poverty .

Food security and rural labour

In general a higher productivity of the land results from higher capital inputs such as irrigation water and fertilizer. This inevitable will provoke lower labour needs. Thus, although productivity of the converted forestland will improve income of farm labour, fewer workers are needed. Higher productivity implies fewer agriculture-related jobs in rural areas. So, jobs in other sectors are needed in the longer run to provide income for the excess of agricultural labourers. Of course, we also are aware of studies for instance in Java, were the green revolution did not decrease rural labour. But this was due to subsidies of rice.

Some of the over complete rural labour force might of course open new agricultural land by converting forestland and wetlands. The question is whether conversion really will provide income above subsistence level. The answer is no. For instance transmigration programmes in Indonesia, clearing forest area in Kalimantan and Sumatra have provided people a living, but as far food security for these people is achieved, this has been achieved from off farm income. Not many crops are produced for the market and part of the land is not cultivated. Besides, most of the income of these people comes from off farm activities.

This is only one example from Indonesia. But even income from existing irrigated land is not always sufficient, because of low market prices. This is for instance the case in the Mekong delta. Also in the Mekong the increase of living costs to keep all labour in rice growing. One of the temporary solutions to improve incomes in the Mekong is additional income from shrimps in shrimp-rice systems. But in the long run other job opportunities outside agriculture should solve poverty and food security problems.

Jobs in the forest

Do forest related activities generate income? Yes. Some 250 million people or more depend substantial on forests for firewood, shifting cultivation activities and the logging industry. But one should accept that job opportunities in forest related activities and agro-forestry (especially on a hectare base) are low compared to agriculture. The number of jobs related to the forestry sector will probably also decrease, because the costs of (sustainable) harvesting will become too high, without investments in value added industries. The point here is that the future is not bright. People depend on the forest, which is there last retreat, but it is questionable to state that forests contribute to food security.

Food security and forest conservation

Nevertheless, it is claimed that forests contribute to food security in the State of the Worlds Forests 1997. In our view this statement should not be interpreted that the large number of people who still depend on the forest are food secure or will be food secure in future. Nevertheless, forests and wetlands provide indirect values and sources of income of forests. On the national level income from tourism is already substantial in many countries. Over 50 % of the international tourism in developing countries is related to the presence the forest and nature and reason to visit tropical countries. In terms of employed labour and income this sector will become very important.

There are in no reasons to convert forest and wetlands from a food security point of view. The opposite is probably true, especially because experiences with opening new land in for instance Indonesia have not yet contributed to improve crop production (apart from the establishment of oil palm plantations). Countries already know. New policies in the tropics already critically review the need of forestland for conversion to cropland. For instance, in Peninsular Malaysia part of the forest set aside for crop production is now added again to the Permanent Forest Estate. Many countries in the tropics are now also committed to sustainable forest management. This implies that especially in forests set aside for logging trees (production forests) harvesting of tress should be such that the rights of the local people are respected, biodiversity is not affected and the environmental functions of a forest as a carbon sink and a supply of clean water is respected. This also implies that forest which is set aside for conversion for agriculture should be critically reviewed as is already the case in Peninsular Malaysia.

The conclusion is that the forest should not longer be converted. Not from a viewpoint of food security, not from a viewpoint of food production. The point of view that forests and wetlands are only not yet developed land, can only frustrate development.

SAVING OF WATER BY MODERNIZATION

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Symbols

Froude number $F = \frac{v}{\sqrt{g\,h}}$

v	=	water velocity (m/s)
g	=	gravitational acceleration (m/s^2)
h	=	waterdepth [m]
S	=	slope of canal bed
f_L	=	silt factor
R	=	A/P = hydraulic radius
A	=	cross sectional area
p	=	wetted perimeter
d	=	mean diameter of dominant type of sediment
Q	=	water discharge
Q_s	=	sediment discharge
V_{CR}	=	critical velocity
C	=	sediment concentration
τ	=	shear stress
B	=	width of the canal
S_c	=	bed slope for incipient bed load
d	=	water depth
γ_w	=	specific weight of water
T_o	=	the time between two sequential gate settings: all gates in the irrigation system are reset at the same time
T_L	=	lag time or travel time of a disturbance
T_R	=	system response time, is the time it takes to go from the original steady state to a new steady after a change in discharge (ΔQ)

Introduction

In the middle of the nineteenth century the colonial powers in Asia were confronted with the sustainability of irrigation systems. The Moghul irrigation systems in India were in disrepair and in Indonesia weirs were flushed away each rainy season and canals were unstable and collapsed totally after several years. British as well as Dutch engineers had no experience in irrigation techniques. This phenomena was unknown in their own country at that time. They send missions on study tour to southern Europe (France, Italy, and Spain). The science of irrigation and especially hydraulics was more or less founded in these countries. The first problems the few colonial engineers had to solve were the structural problems of the big works, for which their knowledge of applied mechanics, material science, hydraulics and geotechnical engineering was needed. Water distribution had not their attention. This changed at the end of the nineteenth century, when it became clear that the water was not equitably distributed within irrigation systems. Based on a better understanding of hydraulics, diversion and measurements structures and the concepts of flexibility and up control were developed. Upstream control was a top-down approach of water delivery, which fitted well in the colonial society. The colonials tried hard to nullify the farmer's influence on water distribution in the main system, although at local level (tertiary unit) this stayed until nowadays the farmers responsibility. The colonial engineers had the idea that the farmers could be kept responsible for the unsatisfactory water distribution. In the middle of the twentieth century it became clear that water use efficiency was very low (between 40-50%). An effort was made to study the water demand of crops under different climatological and soil conditions (Chapter 2). The design of canals as well as the water distribution was based on the steady uniform flow concept. The main problems in irrigation systems then and nowadays are:

1) Maintenance problem, i.e. sedimentation in the canals
2) Equitable water distribution, i.e. unreliability of water supply
3) Unflexible water delivery

It became a belief since the 1960's that the water use efficiency will increase with more flexible water delivery and consequently more farmer's influence on the water distribution in the main system. Already round 1900 the engineers observed unsteady flow condition in irrigation canals causing considerable operation losses. It was not before the 1970's that his flow concept is applied to design new irrigation water delivery methods. Modern agricultural production called for a more flexible water supply. With the downstream control concept were water could be delivered on demand, the problems caused by unsteady flow conditions; i.e. operational water loss could be solved. The downstream control concept means that the decisions concerning flow rate, duration and frequency are placed in the hands of the farmers or their representatives.

An irrigation system does not distribute water alone, but a water-sediment mixture (run-of-the-river systems). The choice of water delivery concept is influenced by many factors: i.e. type of water source, topography, variation in crop water demand, and available storage capacity etc. In the following chapters it is tried to describe how the choice of the water delivery concept is influenced by the before mentioned factors.

The most flexible mode of water delivery, namely downstream control is not yet widely applied and tested. Here we touch upon a main problem. Systematic monitoring of the process and the results of modernization projects is rare. This makes it difficult to learn from experience.
Before to embark on a large-scale modernization program a lot more of research concerning this concept has to be done. Developing countries are warned not to be the forerunner in this modernization process for this may be result in a loss of financial of resources.
When it is necessary to experiment with these modem irrigation techniques in developing countries it is advisable that the developed world pays a substantial part of the bill.

Water requirement of crops as used in design and operation of irrigation systems

Indian subcontinent during the colonial era
In order properly to plan a canal system, the designer must fist decide upon the probable "Duty of water" (Strachey, 1867). The duty of water is the relation between the volume of water and the area of crop, which it matures. The "base" of a duty is the time during which the flow is continued. This flow is steady and uniform. If one cubic foot a second running continuously for four months will mature 100 acres of crop, the duty in that case is said to be 100 acres to the cusec, to the base of four months R.B. Buckley, 1920). Normally, the base of the duty is the whole growing season of the crop, so there is a steady uniform flow in the canals. This duty as used in British India encompass the water use of the crop and the water losses by evaporation and seepage in the canal system (H.M. Wilson, 1903). Before 1900 the water required for the different crops was vaguely known by the civil engineers, who were responsible for the design of irrigation canals. They used in most cases the experience of the local farmers, but the farmer's knowledge was superficial and too imprecise for a good design. In France, Germany and some other European countries research was going on to estimate the water use by different types of vegetation. In the beginning of the twentieth century the best known estimates of the amount of water required by vegetation were those of Risler in Germany (W.H. Burr et al., 1904). Elaborate experiments were conducted in 1902 - 1908 at the Utah Experimental Station, U.S.A., to determine the conditions under which the maximum amount of vegetable substance, of the best quality, could be produced with the minimum of water (J.A. Widstoe, 1909). An important finding was that by cultivation the water consumption of dry land crops, such as wheat, potatoes, Indian corn etc., could be reduced by 50 percent. Cultivation is to keep loose the surface of the soil to a considerable depth and to keep the fields clear of weeds.
These German and American research results gave an impetus to the research executed on the Indian subcontinent and Indonesia. Col. Clibborn and R.G. Kennedy studied the water required for different crops in the United Provinces and the Punjab (R.G. Kennedy, 1905).

The results obtained are given in the Table 2.1.

Table 2.1 Water depth required for a cropping season

Name of crops	*Total depth of Waterings (inches)*	*Number of Waterings*
Wheat, Barley	10.6	4
Sugar cane	25.3	11
Indian com	10.6	4
Cotton	10.6	4
Rice	96.0	-

This discharge "at the Head" of a canal is the discharge which enters it from the source of supply, river or reservoir. The discharge "utilized" is the discharge "at the Head" less that gauged as discharge from escapes or used for any purpose other than that of irrigation.

Duties are subject to great variation all over the Indian sub-continent.
The estimation of the duties for the different crops was not based on a good understanding of the evapotranspiration process of the plants. The duty of water of a crop was considered constant during the entire growing season. Climatic parameters like evaporation and rainfall and soil characteristics as percolation are implicit in the figures of the water duties. (Table 2.2). Water duties differ greatly with different soils and crops and had to be estimated by field experiments for each locality and could not be calculated in a scientific way. During the lifetime of an irrigation system a mix of different crops is grown. It is unknown on beforehand when and where a certain crop will be grown. The capacity of irrigation canals was based on an average water duty for a certain mix of crops.

In Table 2.2. the duty in Rabi (cold weather) season on some Indian canals is given.

Protective irrigation on the Indian subcontinent

The policy of protective irrigation was adopted around 1870 and was of particular importance in that it influenced the whole nature of subsequent canal development in North-India. In the words of Richard Strachey, Inspector-General of irrigation during 1866-1869;

"The new policy aimed at extending irrigation generally and so far as it is possible in a manner that shall to the utmost guard against the worst effects of drought. Taken into account the rainfall conditions and the extent of well irrigation".

Irrigation works were to be designed on the basis that a certain normal standard or proportion of irrigated area should be regarded as claimable by every district to which water can be given (no topographical constraint). The normal standard settled upon during the 1870's was 42.5% of the cultivable area within a village. No canal water was to be given to areas with such a percentage under well irrigation, and where the well

Table 2.2 Duty in Rabi season on some Indian canals (Buckley, 1920)

Province and Canal	B. Base: Number of Days the Canal was in Flow	On the 'Utilized" Discharge at the Head on the Canal			On the 'Utilized" Discharge at the Head on the Distributaries		
		D. Duty of the Discharge	Δ. Equivalent Dept of Water on the Field	V. Volume per Acre Irrigated	D. Duty of the Discharge	Δ. Equivalent Dept of Water on the Field	V. Volume per Acre Irrigated
United Provinces:	Days:	A cres per Cusec:	Feet:	Cubic	Acres per Cusec:	Feet;	Cubic Feet:
Betwa Canal	103	133	1.55	Feet:	-	-	-
Ken canal	134	136	1.86	66,500	-	-	-
Upper Ganges Canal	120	202	1.18	84,700	-	-	-
Lower Ganges Canal	120	183	1.30	51,000	-	-	-
Agra Canal	102	121	1.68	56,200	-	-	-
Eastern Jumma Canal	121	149	1.24	72,600	-	-	-
Rohilkund Canals	135	151	1.78	63,600	-	-	-
				76,900			
N.W. Frontier Province:							
Lower Swat River Canal	159	215	1.48		223	1.2	61,300
Kabul River Canal	158	146	2.16	63,900	266	1.18	51,000
				93,300			
Punjab:							
Western Jumna Canal	155	155	2.00		199	1.56	67,400
Sirhind Canal	118	158	1.48	86,400	184	1.28	55,300
Upper Bari Doab Canal	179	267	1.34	63,900	330	1.08	46,700
Lower Bari Doab Canal	166	105	3.16	57,900	136	2.	105,400
Upper Chenab Canal	155	90	3.44	136,500	103	3.10	133,900
Lower Chenab Canal	162	197	1.64	148,600	224	1.	62,200
Upper Jhelum Canal	167	106	3.14	70,800	119	2.80	121,000
Lower Jhelum Canal	142	179	1.58	135,600	194	1.6	63,000
				68,300			

percentage fell short of 42,5%, provision of canal water was to be limited merely to raising protection to this standard. The water distribution within the villages was the responsibility of the village officials and not of the Public Works department. In the nineteenth century the relation water supply and crop yield were not well known although it was clear that application of too much water reduced the crop yield significantly (Wilson, 1903). So it was better to supply water below unknown optimal conditions, how much below was unknown.
Protective irrigation is not only a thing of the past, but also of the present. In the report of the Irrigation Commission (1 972) the principles of irrigation policy in water scarce and land abundant areas are described as follows:

"In areas other than those with ample water resources our policy should aim at securing the maximum crop production per unit of water (...) the policy should be to benefit as large a section of the community as possible and at the same time enable farmers to obtain a reasonable yield. Surface irrigation systems should be designed to irrigate compact blocks, the blocks being dispersed over a large area to benefit large number of farmers, The number of irrigation's can be fewer than are required for high yields" (GOI/MOIP, 1972, 112 - 113)

Mollinga (1998) gives a more detailed description of protective irrigation and its inn's and out's.
From Macro-economic point of view protective irrigation is an attractive solution. Disadvantages of this method are; long irrigation canals, so high construction costs. Protective irrigation's stated objective to maximize overall production in the command area of the irrigation system contradicts in some way the individual production and income maximisation strategies of farmers. It is clear that protective irrigation can lead to a substantial saving of water.

Indonesia during the colonial era

Indonesia has a real monsoon climate with a very wet season from October till April with an average rainfall of more than 2000 mm and a dry season from May till October with an average rainfall of less than 100 mm. In the wet season mainly rice and sugar cane are cultivated, while in the dry season sugar cane, rice and dry land crops (palawija crops) such as maize, soybean, tobacco etc. are cultivated. During the wet season only rice needs additional irrigation water, but more than 80 percent of the agricultural acreage is planted with rice, for it is too wet to cultivate "dry crops" in the lowlands. The coastal plains of Java experience each year tremendous flood problems. The Dutch started to construct irrigation works in order to safeguard the agricultural (rice) production during the wet season, for dry spells of more than 5 days could lower the rice yield considerably.
In the mid nineteenth century Van Baak and De Bruijn estimated the water requirements of rice
2 - 3 litres/s/ha (Van Gorkom, 1880). In the beginning of the twentieth century some research was executed by C.W. Weijs in the Pemali region, North-Central Java. The result of this research was the so-called Pemali consumptive use graph for rice.

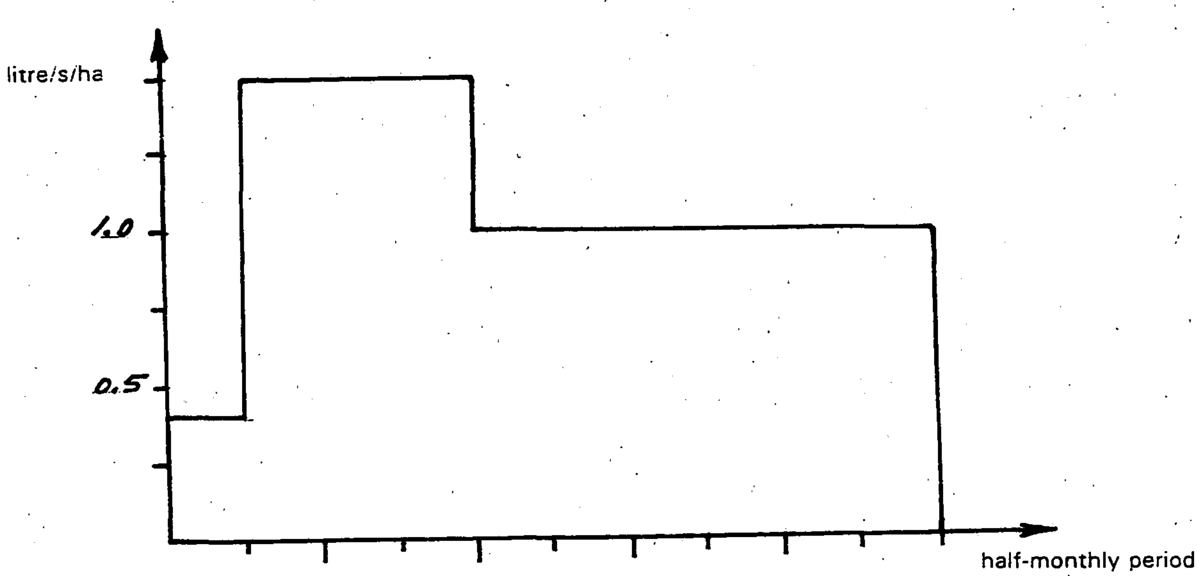


Figure 2.1 Waterrequirement of rice in Indonesia as used in irrigation design in the period 1900-1970

During the first half-month about 0.4 litre/s/ha is needed for the padi nurseries (bibit). These nurseries cover about 10% of the total irrigated area. The land preparation takes 1,5 month and 1.5 litre/s/ha is needed. During the growing period of rice 1.0 litre/s/ha is needed. The optimum water requirement for sugar cane was 0.5 litre/s/ha and for palawija crops 0.3 litre/s/ha. Before mentioned Water requirements were declared valid for all irrigation systems in Java and formed the base for the calculation of irrigation canal capacities. The Dutch engineers were aware that these water requirement figures were a rough estimate and not based on data obtained from scientific research (Van der Ploeg, 1937).

Developments in water requirement calculation after the 1950's

Consumptive use, or evapotranspiration can apply to water requirements of a crop at field, farm and system level. When the consumptive use of the crop is accurately known, the water use of larger units can be calculated. Various direct measurement methods have been used to determine the amount of water consumed by agricultural crops and natural vegetation. Regardless of the method, the problems encountered are numerous. Reliability of consumptive-use determinations by means of tanks or lysimeters is dependent on nearness of reproduction of natural conditions (R.G. Alien et al, 199 1).

Many researchers tried to find a method to calculate consumptive water use of crops based on climatic observations to avoid cumbersome direct measurement methods. How temperature, humidity, wind velocity, vapour pressure, and solar radiation influence consumptive use has been studied by Penman (1 949) and others. Penman has made the most complete theoretical approach, showing that consumptive use is inseparable connected to incoming solar energy (V.E. Hansen, O.W. Israelsen and G.E. Stringham, 1980). He developed a formula to calculate the reference crop potential evapotranspiration of well-watered alfalfa (ET_O). Kind of crop and stage of growth certainly have an influence upon consumptive-use. Variations in consumptive use rate occur from day to day because of changes in weather conditions. Characterizing this weather influence is difficult. Since evaporation integrates many of the weather factors, the influence of climate will be assumed to be well represented by the ET_O. Analyses of consumptive-use and weather data for many crops grown in many countries of the world give strong support for the empirical curve shown in Figure 2.2.

The physiology of the growing plant can be characterized by flowering, fruiting and other distinctive stage of growth. Peak use comes at the beginning of flowering and at the end of the vegetative stage of growth. The consumptive use for different crops (ET_C) and growth stages are related to the ET_O by a crop coefficient (K), so $ET_C = K. ET_O$. (J. Doorenbos and W.0. Pruitt, 1977).

In irrigation system design in Indonesia the average ET_O for a ten days or half monthly period is used together with percolation rates for different soil types and effective rainfall. In Indonesia rainfall contributes for a substantial part to the water need of the crop. The amount of rainfall fluctuates substantially within a cropping season and over

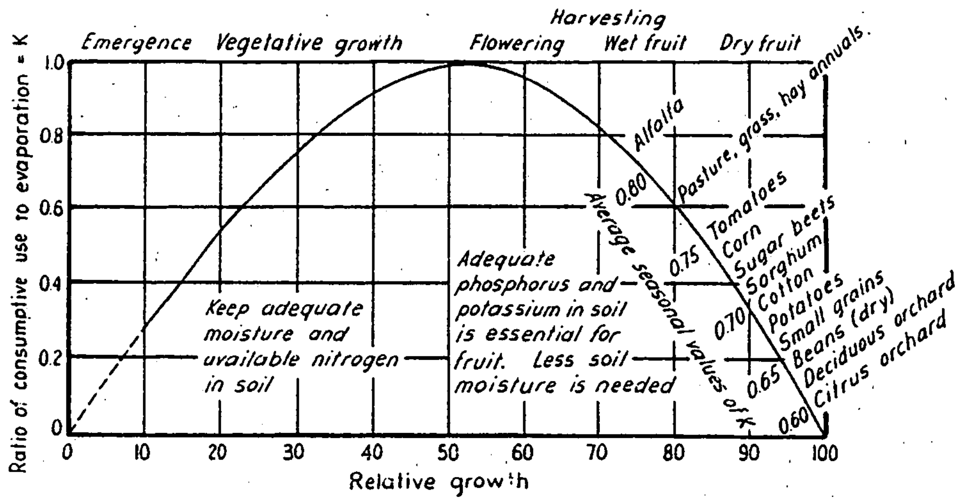


Figure 2.2 Generalized curve comparing consumptive use-vaporation ratio to relative growth of crop (Hansen, Israelsen, 1980)

the years. In Figure 2.3 the system water requirement for one rice crop in the Bedegolan system, Central Java is given.

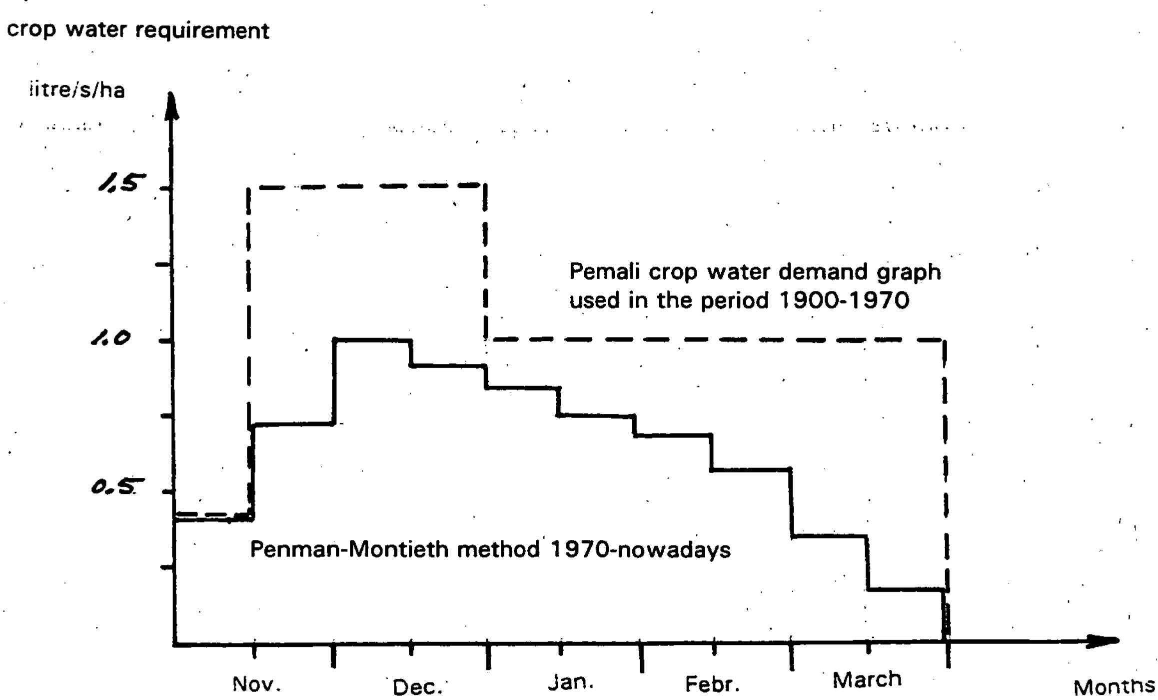


Figure 2.3 Water requirement of the Bedegolan system,Central Java Indonesia for one rice crop in the rainy season based on Penman-Montieth.

The crop water requirement calculations as they are practised nowadays make substantial water savings possible. but complicates the operation of an irrigation system (see chapter 4).

Yield response to water

In the second and third quarter of the twentieth century a lot of research is done to establish crop production functions for different crops. In 1979 F.A.0. published a methodology to quantify yield response to water deficits. This methodology takes into account maximum and actual crop yields as influenced by water deficits using response functions relating relative yield decrease and relative evapotranspiration deficits (Figure 2.4)

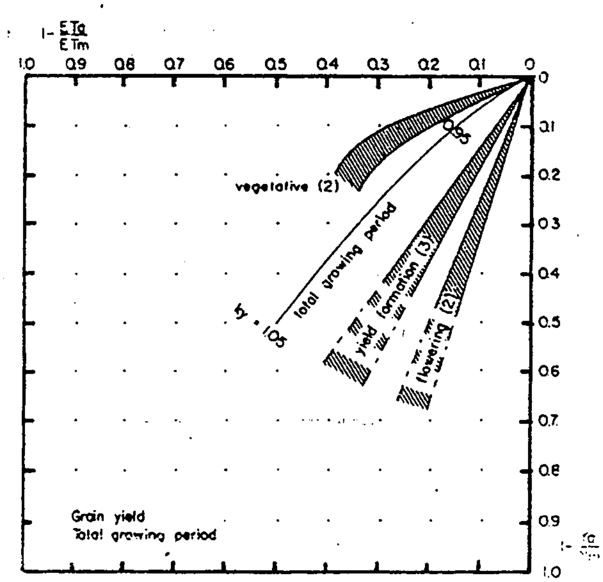


Figure 2.4 Relationship between relative yield decrease and relative evapotranspiration deficit for winter wheat

Application of the method provides the user with:

- guidance in selection of irrigated crops under different growing conditions
- assessment of crop yield under different water supply conditions
- criteria, on which to base priorities for allocation of limited water to crops both between and within projects

Before mentioned methodology can be used for field water management for optimum crop production and water use efficiency.

Recent research gave also insight in crop yield reduction by application of too much water (see Figure 2.5)

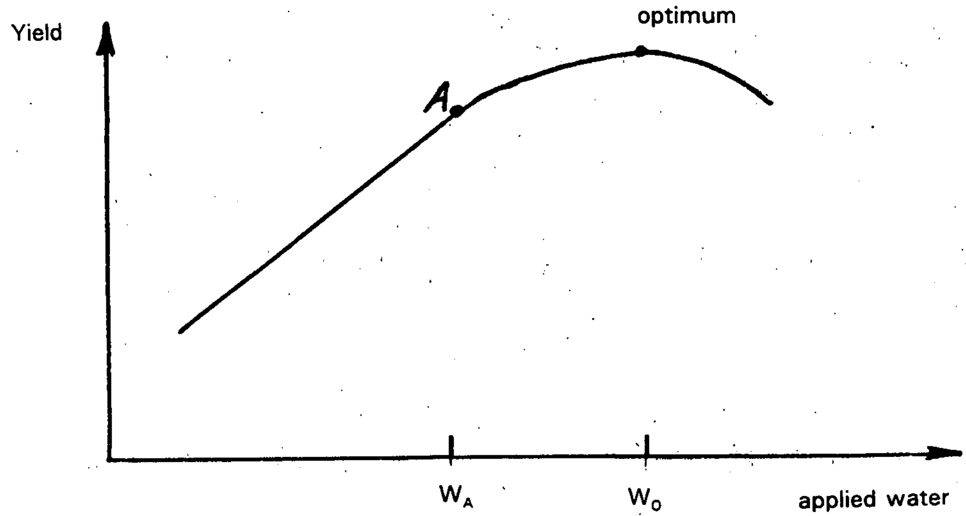


Figure 2.5 General form of a crop production function

crop yield and applied water have a linear relationship till point A. At higher levels the function begins to curve over, reflecting percolation and run off losses that develop as applied water approaches full irrigation (Shearer, 1979). In a word, the application efficiency of the system declines as the amount applied increases. Beyond the maximum yield points such things as lodging, reduced aeration in the root zone, leaching of nutrients, and diseases associated with wet soils will reduce yields (Stegman et al., 1980).

The product of Yield and crop price represents gross income. The revenue function (Figure 2.6) must therefore have the same shape as the yield function of Figure 2.5. The linear function represents total production costs and includes three important features. The first feature is the intercept with the vertical axis, which is associated with all fixed costs. The second feature is the slope, which represents variable costs of production (energy, labour, maintenance. fertilizer. and water). The third feature of the cost function is the upper limit, shown as the design capacity point- which represents the maximum water delivery capacity of the system. Maximum economic efficiency occurs when the cost of an additional unit of water just equals the value of the resulting increment of yield (W,, slope of cost function equals slope of revenue function). The assumption was that water supplies are not limited. that land is the limiting resource and that the objective is to maximize returns to land. Where water supplies are limited, opportunity costs may be the most important consideration in irrigation management. Under such circumstances, farm profits will be maximized by reducing the amount of water applied per unit of land and increasing the amount of land under irrigation until the marginal profit per hectare, multiplied by the number of hectares irrigated, just equals the total profit per hectare (English and Orlob, 1978; English, 1990).

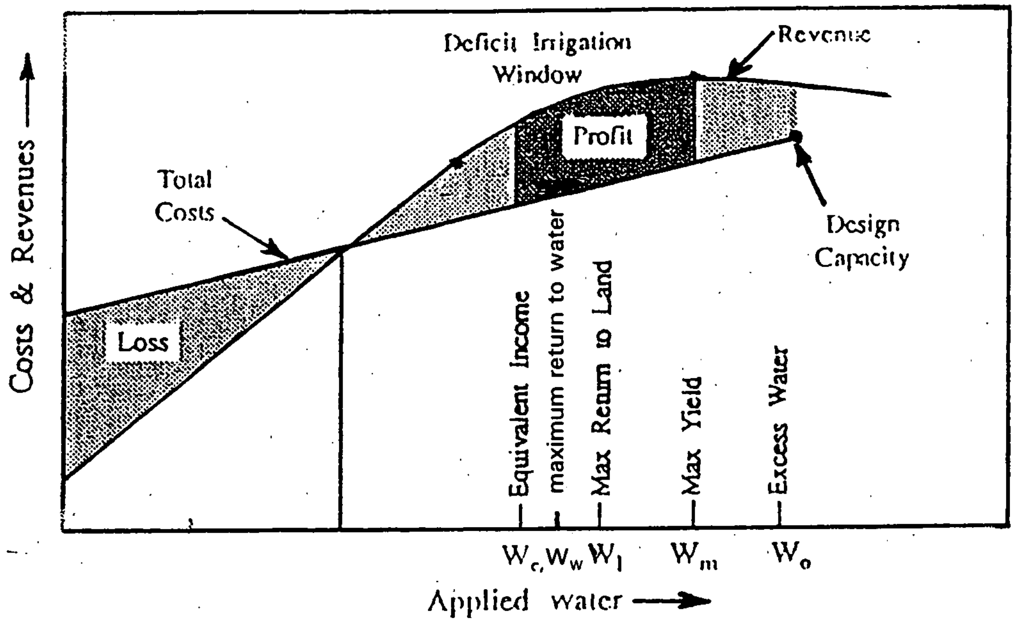


Figure 2.6 Revenue and cost functions

The obvious rational strategy is to irrigate at the optimal level, either yield W_1 or W_w depending upon whether land or water is the limiting resource. If the cost and yield functions discussed above were precisely known, it would be a simple matter to choose an optimum level of water use. In reality it is quite difficult to estimate the applied water - crop yield relationship. This uncertainty implies economic risks. It is obvious that under Indian conditions the optimal level of irrigation will be W_w. The term on which irrigation water is made available to cultivators is an important determinant of the way in which the water is used (see Figure 2.7).

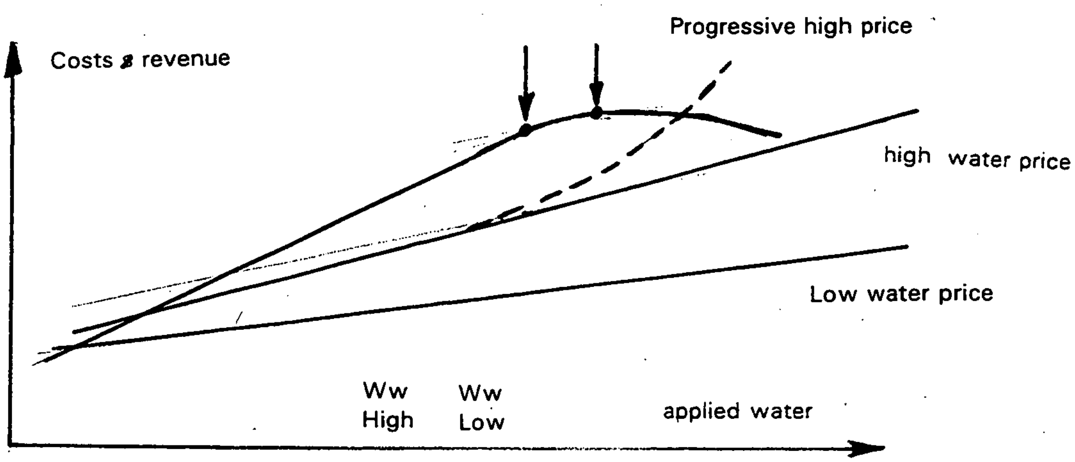


Figure 2.7 Revenue as function of water pricing

To reach the optimum W_w for highly priced water a smaller amount of water is needed compared with cheap water. When the price is progressive with the amount of irrigation water used, the saving of water can be considerable (U.S.A.). Pricing of water is a mechanism to safe water.

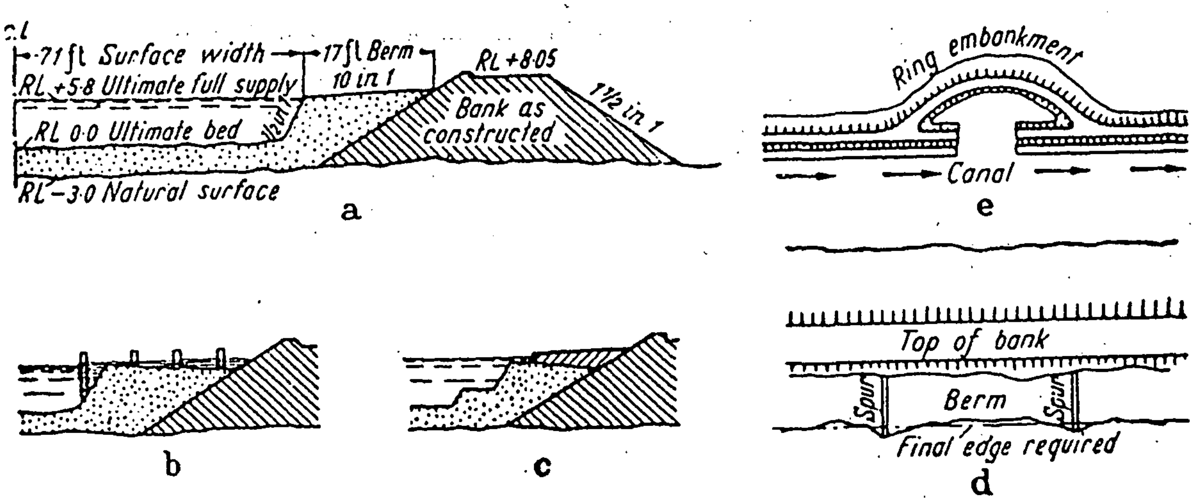
Production/Revenue and costs functions are different for each crop and even for the same crop over different years. The price of inputs (energy, seed, fertilizer, and labour) and the climatological conditions (rainfall, evapotranspiration etc.) change from year to year.
Deficit irrigation applied in a proper way is as sophisticated as productive irrigation.

Design of irrigation canals

The design of alluvial canals, the Indian experience
All irrigation systems in North-India were run-of-the-river systems, so the canals tapped directly the great rivers. The oldest irrigation canals were constructed during the reign of the Moguls. Many of these indigenous works did not achieve what was expected of them, or at least did so for a comparatively short period. Engineering capabilities understandably fell some way short of what was shown subsequently to be necessary for the design and construction of large-scale canal system.
The first purely British work was the Ganges canal (1854).
The engineering experience of the British civil engineers was restricted to design and construction of navigation canals without stream flow.
The study of stream flow started already in the seventeenth century, but Darcy & Bazin (1856) and Ganguillet & Kutter (1869) obtained the first useful results.
The Ganges canal was designed with the formula of Dubuat (1779) and mean water velocities varied between 1.05 – 1.20 m/s. The problem was that Dubuat's formula for open channels proved to be quite unreliable, particularly for large works. The excessive slope (S = 0,0003) given to the bed of the main channel was amplified in its effects by the design of the falls. Upstream and just downstream of these falls, supercritical flow (Froude number F>1) occurred, causing serious damage to the flooring, scouring the bed, and setting up a wave which considerably damaged the banks. This erosion, in turn, caused serious silting problems on the first few furlongs of each distributor (S = 0,00007), which reduced the supply. Although from time to time the distributors were cleared from silt, their bed level was raised considerably over the years. It soon became clear that the design faults were sufficiently serious to endanger the canal itself should it run for a number of years at full supply, thus the intake capacity was reduced. These problems were solved by raising the crest of the falls to reduce the slope of the canal (Stone, 1984).
The lower Ganges canal was constructed with a much flatter slope (S = 0,00002). The velocity in the canal was very low, and as result much silt is deposited (Wilson, 1903). Most of the irrigation canals constructed before the 1890's were subject to erosion or siltation. The most important finding in the second half of the 19th century was that a canal system does not transport water alone, but a water-sediment mixture (P. du Boys, 1879 and Kennedy, 1895) and that the hydraulics of a canal with a loose boundary was quite different from the one with a fixed boundary. In the Punjab

irrigation canals were found, which cross-section and bed slope were stable over a quite long period. The typical Punjab canal has a sand bed, covered with dunes, and berms of silty clay loam. (See Figure 3.1). In practice berm formation requires some assistance to ensure that a meandering channel does not develop.

In the final stage, the original bank and bed has been deliberately built to accommodate a larger channel section than will form and the channel bed has made itself from the sand of the sediment load while the berm has made itself from silt and clay (Blench, 1957). Kennedy (1895) made the first step towards quantitative understanding of the formation of stable channels. His general idea was that the mean speed of flow, when a channel had settled down to what it had chosen for itself, was a function of the depth d. The relation he found was $v = 0.84\ d^{0.64}$ (English units). Uniform flow in an open channel with rigid boundaries is sufficiently described by a single equation, such as the Kutter, Manning or Chézy formula. Uniform flow in an open channel with loose and movable boundaries can only be described with a set of three independent equations. For any given discharge conveyed through a canal cut into movable material (soil) a flow depth will establish itself which depends on the adjusted slope and width, two quantities which in themselves are dependent on the discharge. An open channel with loose boundaries has thus three degrees of freedom develops if a canal is left all by itself and is free to meander.
Any canal system with more than one degree of freedom will take considerable time until equilibrium is reached. Mostly is equilibrium replaced by 'in regime'.



Berm Formation. (*a*) Canal in filling reach (a broad berm has been formed with assistance from spurs and maintenance, to contain channel regime breadth); (*b*) Initial berm formation (canal bed of sand; berm of fine cohesive mixture; top of berm slopes down to bank); (*c*) First maintenance (excavated edge will reform rapidly even without spurs); (*d*) Initial berm formation (uneven edge rectified as maintenance continues); (*e*) Breach repair (berm material deposits between ring bank and canal)

Figure 3.1 Typical Punjab canal

Channels, which do not alter appreciably from year to year, though they may vary during the year, are said to be in regime (Inglis 1949). The Kennedy formula together with the flow formula of Kutter represents a set of two equations, still short of one to satisfy the three degrees of freedom. After the studies of Lindley (1919) and Lacey (1929) this problem could be solved. Lacey found the following equations

$$v_{CR} = 1.17\sqrt{f_L.R}$$

$$Q.f_L^{\ 2} = 3.8\left(v_{CR}\right)^6$$

$$P = 2.67\sqrt{Q}$$

$$S = \frac{f_L^{\ 5/3}}{1788\,Q^{1/6}}$$

Where: f_L = silt factor
$d = f_L^2/_{64}$ (inches)
R = hydraulic Radius
P = wetted perimeter
D = mean diameter dominant type of sediment

With these equations, provided discharge and silt factors are known, the dimensions for a stable channel can be calculated. These regime equations are based on data from alluvial canals in the Indus-Ganges plain. The equations consist of simple correlation's of canal parameters expressed as exponential functions of discharge Q. After the Second World War a lot of research is done to get a better insight in the theoretical background of the Lacey formulas. A known shortcoming of the Lacey formulas is, that they implicitly include the parameters of sediment concentration (C) and the maximum shear strength (τ_S) of bank material to resist erosion. In canals designed adopting Lacey formulas, sediment concentration is low (C < 400) parts per million by weight). Lacey's formula most closely fit Punjab canal data. The value τ_S, implicitly present in Lacey's formulas is, therefore, the same as that of the bank material of Punjab canals ((τ_S = 0.266 kg/m^2). Chitale (1994) stated that: "In spite of their well known – and also unknown – limitations, the Lacey (1930) formulas are in popular use for the design of alluvial canals on account of their simplicity and the non-availability of an alternative proven theoretical approach, which has withstood the test of time".

The unknown limitations arises over ambiguity about a third governing factor besides discharge Q and sediment concentration C controlling canal geometry, which needs to be included in the Lacey formulas. Yang's Stall (1976) and Chang (1980) contented that this third criterion is the minimum energy dissipation rate or maximum transport capacity concept. Adapting this hypothesis, Chang (1985) evolved a complete set of design formulas for alluvial canals. With Chang equations for given discharge Q, sediment discharge Q_S and $d_{50>}$ a unique set of width B, depth D and Slope S can be obtained defining the hydraulic geometry of a canal

$$B = 7.55\left(\frac{S}{d^{0.5}} - \frac{Sc}{d^{0.5}}\right)^{0.05} . Q^{0.5}$$

$$B = 0.049\left(\frac{S}{d^{0.5}} - \frac{Sc}{d^{0.5}}\right)^{-0.3} . Q^{0.5}$$

$$\frac{Sc}{d^{0.5}} = 0.00039\, Q^{-0.51}$$

S_c = slope for incipient bed load.

The Figure 3.2 can be used to design a stable alluvial canal when discharge Q, sediment in flow rate Q_S, and sediment characteristics represented by its mean size d, are determined at the entrance of each canal and at the intake for the canal system.

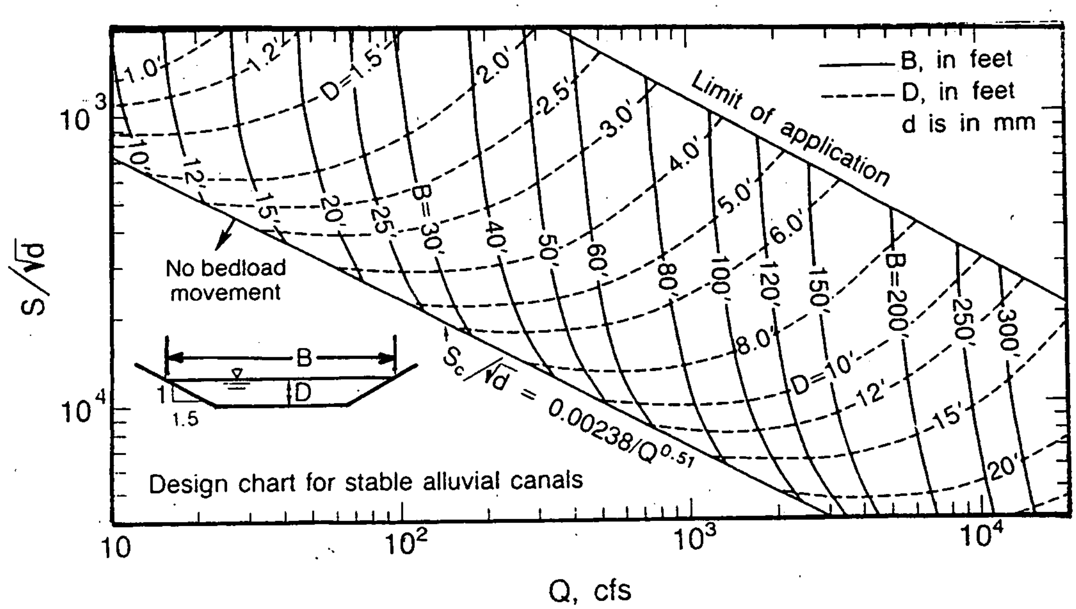


Figure 3.2 Design chart of stable alluvial canals for specified side slope

To maintain the approximate equilibrium slope of a canal in the system, specific load must be admitted. To avoid sediment problems in systems design, the geometries and slopes of all canals in a system must be so selected that these canals neither erode nor silt. Under such an equilibrium condition, the inflow of bed-material load to the system must be in balance with the outflows. The bed material load includes bed load and suspended load but not wash load. To maintain an adequate slope, the off-taking main canal from a river is usually designed to have a lower sediment transport capacity per unit discharge of flow than the river's. Specific measures for sediment exclusion usually must be made at the diversion structure (sediment trap). The distribution of bed load or suspended load at the bifurcation should be more or less proportional to the water discharge under equilibrium condition. Concentration of bed-material load in a sand-bed channel is well related with the channel's overage water velocity-bed slope product or V.S, which represents the rate of energy expenditure per unit weight of water or unit stream power (Chang, 1985). When discharges of canals are given, the slopes of these canals in the system should be chosen so that they fall along a line of constant V.S (see Figure 3.4).

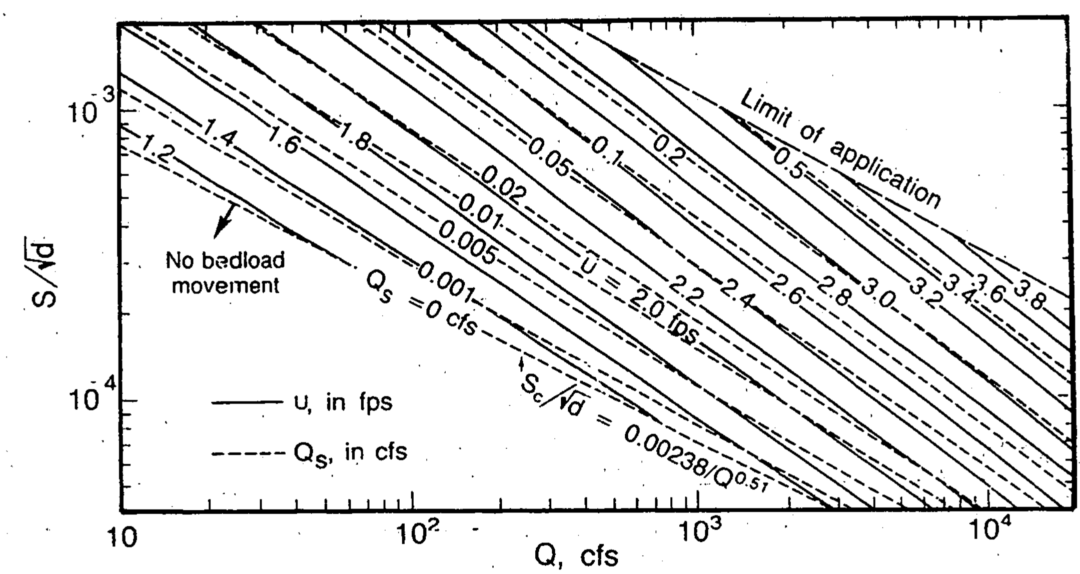


Figure 3.3. Bed load and velocity as functions of water discharge, slope and sediment size

Thus derivation of these equation and graphs by Chang is a step ahead of the Lacey equations in the sense that sediment load is explicitly incorporated. Omission of a factor reflecting strength of canal bank material as in Chang's formulas results in obtaining several combinations of B, D and S for the same Q, d and Q_S as shown by Karaki and Behara (1972). Still a lot of research has to be done to solve the stable canal design problem definitely.

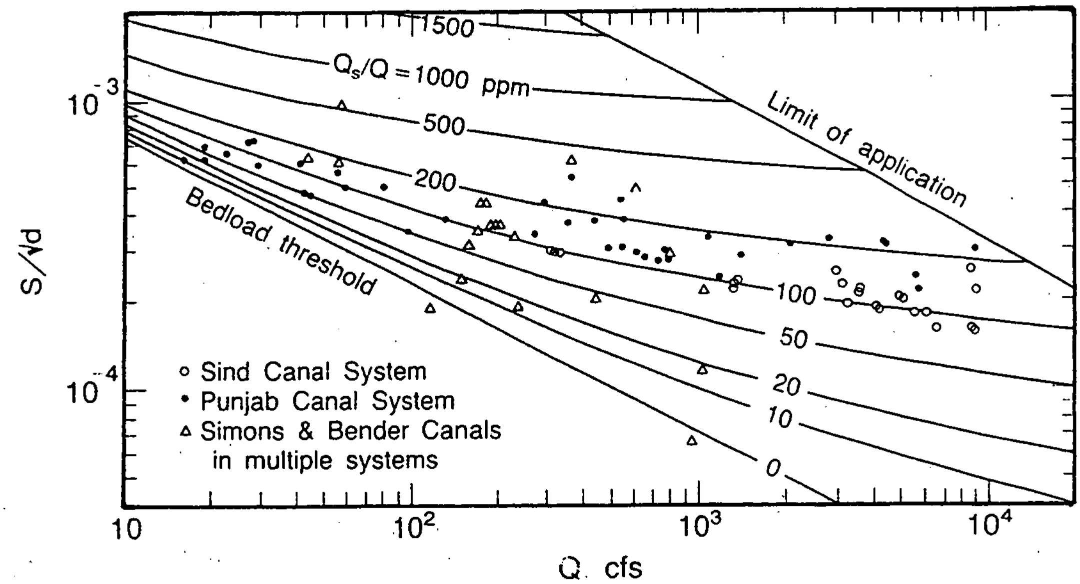


Figure 3.4 Concentration of bed-material load as function of discharge, slope and sediment (source Chang, 1985)

The design of alluvial canals, the Indonesian experience

In Indonesia around 1900 irrigation canals were designed, which were subject to erosion. Some of these canals were protected against erosion with a gravel layer on the bottom. The Dutch irrigation engineers always had a keen interest in the development of the irrigation technique in British-India. Canal design theories developed in India were well known by Dutch engineers. Haringhuizen developed regime equations for irrigation canals on Java, Indonesia, in the 1910's based on the ideas developed by Kennedy (1 895). Haringhuizen distinguished between regions with flat and mountainous topography.

The Haringhuizen equations are:

- flat topography $v = 0.42\, Q^{0.182}$
- $h = 3.00\, v^{1.56}$
- mountainous topography $v = 0.46\, Q^{0.182}$
  $h = 2.54\, v^{1.56}$

The Manning/Strickler equation is the third equation needed for the determination of the three-design parameters h, B and S.

The term's flat and mountainous topography was by some engineers translated in flat and steep alignment This is a wrong assumption, for this means that for the same discharge Q there are two stable channels possible, with different cross sections and bed slopes. In regime theory the soil characteristics, like cohesion and particle diameter of cohesion less soils, are an important parameter. These soil characteristics implicit in Haringhuizen's formulas explain the difference between flat and mountainous topography. The weakness of Haringhuizen's approach was the same as Kennedy's approach, namely not explicitly the soil characteristics taken into account. Lacey tried to overcome this shortcoming. Indonesian rivers transported a lot of sediment in suspension during the wet season. This fertile silt was partly transported to the fields and partly deposited in the canals. The silt transported to the field reduced the necessity of fertilizer application and made this even in most of the cases superfluous. De Vos (1 925) studied sediment transport in irrigation canals on Java and he found that relative transport capacity was a function of energy dissipation per unit of discharge

$$\frac{Q_s}{Q} \alpha\ \rho.g.v.S \qquad (\text{Watt/m}^3)$$

where: Q_S = sediment discharge
Q = water discharge

A canal system must be designed in such a way that in downstream direction v.S = constant. These results are in accordance with the theory of Chang (1985).

The theory of De Vos was based on sediment and discharge measurements in the Serayu irrigation canal, Central Java. He got the following results. To keep sediment, with a diameter less than 0,06 - 0,07 mm and a concentration of I i 2 liter/m' in suspension, the following criteria must be fulfilled $\rho.g.v.S \geq 1$ á 2 watt/m^3.
Vlugter continued the sediment transport and canal design research in Indonesia. Based on energy considerations he found that sediment particles with a diameter d:5 0,07 mm will not settle for a wide range of concentrations. (Vlugter, 1962).

The important finding was $\frac{Q_2}{Q} \alpha$ v.S = constant for a canal system.

In Indonesia almost all irrigation systems were built before 1929, the World economic crises, and the findings of De Vos and Vlugter were not applied. To avoid sedimentation or erosion it is necessary to keep the discharge during an irrigation season as constant as possible.
During the wet season, the Javanese rivers have a big sediment load and to avoid sedimentation the irrigation canals must flow at design (full) capacity. When this is not possible the actual discharge must be within the range of 80 - I 00 percent of full supply.
To reduce sedimentation, desilting basing must be built to trap a large portion of the coarser (d $\geq$ 0,07 mm) sediment fraction.

The design of alluvial channels: the American experience

In the United States the water source of most irrigation systems is a large reservoir. The irrigation canals supplied by these reservoirs convey sediment-free water or water which conveys only a very small amount of sediment but with sufficient energy to erode the canal. The A.S.C.E.'s special Committee on irrigation Hydraulics submitted questionnaires to a number of engineers whose experience qualified them to form authoritative opinions regarding the stability of canals built in various types of material.

The results of these survey were published in 1926 (Fortier and Scobey, 1926) and became the basis for the channel design method known as The Method of Maximum Permissible Velocity. (see Table 3.5). The pioneering work of Fortier and Scobey was the basis of canal design for many years; however, it is a design methodology based primarily on experience and observation rather than physical principles.

Table 3.1 Maximum permissible velocities for straight canals after ageing (Fortier and Scobey, 1926)

Material	N^2	Clear water				Water transporting colloidal silts			
		u Ft/s	τ_O lb/ft^2	ü m/s	τ_O n/m^2	u Ft/s	τ_O lb/ft^2	ü m/s	τ_O n/m^2
Fine sand, noncolloidal	0.020	1.50	0.027	0.457	1.29	2.50	0.075	0.762	3.59
Sandy loam, noncolloidal	0.020	1.75	0.037	0.533	1.77	2.50	0.075	0.762	3.59
Silt loam, noncolloidal	0.020	2.00	0.048	0.610	2.30	3.00	0.11	0.914	5.27
Alluvial silts, noncolloidal	0.020	2.00	0.048	0.610	2.30	3.50	0.15	1.07	7.18
Ordinary firm loam	0.020	2.50	0.075	0.762	3.59	3.50	0.15	1.07	7.18
Volcanic ash	0.020	2.50	0.075	0.762	3.59	3.50	0.15	1.07	7.18
Stiff clay, very colloidal	0.025	3.75	0.26	1.14	12.4	5.00	0.46	1.52	22.0
Alluvial silts, colloidal	0.025	3.75	0.26	1.14	12.4	5.00	0.46	1.52	22.0
Shales and hardpans	0.025	6.00	0.67	1.83	32.1	6.00	0.67	1.83	32.1
Fine gracel	0.020	2.50	0.075	0.762	3.59	5.00	0.32	1.52	15.3
Graded loam to cobbles when	0.030	3.75	0.38	1.14	18.2	5.00	0.66	1.52	31.6
noncolloidal	0.030	4.00	0.43	1.22	20.6	5.50	0.80	1.68	38.3
Graded silts to cobbles when colloidal	0.025	4.00	0.30	1.22	14.4	6.00	0.67	1.83	32.1
Coarse gravel noncolloidal	0.035	5.00	0.91	1.52	43.6	5.50	1.68	1.68	52.7
Cobbles and shingles									

The first step forward is to examine the forces, which cause scour. Scour on the perimeter of a channel occurs when the particles on the perimeter are subjected to forces of sufficient magnitude to cause particle movement. These forces are generated by the flow of water. By definition, the tractive force is the force acting on the particles composing the perimeter of the canal, and is the result of water past these articles.

Duboys (1876) first stated this concept. The unit tractive force is

$$\tau = \gamma_W . R . S$$

where. γ = average value of the tractive force per unit of wetted area
R = h for wide canals
γ_W = specific weight of water

A canal design methodology based on active force was developed by Lane (1955).

When canals convey sediment free-water, sedimentation is no problem. To avoid scour the maximum discharge may never surpass the design discharge. Without causing any inconvenience the discharge of the water flow may vary from zero to full supply (design capacity).

Summary

In table 3.2 a summary is given of canal design theories and their applicability.
Most of the irrigation systems in the World are of the run-of-the-river type with loose boundary canals (unlined).
The sediment load is high, and nowadays mostly much higher than in the past. To avoid sedimentation, it is very important to flow with a discharge around full canal capacity (Q design). Only for this discharge the canals are in regime.

Table 3.2 Canal design steady uniform turbulent flow

Type canal	Sediment charge	Criteria	Theories
Loose boundary canal	High sediment load	Water transport capacity	Manning flow formula Determine: - width-depth ratio - side slopes m Estimate roughness: k
		Sediment transport capacity	Sediment transport theory Chang, Engelund-Hansen
		Avoid sedimentation	Relative transport capacity Q_S/Q must be constant $V_* S$= constant
		Geomorphological equilibrium	Regime theory Lacey, Simons-Albinson

Type canal	Sediment charge	Criteria	Theories
	Sediment free	Water transport capacity	Manning flow formula Determine: - width-depth ratio - side slopes m Estimate roughness
		Avoid erosion	Tractive force theory $\tau \approx \rho.g.h.S < \tau_C$
Rigid boundary canal	High sediment load	Water transport capacity	Manning flow formula Determine: - width-depth ratio - side slopes m Estimate roughness
		Avoid sedimentation	Relative transport capacity Q_S/Q must be constant V. S= constant
	Sediment free	Water transport capacity	Manning flow formula Determine: - width-depth ratio - side slopes m Estimate roughness

Waterdistribution in surface irrigation main systems

The Indian experience

The irrigation systems in North India were even by the standards of the early 1900's strikingly unsophisticated in terms of the design and management of the water distribution infrastructure. Scarce engineering skills were taken up by the main construction tasks to overcome difficult engineering problems and few resources existed for details of distribution, and only gradually did the attention of the engineers move beyond the prestigious main works to the more mundane activity of establishing an effective distribution system. The construction, operation, and management of the actual water distribution system were placed in the hands of the irrigating community. Water was supplied to cultivators' watercourses through cuts in the canal bank. Not only was this wasteful, but it confined the spread of irrigation to villages directly on the main canal (Stone, 1984). A fixed outlet was not insisted upon, and cultivators were free to put outlets where they liked, and very much as they liked. Up to a dozen outlets could serve the same village. Around 1870 a need for improvement of the irrigation canal systems was felt.
An important issue being debated was that of core capacity to be built into the canals. The debate arose when plans were made to remodel the Ganges canal around 1870.

The following two options to estimate maximum discharge (design discharge) of a canal were discussed.

1. The minimum discharge ever measured in the river at the site of the planned intake
2. The average of the minimum discharges measured during several years.

The British engineers choose at last the second option. Discharge measurements were only available for a very short period, mostly less than 5 years. The data available were too few for a statistical analysis. so it was impossible to ascribe a frequency of occurrence to the chosen design discharge. When the design discharge was based on a serie of wet years, the canal failed frequently to deliver this design discharge to the fields. The twin aims of maximisation of famine protection and direct canal revenue pushed the reach of the canal system ever outwards and ruled out the more concentrated and intensive irrigation. The following statement of Chief engineer Preston may clarify this:

"I am convinced from my own experience, and it is also common sense, that we must make the distributary first, and then we shall find water for it.... if a new distributary is added. it too in turn will receive its share of the available supply. It is true this will be done by with drawing a portion of the supply from the remaining distributaries and villages, but all share alike, and it is in my opinion advisable to give as many villages as possible the benefit of a share of the irrigation, even if the present supply is thereby reduced."

This generally accepted basic principle of distribution exerts its influence on the character of canal irrigation in North India in the nineteenth century.
The periodic shortages built in the system made a more even spatial distribution of canal irrigation very difficult. To solve this problem a more sophisticated infrastructure had to be built. In the 1873 Canal Act it was stipulated that outlets were to be constructed and maintained at the expense of the government and thence no private rights to the outlet or use of water from it could be claimed.
A systematic attempt at remodelling got under way in the 1880's. The adopted waterdistribution strategy was a top-down supply oriented system.
A very important principal was to design and construct the irrigation system in such away that the farmers could not influence the water distribution.
Around1900 the canal system design was based on the following principles:

- Irrigation canals transport water and sediment The quantity and quality of the silt and sand carried in suspension by the water entering the canal forms one of the principal points to be considered in designing an irrigation canal. In most rivers the silt is of fertilizing character, and consequently it is advantageous to adopt means whereby it can be conveyed right on to the fields irrigated, instead of being deposited in the channels near the head. The inclination given to the bed should be such that a uniform velocity is induced right through the system, as any sudden changes or checks in the velocity of the current will immediately cause deposit. The matters in suspension in the rivers are often composed in part of heavy sand and in part light fertilising silt. The heavy sand should, if possible, be kept out of the canal.
- The grading of irrigation canals should be independent of the ground slopes, and should be such as to ensure the future regime.

- In well designed canal systems the capacity of the canals is exactly proportioned to the duty to be performed, the cross-sectional area being diminished as the quantity of water to be conveyed is decreased owing to its diversion by village water courses. With the same bed slope the reduction of the cross-section can be best effected by a corresponding gradual reduction of the bed width.
- The distributaries were designed so as to run full. In some cases on alternate weeks, rather than continuously.
- Raising water levels to the surface of the country by means of a cross-regulator is condemned by the British engineers. This practice, they say, converted a freely flowing stream into a series of stagnant pools, encouraging the growth of weeds, the deposit of silt and an unhealthy conditions for the neighbourhood.
- The head of a distributary must be constructed at a point were a fall is needed. Water levels in the distributary do not influence the discharge of the main canal. There should be a watersurface fall of at least 0.40-m from the main canal into the distributary, to avoid cross regulators.
- The watersurface fall from distributary into minor canal should be at least 0. IS m.
- The height of the banks above full supply level depends on the soil conditions and fluctuations in the canal. For fluctuations an allowance of I 0% of the designed full supply depth will generally suffice.
- Ordinarily the water for the village ditches is taken from the distributary by means of pipes into the banks of the nearly bedlevel.

When supplies are plentiful during the critical periods of crop growth, the design of canals is a straightforward process. But when supplies available are not enough to meet the demand, these have to be distributed among the various distributary systems. This may be done in two ways:

a) By continuously running the various canals with their share of the available supplies; the outlets on a canal either running with whatever supply they can draw or in rotation.
b) By giving the authorised full supply discharge to each distributary system in rotation.

The method now adopted in most places, particularly early in the Punjab, aims at (b) above, and it may be useful to remember that this has been evolved from method (a) gradually in the course of time. Method (b) implies that manual control is to be exercised only on the Main Canal but not on the distributiers (Gulhati, 1951) and avoid sedimentation in the distributaries.

The construction of outlets around 1900 was still quite primitive. Wilson (1903) wrote:

> "The difficulties in the way of delivering water by actual measurement have been insuperable, chiefly because no practical method of measuring water under a constantly varying head has vet divided. In larger distributaries the volume discharged is usually obtained by measuring a short length of bank, and knowing the cross section, the velocity is determined by floats on this known length. This method is rather crude".

The standard outlet in use around this time was a non-modular gated pipe outlet (Figure 3. 1).
In most parts of India, there is generally no manual control on the working of outlets, which are so designed that they work automatically and continuously. In the Punjab, even the distributary system (maximum capacity 300-400 cusecs) is so designed that there is no necessity for manual control or regulation at any point in the system.

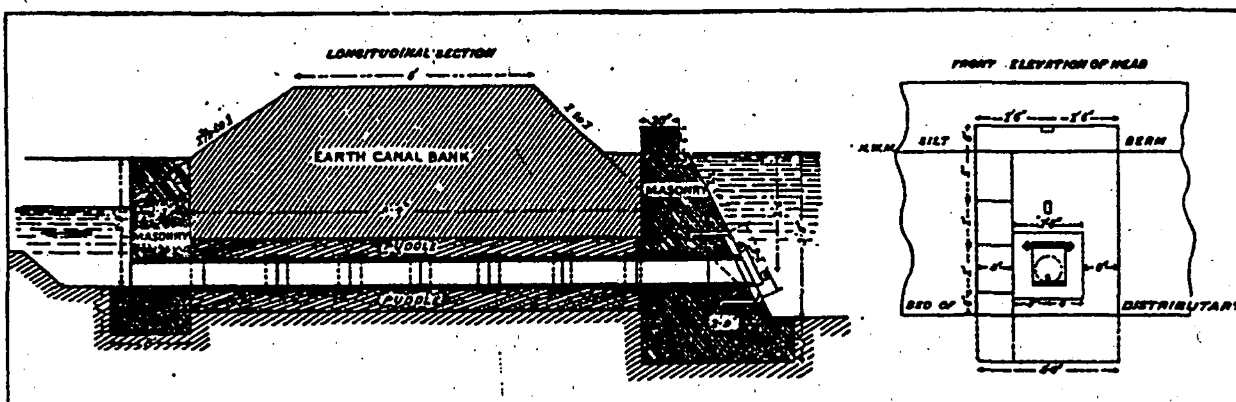


Figure 4.1 Standard non-modular gated pipe outlet in the Punjab (Wilson, 1903)

The water distribution in protective irrigation systems was far from equitable. To combat these water distribution problems the following was suggested (A. Bolding et al., 1995).

1) Control the distribution of water and avoid corrupt practices and cultivator interference.
2) Sell water by volume to cultivator's to avoid waste of water.

To implement volume based distribution of water to the farmers, a technical device is needed that allowed precise, quantitative measurement and regulation. lie gated pipe outlet was not suitable for this purpose. Outlets may be divided into three classes:

a) *Modular outlets,* are those outlets whose discharge is independent of the waterlevels upstream and downstream of the outlet, <u>within reasonable working limits</u>.
b) *Semi-modular outlets,* are those outlets whose discharge, although depending on the waterlevels in the parent canal (upstream), is independent of the waterlevels in the village watercourse (downstream), so long as the minimum required working head is available.
c) *non-modular outlets,* are those whose discharge is a function of the difference of upstream- and downstream waterlevels

The British engineers liked to increase technical control of water distribution by means of a modular structure. Theoretically is the existence of a modular structure without moving parts impossible. A lot of research is done to find a device with a constant discharge within reasonable working limits. This search can be considered a failure. Irrigation science and hydraulics were both in their infancy in those days. Some researches (Kennedy, 1906. Visvesvaraya's, 1905) succeeded more or less to design such device with movable parts.

The advantage of modular devices was that no manual control was necessary and farmers could not influence the discharge. The flexibility for these type of structures is defined by Crump (1 922) as follows:

$$F = \frac{dq/q}{\frac{dQ}{Q}} = o$$

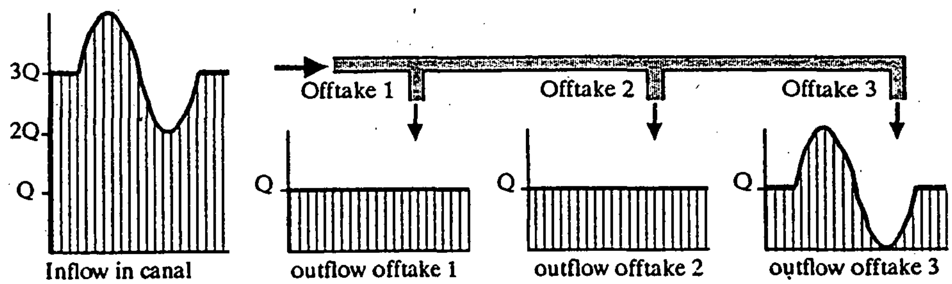


Figure 4.2 Flow diversion with flexibility F = o

Any variation of the incoming discharge is transferred to the tail end. Water shortages or surplus are not proportionally divided over the irrigation system, one of the basic concepts of protective irrigation. Insurmountable objections were raised against Visvesvaraya's device. It was found too expensive, too complicated, too much loss of head, and the farmers would find it easy to increase the discharge by simply putting a stone on the floating barrel (GOI, 1905). The non-modular pipe outlet was still in use and various attempts were made to perfect the design of the pipe outlet, to make tampering difficult and to obtain a constant discharge coefficient over a large range of discharges. The difficulty was and is that the discharge coefficient is a function of the difference in upstream and downstream waterlevel and the waterlevel in front of the device (see Figure 3.4).

$$V c_1 \sqrt{2g\,(A - h_2)}$$

$$V c_2 \sqrt{2g\,(B - h_2)} \qquad C_1 \neq C_2 \neq C_3$$

$$V c_3 \sqrt{2g\,(C - h_2)}$$

A main disadvantage of the non-modular pipe outlet was stated as follows by Crump (1922):

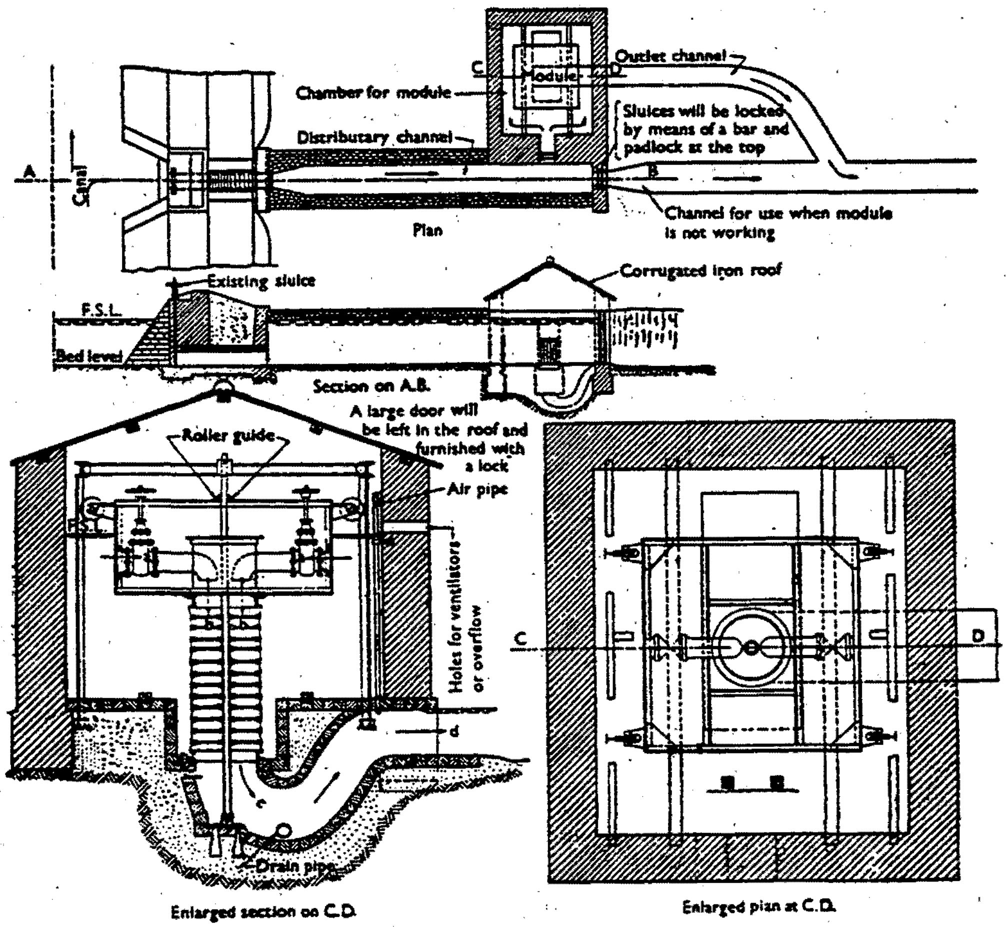


Figure 4.3 Visvesvaraya's self-acting module

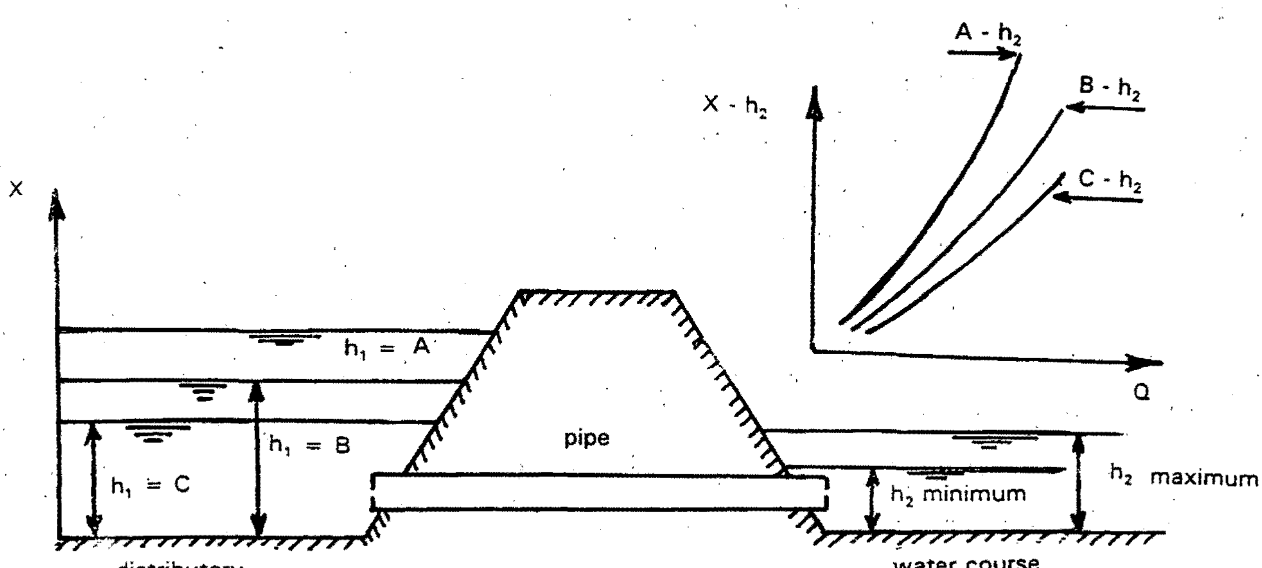


Figure 4.4 Discharge of non-modular pipe outlet as function of upstream and downstream waterlevels

"With varying field levels, and with the farmer at liberty to silt-clear his watercourse whenever and as often as he wishes, the supply drawn by a non-modular outlet is for ever changing independently of surface level in the supply canal, and thereby affecting the general distribution of supply in a manner entirely beyond the control and management of those responsible for distribution. On a semi-moduled canal, on the other hand, distribution is rendered entirely independent of arbitrary changes in watercourse conditions, and dependent only upon conditions in the supply canals under Government control. The non-modular outlets is doomed to disappear".

In the nineteenth century measuring devices were already developed based on the same principal of semi-modularity (Thompson, 1859 and Cipoletti, 1886).
The most important landmark in the development of irrigation outlets in India was the publication in 1922 by Crump. In this paper he formulated the principal of flexibility. Flexibility is defined as the ratio of the rate of change of discharge of an outlet to the rate of change of discharge of the parent canal. The capacity of an outlet to vary its discharge with a change in the discharge of the distributing canal is studied by calculating its flexibility. In Figure 4.5 an example is given for division structures with underflow gate in the ongoing canal and overflow (weirs) in the offtaking canal.

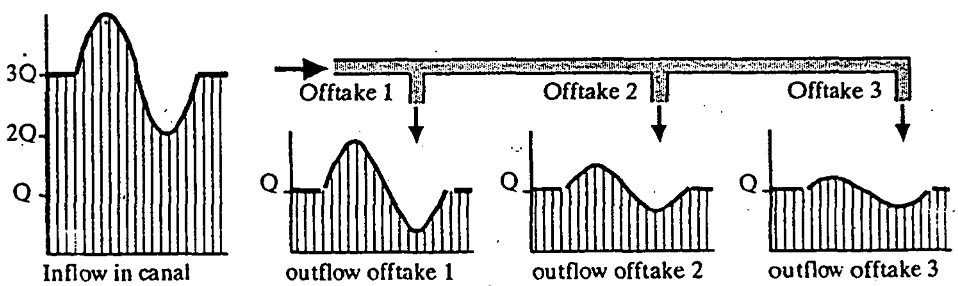


Figure 4.5 Flow diversion for F > I

A second achievement of Crump was the development of a new type of outlet the so-called *adjustable Proportional Module (APM)* By the beginning of 1924 orders had been issued that A.P.M's should be generally adopted in future remodelling of irrigation systems in India.
No experiments were carried out by Crump on the silt-drawing capacity of the A.P.M. but subsequent experience showed that as soon as the outlets on a channel were remodelled from pipes to A.P.M's the silt equilibrium of the canal was disturbed and the canal generally silted up. It became clear that not only water but also silt had to be distributed over the different outlets in order to keep the canals in regime. In the 1930's and 1940's a lot of research is carried out to solve this problem.

This resulted in the development of the Adjustable Orifice Semi-Module (A.O.S.M).

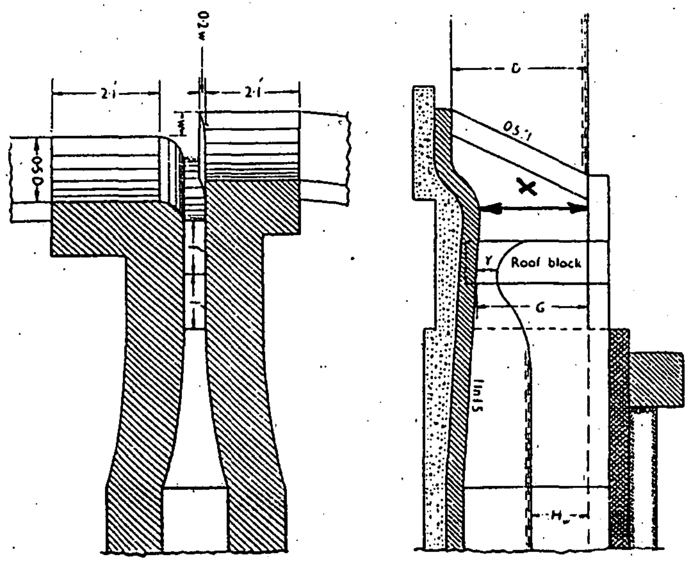


Figure 4.6 Standard design of A.O.S.M. as used in the Punjab

Sharma's experiments showed that the silt draw increased with a deeper setting, the following being the
relative results obtained (Sharma, 1934)

X/D =0.6	100% of distributing canal's sediment concentration
0.8	110%
1.0	120%

These results are quite satisfactory.

Upstream control

General description. Check structures are installed in the-canals to maintain a constant upstream water level, regardless of the flow rate through the structure.

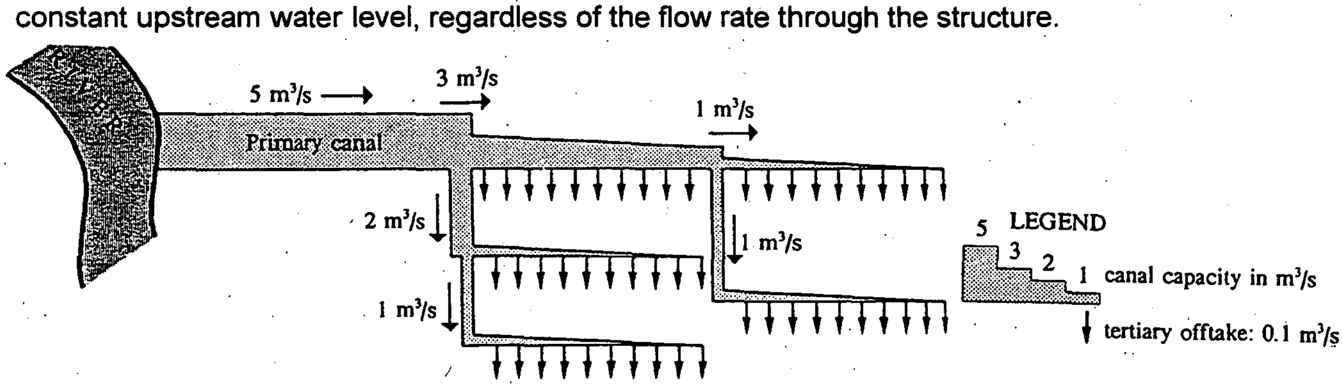


Figure 4.7 Diversion of flow in an irrigation system at a certain time t_1.

Upstream control provides a supply system, which must be operated on a scheduled delivery basis. Flow rates out of each turnout, lateral, and canal are computed in advance, and these anticipated bows are summed to determine the required flow rate at the source.

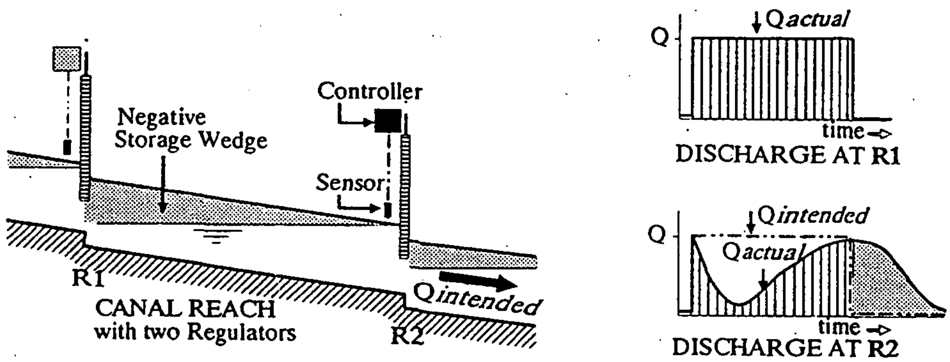


Figure 4.8 An irrigation canal under upstream control (Ankum, 1996)

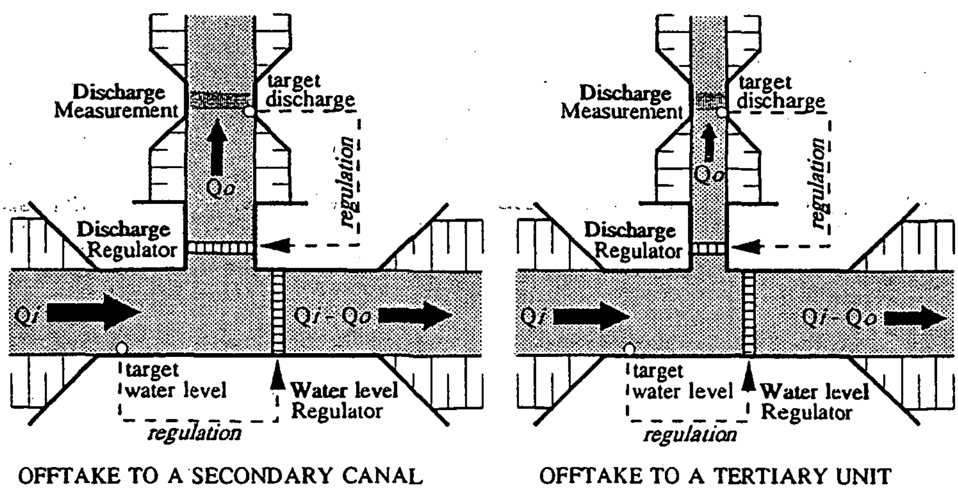


Figure 4.9 Irrigation structures under upstream control (Ankum, 1996)

The American experience. The water sources of irrigation systems in the Western part of the U.S.A. are in many cases a reservoir, still is the mode of water delivery normally conventional upstream control. For a system using an arranged delivery schedule, water users typically contact the ditch-rider or main irrigation office 24-48 hours in advance of the morning they want the water. 'Me ditch-rider or water master will sum up the water orders for each lateral and canal making sure that the requests do not exceed the design capacities. The water will be ordered from the principal supplier. Generally one flow rate adjustment is made at the source each day; more flexible systems may make two or three changes per day. Because the system is not 'responsive' the deliveries must precisely match the amount of water which is turned into the system. If unannounced flow rate changes are made at turnouts, the system will end up with an excess or deficit of water at the downstream end. Water users are not allowed to open and close their turnouts, or to make flow rate adjustments. When a change in flow rate is made, it does not suddenly arrive at the turnouts. It may take hours or days to arrive. Furthermore, it does not arrive all at once but gradually (see Figure 4.8).

The task of the ditch-rider with manual upstream control is not easy,- it takes almost half a day to adjust the check structure as the results of a single pre-scheduled set of flow rate changes made at one time in the day (Californian experience). Flow rates cannot be measured precisely. Commonly used flow meters may have a 5-10% accuracy at best.

The time tag between water diversion and arrival, the gradual nature of arrival of flow rate change, the inaccuracies of flow rate measurement devices, and the fluctuations of flow through turnouts all contribute to a condition in which the 'tailenders', or water users at the far downstream end of a canal, suffer a continual excess or deficit of water.

Who is in control? With conventional upstream control, it is the irrigation agency that is in control. If the ditch-riders/gate keepers do not maintain strict control over the opening and closing of all turnouts and structures, the system cannot satisfy the demand or more flexible 'arranged delivery schedules.

Independent action by farmers is a treat to system operation; automated on-farm irrigation cannot be used.

Water billing and flow meters. A procedure for water billing is built directly into the standard operating mode. All water deliveries are scheduled in advance by flow rate and duration; therefore deliveries records can be used for billing.

Communications. When flow rates adjustments at the source are made each day and on request of the farmers, a dependable and regular communication link is required between the water users and the irrigation agency.

Hydraulics of upstream control. The concept of upstream control is to maintain constant water level immediately upstream of each check structure (cross-regulator), thereby maintaining a constant head on the turnouts at that point and consequently a constant discharge through the turnout. Flow rates in the canal are typically only measured and controlled at canal entrances and at the individual turnouts. In the U.S.A. the water users like to have water delivered to them as flexible as possible. Each day flow rates in the system can be adjusted. Flow rate tag time, the time (T_L) it takes a change in flow rate (ΔQ) to travel a certain distance (L) can be approximated by the travel time of a disturbance (wave) on a water surface:

$$T_L = \frac{L}{v + \sqrt{gh}}$$

where: v = velocity of flow rate (mls)
g = gravitational constant
h = waterdepth (m)

However this does not correspond to the response time to complete a flow rate change (ΔQ) from a canal inlet to the desired downstream delivery point. Actual response time of a flow rate change down a canal are greater because the wave front will arrive before an appreciable volume of water does. As the disturbance moves downstream, the disturbance arrival lagtime between equidistant check structures increases and the duration of unsteady flow also increases.

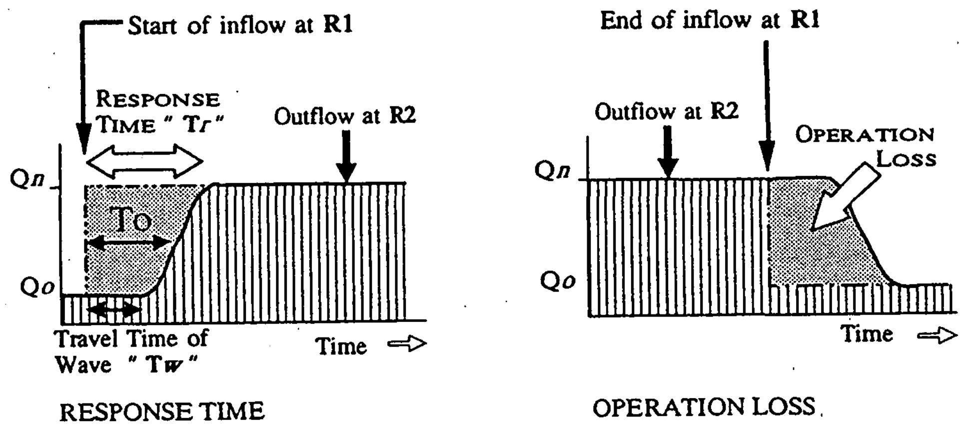


Figure 4.10The response time and operation loss of a canal reach (Ankum,1996)

Some data on the response time of a whole system is available from India.

Table 4.1 System response time (Shanan, 1992)

Area (ha)	Unlined canals		Lined canals
	Q_O to $Q_{100\%}$ (days)	Q_{15} to $Q_{100\%}$ (days)	Q_{15} to $Q_{100\%}$ (days)
2.000	1.25	1	0.75
6.000	1.50	1.25	1
20.000	3-4	2-3	1-2
200.000	14-20	7-10	4-7

Conventional irrigation systems are designed and operated with steady state hydraulics. Fluctuations in water surfaces and discharges are ignored. Changes in flow rates causes unsteady flow conditions. The steady state approach can be useful because even though some fluctuations will occur immediately following a change in flow rates, the system is expected to stabilize at the conditions predicted by the steady state hydraulics calculations. Smaller systems, those with shorter reaches and those with steeper slopes can stabilize more quickly than larger systems with long reaches and relatively flat longitudinal slopes. If flow changes occur more rapidly than the ability of the system to stabilize, the steady state approach is of relatively limited value and an unsteady flow model must be used.

Saint Venant (1871) for the first time correctly describes unsteady flow behaviour with a set of equations named after him. Although the unsteady flow phenomena was already a long time known, hydraulic engineers were not able to solve the mathematically complicated Saint Venant equations before computers became widely available in the 1970's. A time consuming graphical solution of the Saint Venant equations. the so-called method of characteristies, was developed by Massau (1900). This method could not be applied in the case of unsteady flow in irrigation systems. Nowadays unsteady flow computer programs are available which can accurately describe the waterlevels and discharges as function of time. The accuracy of the prediction depends on the accuracy of the input data, including roughness, canal geometry, and gate discharge coefficients. Theoretical or 'typical' values of input data must not be taken from handbooks or other references, they should be measured in the canal system. Modelling with the Saint Venant equations is very valuable for development of control algorithms, but use for day-to-day predictions is almost impossible.

For conventional upstream control of a long canal, the response time (T_R) can be approximated by:

$$T_R = \frac{\text{Change in volume of canal wedge storage}}{\text{Change in flow rate } (\Delta Q = f'(t))}$$

The response time can best be calculated with the diffusion approximation of the Saint Venant equations (Schuurmans, 1990). Basically, the system response time can be seen as the time that is required to fill or empty a canal reach. What make things complicated is that the outflow discharge is not constant but variable during the process.

Figure 4.10 shows the conceptual difference between the steady and unsteady models. A change in deliveries as made in point A, and presumably the system will stabilize at a new hydraulic condition at point B. The steady state model 'leaps' from point A to point B without providing any information about what might occur before the system stabilizes again at point B, nor is able to esthnate the duration of the stabilizing period.

The unsteady model does follow waterdepth and flow rate fluctuations during the stabilization period (response time), and can accurately predict the time going from A to point B. When the stabilization period is indefinite, due to frequent changes in deliveries or illegal turnout gate adjustments by the water users, the steady state model's 's 'leap of faith' to point B is incorrect because the system never stabilizes, or takes a great deal of time to stabilize. In some canal systems it is not enough to fortnulate an Operations Plan based on final, steady flow conditions because:

(1) The system rarely, if ever, actually achieves a steady state.

(2) The flow depth and or discharge fluctuations during the transition period are too large to ignore.

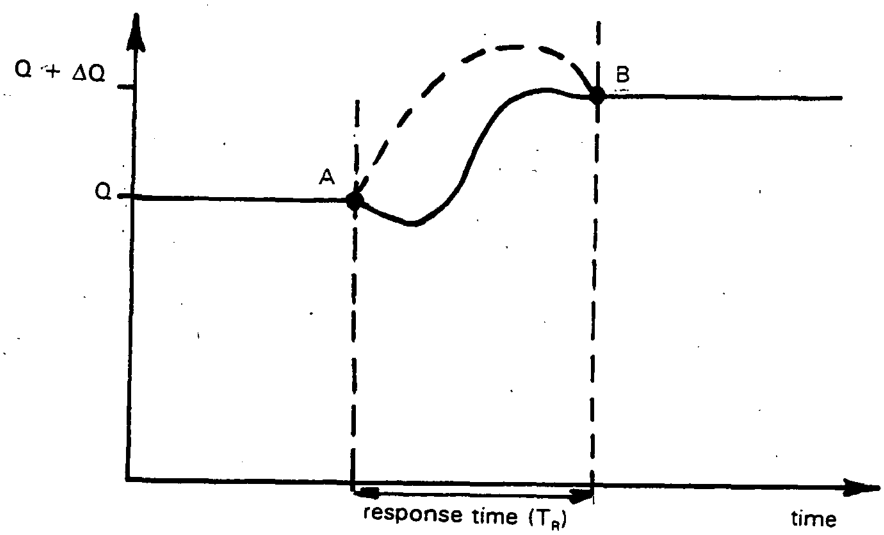


Figure 4.11 Conceptualization of the difference between steady and unsteady canal flow models

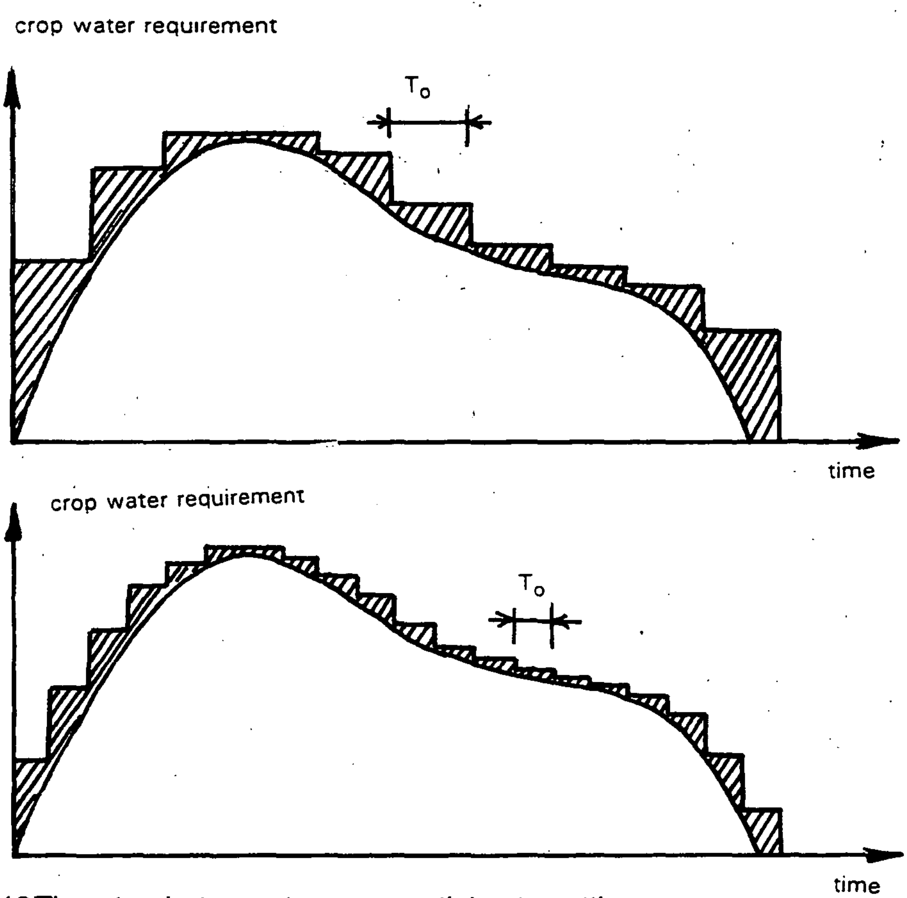


Figure 4.12 Timestep between two sequential gate settings

It is important to avoid before mentioned situations. The delivery scheduling is mostly based on crop water requirement calculations.
The highest irrigation efficiency is reached, when the timestep (T_O) between two sequential gate settings is short. When $T_O >> T_R$ the results of a steady state simulation will be equal to the final result from a transient situation.
Climatological data are published as average values over a 10 days, half-monthly or monthly period. In Indonesia the water requirements are calculated for 10 days period based on historical records. These average values were used for the irrigation scheduling, which is made at the start of the irrigation season. The gate settings of the tertiary unit turnouts are adjusted each I 0 days. The water delivered to t e tertiary units for a certain 10 days period was the predicted value plus or minus the correction for water shortages or surplus' of the foregoing period. Most of the Indonesian irrigation systems are smaller than 20,000 ha, so unsteady flow conditions will not be important when the water users do not change the gate settings illegally. Nowadays illegal gate setting changes are a big problem, with as result too much water at the tail in the rainy season (November - April) and water shortage in the dry season.
When the criteria $T_O >> T_R$ is not fulfilled as is the case of the Western part of the U.S.A. were water deliveries change each day, it is better to shift to downstream control.

Modern water control in irrigation

Flexibility of water delivery. "Improved reliability and flexibility of water deliveries to the farm will result in both improved on-farm use and less spillage and loss within the conveyance system. These two factors will definitely decrease the volume of water required for the same crop yield, and in some cases can contribute to a decreases flow requirement at the system water resource, even though the water supply is available on a more flexible basis to farmers". This is a believe expressed by some authors (Plusquelec et al., 1994) but is never proven. In the irrigation literature you do not find descriptions of irrigation systems, which shifted from rigid to a more flexible water delivery method which resulted in substantial water savings.

Water deliveries to the farm, which are inflexible, unreliable, and/or unpredictable, restrict the attainment of high on-farm irrigation efficiencies. This may be illustrated as follows (Burt, 1990)

1) Effective implementation of modem on-farm irrigation techniques is inhibited.
2) High-tech soil moisture/plant water stress measurements are useless.
3) To handle the problem of on-farrn irrigation systems shutting down unexpectedly is difficult or impossible.

All these arguments are valid for U.S-A. and Europe but in my opinion not for small holder irrigation systems in Africa and Asia.

Downstream control. Downstream control can provide flexible and demand operation. Any change in flow rate within the system causes upstream gates to make a corresponding adjustment automatically, until eventually the gates at the far upstream supply point respond.

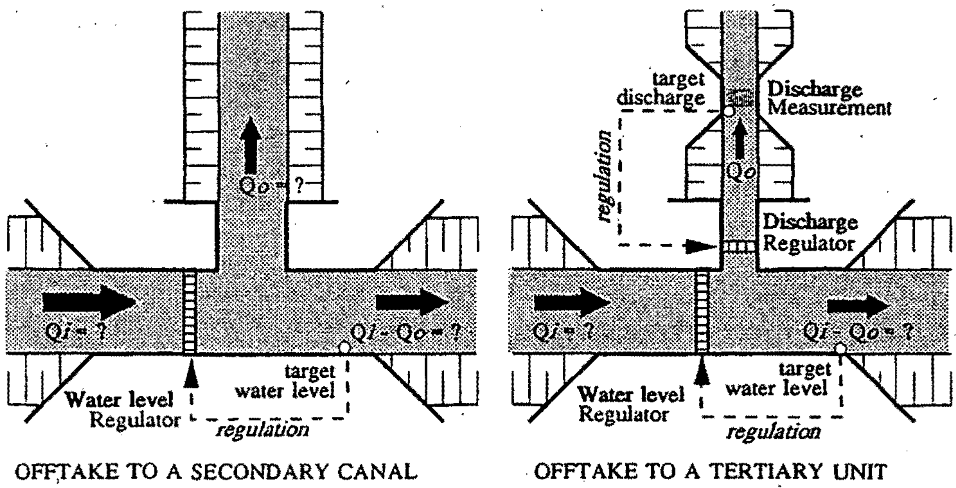


Figure 4.13Irrigation structures under downstream control (Ankum. 1996)

It is essential in downstream controlled systems that the water itself, transmits "information (water levels) upwards throughout the system. It means that, except at the AVIO/AVIS gate sites, super critical flow cannot be allowed, unless special provisions have been made.

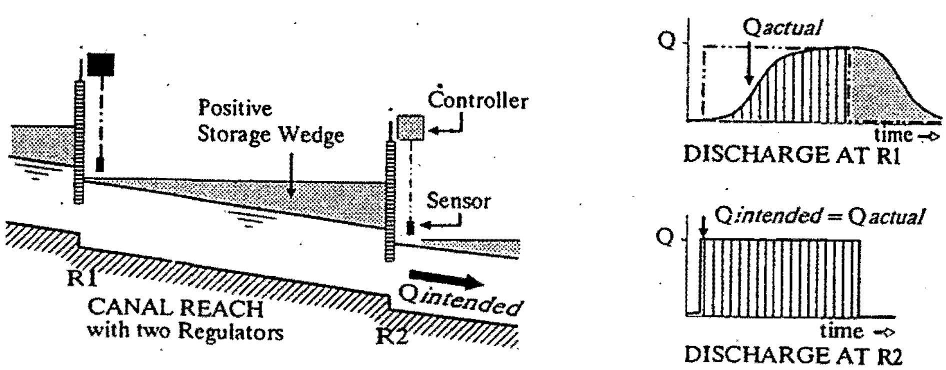


Figure 4.14An irrigation canal under downstream control (Ankum, 1996)

The gates in check structures (cross regulators) for downstream control must be automated unless persons are posted at each structure around the clock to maintain the downstream level. Hydromechanical gates, such as AVIS and AVIO gates which are developed in North Africa and France by French irrigation engineers in the 1930's, are frequently applied.

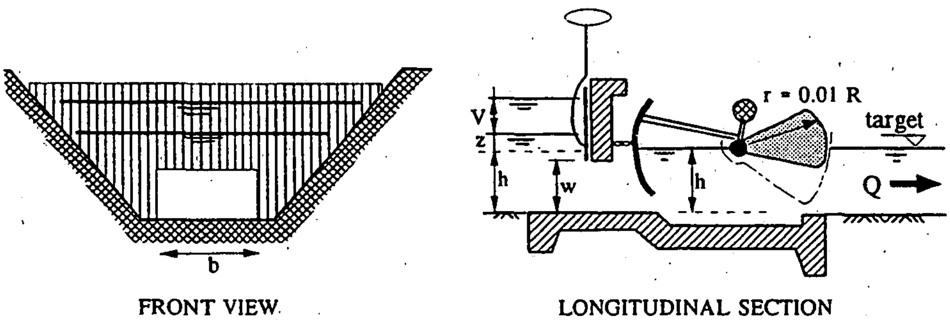


Figure 4.15a AVIO gate for automatic downstream control

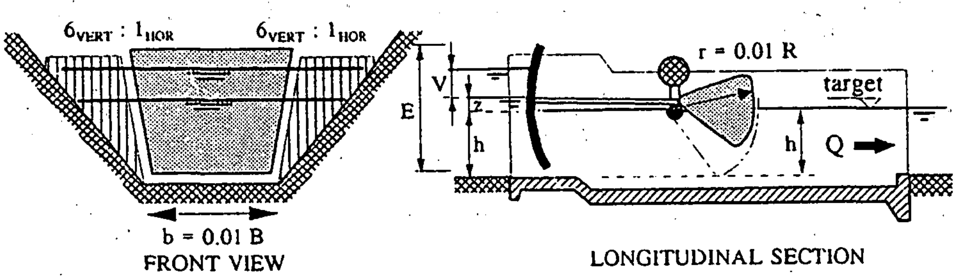


Figure 4.15b AVIS gate for automatic downstream control

Downstream control offers the option of either "limited rate demand" or "arranged" schedules.
If canal capacities and in-canal storage are quite large it may be possible for users to take water without advance notice, response time is zero. More commonly, the canals are operated on a fairly liberal arranged deliver, basis, with the provision that users can turn water off at any time without providing advance notice. If users order water in advance, irrigation Service employees can check that the canal capacities will not be exceeded. It is a misunderstanding that individual water users or Water User Associations can determine the amount of water released at any time, for canals have mostly not sufficient capacity and insufficient storage capacity is available. Moreover farmers of smallholdings in developing countries have not the high tech facilities at their disposal to estimate the need of irrigation water and distribute it with such accuracy that water savings can be expected. Because the system automatically responds to flow rate changes, canal operators do not have to worry about balancing flows. Downstream control is only found in the main and secondary canals and not within the tertiary units. Some systems in the U.S.A. utilize closed or semi-closed pipeline laterals (J.L. Merriam, 1987). Systems with a high degree of flexibility in the U.S.A. use totalizing flow meters, generally propeller meter design. Irrigation systems with an on-demand supply have to charge for the volume of water available per hectare. Flow meters are not necessary for control but only for billing.

Level top canals provide the simplest method of achieving downstream control. The horizontal embankments between two cross regulators are necessary to meet the zero flow condition. The construction costs of top-level canals is high. On steep ground with long pools, level-top canals require considerable earthwork to construct the canal banks. For a general idea, maximum ground-slopes should not exceed 0.0002 for big canals and 0.0003 for medium sized canals.
Several innovative approaches in the 1980's and 1990's have been taken, to achieve downstream control on sloping canals. This is an area of current research and limited field implementation. Achieving downstream control on sloping canals presents special hydraulic stability problems when a series of pools is involved. Several control techniques, such as EL-FLOW (Buyalski and Serfozo, 1979), CARDD (Burt, 1983) and Bival (SOGREAH), utilizing computer techniques are developed to make downstream control on sloping canals possible.

Canal capacity. It is always necessary to increase the design capacity, especially at the downstream end to offer a more flexible schedule. Canal sizing criteria for on-demand supply have been developed using a variety of assumptions. The most significant work was done by R. Clement (1965) and used in the design of the Canal de Province in Southern France and has since be used elsewhere.

Table 4.2 *Capacities required* for demand operation*

Relative Service Area d/s of this point	Relative turnout (T.O.) size (3 means the T.O. is sized 3 times larger than a T.O. with continuous flow)						
	1	1.5	2	3	4	5	10
10	10	15	18	22	25	27	36
40	40	50	55	62	67	72	89
100	100	115	121	132	139	146	173
500	500	526	536	553	568	581	635
1000	1000	1031	1042	1063	1081	1097	1167

* Assumes probability of congestion – 1%. Operation 100% of the time, assuming no difference between day vs. night, or weekday vs. weekend. (Based upon work by R. Clement, 1965).

Clement found that the difference between canal capacities required for arranged versus demand schedules diminishes as the number of turnout increases. The more flexible the system (larger turnout size) the bigger the needed canal capacity must be. The introduction of on-demand delivery in small irrigation system is prohibitive expensive.

The limitations of the introduction of modern irrigation techniques and the possibility of water saving

Water requirement and yield response of crops
Until the beginning of the century, the waterdistribution in irrigation systems was based on the assumption that water demand of the crops was constant during the whole crop growth period. In the last eighty years enormous progress is made in crop science, Methods were developed to calculate the water requirements of different crops as function of crop growth stage. In the same time we better understood of crop yield response to water, especially of crop production under water stress conditions. These new insights made it possible to make irrigation scheduling more precise, with as result the possibility of water saving.

Canal design methods
For the distribution of water in irrigation canals the unsteady flow phenomena can be very important. When this flow phenomenon occurs the water distribution is influenced. To calculate the required design capacity of irrigation canals the assumption that the canal flow is uniform and steady is a good approximation. The required capacity of a canal with a fixed boundary can be calculated with the Manning/Strickler flow formula. Incorrect designs of canals with a loose boundary can be unstable; erosion or sedimentation may occur. To design irrigation canals in run-of-the-river systems in geomorphological equilibrium on a yearly base, the regime theory is developed. Unlined irrigation canals downstream of big reservoirs, as in the U.S.A., transport sediment-free water, so siltation is no problem but scouring of the canal bed may occur. For this type of canals the 'tractive force theory ' is developed. The discharge may fluctuate from zero to full capacity.
When water with a lot of suspended sediment is transported, sedimentation can be prevented to operate the canal around full supply level.
An additional criteria which must be fulfilled is that the sediment transport capacity may not decrease in downstream direction of the irrigation system, so $V \cdot S$ = constant.

The propagandized shift from upstream to downstream control
Flexibility. Downstream control is a very flexible mode of water delivery and solves the problems of response time and the operational losses as experienced in upstream control. The delivery of irrigation water in a sufficient quantity and at the right time results in saving of water. Downstream control is only applied in the main canal system. In the U.S.A. you find one farmer at the downstream side of the turnout and to arrange the on-farm irrigation and other activities in a flexible way, he needs a flexible method of water delivery in the main system. A modern American farmer with his agricultural knowledge and high tech equipment is able to measure soil moisture content quite accurately and to determine when, where and how much irrigation water is needed on his farm. In developing countries with smallholders in the irrigation systems you will find

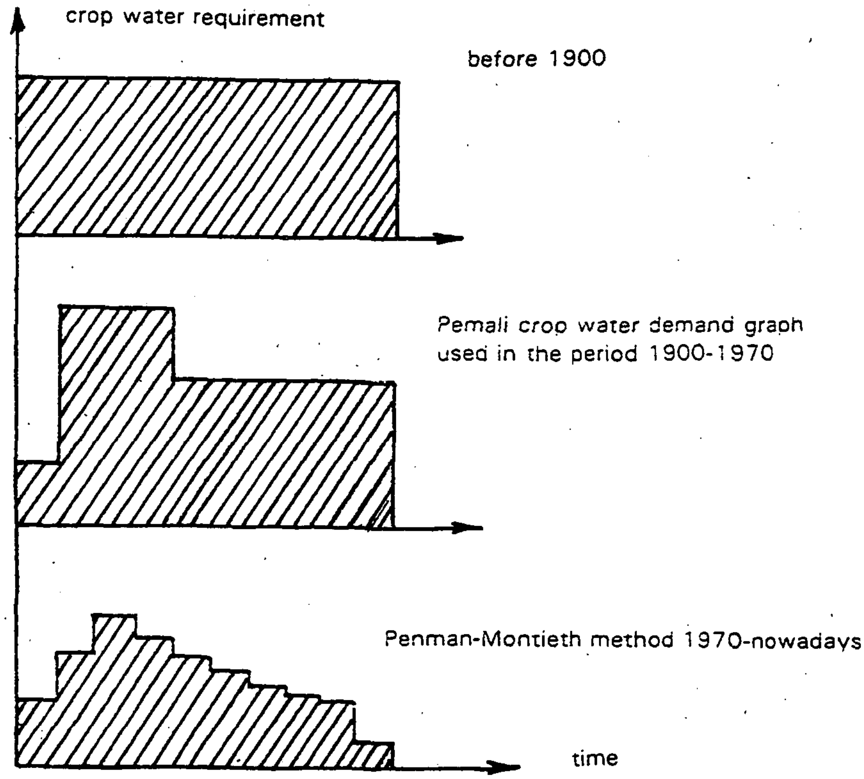
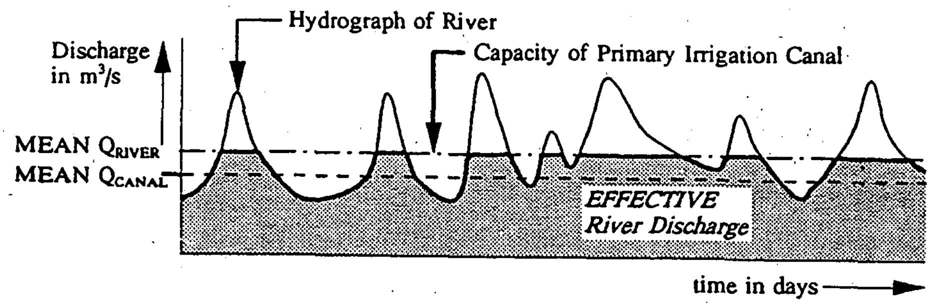


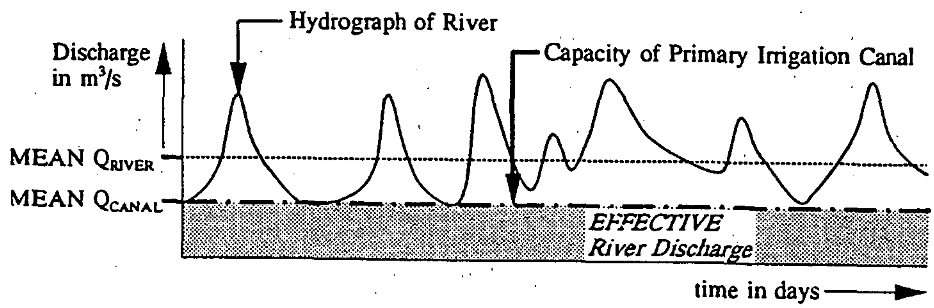
Figure 5.1 Crop water demand Bedegolan irrigation system Java, Indonesia. Calculated with different Methods

a group of farmers, sometimes up to 200-300, at the downstream side of the turnout This group of farmers must be organized, and a representative of this group has to request for irrigation water. 'Me water distribution within the tertiary unit is proportional and the delivery is rotational. In India and Pakistan (Punjab) this mode of water delivery (Warabandi) is quite successful. Within the tertiary units (Chaks) an illegal water market is established and irrigation shares are traded. This system is quite flexible and the farmers are satisfied and do not like a change (Jacobs, 1997).
Berkhoff (1990) believes that in those areas in Northwest India that are underlain by fresh and shallow groundwater, there is no need to make the surface water available on a demand basis.

Since water is scarce relative to land. the objective must be the conjunctive use of all water resources, defined here as the optimum use of rainfall, surface and groundwater where the only significant public intervention is the way that surface water is distributed in the canal system.
He argues that flexibility will be provided through groundwater use, where as surface water will be strictly controlled and managed by a central authority.



MINIMUM Q_{RIVER} ≤ CAPACITY OF CANAL ≤ MAXIMUM Q_{RIVER}
(mean Q_{CANAL} < mean Q_{RIVER}, *daily* fluctuations in Q_{CANAL})



CAPACITY OF CANAL ≤ MINIMUM Q_{RIVER}
(mean Q_{CANAL} << mean Q_{RIVER}, *no* fluctuations in Q_{CANAL})

Figure 5.2 Canal capacity and effective river diversion (Ankum, 1996)

Storage. To make downstream control successful a certain amount of storage is needed at the water source. For run-of-the-river irrigation systems under water scarce conditions an on-demand water supply system will fail. When the water availability in the river is abundant the whole year round (capacity canal << Q_{river}) an on-demand system is possible.
Modern water control concepts are most valuable in schemes that include upstream reservoirs and/or substantial buffer storage. Water released from reservoirs is sediment free, thus siltation problem is solved.
Water from reservoirs is always released under upstream control. Water from reservoirs is too expensive to use it only for agricultural purposes. Mostly it is also used for electricity generation.

Immediately downstream of a reservoir the primary canal is operated under up control, while the secondary canals are operated under downstream control. Such a transition of control is only possible with a regulating reservoir. These are needed to handle the anticipated fluctuations in water orders along the canal for one to two days.

Siltation. An important problem is the silt removal costs in run-of-the-river irrigation schemes with high sediment load. Silt loads from 400-3000 p.p.m during the rainy season are quite normal. Flexible delivery results in unsteady flow conditions and occasionally low flow velocities, thus increasing siltation. The downstream parts of

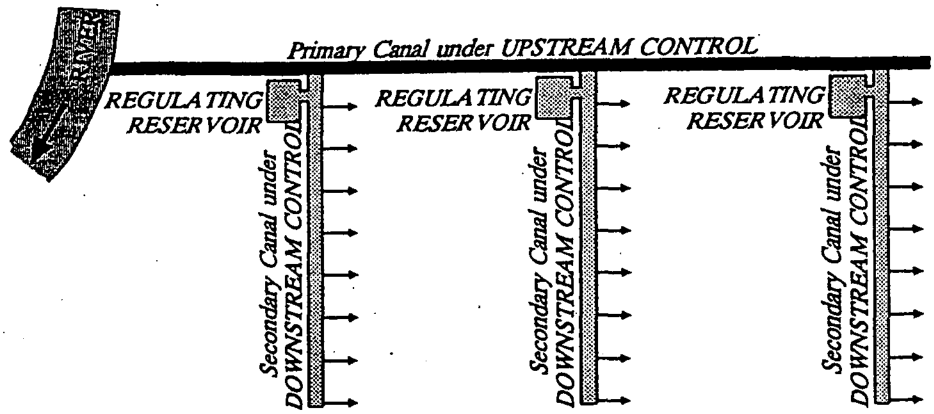


Figure 5.3 Transition from upstream to downstream (Ankum, 1996)

flexible systems can be up to two times as large as canals with continuous flow. This violates the concept of V·S = constant in an irrigation canal network. Sediment in suspension will be deposited. This is another strong reason not to apply the downstream control concept in run-of-the-river irrigation schemes.
Vortex tubes and tunnel extractors can be used to remove the bedload out of the irrigation canal but not the suspended load. Silt traps are very expensive and are not a guarantee to remove the total suspended load from the water.

Rehabilitation. To introduce downstream control on sloping canals is still subject of research and has limited field implementation. Expatriate engineers/consulting firms use the rehabilitation of some irrigation projects in developing countries for experimentation's with modem irrigation techniques not yet fully developed in their home country. The rehabilitation of the Sidoredjo irrigation system on Java, Indonesia is such an example. Although described as a successful project (Plusquellec et al, 1994) it was a complete failure.[1]

Unsteady flow condition. When the time T_O between two sequential gate settings are chosen in such away that $T_O << T_R$ unsteady flow conditions have not much influence on the water distribution in the main canal system. In this way operational losses can be substantially reduced.

Conclusion

Before in a rehabilitation program the water control concept is changed from upstream-to downstream control a detailed study must be executed to look at the desirability of the change.
Keep in mind that crop water demand (when, where and how much), water distribution concept and canal design theory are interrelated.

[1] Personal communication by Ir. Soebandi, Director-General of the Directorate General of Water resources Development (D.G.W.R.D.) September 1995.

To operate smallholders, run-of-the-water irrigation system (no storage, water with high suspended sediment load) under downstream control is not advisable.

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REGIONAL WATER DISTRIBUTION IN THE NILE DELTA OF EGYPT

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Introduction

In water scarce countries depending on external water supplies, such as Egypt, water distribution to the different water users is of paramount importance. For its water resources Egypt is depending mainly on the supply of fresh water transported to the country through the rive Nile. In addition to the Nile water, exploitation of groundwater from the Nubian aquifer and rainfall along the northern coast and in the Sinai Peninsula provide some potential for agriculture. The expanding population of Egypt creates an ever-growing pressure on the government to provide for new land reclamation areas. At the same time public water supply and industrial water requirements are increasing at the expense of agricultural water use.

All these developments resulted in the recent past to adopt a strategy to reuse drainage water for irrigation on strategic locations where the drainage water is of sufficient quality to be mixed with irrigation water for downstream use. This reuse of drainage water complicates management and planning of water distribution, but certainly is a fast and cheap way to improve the overall efficiency of water use in the Nile Delta.

In this monograph, regional water distribution in the Eastern Nile Delta will be analysed. It will be shown that reuse of drainage water improves the total efficiency of water use. It will be shown that the efficiency of the main irrigation-water conveyance system is quite high. The same is true for field irrigation operations. The majority of irrigation water losses occur in the connection between the regional system and the local (farming) system. Efforts to cut down these losses have repercussions for the amounts of reused drainage water. Consequently, improvements to reduce operational water losses are less effective than assumed by decision-makers.

The Nile Delta

The Nile Delta is located in the north of Egypt along the two Nile branches to the Mediterranean Sea (Figure 1). Since ancient times, the Nile has deposited a highly fertile clay soil in the Delta. Along the fringes with the desert this clay layer is just a few meters thick, but in the centre it may be up to twenty meters thick. The clay swells upon wetting and shrinks upon drying. It is this swelling and shrinking behaviour that makes the soil suitable for irrigated agriculture. Without the resulting soil cracks, the infiltration rate of the soil would be too slow to apply surface irrigation.

The land surface is gently sloping from Cairo, in the south, to the Mediterranean Sea in the north. In the southern part of the Delta losses from the irrigation system and the agricultural land occur. To a certain degree these losses are balanced by groundwater use in the south. In the north saline upward flow is dominant and the groundwater is unsuitable for agriculture. The drainage water in the south and along the two Nile branches is presently of good quality and is partly or completely reused in irrigation by mixing.

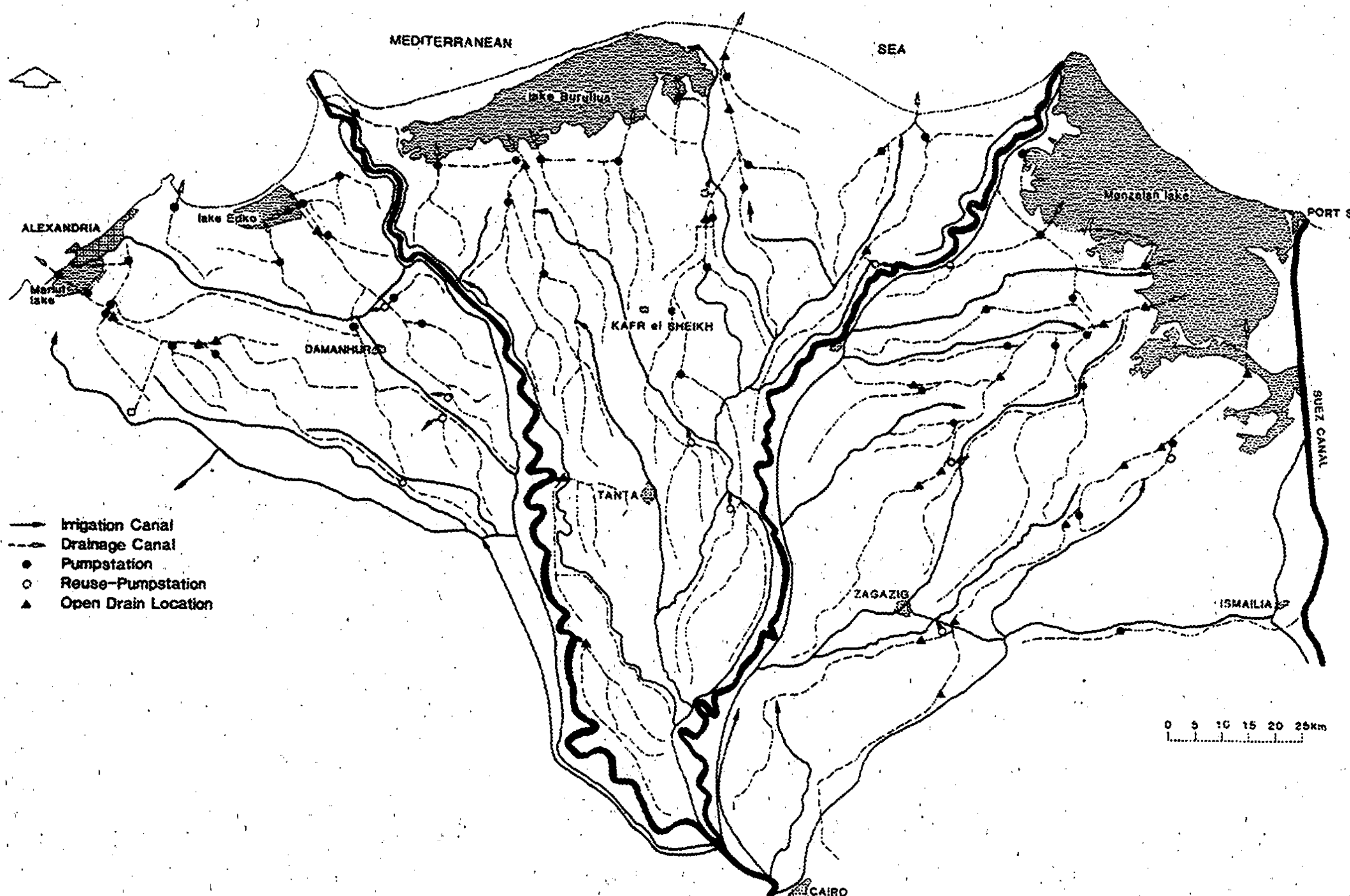

Figure 1. The Nile Delta has an agricultural area of about 1.7 million hectare.

Agriculture in the Nile Delta is characterised by small farm holdings with an average size of about 1.5 hectare. The main summer crops are cotton, maize and rice. The main winter crops are wheat and berseem (Alexandria clover), which is used to feed cattle. Field irrigation is implemented by subdividing the field in very small checks and flooding them.

Irrigation water supply is regulated at the apex of the Nile Delta, near Cairo. At this location the Delta Barrages were constructed and the water is distributed over the main canal intakes. The Eastern Nile Delta of about 755,000 hectares has nine of such intakes

(Figure 2). Water distribution to the main side branches (average size 60,000 hectares) of these irrigation command canals is by discharge control. The minor irrigation canals (called distributary canals) with an average command of 3,500 hectares are under rotation. Water supply to these canals is below land surface and control is based on downstream level. Farmers use diesel pumps to lift irrigation water from mesqaas, which are side branches of the distibutary canal, to irrigate their land. Nearly all irrigation canals, branches, distributaries and mesqaas, have tail end connections with the drainage system to prevent flooding of agricultural land in emergency situations.

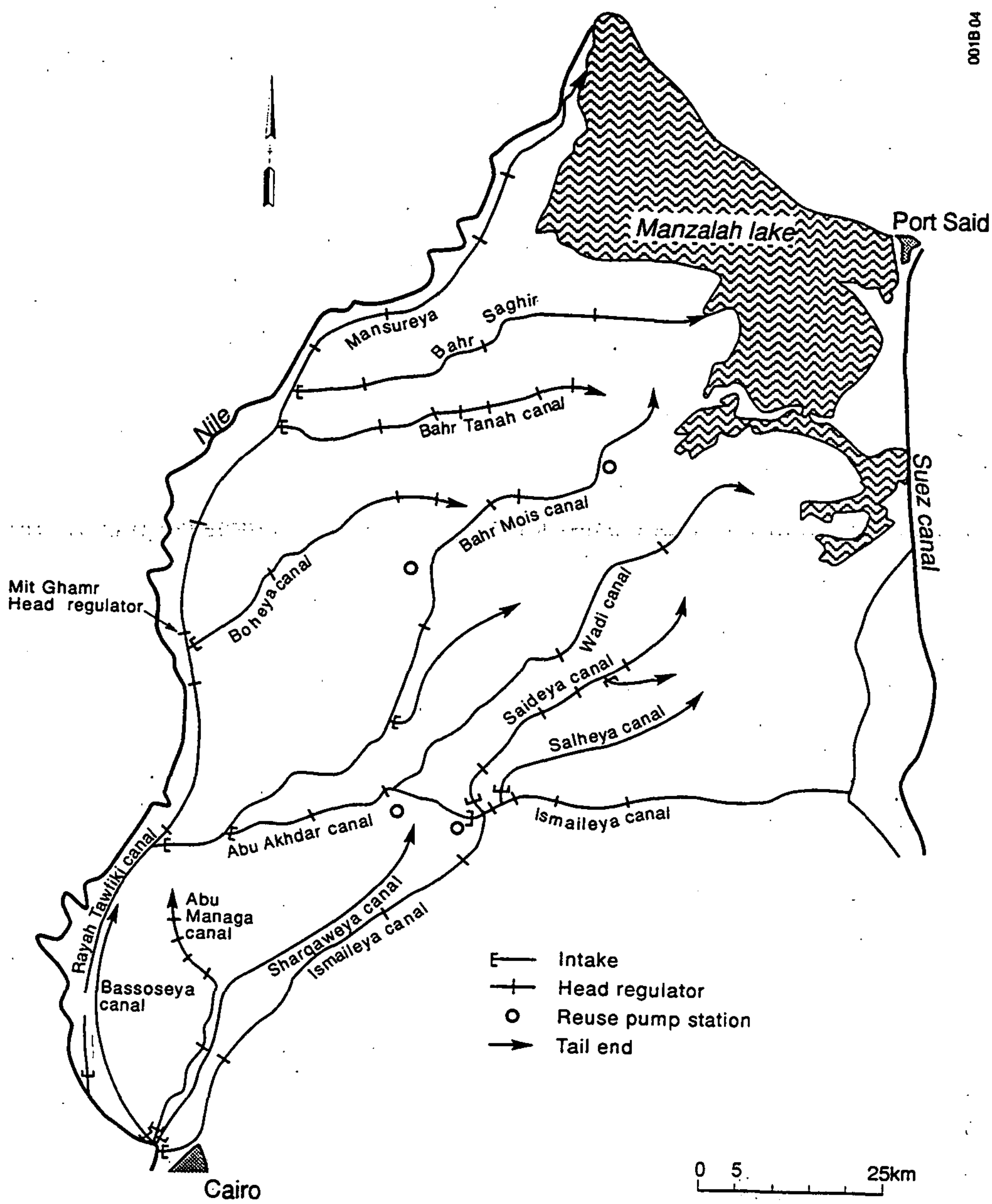

Figure 2. Irrigation canals to distribute the water in the Eastern Nile Delta.

The drainage system is a separate dendritic canal system to collect the agricultural drainage water, irrigation water losses and the sewage water from villages in the Nile Delta. Drainage water is conveyed to the north, where the majority discharges in the coastal Manzalah Lake (Figure 3). The Manzalah Lake is an important resting place for migratory birds and provides fish to the local population.

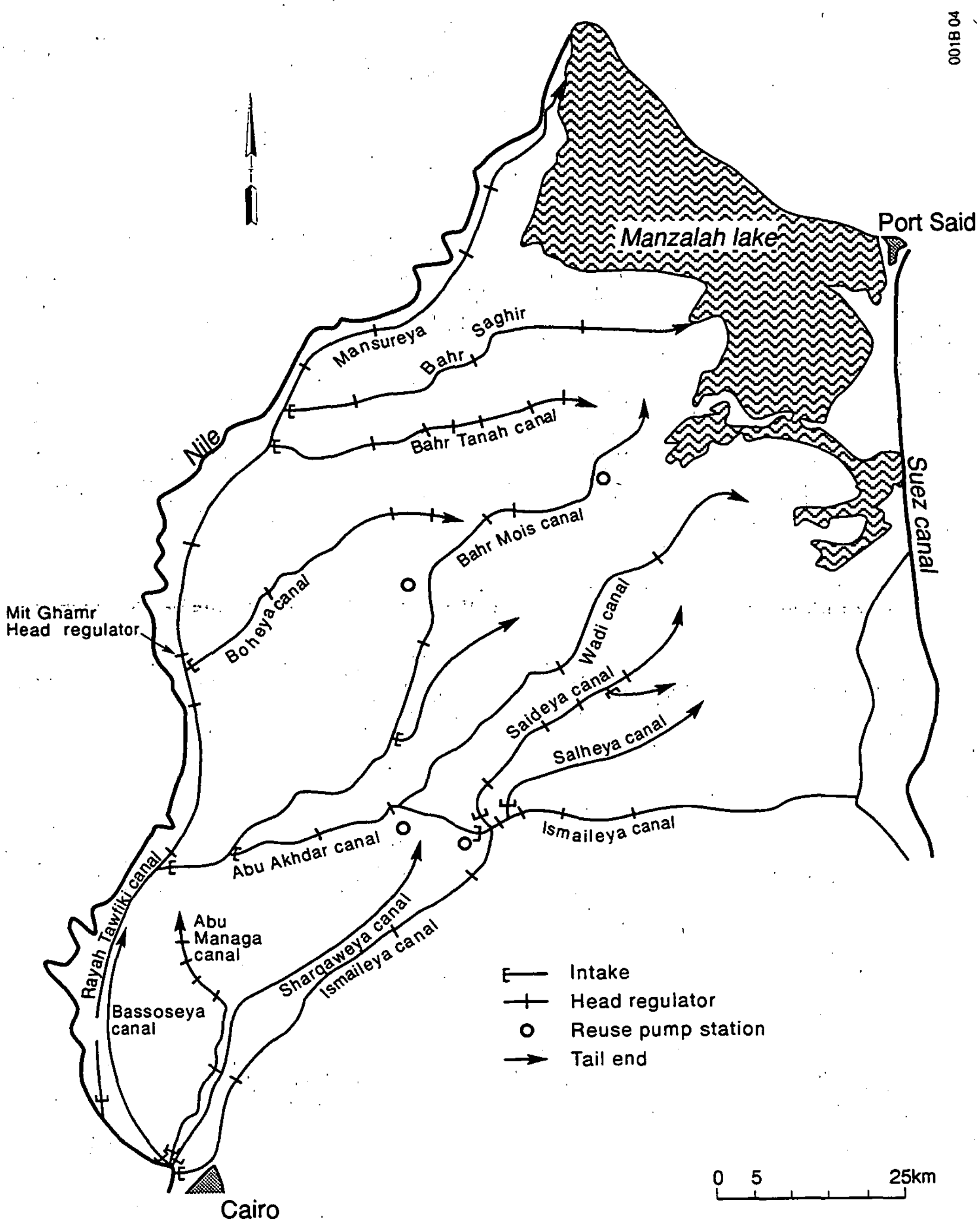

Figure 3. Drainage canals to collect and transport water from the Eastern Nile Delta.

Data used for the analysis

The discharge data of the main irrigation canals are under full control of the Ministry of Public Works and Water Resources in Egypt. These data were used for the analysis. The second data source is the discharge and salinity of the main drainage commands collected on a regular basis by the Drainage Research Institute in Cairo. Such data (water supply on about 14 locations and water discharge on about 23 locations) is not sufficient to make an analysis of water management for an area with the size of the Eastern Nile Delta of 775,000 hectare.

The majority of data used for the analysis have been taken from model simulations with the SIWARE model. This model package has been developed for the analysis of reuse of drainage water options in the Nile Delta of Egypt (Abdel Gawad et al, 1991, Abdel Gawad and Roest, 1991, Abdel Gawad and Smit, 1991, DRI/SC-DLO, 1995, Roest et al, 1993, Sijtsma et al, 1995).).

The SIWARE model consists of four main modules (Figure 4), each one with special functions:

- DESIGN to allocate the available irrigation water to the main canal intakes, based on the areas with different crops grown in the respective commands. The allocation takes also care of the (assumed) availability of drainage water ate selected locations in the system. DESIGN also computes the target levels throughout the irrigation system for all location where regulating structures are present.
- WDUTY to compute the farmers' water-demand, based on an unlimited supply of good quality irrigation water.
- WATDIS to compute the actual water distribution. WATDIS is a hydraulic model and confronts the target levels to be maintained by the irrigation authority for a fair distribution of water with the water demand of farmers, which try to maximise their share. Direct losses from the irrigation system to the drains are included in the computations through accounting for the day – night discrepancy between supply in the canals and the water uptake by farmers. Reuse of drainage water from the drainage system is included in the hydraulic computations and the resulting salinity of the (mixed) irrigation water is computed.
- REUSE to compute the actual consumptive use of water by crops, the soil salinity and the field water irrigation and drainage losses. Based on the supply of irrigation water, the crop water needs and the availability of and access to drainage water the module computes the unofficial reuse of drainage water by farmers. REUSE also accounts for municipal drainage water and computes the transport of the generated losses to the coastal lakes.

Data reliability

The simulation results were compared with the available data of irrigation supply and drainage discharge. Simulated water distribution agrees fairly well with reported values by the Ministry of Public Works and Water Resources (Figure 5).

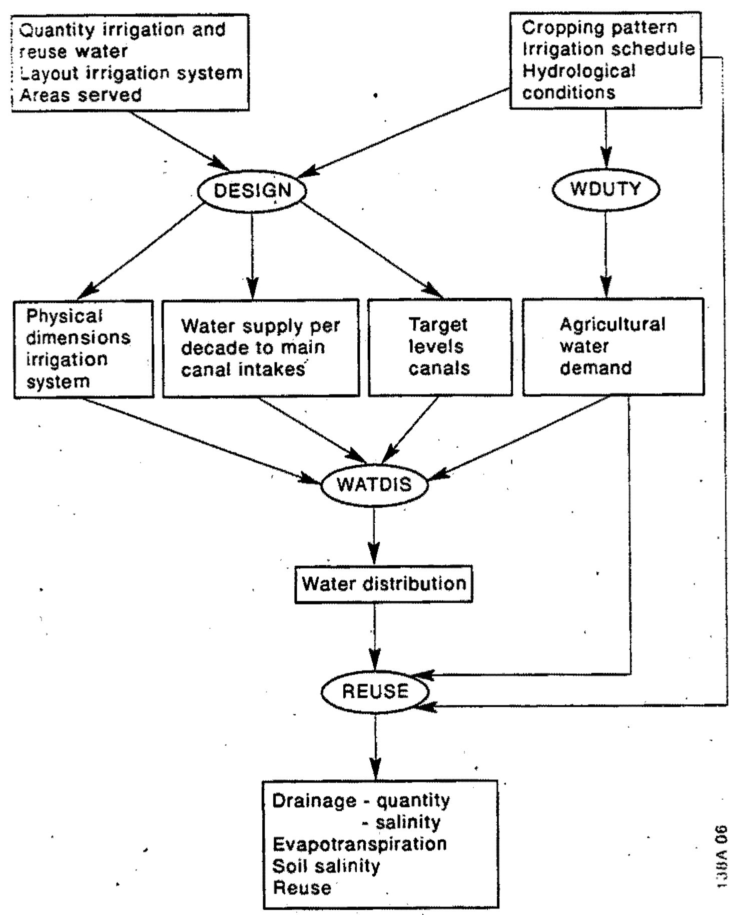

Figure 4. The SIWARE model consists of four modules and requires different types of input.

Total simulated discharge to the Mediterranean Sea from the Eastern Nile Delta agrees quite well with observations for 1986 (Figure 6). The same is true for the salinity and salt load.

The model has also been applied on the period from 1984 till 1988 to cover a substantial range of variation in water supply to the Eastern Nile Delta. Total simulated discharge and average salinity for this period shows a fair agreement with observations for the complete period (Figure 7).

In the international literature many researches have been reported giving the relation between soil salinity and crop yield. Since soil salinity is only one of the many production factors for crop yield, these experiments are normally performed under optimum crop growth conditions (sufficient water and nutrient supply), with the soil salinity as the only

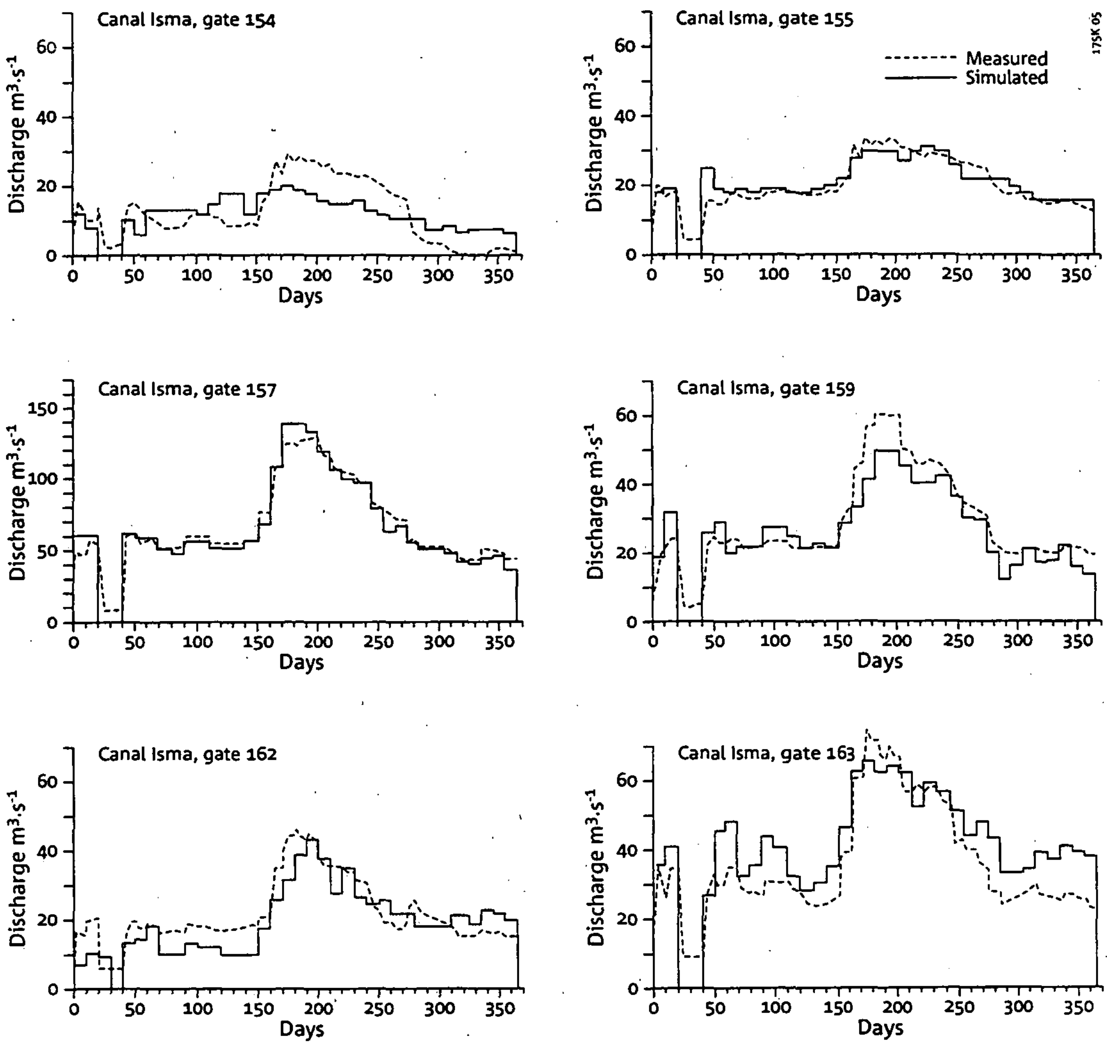

Figure 5. Measured and simulated discharges of six canals in the Eastern Nile Delta during 1986.

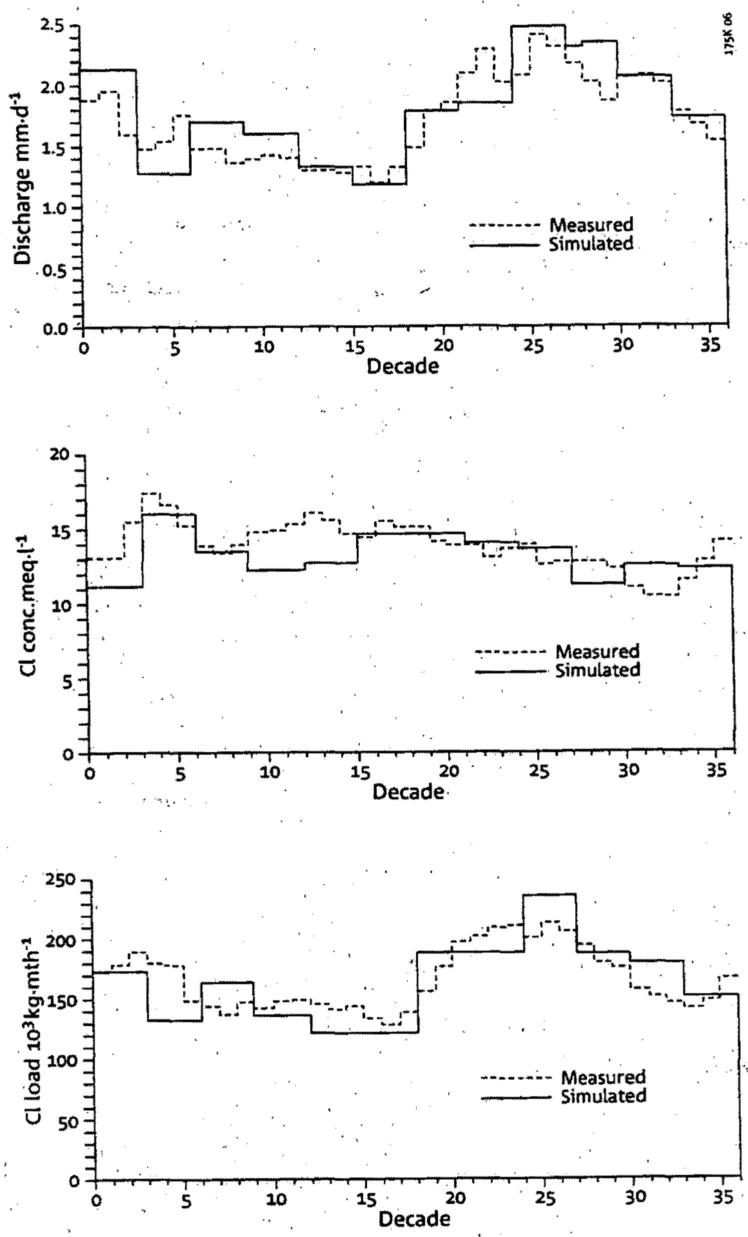

Figure 6. Simulated and observed drain discharges, chloride concentrations and chloride loads from the Eastern Nile Delta in 1986.

parameter to be varied. Maas and Hoffman (1977) report an extensive overview of this literature. The general shape of the crop yield response to soil salinity is a horizontal line until a certain threshold soil salinity value, and a linear decrease of crop yield with increasing soil salinity above this threshold value

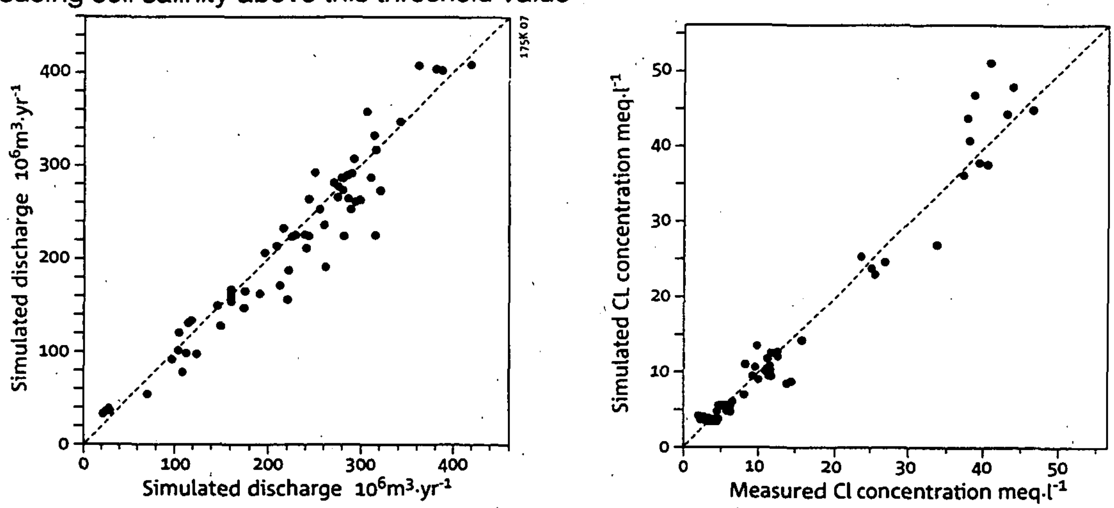

Figure 7. Simulated discharge and average salinity for catchments smaller than 100,000 hectares for the validation period 1984 - 1988.

Research, carried out by the Drainage Research Institute since 1977 on farmer's fields into the relation between soil salinity and crop yield (Amer et al, 1989, Morsi et al, 1987, Ramadan et all, 1981a, 1981b, 1983), consistently showed a large scatter in the soil salinity - crop yield relation. This scatter is supposed to be caused by variations in the production factors, other than soil salinity.

For the SIWARE model simulations the Eastern Nile Delta has been schematised into 82 calculation units (Figure 8). In each calculation unit a number of crops have been distinguished. In the model simulations such a crop is considered as a representative field plot. The simulation results of these representative field plots can be compared with field research results. The SIWARE model does not simulate the crop yield, but the relative evapotranspiration (relative to the optimum). It is generally accepted that relative evapotranspiration is correlated with crop yield and, consequently, the reduction of actual evapotranspiration rate may be used as an indicator of crop yield depression due to soil salinity or water stress conditions. The mentioned field research results relating crop yield with soil salinity, conducted in the Nile Delta in Egypt, can be compared with the model simulation results relating the relative evapotranspiration with soil salinity (Figure 9). Doing so, two observations can be made:

- the SIWARE simulation results show a similar scatter of data as the reported field researches;
- the crop yield reductions measured in the field research tend to appear at lower soil salinity than the evapotranspiration reduction simulated with the SIWARE model

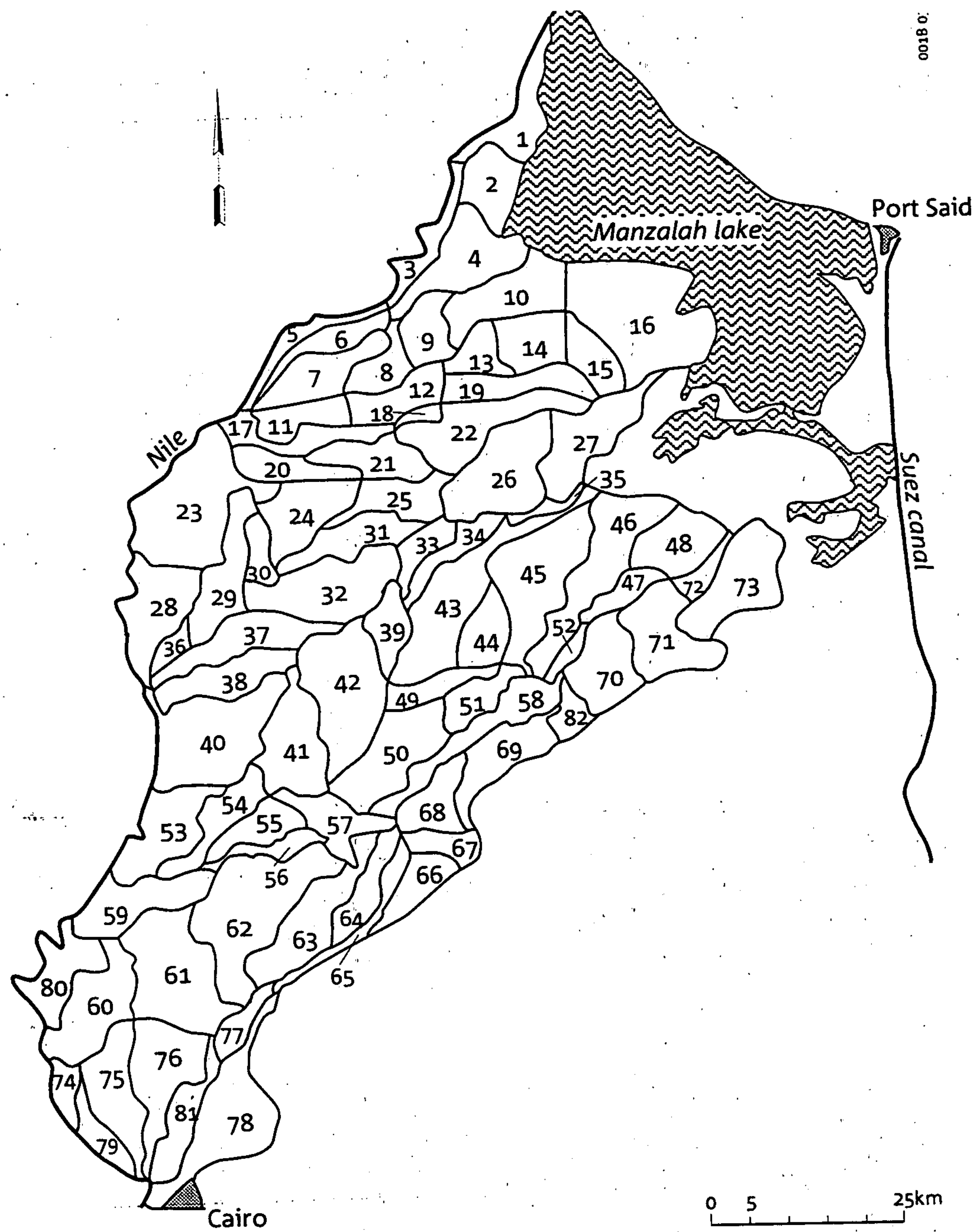

Figure 8. Calculation units distinguished in the Eastern Nile Delta

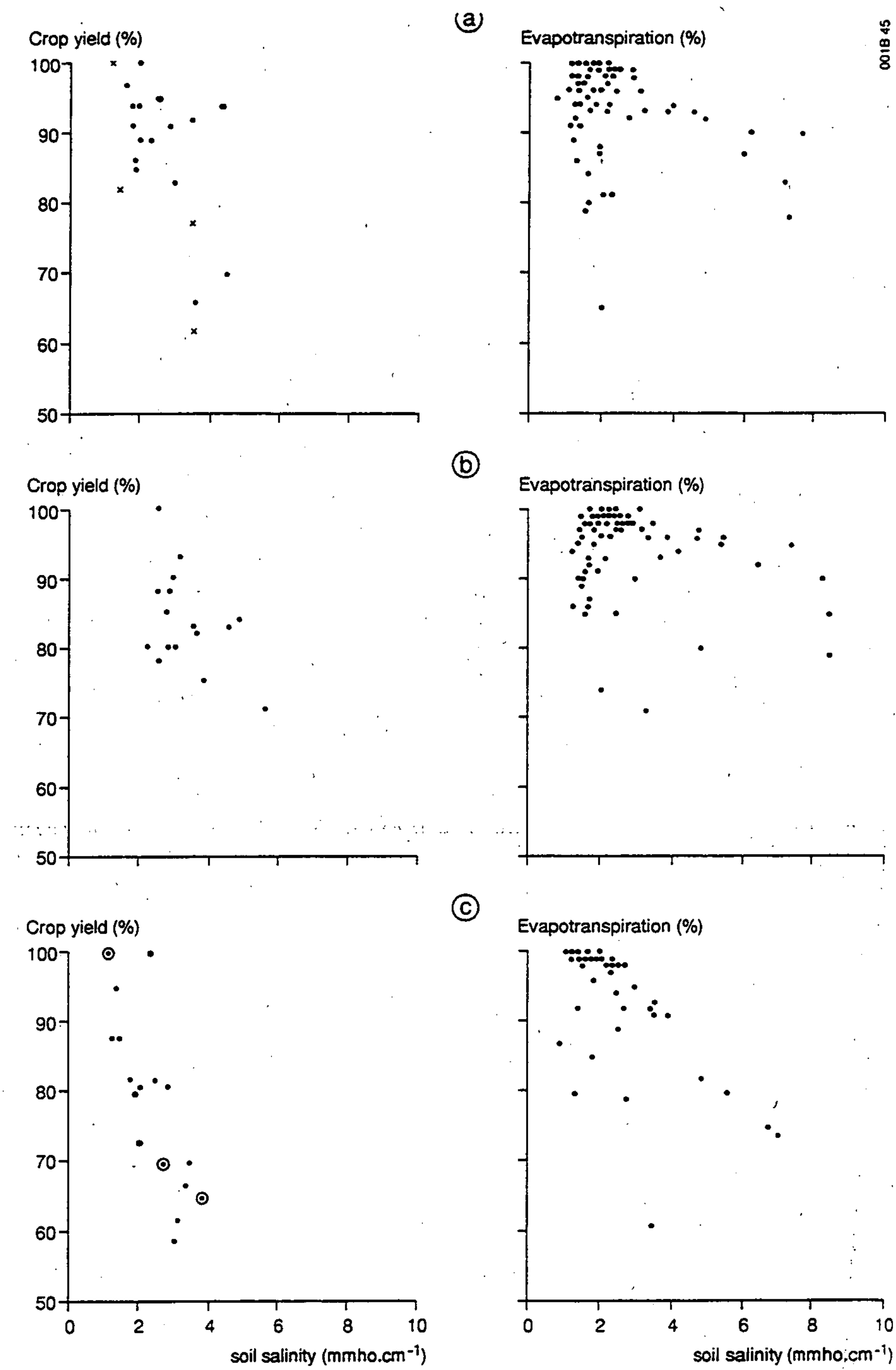

Figure 9 Comparison of observed crop yield response to soil salinity (field research results at farmer's fields - left) and simulated relative evapotranspiration response (simulated with the SIWARE model for the 82 calculation units in the study area - right).
a - berseem; b - wheat; c - rice

For the interpretation of the SIWARE simulation results with respect to crop response there is an advantage over the field researches carried out in the past. In the model simulations the water supply to the crops is also known. By singling out the model results for which the water supply is clearly at, or above, the optimum, the only production factor left (in the model) is the soil salinity. Taking the results for the crop long berseem as an example, no clear-cut relationship between soil salinity and relative evapotranspiration can be observed taking all simulated values into account (Figure 10). Below the soil salinity value of 2 mmho.cm^{-1} the reduction in evapotranspiration varies from 0% to 32% and in the soil salinity range between 4 and 8 mmho.cm^{-1} this reduction ranges between 12% and 21% (Figure 10). By selecting only the simulated values for which the total seasonal crop water supply is larger than 95% of the agricultural demand (simulated with the model WDUTY), a good correlation between soil salinity and relative evapotranspiration can be obtained (Figure 10). The remaining scatter in the data given may be explained by the fact that the average soil salinity till drain depth is given and in the SIWARE model the evapotranspiration reacts to the soil salinity of the root zone. Also the temporal water supply pattern may explain part of the remaining scatter. It is very well conceivable that during certain parts of the growing season shortages of water occurred, and that crop evapotranspiration was reduced due to water shortages, although the seasonal water supply may have been sufficient. The crop yield response reported by Maas and Hoffman (1977) is also included in this figure. For long berseem the crop yield appears to react at lower soil salinity than the simulated crop evapotranspiration response (Figure 10). This seems to confirm the second observation made by comparing the field research results with the SIWARE simulation result (Figure 9).

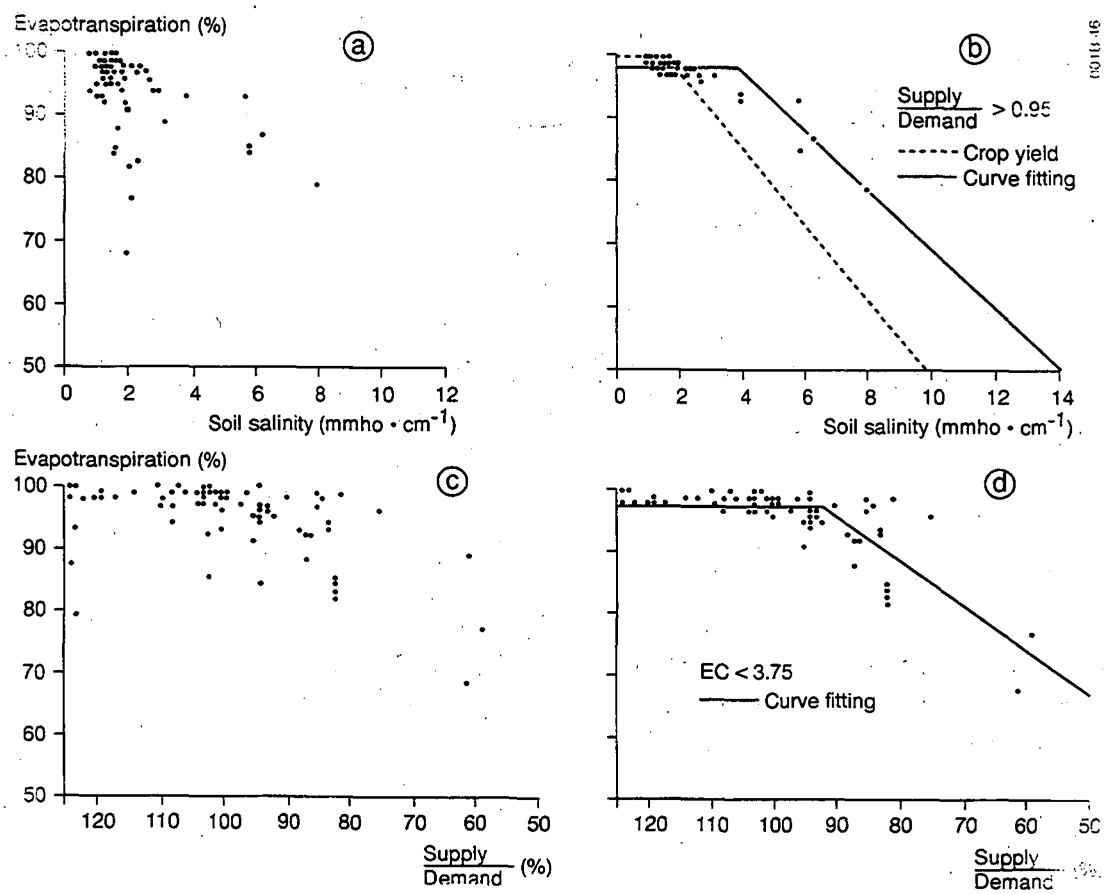

Figure 10 Relationship between the relative crop evapotranspiration of long berseem simulated with the SIWARE model for the 82 calculation units in the study area and the two production factors considered: soil salinity and water supply.

- a - relation soil salinity and relative evapotranspiration
- b - relation soil salinity and relative evapotranspiration under conditions of sufficient water supply
- c - relation water supply and relative evapotranspiration
- d - relation water supply and relative evapotranspiration under non-stress soil salinity conditions

Water and salt balances

The SIWARE model computations for the year 1986 have been used to draft the complete water balance of the Eastern Nile Delta (Figure 11). A number of balance components was given as input to the model. These are the total Nile water supply; the official reuse quantity, the municipal water use; and the groundwater use. Two water balance components have been computed and were validated against observations. These are the distributary water supply (validated at about 15 locations in the irrigation supply system), and the distributary drainage discharge (validated at about 27 locations in the drainage system). The remaining components are purely computation results. The WATDIS model with time steps of hours computed the conveyance losses, tail losses and spill losses. The REUSE model with time steps of days computed the unofficial reuse, leakage, seepage, evapotranspiration and crop drainage.

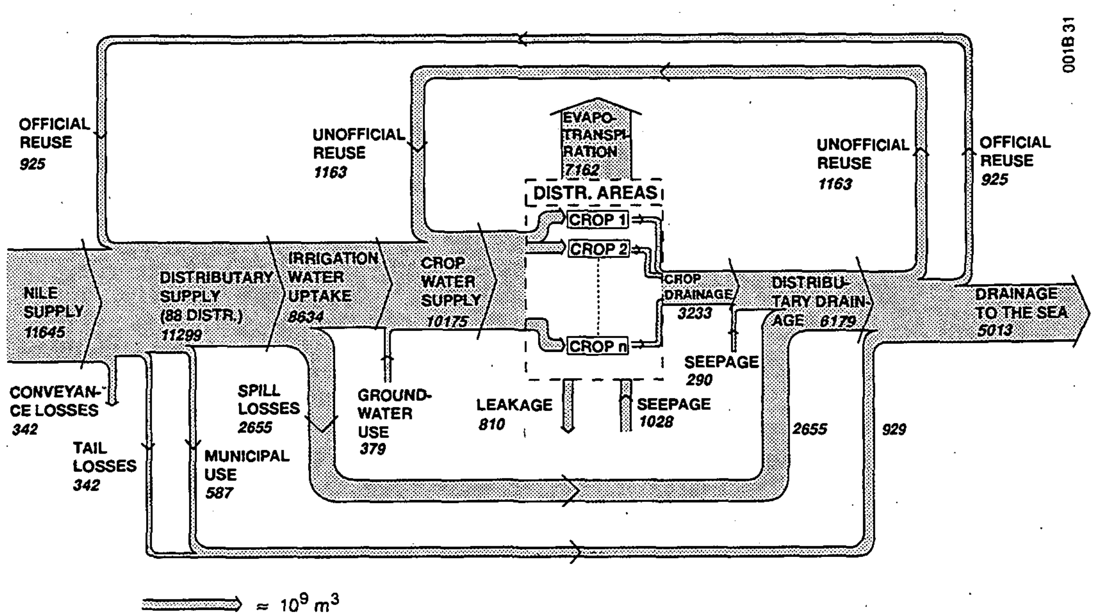

Figure 11 Water balance components Eastern Nile Delta in 1986

3% due to conveyance losses in the main canal system and 3% due to tail end losses reduces the total water supply to the Eastern Nile Delta of 11,645 million m3. Some 5% of the water supply is for municipal water use. Augmentation with reuse of drainage water with 8% results in 11,299 million m^3 or 97% of the total supply for agriculture (district water supply). According to this analysis, water management on main canal level is extremely efficient in the Eastern Nile Delta.

On district level the continuous water supply to distributary canals is distributed to mesqaas on rotational basis. Since farmers have a preference for irrigation during daytime, those farmers located near canal inlets tend to do so. Since withdrawal is free, farmers at the tail ends of the system can only irrigate at night. The system of continuous water supply at irrigation district level and periodically uptake of water by farmers results in daily variations in the water levels in the water supply system. The irrigation canal system at district level functions as storage reservoir buffering discrepancies between supply and demand. During periods with high water demand and supply, the storage capacity is insufficient and water spills to the drainage system. This amounts to about 23% of the total supply to the irrigation district (Figure 11).

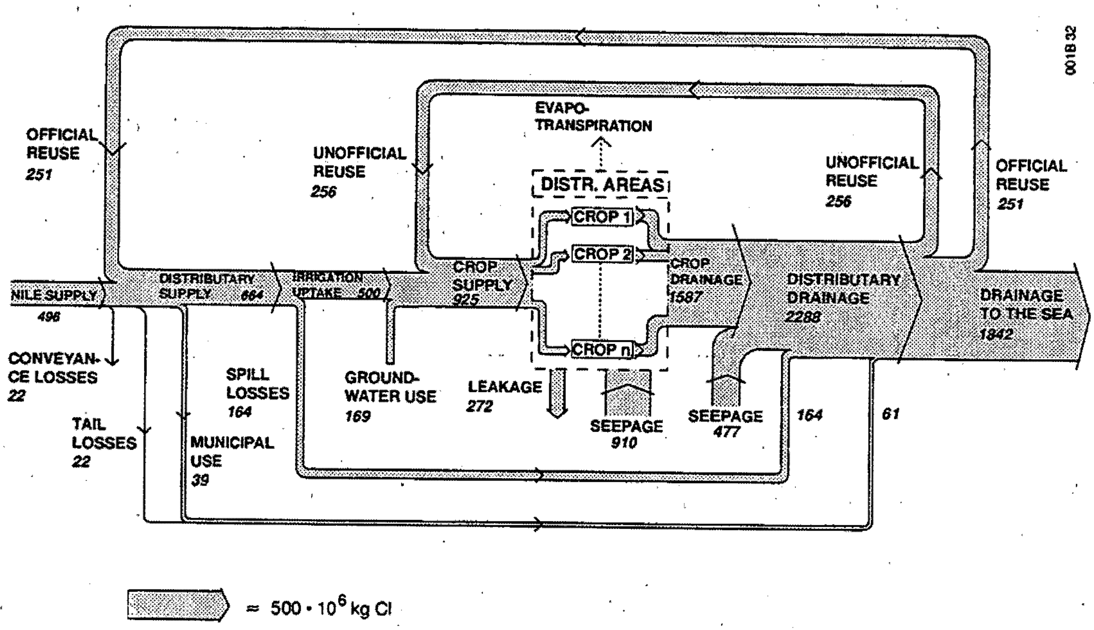

Figure 12 Chloride balance components Eastern Nile Delta in 1986.

At farm level, the irrigation water supply of 8,634 million m^3 is augmented with 13% by unofficial reuse of drainage water and 4% of groundwater to compensate for shortages in water supply to tail end farmers. The resulting evapotranspiration is about 83% of the irrigation water supply. Taking into consideration that a certain amount of leaching is required for sustainable field irrigation water management, the analysis suggests that at farm level the system operates at a high efficiency.

Each quantity of water transported includes the transport of salts. In the SIWARE simulation model the salt transport is confined to the chloride ion. Based on the simulation results the overall balances of chloride can be drafted (Figure 12). For drafting this balance two chloride concentrations were used for input. These are the chloride concentration of the Nile water (one value), and the chloride concentration of the groundwater used both for groundwater use and vertical upward seepage (values for each of the 82 calculation units). Validation of simulated chloride concentrations took place for the distributary drainage for the 27 observation locations. All other values are pure computations.

The efficient main canal and farming systems in the Eastern Nile Delta are enhanced by the reuse of drainage water practices at regional and local level. The salt balances clearly indicate the drawbacks of these practices. Official reuse of drainage water in the main system adds 3% of the total water supply, but adds 51% to the salt load in the main canal system. Similarly, unofficial reuse of drainage water and groundwater add 18% to the irrigation water supply to farmers, but 85% to the salt load. According to this analysis, the major source of salt in the Eastern Nile Delta is the upward saline seepage in the northern part of the Delta.

Performance indicators

In irrigation water management it is common to judge the performance on its irrigation efficiency. Generally, irrigation efficiency is determined on the basis of the ratio of water that reaches its destination over the water diverted to this purpose (Israelsen, 1932). In agriculture, water is diverted to satisfy crop water requirements and the definition of crop water requirements itself interacts with the (calculated) irrigation efficiency. One of the problems is whether the leaching requirements should be included in the crop water requirements and how much the leaching requirements should be. Another is the degree to which the potential evapotranspiration should be satisfied and to which degree it may be reduced.

A practical approach is to relate the losses from (sub) systems to the total supply to (sub) systems. This avoids the tedious work of defining crop water requirements. In this case we cannot talk about irrigation efficiency (Bos, 1980, ICID, 1978) and the term irrigation performance indicator is used here. A further simplification can be applied by neglecting the interaction with the groundwater system (losses to and gains from the aquifer), because they are difficult to measure.

In this monograph the following (sub) systems and performance indicators have been defined (see also Figure 11):

The main canal system is under control of the Ministry of Public Works and Water Resources and has the main functions to supply water to municipalities and to irrigation districts. Consequently, the main canal system performance indicator would read:

100 (Municipal water delivery + District water delivery) / Nile water supply

Taking the numbers from figure 11 for the situation in 1986, an efficiency indicator of 102% is calculated. The reason for this incredibly high value is that the losses from the main canal system are more than compensated by the official reuse of drainage water.

The district canal system is under control of the irrigation district engineers and has the main function to distribute the available water within the irrigation district to satisfy the crops in the field. Consequently, the district canal system performance indicator would read:

100 (Crop water delivery) / District water delivery

Taking the numbers from figure 11 for the situation in 1986, an efficiency indicator of 90% is calculated. Again, the reason for the fairly high value of this indicator is the compensation of the losses from the distributary canals and mesqaas by groundwater use in the south and unofficial reuse of drainage water by farmers (Figure 11).

Taking the farmers' fields as the focus of attention, also system indicators can be defined. Neglecting the interaction with the groundwater system, the farm system performance indicator can be defined as:

100 (Crop water delivery – Crop drainage) / Crop water delivery

Taking the numbers from figure 11 for the situation in 1986, an efficiency indicator of 68% is calculated. Keeping in mind that leaching requirements are not included in the analysis, this gives a clear indication that such performance, as an average, is proof that farmers do not waste water and that field irrigation efficiencies are quite high. This does not indicate that wastage of water does not occur, however, because this is an average figure. It does implicate that wastage of water on one place may be compensated by shortages on other places in the system.

Enlarging the focus by moving form the farmers' fields to the irrigation districts the performance indicator for this scale level can be defined as:

100 (District water delivery – District drainage) / District water delivery

Taking the numbers from figure 11 for the situation in 1986, an efficiency indicator of 45% is calculated. This extremely low figure is explained by the large spill losses in the distributary and mesqaa canals and the connection between the continuous water supply at district level and the day – night variations in the uptake of water by farmers. Obviously, the tail end – head end inequity is also playing an important role in these large losses.

For the complete Eastern Nile Delta, the municipal water supply has to be taken into account for the system indicator:

100 (Nile water supply – Drainage to sea + Municipal water delivery) / Nile water supply

The overall system performance indicator for the Eastern Nile Delta calculated with the data for 1986 comes to 62%, which is a fairly good performance for a system with the size of the Eastern Nile Delta.

Water saving strategies

The weak point in the performance indicators derived for the Eastern Nile Delta obviously lies in the connection between the regional water supply system with continuous water supply and the local uptake system with a daily pattern. The system is especially vulnerable during periods with relatively low storage capacity in the district irrigation system. This is during the peak demand period in summer, and especially in the areas where a large proportion of the land use is rice during summer. Due to the ponded growing conditions of rice, this crop has an almost triple water requirement compared to the remaining summer crops. The effect of water savings on rice crop water use on the performance indicators has been studied in two ways by applying the SIWARE model to the Eastern Nile delta case:

1. By replacing in the model simulations the rice crop in stages from south to north by maize. This measure represents a strategy of demand management: the water requirements are reduced.
2. By reducing the water allocated to the rice crop in steps from the original triple value to the water requirements of the other summer crops. This measure could be considered as a special form of supply management. By creating local water scarcity, it is left up to the farmers to use the supplied irrigation water more efficiently and/or look for additional drainage water to compensate for this scarcity.

Total water savings in both strategies are up to 24% of the normal Nile water supply (Table 1). The effect on the main canal supply indicator is only minimal, but negative for both strategies. Tail end losses are reduced, but at the same time the possibilities for reuse of drainage water are reduced. In other words: the system was efficient and remains efficient when these water saving strategies are implemented.

Table 1 Effect of two water saving strategies in the Eastern Nile Delta on performance indicators. Area indicates the strategy to replace rice by maize. Duty indicates the reduction of the allocation uty of rice.

	Supply system indicator (%)				Total system indicator (%)					
Water savings	Main canal		District canal		Farm		District		Eastern Nile Delta	
(%)	Area	Duty	Area	Duty	Area	Duty	Area	Duty	Area	Duty
0	101	101	87	87	71	71	45	45	61	61
2	100	101	87	88	71	71	45	46	61	62
6	100	101	88	91	72	71	46	48	63	65
9	100	101	89	93	73	72	47	48	64	66
12	99	101	89	94	73	72	48	49	64	67
14	99	100	90	95	74	73	48	50	65	68
17	99	100	91	96	75	75	50	51	66	70
24	99	100	93	95	78	78	53	53	70	72

The effects on the district canal performance indicator are significant. In the duty scenario spill losses remain larger than in the area scenario, but this is compensated largely by an increase of unofficial reuse (Table 1).

On farm level the performance indicator for the rice area reduction strategy is larger than that of the duty reduction strategy (Figure 13). With the rice area reduction strategy rice is replaced by maize and the associated losses with rice cultivation are decreased proportionally with the reduction in the rice area. For the duty strategy, apparently sufficient additional reuse of drainage water is organised by farmers to keep crop drainage on a higher level than in the alternative, resulting in lower performance indicators.

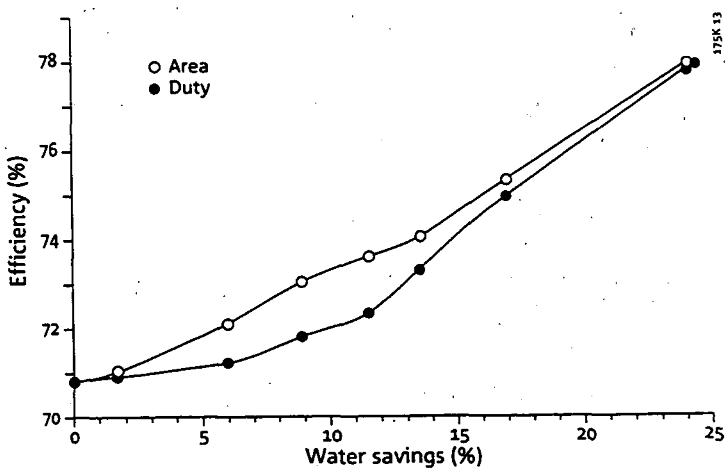

Figure 13 Crop system performance indicator (efficiency) for the two water saving strategies (Area and Duty).

The district performance indicator is affected by the water savings up to 24%, but much less than would be expected (Figure 14). Total water savings in both strategies is in the order of magnitude of the spill losses incurred in the reference situation. The increase in efficiency is much less than the reduction in the water supply. Apparently, the unequal water distribution problems and limited storage capacity in the district canal system still is insufficient at the lower supply rates. Contrary to the crop system indicator, the duty reduction strategy performs better than the rice area reduction strategy (Figure 14).

The same observations can be made for the total Eastern Nile Delta performance indicator (Figure 15). The duty reduction strategy is more effective than the rice area reduction strategy. In total the reduction of 24% in water supply results in an increase in performance of about 9 to 11%.

Conclusions

The analysis of water management for the Eastern Nile Delta in Egypt using the SIWARE model for filling in the gaps in observations clearly indicates a conflict of interest in water

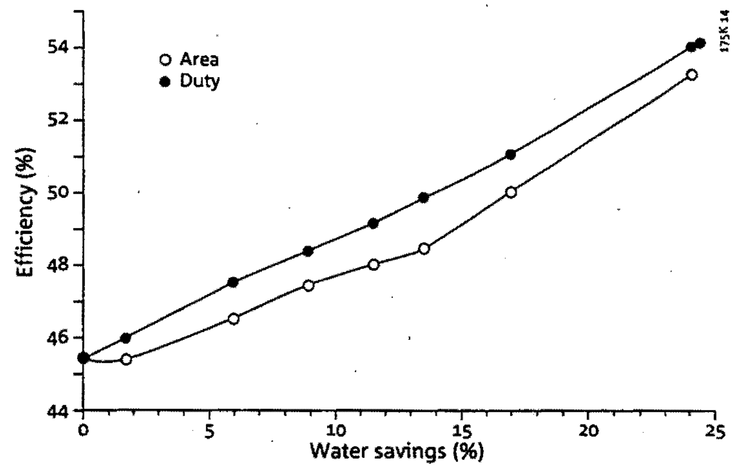

Figure 14 District system performance indicator (efficiency) for the two water saving strategies (Area and Duty).

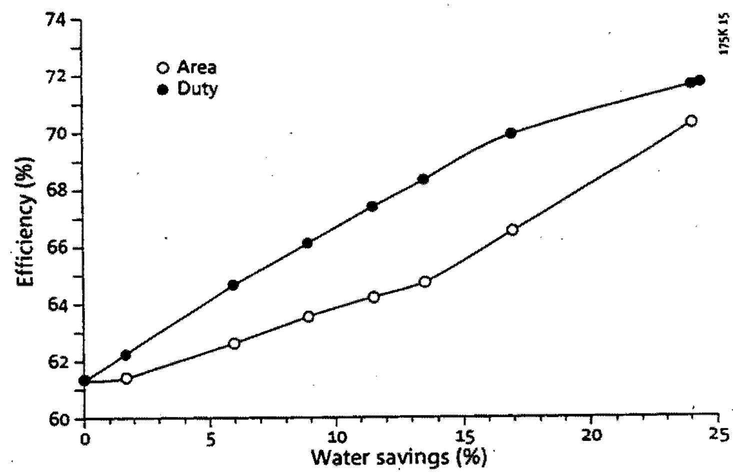

Figure 15 Total Eastern Nile Delta system performance indicator (efficiency) for the two water saving strategies (Area and Duty).

management between the local scale and the regional scale. On regional scale water management is very efficiently organised and water losses are limited and more than compensated by reuse of drainage water. On local scale (field level) water management is quite efficient and farmers appear (on average) to waste only limited water. The connection between the regional system and the local system involves the transition of continuous supply to the daily water uptake pattern of farmers and the storage capacity of the local district irrigation system is insufficient for complete storage of the excess supply during night. Combined with the tail end – head end discrepancies this results in very large irrigation water losses in this connection between regional and local system.

The overall efficiency of water use in the Eastern Nile Delta is quite high due to the reuse of drainage water practices on regional and local scale. Irrigation water management improvements by the introduction of water saving strategies on regional level to reduce these losses are therefore less efficient than one would expect. A better operation of water distribution on the connection between the regional and local level for instance through the introduction of water user associations would be required to avoid such losses. Such institutional improvements most probably would at the same time decrease the possibilities for reuse of drainage water.

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MODELLING FIELD SCALE WATER FLOW AND SOLUTE TRANSPORT FOR IRRIGATION AND DRAINAGE DESIGN

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Introduction

Deterministic simulation models are important tools in fundamental and applied hydrological research. They allow detailed analysis of flow and transport mechanisms at laboratory and field experiments. Once deterministic models are properly calibrated, they can be used to simulate all kind of scenario analysis. Currently a revolution in data communication occurs. For the first time in history huge amounts of digital data can be exchanged by anyone almost instantly to any place on earth at low costs. The rapid development in data communication enhances the versatility of simulation models, as it facilitates exchange of input data and online support.
One of deterministic agro-hydrological models, the SWAP model, aims to simulate water flow, solute transport, heat flow and crop growth in the Soil-Water-Atmosphere-Plant environment. The model employs the experiences of many researchers at the Wageningen Agricultural University and the Winand Staring Centre in Wageningen over the past 20 years. In this paper we describe the philosophy behind the development of SWAP and its current main features. We illustrate the program potential by an irrigation application in Pakistan and a salinization application in The Netherlands.

The SWAP model

SWAP development was guided by the following basic demands:

- Allow direct interaction between water flow, solute transport, heat flow and plant growth
- Simulate physical, chemical and biological processes at field scale level
- Accomodate long term simulations, with multiple crops a year
- Employ experiences with SWATR and its derivatives
- Develop for researchers, engineers and students

In the soil many interactions between water flow, solute transport, heat flow and plant growth occur. For instance, the water fluxes affect the rate of salinization, while the salt concentrations affect the actual root water uptake rate. Solute decomposition is sensitive to soil temperatures, which on their turn are directly influenced by the soil wetness. Water and salinity stress may affect crop development and soil cover, which vice versa affects soil evaporation and crop transpiration. In order to analyse all these interactions, SWAP solves simultaneously the numerical equations for water flow, solute transport, heat flow and crop growth.

The spatial scale at which the physical, chemical and biological processes are described is the farmer field. At this scale, the meteorological conditions, cultivation pattern, soil profile and drainage conditions are more or less homogeneous and clearly defined. This is important, as the input data are not a weighted areal average, in general requiring calibration, but the input data can be directly measured in the field or derived from geographical information systems.

In most applications, we are not only interested in one or some average meteorological year, but also how plant growth and solute leaching are affected by extra-ordinary meteorological periods. Furthermore, some processes, as salinization and groundwater recharge, require analysis over a large number of years. Therefore long term simulations, without loss of short term accuracy, is one of the basic demands.

Feddes et al. (1978) developed the agrohydrological model SWATR to describe transient water flow in cultivated soils with various soil layers and under the influence of groundwater. The model was further developed to accommodate more boundary conditions (Belmans et al., 1983), crop growth (Kabat et al., 1992), shrinkage and swelling of clay soils (Oostindie and Bronswijk, 1992), and salt transport (Van den Broek et al., 1994). Gradually the need was felt for a program that included the options of the various SWATR derivatives and to update the numerical schemes, program structure and user interface.

The model should assist researchers in their analysis of experiments and allow to test alternative theoretical concepts and to run all kind of scenarios. Also the model should be useful to students to illustrate the interaction between agrohydrological processes.

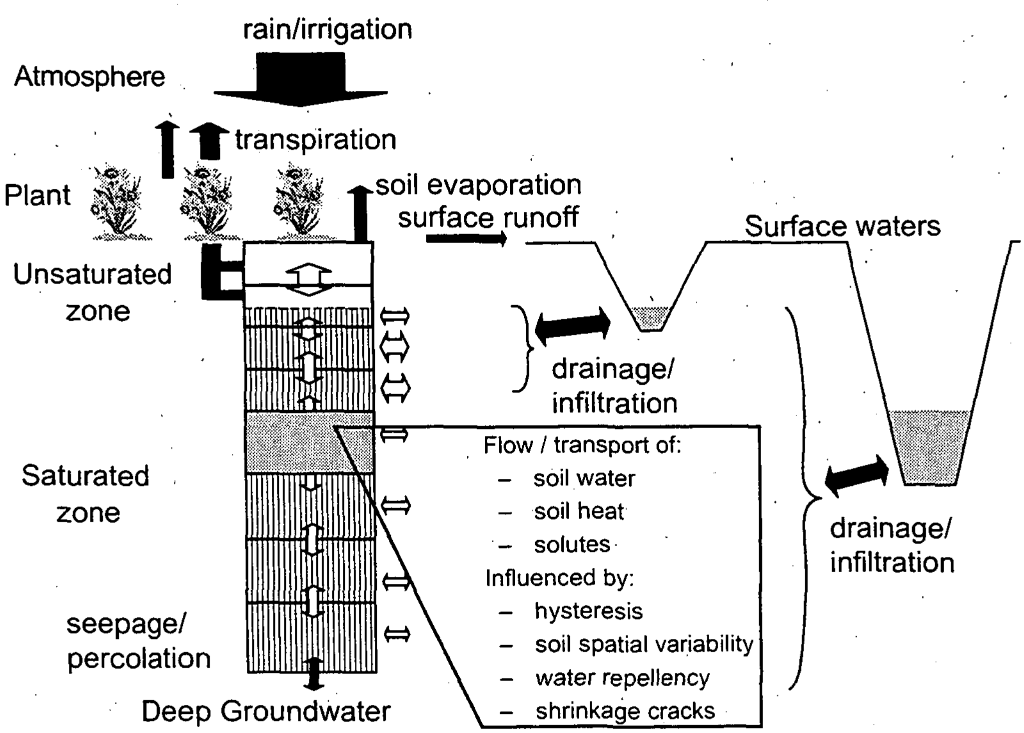


Figure 1: Schematization of the simulated processes by the SWAP model

Figure 1 schematizes the processes incorporated in SWAP. The upper boundary is located just above the vegetation, the lower boundary in the top groundwater system. At the region in between, the main flow and transport processes are vertical, which allows a one-dimensional model structure.
The upper boundary conditions are determined by the potential evapotranspiration, irrigation and precipitation. Basic, daily meteorological data are used to calculate daily, potential evapotranspiration according to Penman-Monteith (Smith, 1992). If basic meteorological data are not available, potential evapotranspiration or reference evapotranspiration can be input. Precipitation may be provided either at a daily basis or at actual intensities. Short term rainfall data allow the calculation of runoff and preferential flow.
In SWAP, irrigation may be prescribed at fixed times or scheduled according to a number of criteria. The scheduling option allows the evaluation of alternative application strategies. The timing criteria include allowable daily stress, allowable depletion of readily available water in the root zone, allowable depletion of totally available water in the root zone, and critical pressure head or water content at a certain depth.
Crop growth is simulated by the code WOFOST 6.0 (Spitters et al., 1989). The processes considered include rate of phenological development, interception of global radiation, CO_2 assimilation, biomass accumulation of leaves, stems, storage organs and roots, leaf decay and root extension. The assimilation rate is affected by water and/or salinity stress in the root zone. If simulation of crop growth is not needed, the user should prescribe leaf area index, crop height and rooting depth as function of development stage.
The potential evapotranspiration rate is divided into potential transpiration rate and potential evaporation rate based on the actual leaf area index or crop cover. Reduction of the potential transpiration rate depends on the soil water pressure head according to Feddes et al. (1978), and the salinity concentration according to Maas and Hoffman (1977), as depicted in Fig. 2. Reduction of potential evaporation rate depends on the maximum soil water flux in the top soil according to Darcy, or is calculated by an empirical function following Black et al. (1969) or Boesten and Stroosnijder (1986).

SWAP employs the Richards' equation for soil water movement in the soil matrix. A physical description rather than a parametric description of water flow is important as it allows the use of soil physical data bases and the simulation of all kind of management scenario's. In order to solve the Richards' equation, the soil hydraulic functions of each soil layer should be known. The soil hydraulic functions, expressing the relations between soil moisture content, pressure head and unsaturated hydraulic conductivity, are described by tables or the Van Genuchten-Mualem analytical model (Van Genuchten, 1980).

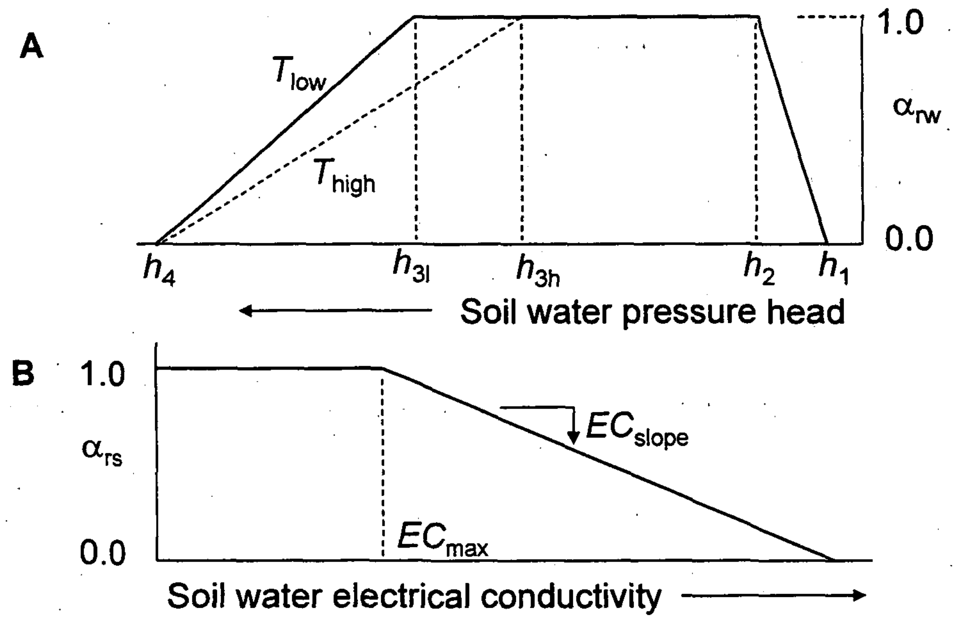


Figure 2: (A) Reduction of the potential transpiration rate due to water stress (Feddes et al., 1978); (B) Reduction of the potential transpiration rate due to salt stress (Maas and Hoffman, 1977)

As SWAP is designed to simulate field scale conditions, the inherent spatial soil heterogeneity should be considered. Spatial variability of the soil hydraulic functions is described with the scaling concept of Miller and Miller (1956). The user may provide the reference curve and a number of scaling factors, and SWAP will generate for each scaling factor the soil hydraulic functions and the corresponding water and solute balance and relative crop yield. The concepts of Bronswijk (1991), including the shrinkage characteristic, are used to calculate crack width and crack depth in shrinking and swelling clay soils. The shrinkage characteristic is described with an analytical function. When the rainfall intensity exceeds the maximum matrix infiltration rate, the runoff water collects in the cracks. In order to calculate runoff, instead of daily rainfall averages, actual rainfall intensities should be provided. Water in the cracks may infiltrate laterally into the soil matrix or flow rapidly to nearby drains or ditches. Once the water fluxes are known in the cracked clay soil, calculation of the solute fluxes is relatively straightforward. Due to water repellency, soil water may bypass large parts of the unsaturated soil domain. The water flow and solute transport in water repellent soils is solved by the mobile/immobile concept (Van Genuchten and Wagenet, 1989).
Options for the soil water lower boundary include soil water flux, groundwater level, soil water flux as function of groundwater level, free drainage and lysimeter with free drainage. In addition, the user may define a drainage system. Field drainage is

calculated by a specified groundwater-drainage relation, or by analytical drainage formulas (Ritzema, 1994). In this way different drainage designs can be evaluated. Regarding solutes, SWAP simulates convection, diffusion and dispersion, non-linear adsorption, first order decomposition and root uptake (Boesten and van der Linden, 1991). This permits the simulation of ordinary pesticide and salt transport, including the effect of salinity on crop growth.
SWAP theory is in more detail described by Van Dam et al., (1997), the program use is documented by Kroes et al., (1999). The program is written in FORTRAN 77 and may run on 486 or higher IBM compatible PC's. A graphical user interface facilitates Windows-based input of data and analysis of simulation results (Huygen et al., 1998).

Irrigation application in Pakistan

Introduction

In ancient times agriculture attributed to the wealth of the Indus Valley Civilization. Also nowadays agriculture is an important part of Pakistan's economy, employing almost half of the labour force and producing 25 % of the gross national product. About 75 % of the total cropped area in Pakistan is under irrigation. The current irrigation system in the provinces Punjab and Sind is one of the most extensive irrigation systems in the world. In the second half of the 19th century perennial irrigation was introduced to supply water both during the summer and winter season. The continuous irrigation supply caused a gradual rise of the groundwater table. Along the canals and in lower areas waterlogging started to hamper agricultural production (Fig. 3). At fields with shallow groundwater tables, capillary rise brought salts back into the root zone. Already in the beginning of this century, waterlogging and salinity posed such problems that remedial measures became necessary. Measures taken to lower the groundwater table were canal closures, lowering of canal levels, lining of canals, planting of eucalyptus trees, drainage by open surface and recently drainage by tile drains and water extraction by tube wells.

Tubewells might be used to relieve the shortage of canal water, to lower the groundwater table, to leach saline/sodic soils and to add flexibility in time and amount of irrigation. The Indus plain is underlain by deep deposits of unconsolidated sediments consisting of fine to medium sand. The high transmissivity of this aquifer favours the use of tubewells. Since 1959, as part of Salinity Control and Reclamation Projects (SCARP), 20.000 deep, public tubewells were constructed. The last 15 years, shallow, private tubewells became popular. IWASRI (1991) estimated that in 1985/1986, 11.0 10^9 m^3 of water was extracted by public tube wells and 30.2 10^9 m^3 by private tube wells. Regarding its effect on waterlogging and salinization, Kuper and van Waiijen (1993) mention a survey among 200 farmers in 40 water courses in Fordwah and Azim distributaries in Punjab, which showed that a majority of the farmers observed a decrease in salinity levels during the past 6-7 years. Some farmers were able to reduce

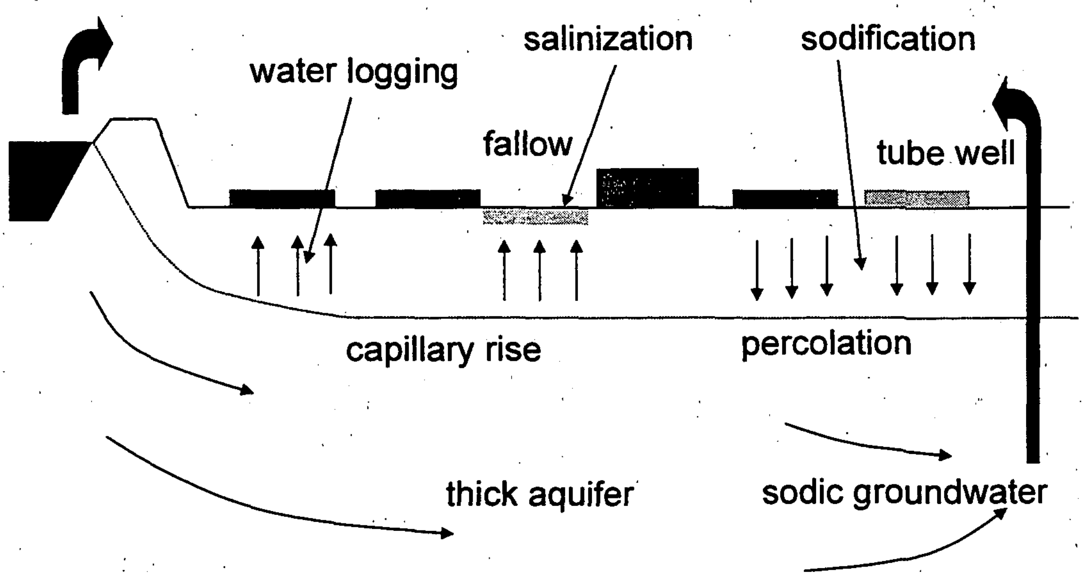


Figure 3: Side effects of irrigation in Punjab, Pakistan

salinity levels from 8 dS/m to 3 dS/m within 2-3 seasons. However, despite the clear advantages, also serious concerns exist of the long term effects of irrigation with tubewell water (Fig. 3). Groundwater with a high sodium content will be brought back in the root zone, which may detrimentally affect the soil structure, root water uptake and plant growth.

Since 1988, the International Irrigation Management Institute (IWMI) has conducted integrated field research on inter-related aspects of irrigation, salinity and agricultural production (Kuper, 1998). The research was conducted on farmers' fields in order to capture the wide range of irrigation practices that are employed by farmers in response to the physical environment with which they are faced. Currently, research efforts are focused on the Chishtian Sub-Division in south-east Punjab, a 70,000 ha irrigation scheme, receiving it's surface irrigation water through the Fordwah Branch canal. Increased cropping intensities have prompted farmers to augment available canal water supplies by groundwater, pumped by over 4000 tube wells in the area (about 7 per 100 ha). Consequently, groundwater tables have dropped and waterlogging is generally not a problem. The average electrical conductivity (EC) of all the tube wells amounts 0.89 dS/m, with 90% of the tube wells showing an *EC* between 0 and 4 dS/m. The study area is located in the arid agro-ecological zone, with cotton and wheat as dominant crops in the summer (June till December), respectively the winter season (January till May). The soils are of alluvial and eolian origin, resulting in a mixture of silty to sandy deposits (Smets et al., 1997).

Experiment

Four farmers' fields of 0.4 ha each were monitored during three growing seasons in order to collect an extensive data set to calibrate and validate the SWAP model (cotton-wheat-cotton cycle from July '94 up to December '95). The four fields represent the predominant soils in the study area, ranging from a loamy sand to a silty clay loam. In Table 1, soil type and availability of canal water and/or tube well water is indicated for the four fields. The farmers of field 1 and 2 have access to canal water and both own a tube well to supplement their canal water supplies. The farmers of field 3 and 4 do not have access to canal water, but have a shared ownership of a tube well. The water quality of canal water is excellent with an *EC* of 0.2 dS/m. The farmers of field 1 and 2 use groundwater from various tube wells with an *EC* ranging from 0.8 to 1.6 dS/m. The farmers of field 3 and 4 use only water from one tube well, whose quality ranges during the season from 0.75 to 1.3 dS/m. Irrigation regime and crop development was registered by IWMI field staff. Farmers irrigate their bounded fields by flooding, whereby in the case of cotton small beds and furrows are made. Wheat is grown in basins. In each field tensiometers were installed at eight depths (at 15, 30, 45, 60, 90, 120, 150 and 200 cm) and were read almost every other day. At the beginning of a growing season, in each field, ten soil samples were taken at different depths and analyzed in the laboratory to determine the soil texture, moisture content and the *EC* of the saturated extract, EC_e. In the surrounding area of the sample fields, piezometers were frequently read and used to determine groundwater table depths of the four fields. Meteorological data were derived from the nearest meteorological stations and precipitation was recorded with rain gauges near the sample fields. Precipitation is about 150-200 mm annually (Smets et al., 1997).

Table 1. Characteristics of sample fields: soil type, irrigation water origin and quantity during the data collection period.

field	soil type	% canal water	% tube well water	depth irrigation water (cm)
1	loamy sand (LS)	75	25	396
2	sandy loam (SL)	67	33	167
3	loam to silty clay loam (L to SiCL)	-	100	159
4	loam to silty loam (L to SiL)	-	100	150

SWAP simulations

The water and salt balance of the four fields was simulated with the following input data (Table 2):

- Daily reference evapotranspiration, as calculated with the CROPWAT model (Smith, 1992)
- Daily rainfall and irrigation data, including irrigation water quality

- Relations between volumetric water content, soil water pressure head and unsaturated hydraulic conductivity of each soil layer, as expressed by the Mualem - van Genuchten parameters
- Crop factors, soil cover and rooting depth of the crop during the growing season
- Limiting pressure heads and *EC* values, to determine reduction of root water extraction due to water and/or salinity stress (Fig. 2)
- Groundwater levels (if less than 3 m from soil surface)
- Initial water contents and salinity levels

Table 2. SWAP input data.

General								
Boesten parameter	β = 0.90 $cm^{1/2}$							
Crop factors	Cotton: 0.5 - 0.8 - 1.2 - 0.9 - 0.7; wheat : 0.4 - 0.8 -1.15 - 0.7 - 0.3							
Maximum rooting depth	Cotton: 140 cm; wheat: 110 cm							
Limiting pressure heads	h_1= -0.1 cm; h_2=-1.0 cm; h_{3h} =-500 cm; h_{3l} =-900 cm; h_4=-16000 cm							
Field specific	Field 1		Field 2		Field 3		Field 4	
	Layer 1	Layer 2	Layer 1	Layer 2	Layer 1	Layer 2	Layer 1	Layer 2
Depth of layer (cm)	0-140	140-	0-125	125-	0-105	105-	0-105	105-
Soil texture	LS	315	SL	290	SiCL	210	SiL	210
Res. moisture content θ_r	0.01	S	0.045	LS	0.05	LS	0.045	LS
Sat. moisture content θ_s	0.33	0.02	0.33	0.02	0.39	0.02	0.38	0.02
Sat. hydr. cond. K_s (cm/d)	45.0	0.35	40.0	0.35	16.0	0.35	12.0	0.35
Shape parameter α	0.028	150.0	0.050	90.0	0.030	90.0	0.016	90.0
(1/cm)	2.1	0.026	1.8	0.028	1.6	0.028	1.6	0.028
Shape parameter n	0.0	2.6	-0.5	2.6	-1.0	2.6	-1.0	2.6
Shape parameter λ	-	1.0	-	1.0	-	1.0	-	1.0
Groundwater table depth (m)		2.80		2.50		free dr.		free dr.

After a period of one year, at ten locations in each field the soil water pressure head, water content and electrical conductivity of the soil profile were measured. These measurements were compared to the SWAP simulations in order to evaluate the model performance.

The hydraulic conductivity is not homogeneous in a field, and more water will infiltrate in the higher conductive parts, especially in case of basin irrigation. Also, non-uniform water distribution over a field may contribute considerably to a heterogeneous infiltration. Heterogeneous infiltration leads to a higher average percolation over a field. At the same time, the lower salt concentration in the percolation water results in less salt leaching on field scale basis. Therefore, we simulated three cases: one with field-average data, one with the mobile/immobile concept, and one with an inhomogeneous distribution of irrigation water over the field. In case of the mobile/immobile concept, percolation of water and salts takes place in the mobile phase, while the immobile phase keeps part of the salts in the soil and delays the leaching. In case of the inhomogeneous distribution of irrigation water, the irrigated field was divided in three rather arbitrary units: 0.375 part, receiving 67% of the irrigation water depth, 0.375 part receiving 100% and 0.25 part, receiving 150%. For conservative variables such as soil moisture content and EC_e, the weighted averages of the simulation results are compared with the measured data.

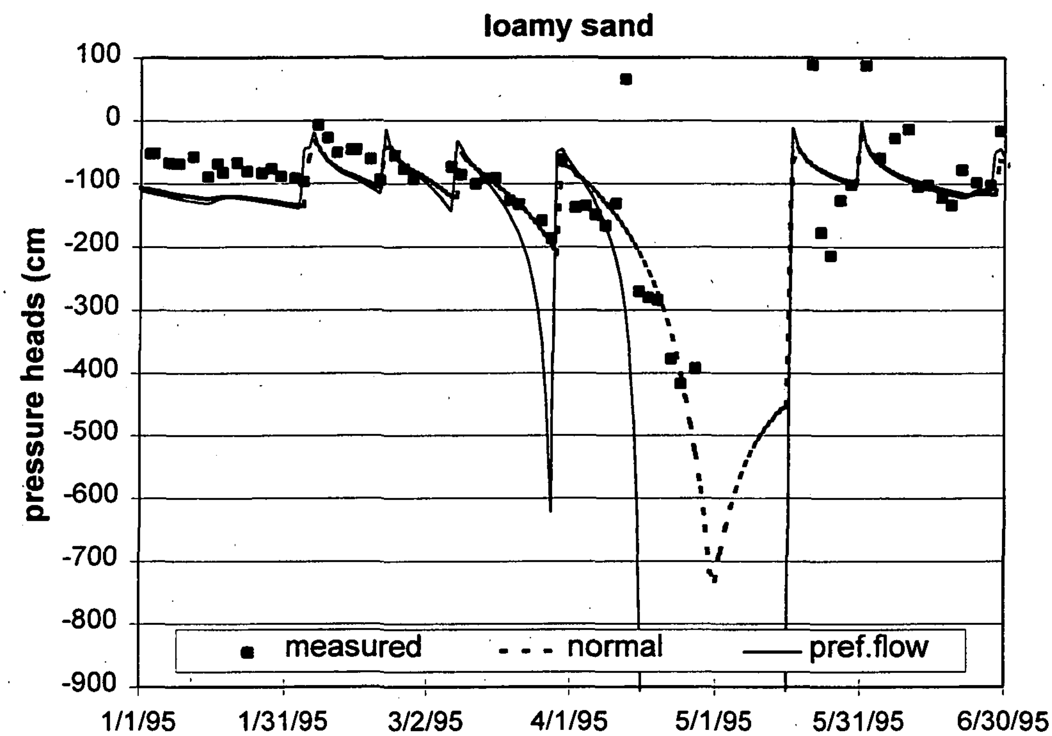


Figure 4: Measured and simulated soil water pressure heads with normal and preferential flow concept on a loamy sand

Generally, the simulated pressure heads match quite well with the measured pressure heads. As a typical example, the measured and simulated pressure heads for a loamy sand (field 1) are shown in Fig. 4. The simulated pressure heads obtained with the preferential flow concept show more pronounced peaks and declines, since the water movement takes place in the mobile phase only, causing a quicker wetting and drainage of the soil profile.

The soil moisture content profiles are satisfactorily simulated by the model for all soil types. In Fig. 5 a typical example is given for a silty clay loam (field 3). The width of the rectangles in Fig. 5 represent the augering inaccuracy of 5 cm depth, while the length of the rectangles represents twice the standard deviation of the measured soil moisture content at ten samples. In case of the preferential flow concept, less water is stored in the total soil profile, since the soil moisture content in the immobile fraction is relatively low. For the non-uniform concept, less water is stored in the under-irrigated part of the field, which cannot be compensated by a higher moisture storage in the over-irrigated part, since field capacity is already reached and the surplus of water percolates. Thus both the mobile/immobile concept and the non-uniform concept result on field-scale basis in lower water contents.

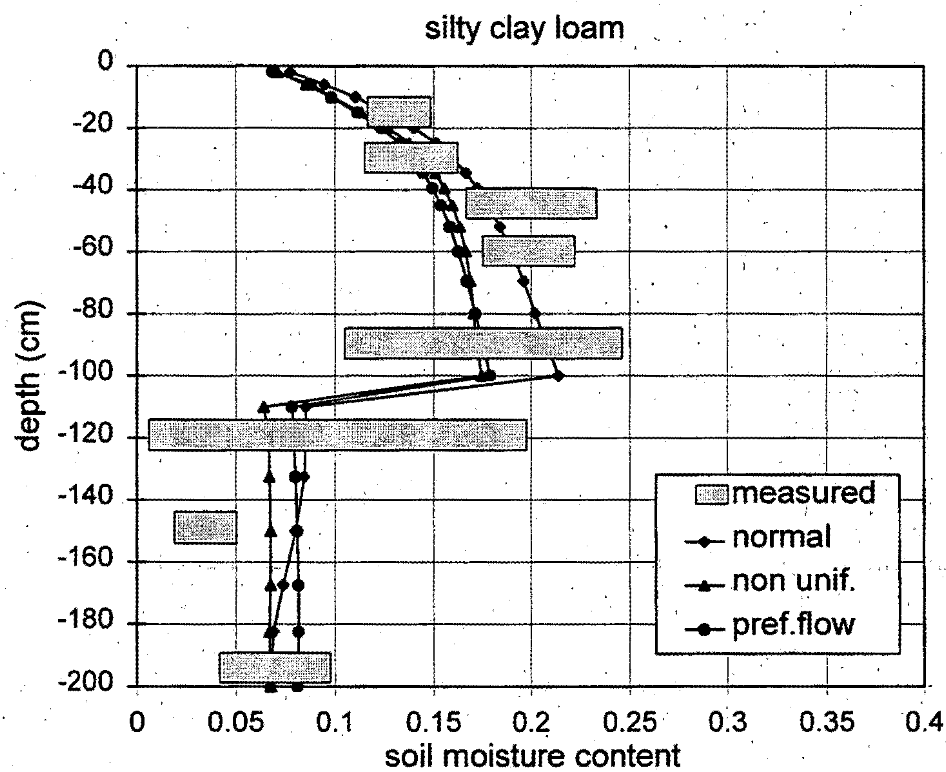


Figure 5: Measured ad simulated moisture content profile with normal and preferential flow concept on a silty clay loam

Figure 6 illustrates the EC_e profiles in the beginning of July '95 for the sandy loam (field 2). In general the model simulations show more EC_e fluctuations of the salinity concentrations than the measurements. This is probably caused by the fact that the measurements are averages of 10 locations, while the simulations mimic the salt transport at one, more or less average spot. In case of non-uniform and preferential flow, less salts are leached to the groundwater, causing higher EC_e values at the end of the agricultural year in comparison to a normal simulation.

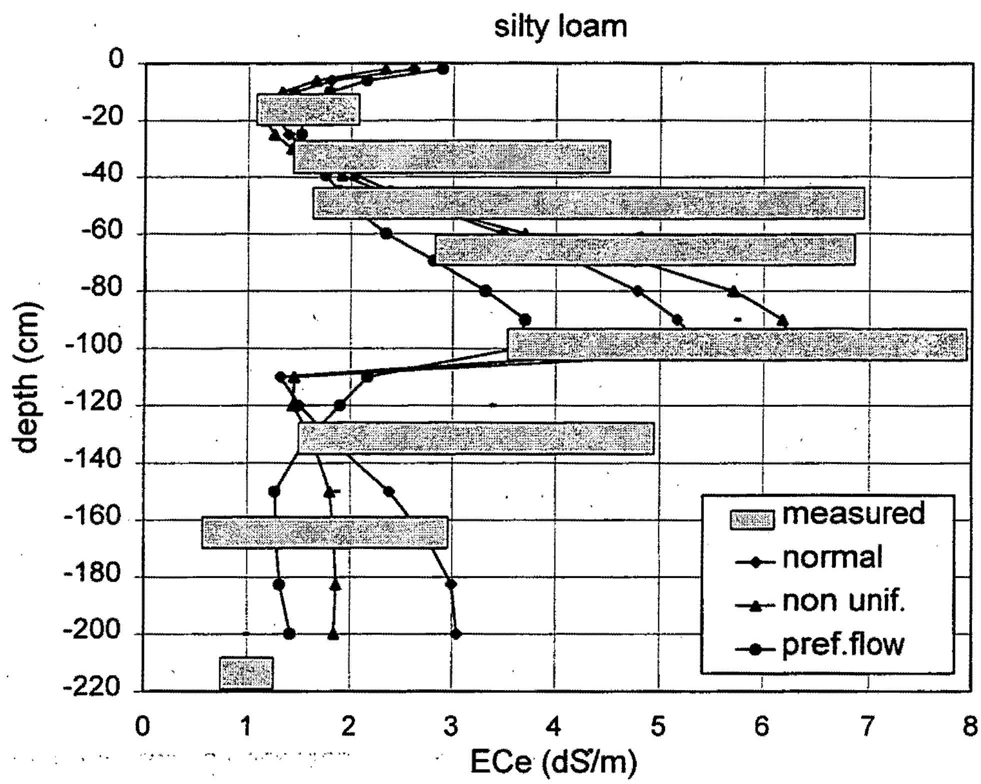


Figure 6: Measured and simulated EC_e profile with normal and preferential flow concept
on a silty clay loam.

Sensitivity analysis
A sensitivity analysis has been performed to determine which input parameters affect the simulation results the most. As one criteria, we used the relative transpiration RT (-):

$$RT = \frac{T_{act}}{T_{pot}}$$

where T_{act} is the actual crop transpiration and T_{pot} is the potential crop transpiration (cm). The relative transpiration can be related to the reduction of plant photosynthesis, and thus reduction of crop yield (De Wit, 1958). Another criteria, the salt storage change SSC (-), is related to long term sustainable irrigation, and is defined as:

$$SSC = \frac{\Delta S}{S_0}$$

where ΔS is the change in salt storage of the soil profile over a certain time span (g/m^2) and S_0 is the initial salt storage of the soil profile (g/m^2).

Table 3. Results of SWAP sensitivity analysis in case of a silty loam soil.

Scenario	Relative Transpiration (RT)	Salt Storage Change (SSC)
Reference	0.93	0.14
Decrease rooting depth (with 50%)	0.89	0.10
Decrease crop factors (with 25%)	0.99	-0.48
Decrease Boesten parameter (with 33%)	0.95	-0.15
Decrease sat. moisture content (with 16%)	0.91	-0.02

Table 3 shows some of the results. Decrease of the rooting depth with 50 % has only a small effect on both criteria, suggesting that for the research area no accurate data of the rooting depth are required. The crop factor, however, has a large effect. Decrease of the crop factor with 25 %, increases the relative transpiration to 0.99, and decreases the salt storage change to -0.48. The effects of the soil evaporation parameter and the saturated water content, are in between the effects of rooting depth and crop factor.

Short term scenarios

Several irrigation management scenarios were simulated and compared with the simulation results of a reference irrigation scenario, which was based on the recommended irrigation practices of the authorized Agricultural Department (see Table 4).

Table 4. Description of short term scenarios by quantity (cm), quality (dS/m) and application frequency (-).

Scenario	Wheat season						Cotton season					
	Quantity		Quality		Frequency		Quantity		Quality		Frequency	
	Pre	Other	Pre	Other	Pre	Other	Pre	Other	Pre	Other	Pre	Other
Reference	15.0	7.5	0.2	1.5	1	5	10.0	7.8	0.2	1.5	2	8
Under-irrigation	10.0	5.6	0.2	1.5	1	5	7.5	5.9	0.2	1.5	2	8
Low frequency	15.0	12.5	0.2	1.5	1	3	10.0	10.4	0.2	1.5	2	6
Pre-sowing	15.0	7.5	1.5	1.5	1	5	10.0	7.8	1.5	1.5	2	8
Tube well	15.0	7.5	3.0	3.0	1	5	10.0	7.8	3.0	3.0	2	8

A pre-sowing irrigation with canal water (EC_{iw}=0.2 dS/m) is recommended to leach the salts at the beginning of the growing season and to wet the profile. In the under-irrigation scenario, the irrigation depths are decreased to 75% of the reference depths. In the low frequency scenario the number of gifts is reduced, while the total amount of irrigation water is kept the same as for the reference scenario. In the pre-sowing scenario, there is no longer irrigation with canal water at the beginning of the growing season, but with water of an inferior quality. The tube well scenario simulates a situation where a farmer has access to poor quality tube well water only. The initial salt storage of all scenario simulations was set equal at about 1000 g/m^2 in order to compare the obtained results.

Table 5. Simulated relative transpiration (RT) and salt storage change (SSC) of short term scenario analysis in case of a silty loam soil.

Scenario	Wheat season		Cotton season		Total agricultural year	
	RT	SSC	RT	SSC	RT	SSC
Reference	1.00	0.00	0.99	0.24	1.00	0.20
Under-	0.98	0.26	0.85	0.37	0.89	0.73
Irrigation	0.99	-0.22	0.98	0.55	0.99	0.18
Low frequency	1.00	0.12	0.98	0.33	0.99	0.44
Pre-sowing	0.99	0.61	0.93	0.67	0.95	1.66
Tube well						

The results of the scenario-analysis are listed in Table 5. In the reference scenario, the wheat crop is over-irrigated to a larger extent than the cotton crop, which is evident from the higher salts storage change over the cotton season. For the under-irrigation scenario, the water requirements of the wheat crop are still met, but there is hardly any percolation and salts build up in the soil. During the cotton season, a considerable reduction in crop transpiration takes place and the salinization process continues. In the low frequency scenario, the larger irrigation gifts saturate the soil and the wetting front moves faster through the soil profile, so less water is extracted by the roots and more salts are leached. This phenomenon not very pronounced on a silty loam (Table 5), but is strongly present on permeable sandy soils with a smaller retention capacity. Managing the water and salt balances by means of changing the irrigation interval is only effective in case there is still a percolation component. In case of under-irrigation, when all the applied irrigation water is extracted by the roots, there is no leaching of salts. Thus, the build up of salts in the soil is equal to the amount of salts applied with the irrigation water, regardless of the frequency of irrigation. The simulation with a pre-sowing irrigation with poor quality water results after one year in a clear increase of salinity level, but hardly decrease of crop transpiration. Still, a pre-sowing irrigation with canal water is prefered, since the germination stage is the most sensitive period of most crops with respect to salinity. The simulation, in which exclusively tube-well water was used, showed a 66% increase of salinity in just one year, and crop salinity stress especially in the cotton season. In this case the crop salinity stress increases considerably in following seasons.

Long term scenarios

Long term scenarios of 10 years were performed in order to predict trends in soil salinity and crop transpiration in the area. The scenarios were based on the previously discussed reference scenario, changing the irrigation depths and the irrigation water quality, while keeping all other variables constant (e.g. irrigation interval). Often, farmers do not have enough irrigation water at their disposal and crop water requirements are not fully met. Therefore, five under-irrigation scenarios are performed, decreasing the application depths up to 60% of the reference application depths (10% interval). As farmers are using more and more tube well water for irrigation, the irrigation water quality of the scenarios is varied from 1 to 4 dS/m (interval 1 dS/m). After a few years, the salinization process reaches a certain equilibrium state with a constant salt storage: the amount of salts added to the soil is equal to the amount of salts leached from the soil. The equilibrium state is reached earlier on sandy soils (after two years) than on loamy soils (after four years).

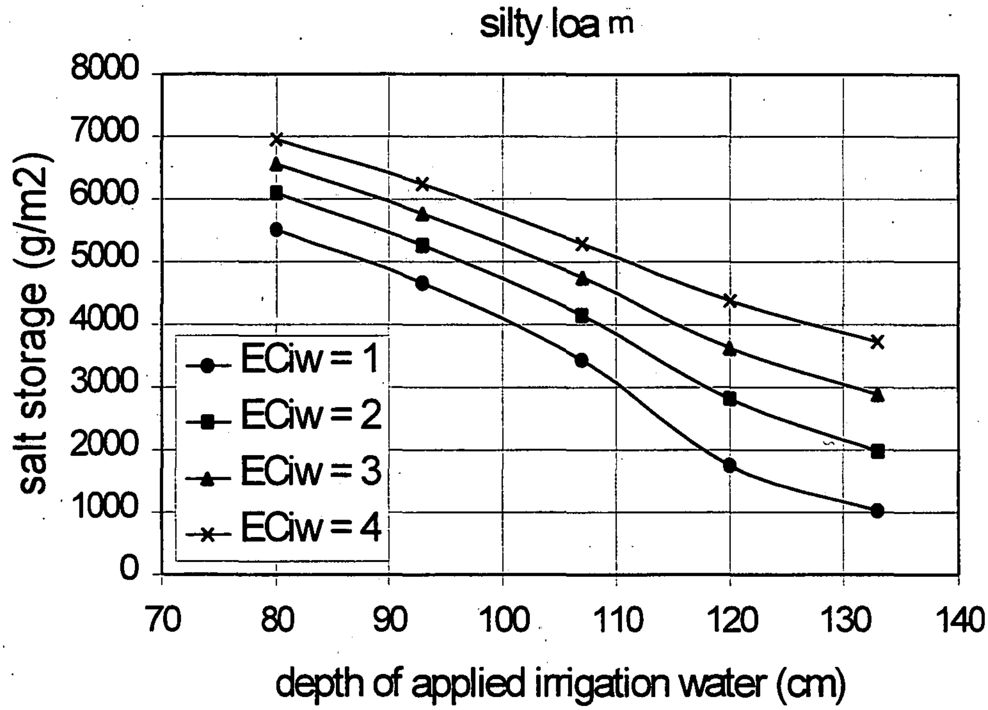
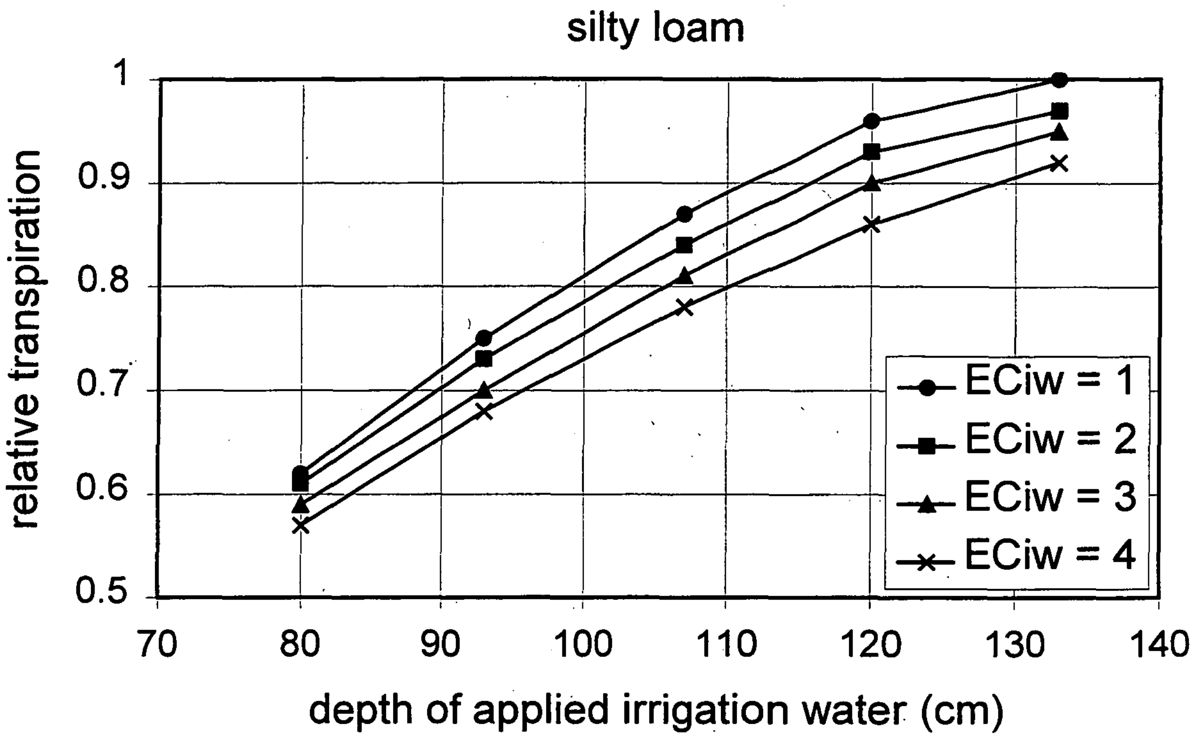
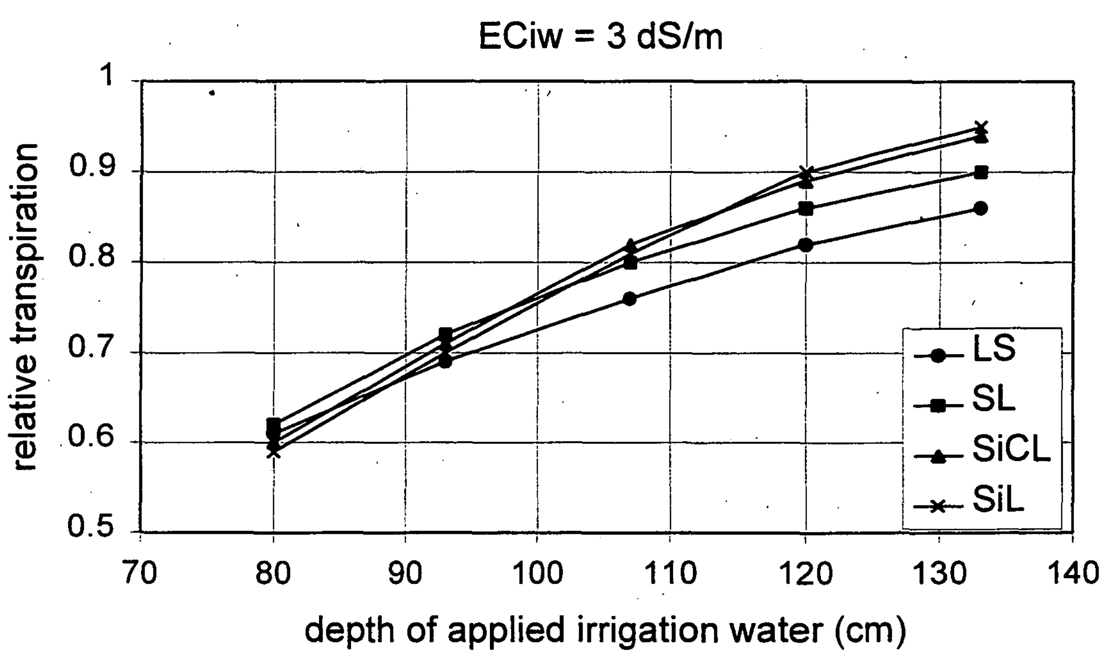


Figure 7: Relative transpiration and salt storage on a silty loam for long term under-irrigation scenarios with different water qualities

As a result of the simulations, Fig. 7 illustrates in case of silty loam that the relative transpiration is increasingly reduced with under-irrigation, while salts accumulate in the soil profile. The decrease in relative transpiration due to a poorer water quality of the irrigation water (from 1 to 4 dS/m) is approximately 8%, while the reduction in relative transpiration due to under-irrigation (from 133 to 80 cm) is 38% at the silty loam. The build up of salts in the soil (calculated up to a depth of 210 cm) increases with a higher electrical conductivity of the irrigation water, but is mostly affected by the extent of under-irrigation.


silty loam
relative transpiration
1
0.9
0.8
0.7
0.6
0.5
70
80
90
100
110
120
130
140
depth of applied irrigation water (cm)
ECiw = 1
ECiw = 2
ECiw = 3
ECiw = 4


ECiw = 3 dS/m
relative transpiration
1
0.9
0.8
0.7
0.6
0.5
70
80
90
100
110
120
130
140
depth of applied irrigation water (cm)
LS
SL
SiCL
SiL

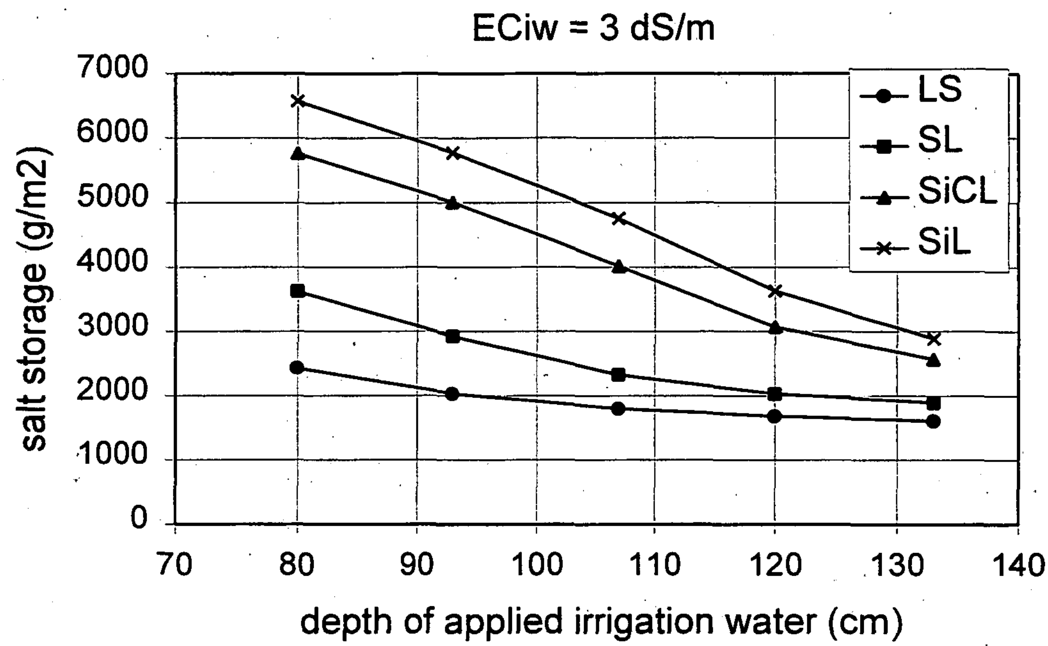


Figure 8: Relative transpiration and salt storage on four soils for long term under-irrigation scenarios with EC_{iw} = 3 dS/m

The salinization process takes place differently on sandy and loamy soils, which is shown in Fig. 8. Due to a lower conductivity and higher retention capacity, relative transpiration is generally larger on a loamy soil compared to a sandy soil. The higher transpiration of the loamy soils means less leaching and higher salinization at these soils. Figure 8 also shows that the effect of soil texture on relative transpiration becomes smaller if the amount of irrigation is reduced.

Based on the model output, an indicative risk analysis can be carried out for the current irrigation practices in the Chishtian Sub-Division. For a certain irrigation water quantity and quality, the reduction in crop transpiration on a certain soil type can be estimated and evaluated (Kuper, 1998).

Conclusions

From this analysis we may conclude for irrigation and salinization in the Chishtian area:

- Non-uniform water infiltration results in more water loss and less salt leaching
- Accurate data on crop factors and soil hydraulic functions are needed for reliable water and salt balances
- Stress due to water shortage is more affecting plant growth than stress due to high salinity
- Soil texture has a significant effect on the water and salt balance, if irrigation amounts are not too low
- The recommended irrigation amounts are sufficient to prevent serious salt stress on long term

Salinization application in The Netherlands

Introduction

De Grevelingen is a former estuary in the South-Western part of The Netherlands. In 1971 a closing dam has been constructed, which eliminated the tidal water level differences. After dam closure, a constant water level has been maintained at -0.20 m New Amsterdam Level (NAL). Gradually the rainfall surplus leached the salts from the top soils of the islands and plates. Very soon saline pioneer vegetation settled on the bare islands and plates along the shore. After a number of years, the saline pioneer vegetation transformed to grass and bushes, with exception of a several hundreds meter wide strip next to the shore. In the past 25 years, a botanically very precious area developed with all kind of transitions from salt to fresh, from wet to dry and from nutrient rich to nutrient poor environment. Birds intensively use the bare transition zone as breeding ground. Nature conservation organisations are afraid of further narrowing of the transition zone, due to continuing leaching of salts. They recommended sustainment or even enlargement of the transition zone by increasing water level fluctuations in the Grevelingen lake, imitating the former tidal fluctuations. Various water management scenarios were proposed with different water levels in winter and summer season. SWAP was used to analyse the effects of the five water management scenarios on the desalinization rate in the transition zone along the shore (Van Dam, 1997).

The water contents and salinity concentrations in the soils along the shore change rapidly. As an illustration, Fig. 9 shows the chloride concentration at three times of the year, simulated for a location with soil surface level at +0.10 m NAL on the Flakkee South plates. At the end of June, the chloride concentration at the soil surface amounts 2 g/l. At the beginning of July a flood occurs with saline lake water due to strong wind. Subsequently, the salinity concentration in the top soil increases due to water extraction by soil evaporation and plant transpiration. At the end of August, the soil surface chloride concentration has reached values as high as 23 g/l. In the autumn months that follow, surplus rain water causes chloride dilution and leaching. The salinity increase at the soil surface due to the flood in July, has totally disappeared at the end of the year. These simulated fluctuations were confirmed in the measurements.

SWAP calibration

SWAP was calibrated by using groundwater level and soil salinity measurements during the period 1971 - 1996. Figure 10 shows measured and simulated groundwater levels for a location at Flakkee North plates in 1978.

During winter months the groundwater level reached the soil surface. In summer time, the groundwater levels were drawn down to approximately 1 m below soil surface. Near day 170, a sudden increase of the groundwater level occurred, which probably was caused by a flood due to strong wind. The range and dynamics of the simulated groundwater levels correspond reasonably to the measurements.

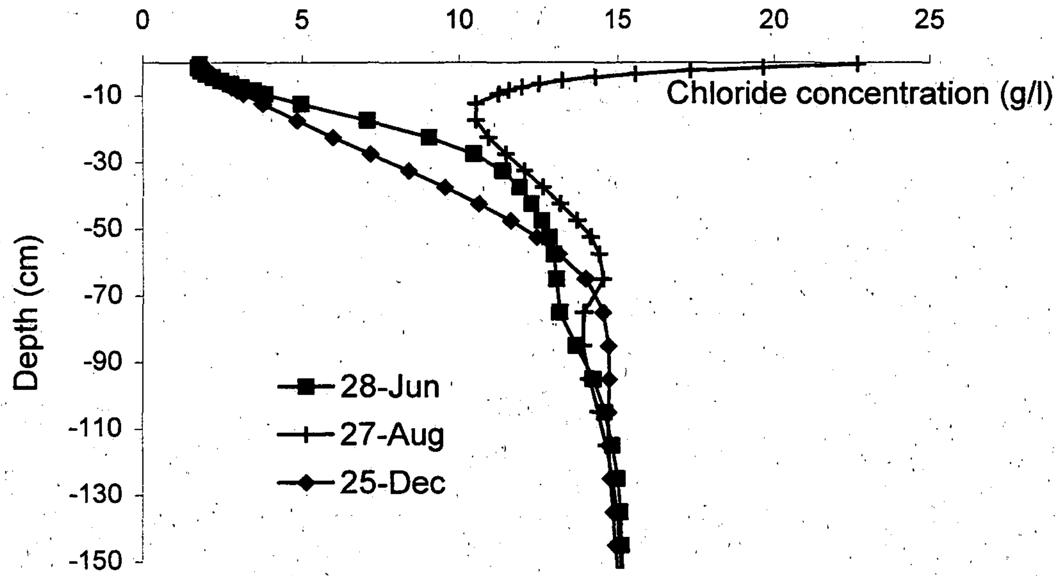


Figure 9: Chloride concentration profiles at three dates in a year with a flood at the beginning of July (Flakkee South plates)

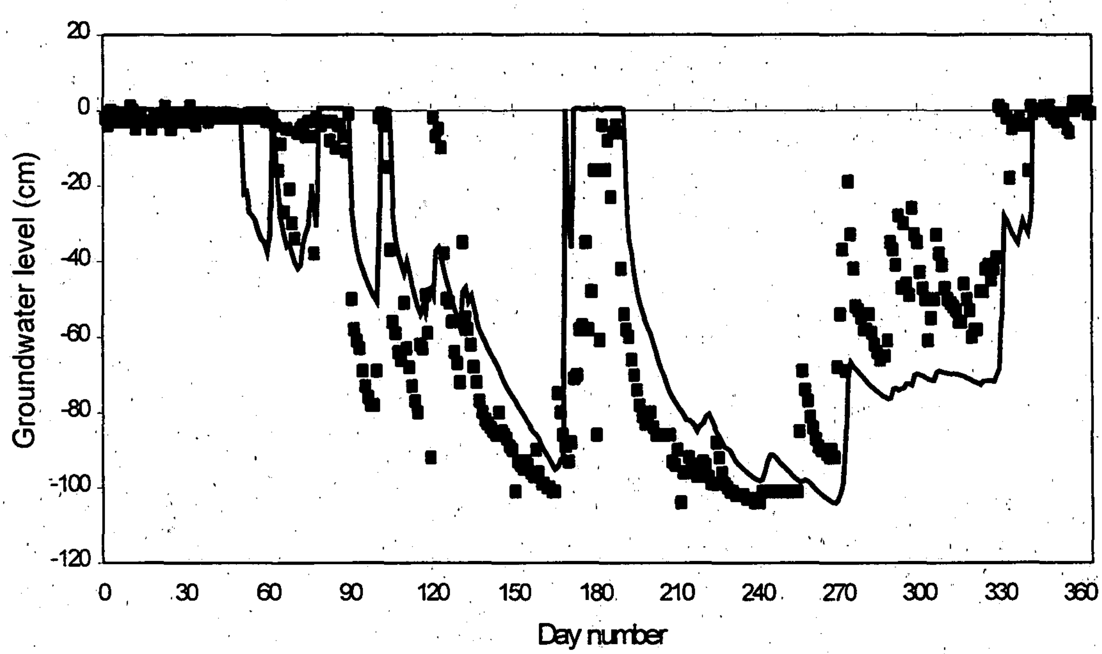


Figure 10: Measured (■) and simulated (-) groundwater levels at location C3 of Flakkee North plates in 1978.

South plates

Figure 11 shows the measured and simulated chloride concentrations at 1 m depth for three locations at Flakkee South plates. The three locations are part of a cross section perpendicular to the coast, whereby location A is most close to the shore. In case of location A, during the period 1974-1980, SWAP overestimates desalinization. This is probably caused by infiltration of salty runoff water from higher parts of the plates, which was not included in the simulations. In case of location B, the desalinization rate during the ten year period is reasonably reproduced. Only during the winter periods of 1974-1975 and 1975-1976, the simulated desalinization rate was larger than measured. At location C, which is situated most far away from the shore, the relative fast desalinization rate is properly reproduced by SWAP. Calibration of SWAP to the measured salinity levels showed that chloride leaching is mainly affected by the level of the soil surface with respect to the lake, the drainage resistance of the subsoil, the vegetation cover and the number of floods during the summer season.
Validation was performed for other years and other locations. Differences between simulated and measured groundwater levels and chloride concentrations could be

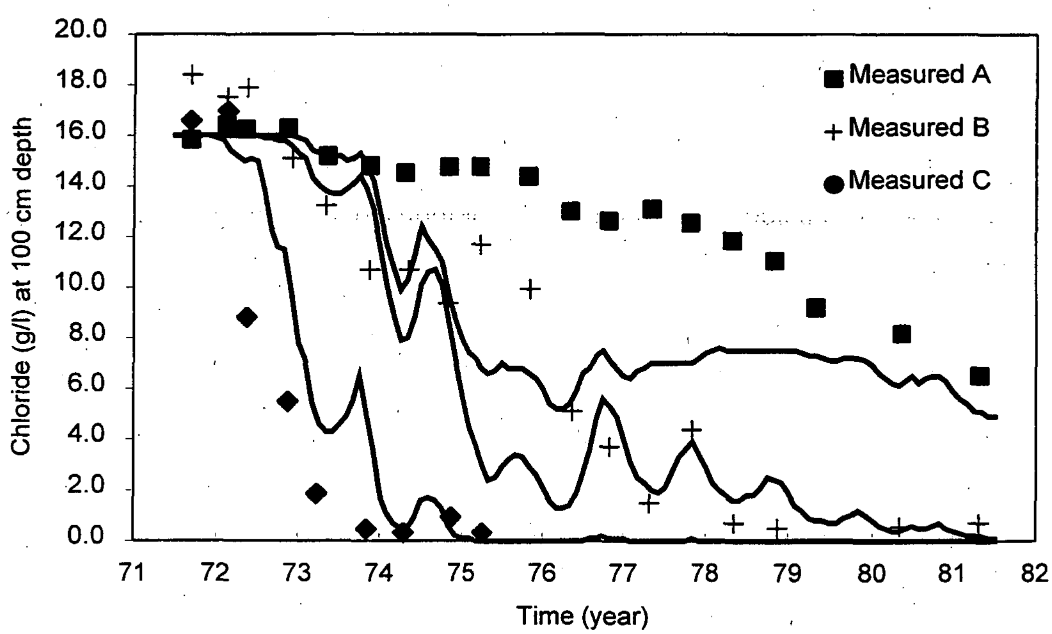


Figure 11:Measured and simulated desalinization rate at three locations on Flakkee

explained by spatial variation of soil physical properties and extra salinisation/leaching due to local differences of soil surface level. Fluctuations of the groundwater levels, the relative differences of the chloride concentrations in the measured cross sections, and the long term leaching rate, were satisfactorily reproduced by SWAP.

Scenario analysis

The calibrated model was used to simulate the water flow and chloride transport in four cross-sections in the area during a ten-year period. For future water levels in the Grevelingen lake, the following 5 scenarios were proposed:

1) Current management, water level constant at -0.20 m NAL;
2) During the months February and September higher water level at 0.00 m NAL, during the remaining period -0.20 m NAL;
3) During the months February and September higher water level at +0.20 m NAL, during the remaining period -0.20 m NAL;
4) During period September - March higher water level at -0.10 m NAL, during the remaining period -0.30 NAL;
5) During period September - March higher water level at 0.00 m NAL, during the remaining period -0.20 NAL.

Starting with the current concentrations, after 4 - 9 years the effects of the different water management scenarios become clearly visible. Figure 12 shows the simulated chloride concentrations at 30 cm depth for years 4 - 9 on Flakkee North plates at a location with soil surface level +0.20 m NAL. The salinity concentrations show clear seasonal fluctuations with the highest value in August and the lowest value in February.

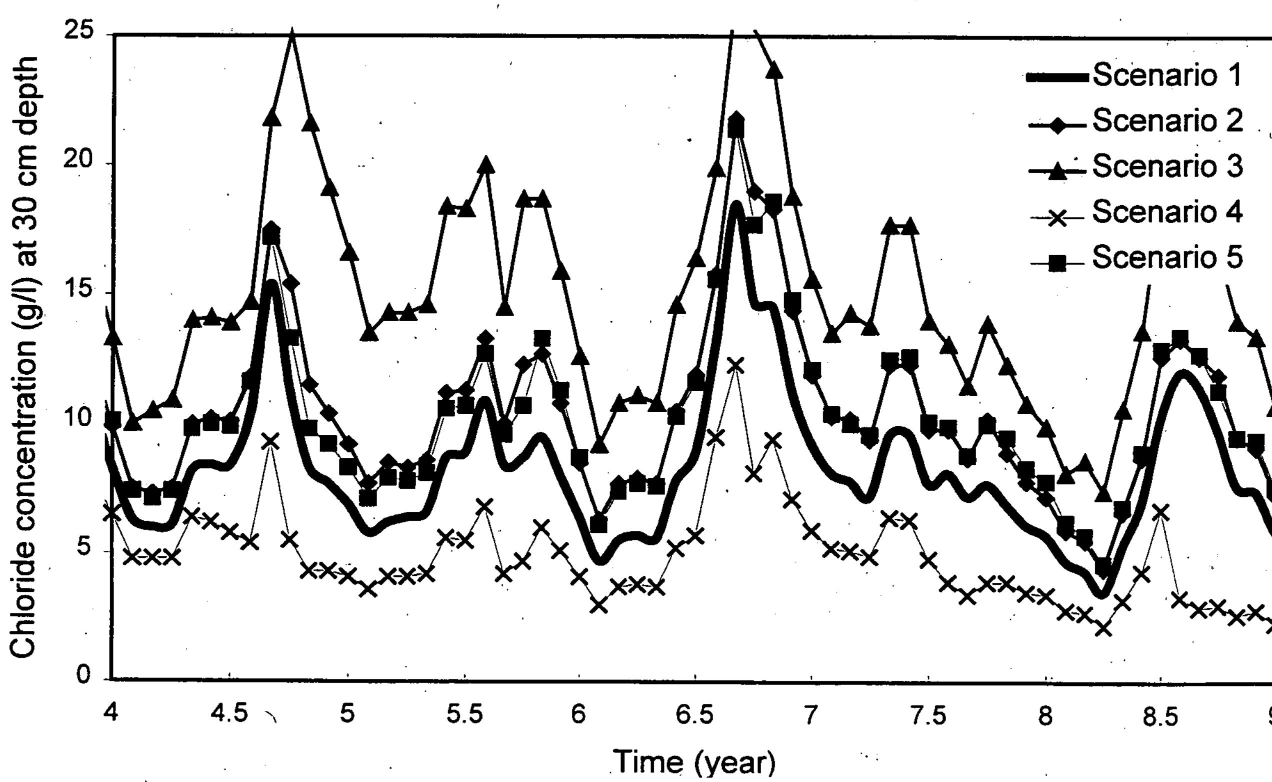


Figure 12: Calculated chloride concentrations at 30 cm depth at a location with height + 0.20 NAL on Flakkee North plates for the five management scenarios

In summary, the analysis showed that bigger fluctuations in the lake water level clearly enlarge the transition zone from saline to fresh water. Most effective to prevent further freshening of the soil water is increase of water levels during the winter months. Accordingly, the proper water management scenario could be selected (Van Dam, 1997).

Concluding remarks
The SWAP model is based on the knowledge and simulation experiences of hydrology, soil and agronomy scientists in Wageningen during the past 20 years. The model does focus on field-scale flow, transport and growth processes, which can be directly measured. For this reason SWAP is often used to analyse the processes in agrohydrological field experiments and to simulate all kind of optional management scenarios. Applications include analyses of field scale water balance, irrigation scheduling, dynamic drainage criteria, soil salinization, effects of water and salinity stress on plant growth, pesticide leaching to groundwater and surface water, optimisation of surface water management, and effects of soil heterogeneity. Although the model has been developed as a tool for researchers and students, a user's friendly graphical user interface makes the model accessible for more practically oriented people.

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STRATEGIC WATER POLICY FOR FOOD SECURITY IN THE SINAÏ DESERT, EGYPT[1]

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Introduction

First of all, I wish to thank the organisers of this workshop for giving me the opportunity to address this meeting. I will discuss two issues: first, why is integrated irrigation development in Egypt needed, and second, what is integrated irrigation development in the context of Egypt. I will answer this second question by briefly introducing you to an experimental project which the Egyptian government is presently carrying out with the assistance of foreign donors.

The information I present is complex in nature and it would take longer than the time available to explain it all in detail. Therefore I ask your understanding if I leave out details and confine myself to main issues only.

Why integrated irrigation development?

If we visualise in our minds the map of Egypt, we see the great Aswan dam in the river Nile in the South and the lands irrigated with the waters held by the dam at great distance from the dam. At its extreme, water is carried over a distance of not less than 1200 km. The total area under irrigation is 3.5 million ha. In comparison to the total land area of Egypt, this is only a small proportion, as the total land area measures 100 million ha. But as we all known, it is by far the most productive agricultural area, and the most populous.

A complicated and extensive network of main canals, distributors, etc. exists to bring water from one point to another and eventually to the demesca's, which are the tertiary units in which farmers have their fields. The system exists for already two hundred years and was hardly improved since it was constructed. Water is distributed making use of rotation schedules that are based on experience rather than on scientific rules. The Ministry of Public Works is responsible for the irrigation in the country.

It is important to realise that the average farm is small: it measures only .25 ha of – usually highly fertile - land. I will come back to that later. In Egypt, after much discussion and based on the evidence of research, we have come to the conclusion

[1] The text of this paper was written by A. Schrevel, on the basis of the recorded presentation by Adel Hashim Saleh.

that we have to work at farmers' level to improve irrigation efficiencies. And from this level upwards to distributary level, etc. The area commanded by a distributary measures 3-5,000 ha.

It was already said that Egypt's irrigation network has hardly been upgraded since it was constructed. Egypt itself did change considerably in the mean time, however. The social and economical changes, and also the environmental changes, have been dramatic. I mention only the change in population numbers in the irrigated Nile delta. At the beginning of the century the population measured some 5 million people; today this number has increased to 61 million people. The effects on irrigation are felt in many ways. Competition for water has increased, and the quality of water has decreased because of pollution from sanitation, etc. The problems are many and often are of an entirely different nature than the problems that engineers are trained to solve. Many irrigation problems today cannot be expressed in, or solved with the help of, hydrological equations.

I will give you another example of a change that occurred and that has great implications. In former days, farmers used to use simple water lifting devices to lift water from canals onto their fields. These were capable of moving some 10 l/sec. Today, farmers use pumps with extraction capacities in the order of 30-40 l/sec. The result of this is that head end farmers take more water and that tail end farmers are receiving less.

Integrated irrigation development is required to solve these and associated problems. Applying technical measures only will not do. An integrated approach in which farmers play an important role is necessary.

What is integrated irrigation development?

It was already said that the existing rotational system to distribute water is inadequate. In stead we are experimenting now with a system of continuous flow. To be able to apply a system of continuous flow, we need to adapt the canal system. Among others we need cross regulators in main canals. And we need automatic floating gates to keep up downstream water levels (as the overall topography is flat). In this way we will be able to apply night storage, which will be needed to compensate for too much water abstraction at peak hours, that is in between 10.00 hrs pm and 14.00 hrs am.

You will have noticed that these are measures at the level of the tertiary unit. It is at this level that efficiencies must increase. Here systems have deteriorated, here water is being polluted with sanitary discharges from households. Not only engineering solutions are required, but a package of measures to achieve maximum benefits. These we try out in an experimental project, the Irrigation Improvement Project.

The Irrigation Improvement Project is a joint effort from the World Bank, IDA, and the German Bank for Investment, which donors are covering 70% of the costs, together with the Government of Egypt, which pays 30% of the cost. The funds are made available under soft loan conditions, not as a grant. The works include improving irrigation canals and constructing tiled drains to remove excessive water. Eventually responsibility for effective operation and maintenance of the improved infrastructure is to become the responsibility of the farmers. Here a problem manifests itself which is associated with the small average farm sizes which I mentioned earlier. With an average farm size of only a quarter of a hectare, a tertiary unit has easily 200 and more farmers. Thus, in each tertiary unit a large group of people, each with his own personality and interests, will have to be organised in a farmers' group. All these farmers have to be made aware of the fundamentals of integrated water management. They have to be organised, because otherwise the irrigation authorities cannot talk to them.

We know now that to form farmers' groups is important. We have a Director General Water Advisory Services, who is a specialist in this field. We have already organised many farmers, we have identified the responsibilities of individual farmers, and we have set up public committees that have the authority to dismiss malfunctioning heads of farmers' groups. We do not pay the farmers, but we do assist them to organise themselves and to assume responsibility for their new tasks.

The experiments with the physical infrastructure are equally interesting. We discovered that each farmers has his own pumpset, which he brings from his house to the intake when he needs water. At times, 10-12 farmers irrigate at the same time. In consequence, tailend farmers find the irrigation canal dry. They have no choice but to take water from drainage canals, which is often salt and should not be used. Therefore, we construct pump houses; from these singly point intakes farmers get their water and water extraction from the irrigation canal is done in a more controlled way, that is per canal section.

Another technique that we introduce is to lay irrigation pipes at 80 cm below the surface. At regular distance vertical outlets are constructed. They deliver water under pressure, maximally 30 l/sec.

Cost recovery is an important aspect. The government cannot provide irrigation services for free. Therefore the irrigation law was amended recently. Costs for physical and other improvements need to be repaid per tertiary unit within 20 years after the improvements. Repayment has to start at year two. Farmers will have to pay roughly one dollar per month over the entire period, which we believe is not excessive. Cost recovery is now ruled by law. This year the agency to collect the repayments is being set up.

FLOWLANDS

BASING PLANNING ON TRANSPORT AND WATER NETWORKS

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Flowlands is one of four 'perspectives', prospective scenarios for physical and social developments in The Netherlands up to 2030. The National Spatial Planning Agency has initiated and guided the making of these 'perspectives' to stimulate public and professional debate that should lead to a policy document providing a framework for decisions on environmental planning in the next decades[1]. This article, written by members of the Flowlands team, summarizes the scenario and discusses the approach.

Introduction

Vision: 'flows' as the starting point for planning
Flowlands explores a new perspective that opts for using transport and water flows as the starting point for Dutch spatial planning up to 2030. It implies a shift in the paradigms on the importance of nature, from 'the value of a green area' to 'ecological processes' important for human activities in town and countryside. The transactions are primarily the management of flows of traffic and water, and these direct local decisions, rather than *vice versa*. This brings about a 'switch in perspective' in the relationship between Man and Nature, between 'red and green' or, more generally, a perspective switch in the relationship between environment and economics. In *Flowlands*, people and nature are both taken seriously, which means taking account of both. Will the result of this be the economy being hamstrung in the name of nature and landscape? Or will it be a semi-urbanised landscape? Is this the dilemma *en route* to 2030? *Flowlands* opts for a different route, as will be explained below.

[1] The four perspectives for The Netherlands in 2030 are *Stedenland* ('city-land', the compact city approach), *Parklandschap* ('parkland', interweaving of town and countryside), *Palet* ('palette', a free market approach to suburbanization), and *Stromenland* ('flowlands', the networks of traffic and water as startingpoint for spatial planning). The four 'perspectives' are based on the economic space defined by the three scenarios of the Dutch Central Planning Bureau: *Global Competition*, *European Renaissance*, and *Divided Europe* (CPB, 1992; RPD,1997a).

Opting for managing flows means working on the water and transport infrastructure. This structure creates the basic conditions for satisfying as many of society's wishes as as possible in a sustainable way while showing due respect to nature. Society's wishes include mobility, production, consumption, recreation and pleasant surroundings. As regards nature, it is both the intrinsic value of nature and the relationship between people and the plant and animal world that are involved, with the interaction between people and natural processes being paramount. In a broader sense, this interaction can be called technology. It is this technology that plays the main role in the perspective of *Flowlands*. In this context, Man and Nature are seen as partners, which means an emphasis on active interaction rather than on major interventions and stringent control. The aim of this approach to technology is to create the conditions for diversity in social and economic terms as well as for the plant and animal world[2].

From vision to strategy: water and traffic as starting points

This perspective is called *Flowlands* because transport and water flows were chosen as its starting point. These flows were initially examined independently while this perspective was being worked out, which led to a transport strategy being developed with the aim of improving efficiency and averting the devolution of responsibility. The strategy developed for water is aimed at working with natural processes of retention an purification. There is an obvious link to be made between transport, economy and industry on one hand and water, ecology and nature on the other. This fits in well with the distinction between material needs (goods and services) and the spiritual need to enjoy nature. As we approach 2030, water is also a key economic factor, however. It is essential for agriculture and for human consumption. Furthermore, most of the world's goods are transported by water. On the other hand, transport is a key factor for ecological (habitat) management. Transport networks are essential instruments for creating tranquillity in nature conservation areas. And just as every road is part of the water system because of its runoff, so navigable waterways are part of the transport system. In short, in real life the water and transport flows run through areas designated for industry, as well as through areas designated for housing or for nature conservation. The synergy of the combination of principles for regulating water and transport became clearer while the *Flowlands* perspective was being elaborated.

Guiding models as strategic tools

In *Flowlands* the strategy for water and transport as carrying the development of areas has been translated into *guiding models* that indicate solutions to problems of flow management and land use.

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[2] The basic philosophy of *Flowlands*, the strategy of the two networks, has developed from *Ecopolis* (Tjallingii, 1995) and *Ecological Conditions* (Tjallingii, 1996).

Guiding models point the way to a basic quality, but allow a large degree of freedom to seek for a solution appropriate to a given area and its inhabitants. There are two general guiding models. These can be applied at all scales, but their outcomes may differ, depending on the scale and the situation.

Transport guiding model (figure 1)
The aim is to improve efficiency and limit the devolution of responsibility, under the motto 'sustainable mobility'.The following principles have been elaborated in this guiding model[3]:

- traffic (cars, trains, boats) will be channelled in *corridors*. Town centres and tranquil green areas will be protected against traffic; This will restrict spatial problems and promote investment in through traffic, safety and environment;
- making *segregation* possible *of short haul and long distance flows* will promote throughflow;
- a *multi-modal structure* will be achieved, making it possible to change from road to rail to boat;
- *collective transport* will be promoted between nodes, and *individual transport* around nodes.

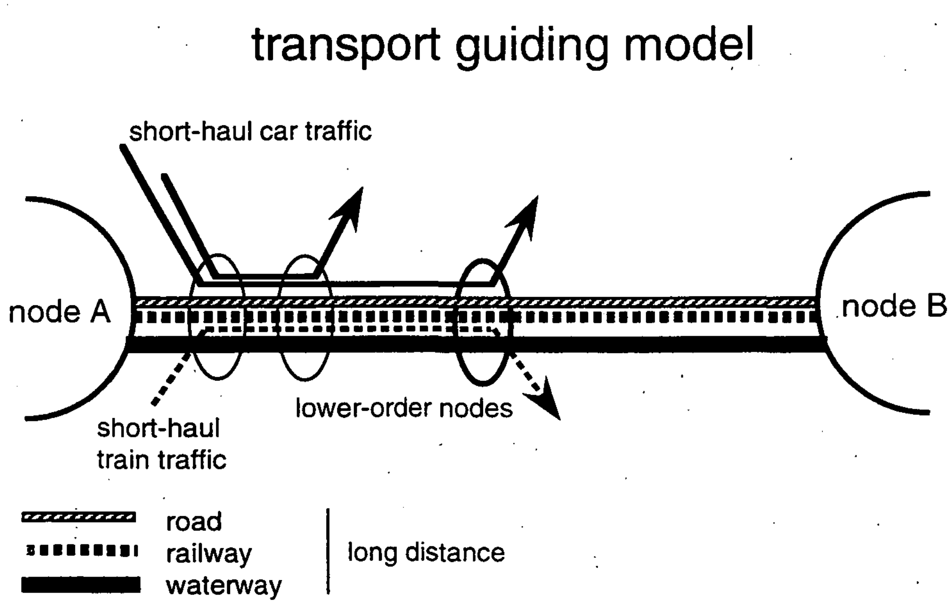

Figure 1. Transport guiding model

[3] The guiding model is partly based on a Dutch study of transport developments and perspectives: *Kiezen voor bewegingsruimte, eindrapport project Ruimpad* (Choice for mobilityspace, final report of the 'Ruimpad' project), Ministry of Housing, Spatial Planning and Environment, The Hague, 1997b.

Water guiding model (figure 2)

The aim is to work with natural processes, under the motto 'keep it clean and keep it longer'. The following principles have been elaborated in the model for this guiding model. They illustrate how the 'battle against water' paradigm has given way to 'living with water' - the resilience principle[4].

- water management will be attuned to the natural action of*water systems*; the combination of natural water storage and natural water purification (the relationship between quantity and quality) will be strengthened. The devolution of responsibility to downstream areas will be prevented;
- the storage of clean water is paramount for the policy on *managing water quantity* assuring sufficient amounts of water and preventing floods. This will enhance the role of autochthonous water (i.e. water natural to the area) and thereby counter problems associated with the nation-wide fall in hydraulic head;
- *managing water quality* focuses on preventing pollution, separating polluted water at source and purification after use. This will avert eutrophication and pollution of surface and groundwater;
- *sediment management* includes preventing erosion, limiting sedimentation in river channels and tidal gullies, and also encouraging deposition to strengthen the coastline. In this way, security will be combined with habitat development.

As illustrated by these guiding models, *Flowlands* primarily adresses physical and social processes related to flows. This distinguishes the approach from others that start with spatial patterns of land-use.

Further guiding models for area-flow interactions

As a next step, some second order guiding models were designed, involved in the relationship between areas and flows, considering four categories of commonly occurring situations.

- *lines and nodes*: a set of transport nodes with optimal facilities for passengers or goods to change from one form of transport to another. As well as being in town and city centres and on the edges of conurbations, these nodes will also be 'en route', to allow people to transfer from car to train or vice versa;
- *water and land use* (figure 3): nature conservation, agriculture, housing and other forms of land use will be combined with water system functions such as water storage, natural purification and water supply, such that clean water will flow into less clean water, rather than vice versa[5];

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4 The guiding model is based on recent developments in water planning. See for example *Hydropolis*, Van Engen, Kampe & Tjallingii 1995 and Plannen met Stromen (Planning with flows), Kamphuis et al. 1995.

5 This guiding model is based on Tjallingii 1996, p. 203-213 and on *Plannen met stromen* (Planning with waterflows), Kamphuis et al. 1995, Spatial Planning Agency, The Hague.

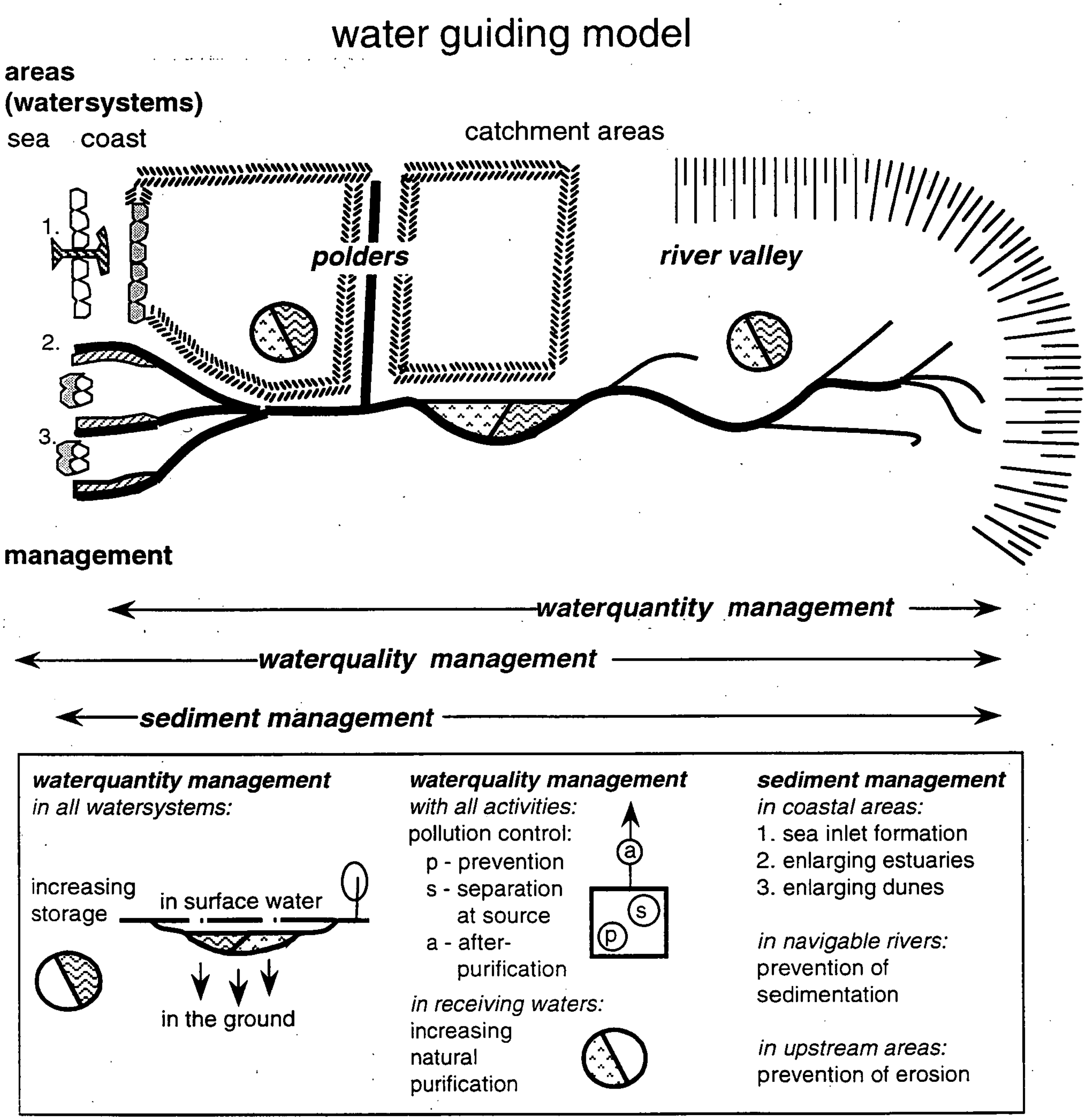

Figure 2. Water guiding model

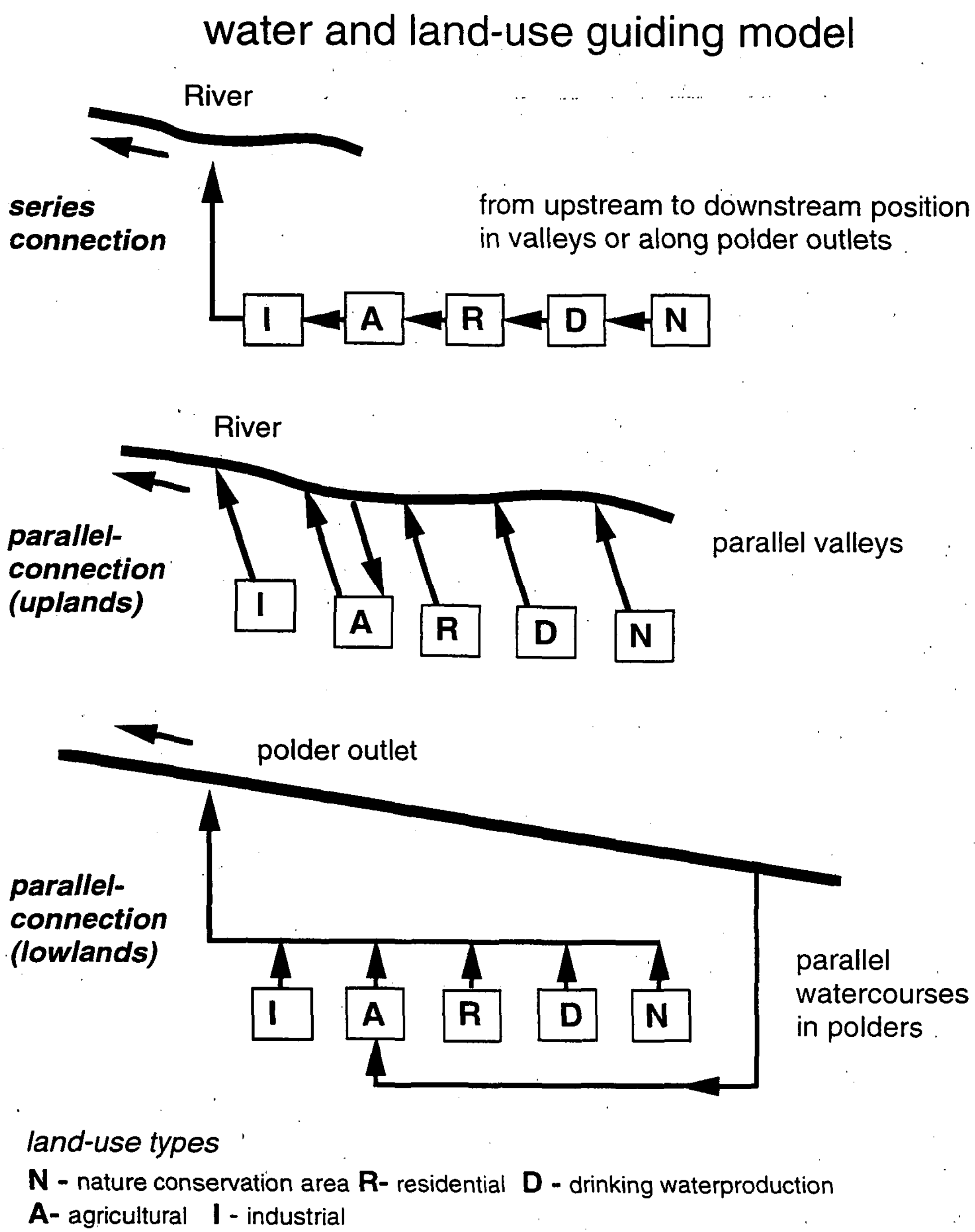

Figure 3. Water and Land-use guiding model.

- *border length and 'string of beads'* (figure 4): urbanisation will take place in 'strings of beads' along the public transport axes.The border between red and green will be enlarged. Access to public transport and distance to nearby urban centres are equally important here. The distance between the 'beads' can be used to allow vulnerable green zones with water functions (infiltration areas, or areas with water courses) to cross the axes;

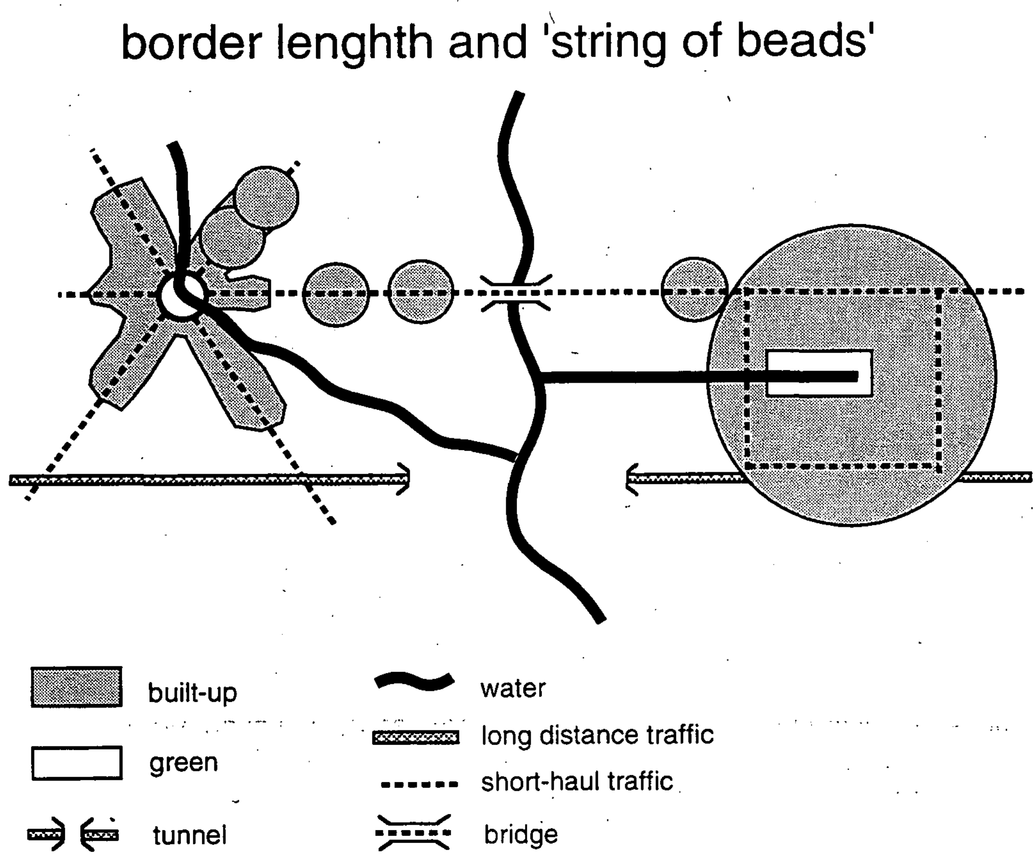

Figure 4. Border length and 'string of beads' guiding model.

- *zoning and the two networks*: the use of space will be restructured to make optimal use of location in terms of the two networks; the combination of transport with industry and agriculture, the combination of clean water system with nature conservation and recreation, and the two sides of residential areas - the tranquil green side and the dynamic side of transport and urban facilities.

What distinguishes the Flowlands' spatial perspective from other approaches such as the 'compact city' or 'new estates in the countryside' is the picture of residential areas along contrast-rich borders.

Policy guiding models

The strategic tools for policy-guiding are based on the vision that economic and ecological processes can be regulated by decisions about the management of water and transport flows and, concomitantly, decisions about the spatial networks of both these flows. These networks reinforce each other at strategic points and form the backbone of infrastructure. Government has an important role in providing and maintaining this infrastructure. The guiding models here are:

- *investing in projects*: purposive and substantial investments in strategic projects that fit in with the guiding models from the *Flowlands* perspective. Support for this will be enlisted by negotiating with users and financiers. During the negotiations the government will stand up for security and environmental aspects.
- *pilot projects*: an important guiding strategic tool is directed at 'internalising' the principles from the guiding models. Experimental projects and sample plans can be initiated and encouraged to illustrate the potential of the dual-network approach, thereby stimulating all actors to apply the principles. Even those solutions that do not have widespread support, such as car-free neighbourhoods, should be developed in small experiments, so that if support for them grows (for instance as a result of dramatically increased congestion), there will be tried and tested alternatives available.

It is this project approach, characterized by joint investment and 'learning by doing' that distinguishes *Flowlands* from other guiding principles such as drawing contour lines around urban areas and protecting green areas. In *Flowlands* the government is primarily the instigator of joint projects, rather than the protector of boundaries.

The issues

The process of scenario-building included five steps:

- interpreting data on social and economic development;
- interpreting data on the environmental effects (resources, pollution, wildlife) of these developments;
- interpreting the data on the effectiveness of policy measures addressing environmental and spatial issues;
- deciding about the choice of policy measures; the guiding models resulted from this step;
- predicting the extent to which *Flowlands* fulfils the issues deemed important for the development of the Netherlands up to 2030.

The last point is discussed in this chapter.

Mobility

In order to accommodate the massive increase *passenger transport* and the travelling public without substantially expanding the road network, *Flowlands* opts for greater use of public transport and bicycles, an increase in the capacity of existing roads, and more passengers per vehicle. Public transport will be made attractive by developing efficient transfer points for attuning the first, main and last stages of the journey. The car will initially be allowed to remain a form of

transport for the main part of the journey, but its major role will eventually be switched to the first and last stages of journeys.
The roads will not be able to accommodate the massive increase in *transport of goods*. The capacity of vehicle transport will be enlarged by logistic improvements and this form of transport will continue to be important at regional level. However, to cope with the increase, waterways and rail transport will have to be used for longer distances between nodes. This switch will be made easier by ongoing developments in the techniques for container transshipment.

Sustainable economic development and traffic
Economic development, employment, emissions and regional quality are all facets of sustainability. *Flowlands* is founded on the principle that a good transport infrastructure will create the right preconditions for *economic development*. Linking added-value activities to the flow of goods will be stimulated by building larger transshipment facilities, and by earmarking areas for industrial estates along the transport axes. These preconditions for economic development can be expected to have a positive effect on *employment*. The steady growth in the transport of people and goods will lead to a rise both in CO_2 emissions (thereby exacerbating the greenhouse effect), and also in other emissions. Although technological advances will bring about considerable reductions in emissions per vehicle, we can only note that, in the past, the benefits of such advances have consistently been cancelled out by increased traffic volumes. The only means by which the environmental effects of traffic can be reduced in the short term is by a shift from the use of cars towards public transport and bicycles. Future transport policy will therefore have to increase the attractiveness of environmentally-friendly alternatives, although in the long term significant advances can be expected with regard to electrically-powered vehicles and to hydrogen technology. Even then, car traffic will still represent a threat to human and animal safety, especially on the roads providing access to transport axes and transport nodes. Protecting (decoupling) vulnerable *areas* from traffic will thus remain an important objective, both in urban areas and in nature conservation areas.

Sustainable economic development and water
The abstraction of groundwater for purposes of *economic development*, for industry and for use in agriculture will gradually be phased out. Switching to surface water will supply sufficient water to meet these needs, and it will nonetheless be possible to reduce parching in nature conservation areas. The increased use of surface water will increase pressure to reduce *emissions*; such reductions will be made possible both by the developments in agriculture (environmentally-efficient industrialisation and a more extensive method of farming using less fertiliser and pesticide). Security and quality at *regional level* will be guaranteed by river management and coastal management conducted according to the 'resilience principle'. Despite the rise in sea level, it will still be possible to assure security from flooding without the need to resort to a new round of dike reinforcement. Water will make a significant contribution to the sustainable quality of residential areas, nature areas and recreation.

Nature, landscape and biodiversity

Rather than stressing species management, *Flowlands* will emphasise a great habitat richness. Wet habitats will be stressed. Parching and eutrophication will be combatted, and the effects of allochthonous water will diminish. In this way, greater justice will be done to the diverse qualities of diverse landscapes types. Larger areas of tranquillity will be created by decoupling currently fragmented green areas from the transport network. The 'string of beads' principle will allow greater attention to be paid to wildlife corridors, thus creating more stable plant and animal populations.

Social diversity

Flowlands will create the preconditions for clean and efficient transport (together with the allied social functions), and for sufficient quantities of clean water (with the concomitant agricultural, industrial and domestic functions and its value for nature conservation). Furthermore, by following the dual-network approach to spatial planning, the preconditions for personal human development will be enhanced. Not only will this allow the mobility that creates conditions for economic and cultural development, it will also create the space for quiet and inspiration. Many people will be able to live at the waterside or in green areas, and there will be an abundance of greenery in residential areas. Under such conditions, environments for a great variety of lifestyles will come into being.

A great deal of employment will be created by having the accent on investment in projects such as transport infrastructure, nodes, hydrological projects and a combination of urban reorganisation and tunnel-building. Indirectly this will contribute to decreased social divisiveness, i.e., to a reduction in an unwelcome form of social diversity.

Spatial claims

In principle, areas for housing and for industrial estates will be made available by the expansion of existing towns along public transport axes, and by the creation of new living and working areas along these axes. Both this and the 'string of beads' principle will allow space to be reserved for green and tranquil areas and for linking zones for wildlife and recreation. In these areas, the hydrological system will provide a structure and supply clean water. New large-scale *road, rail and waterway infrastructure* will be limited to the corridors; it is primarily rail connections that will be added. Necessary additions can be made both above and underneath existing roads.

The situation with regard to farm management is of relevance to *agricultural* land that becomes vacant, and to those forms of nature conservation and recreation that require more space. Agriculture will develop in two opposite directions: further industrialisation on one hand, and on the other the development of extensive management methods in which nature management techniques will also have a place. Farms in the first category will be linked to the transport axes and industrial estates, while those in the second will fulfil an important function in the management of the large green spaces lying between these axes. The latter spaces include the National Ecological Network (NEN) proposed in the government's Nature Policy Plan. *Hydrological management* will require more space within the framework of *Flowlands*. It is largely in multiple land-use that such space will have to be found, however.

The image of the Netherlands; proposed projects

Strategic map of the Netherlands in 2030

Flowlands' image of Netherlands in 2030 has been created by analysing transport and water flows in relation to land use, and then by using the guiding models in the development of proposals. An exceptional feature of the Netherlands with regard to *transport* is the position of the 'main ports' of Rotterdam and Schiphol Airport *vis-à-vis* the industrialised hinterland. This will give rise to the further development of the principal east-west corridors and of the less important corridor to Antwerp. Traffic flows in these corridors will become yet more concentrated. Multi-modal nodes will be developed. In addition to the international corridors, there will be north-south axes of importance at a national level; at certain points in these, rail connections will be established. Along the national transport axes, too, nodes will be developed into multi-modal transfer and transshipment stations.

With regard to *water*, the Netherlands is exceptional not just by virtue of its coast, Rhine/Meuse area and small rivers areas, but especially by virtue of the *blue zone*, the low-lying area in which the sea and the rivers meet (figure 5). In these areas, water storage, natural purification and the improvement of recreative links will be accentuated.

The function of the *rivers* as linking routes for plants and animals will be reinforced, both by allocating more space to the rivers and by strengthening national and international policy with regard to cleaner river catchments.

Space will be made available in the *coastal zone* for sediment management conducted according to the 'resilience principle'.

In the higher-lying areas of the Netherlands (i.e. the area of *small rivers* and natural brooks), the guiding principle will be that water must flow from cleaner areas to less clean, rather than the reverse. This will be combined with brook restoration work.

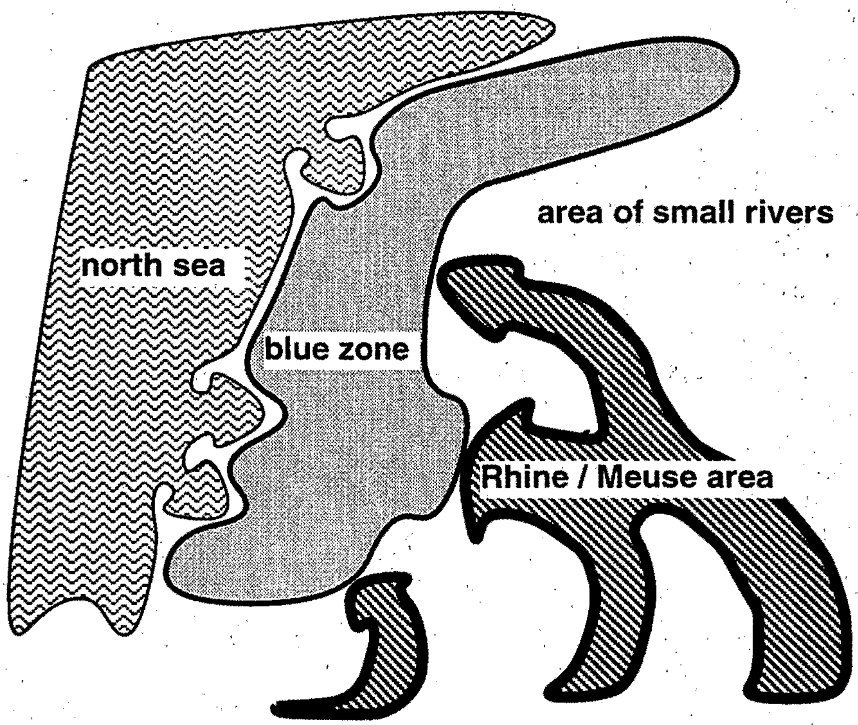

Figure 5. Specific qualities of watersystems in the Netherlands

On the map of the Netherlands a great deal of attention has been devoted to the places at which the blue zone (one of the carriers of this perspective) crosses the most important corridors and transport axes: between Amsterdam and Muiden, between Gouda and Utrecht and around Dordrecht. Here the beads have been kept separate, and only the thread continues. At these points the barrier effect of these intersections is diminished by cuttings, tunnels and wildlife viaducts. The same principle will apply to national and regional transport axes that cross nature conservation areas.

The guiding models provided by *Flowlands* can indicate approaches to solving problems in a number of currently debated projects. It is important in this regard that projects have a dual objective: while they should contribute to reinforcing transport and water flows, they should also contribute to economic and ecological development.

Projects

Flowlands proposes a number of projects, both small and large. Of these, some are new, such as the project to make the northern part of the Netherlands more independent of throughflowing Rhine water by drawing on its own reserves.

Many projects are already at the discussion stage, such as one (related to the project just mentioned) which will allow greater fluctuations in the level of the

IJsselmeer and various coastal management projects (including those involving widening of the dune belt and the formation of tidal gullies).
Also under discussion is the construction of new railway routes between Lelystad and Groningen, Utrecht and Breda, and Arnhem and Twente, and the plan for an orbital railway in the Randstad area. In many plans the first steps have already been undertaken, such as the *Ruimte voor Rivieren* (i.e. Space for Rivers) Plan, 'water in the cities' projects, the development of urban distribution centres, transfer points, and roofing and tunnel projects in urban areas and where infrastructure crosses sensitive rural areas. Some projects are effectively an extension of existing policy, such as those with respect to a pro-active technological innovation policy and to linking this with innovative pilot plans.

The discussion on *future airport infrastructure* will focus on the question of whether Schiphol can expand, and by how much. We proceed on the assumption that expansion will be desirable for the flow of air traffic and for the economic development associated with it. Provided noise guidelines are respected, some expansion of capacity at the current location can be accommodated within ecological development. In this respect, the relocation to the village of Zwanenburg is a realistic option. However, should future capacity become insufficient, it is entirely uncertain what the effect of air traffic would be on ecological systems in the coastal area, in the vulnerable 'blue zone' and in other areas. As economic uncertainty is also great, there are no dicisive arguments for a shortterm decision regarding the desirability and integration of a satellite of Schiphol.

The *Tweede Maasvlakte* (the project to further expand Rotterdam Harbour in the North Sea) is seen as a useful reinforcement of the 'main port' of Rotterdam. The timing of the expansion is generating greater controversy than the anticipated benefits of such expansion to multi-modal transport and economic development. However, although the previous harbour expansions have generated some understanding of the ecological effects of this project, this understanding is still far from complete. The Flowlands approach implies that projects should meet both ecological and economic demands. In the case of the harbour expansion further research should clarify the decision situation.

The new railway line through the *Betuwe* district is entirely in harmony with the plan to reinforce the multi-modal corridor through this district. Options for combining the transport corridor and the wildlife corridor were explored in a study at regional level. With its extensive transshipment facilities and the extension of a branch of the Betuwe line to Twente, the Valburg junction (near Nijmegen) will be fully in keeping with the objective of exploiting the flow of goods through the Netherlands for the purpose of value-adding activities. However, the greatest possible care will have to be paid to the proper integration of the railway line into the landscape of the Betuwe district. The guiding models presented in *Flowlands* provide useful tools for the fine-tuning of local plans to local conditions.

Discussion

Flowlands and other perspectives

The leading proposals, ideas and interpretations of the other perspectives have not been discussed here. It is therefore impossible to compare the four approaches systematically. However, we may highlight some arguments the *Flowlands* approach contributes to current debate on spatial and environmental issues.

One of the persistent issues in spatial planning is the debate on concentration versus deconcentration of built-up areas. The first view is represented by the 'compact city' perspective, the second by the 'parkland' and 'palette' perspectives (see note 1). The dream of an increasing number of city dwellers - a suburban house with a garden - is the nightmare of others who fear the loss of openness and quiet of the countryside. The contribution of *Flowlands* to this debate is fourfold:

- *Flowlands* stresses the central role of traffic, that is being disregarded if the discussion is limited to a 'red and green' debate;
- *Flowlands* introduces groundwater and surface water management as a central issue in environmental planning. This leads to a more important role of the local hydrological system and to new carrying structures for green functions.
- By opting for a 'string of beads' strategy, *Flowlands* focuses on the length of the red and green border. The proximity of both public transport and green recreation areas contributes to the quality of this border. In this way, a planning perspective is created that may preserve openness in essential parts of the countryside and prevents us from building in vulnerable urban green areas.
- In this perspective, the role of the government in regulation and control will decrease to the benefit of a project approach with joint investment and joined learning being paramount.

Strategic planning and communication

Flowlands, as a scenario, is neither *projective* (extrapolating trends, forecasting) nor *prospective* in the strict sense of designing a picture of he future and then 'backcasting' to determine the steps to be taken (Jansen, 1994, 503). As a strategic plan, *Flowlands* shows the overall direction and provides the tools, the guiding models. As a consequence, the ultimate result, the map of The Netherlands in 2030, is difficult to communicate. This became evident during the sessions of public debate that followed the publication of the four perspectives. Yet, in a strategic plan, there cannot be a final picture. The map is full of zones, indicating 'space for search' and leaving the concrete planning proposals to local planning with due respect to local conditions. Here, the guiding models are useful in creating imaginative and innovative pilot projects that are vital in a process of learning by doing. At this level communication is easy.

The concreteness of the national map is in its frame of the two networks. These are essential to create conditions for economic and ecological processes. The networks also have a spatial form, but the picture remains abstract, the processes remain invisible. The challenge to communicative planning is to link pilot projects to a general strategy. Possibly, guiding models may play a role in bridging this communicative gap.

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THE POLICY PROCESS IN IRRIGATION REFORM: TECHNOLOGY, RURAL DEVELOPMENT AND POLITICS

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Introduction

This paper was originally written for the fourth international INPIM[1] seminar in Bali in July 1998. The question the organisers of that seminar put in front of the author was the following.

> *Are top-down strategies to be preferred over grass roots strategies in the introduction of PIM?*

For reasons that will be explained below I prefer to rephrase this question in the following way.

> *What should be the characteristics of the process of policy formulation and implementation for the introduction of PIM?*

This is a big question, and no general answer to it exists that applies to all cases. What the PIM process should look like to achieve its objectives will vary from country to country and from irrigation system to irrigation system. What we can say something about is what our starting points or assumptions are when an approach to the introduction of PIM is designed. It are these starting points or assumptions underlying the design of PIM approaches that I want to discuss in this paper[2].
The argument of the paper runs as follows. In section 2 it starts with a discussion of the dichotomy of top-down *versus* bottom-up approaches to the introduction of PIM. I argue that this opposition does not capture the choices involved very well. Instead I argue for a framework that distinguishes between a prescriptive approach to policy and a process approach to policy.

[1] INPIM = International Network for Participatory Irrigation Management, based in Washington DC
[2] I am assuming here for the sake of argument that it is clear what we mean by PIM. However, the meaning of PIM itself will be subject to debate and contestation in the policy process. This issue is only indirectly treated in this paper.

In section 3 some of the problems of prescriptive approaches to PIM introduction are sketched by means of examples drawn from India, Pakistan and Indonesia. The gloomy picture that these example give of PIM in practice, leads to three issues for further discussion.

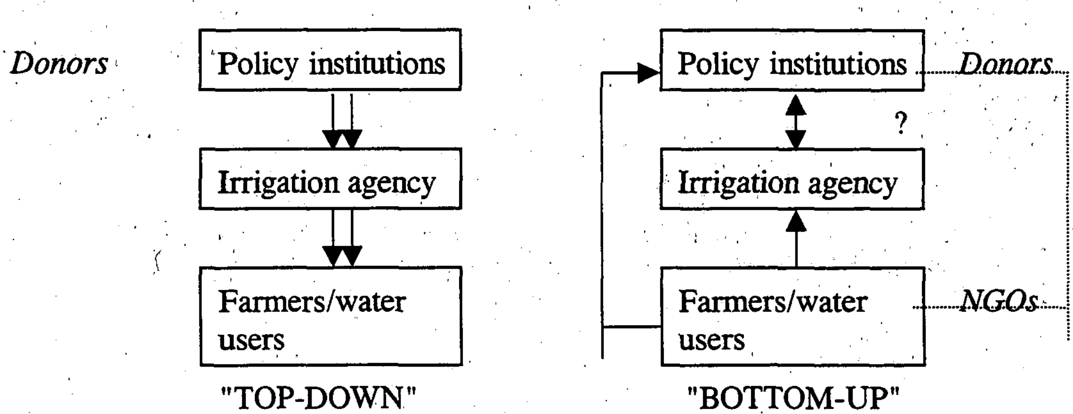
These are:
1) the need to enrol engineers in the reform process, and how this can be done by providing technical challenges (discussed in section 4);
2) the need to situate irrigation reform in a broader approach to integrated water resources management and rural development (discussed in section 5); and
3) the need to understand policy formulation and implementation as political processes, which require the forging of political coalitions to achieve policy reform (discussed in chapter 6).

I conclude the paper with a few short remarks on the possible role of the INPIM network in a `policy as process' approach (section 7).

Before commencing the presentation of the argument however, it is useful to point out that the paper takes large scale canal irrigation in Asia, particularly South Asia as its reference point. These systems are characterised by large numbers of farmers, many with small, and decreasing, holdings, widespread poverty, and strong social inequalities and dependencies among the rural population. Many systems have water scarcity as a design principle, and water needs to be rationed. The systems are managed by old and large irrigation bureaucracies with strong hierarchical orientations. Canal irrigation in this region may constitute one of the most difficult cases for irrigation reform.

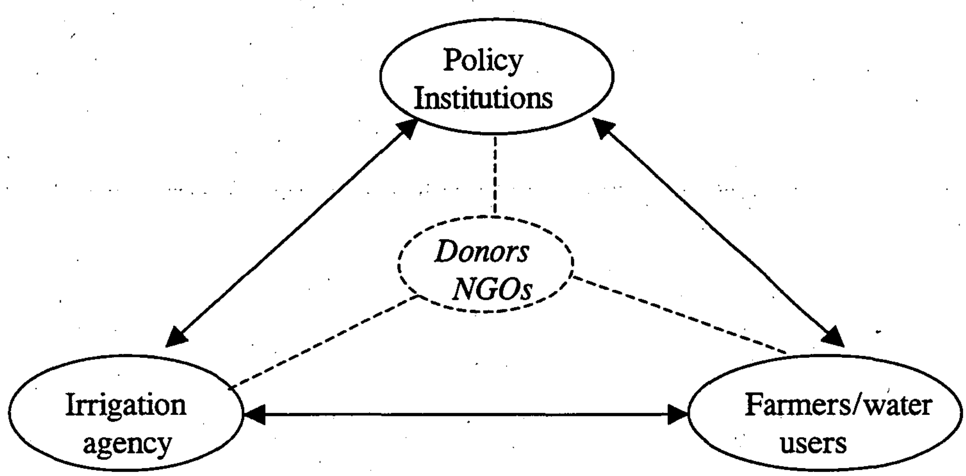
Top-down vs. Bottom-up or Prescription vs. Process ?

My guess is that the question given above and the text that accompanies it[4] has approximately the following model of policy formulation and implementation in mind.



[4] See *Call for contributions to the fourth international INPIM seminar to be held in Bali, Indonesia, 14-20 July 1998.*

In the top-down model new policies are formulated by policy institutions, which are mostly government agencies (the Cabinet, the Planning Board, special committees, or other institutions). The sources of the policy change may be different. They may be internally generated on the basis of accumulated experience, they may be forced by donor and lending agencies' pressure, they may be induced by INPIM conferences, or they may come about in other ways. After formulation follows implementation, generally by the government agency responsible for irrigation or water resources. Institutional reform of this agency may be part of the policy. The farmers/water users are the recipients of the policy implementation, and may be induced to participate in or adhere to it by means of different mechanisms, based on enforcement and/or the creation of incentives.
In the bottom-up model the process starts at field/canal level, where farmers/water users organise, perhaps assisted by NGOs. NGOs may do this organising work on their own account, or be invited and funded by government, and donors can also support it. The idea is that by using the room to manoeuvre in existing policy and regulations, a different relationship of water users with the irrigation agency can be negotiated. And, improvement and success in some cases creates a demand for more general policy change. In this way the reform ball starts to roll.
The bottom-up model can be represented more effectively as follows.



This figure shows a triangular relationship between policy institutions, irrigation agencies and farmers/water users. Farmers/water users are citizens who can be involved in the process of policy formulation and implementation in different ways: via representative politics, via public action of farmer/water users/citizens organisations, via public debate and hearings and other platforms for state-citizen interaction, and via the contribution of labour, knowledge, money and organisational capacity. Farmers/water users relate to irrigation agencies via formal or informal accountability mechanisms, and through contractual arrangements (for water delivery, fee payment, maintenance and other items). The relationship between policy institutions and irrigation agencies is one of governance, but should also be two-sided in the sense that policy decisions are informed by administrative/ bureaucratic realities.

The donors and NGOs are put in the middle of the figure not because they are central to the process (they may in fact be absent), but because they may play a catalysing role in the reform process, and may have relationships with all three parties.
The characteristic difference between the triangular interactive model and the top-down model can be captured by the phrases `policy as process' and `policy as presciption' (the

Box 1: Extracts from the Mexican National Water Law (1992)

Article 51 For the management and operation of systems and for the common use of the water (...) bodies corporate must be governed by bylaws that include regulations with regard to:

I. The distribution and management of the water conceded to them, and the manner in which decisions are to be reached by the group of users;
II. The form in which the individual rights of their members or the users of the irrigation service are guaranteed and safeguarded, and the forms in which they may participate in the management and oversight of the system;
III. The form in which the infrastructure or common system is to be operated, conserved and maintained; the form in which investments are to be made in improvements; and the form in which the costs incurred are to be recovered. It shall be compulsory for the members or users to pay the requisite fees if they are to continue to receive the service or to use the water;
IV. The rights and obligations of members and users, and sanctions for failure to comply;
V. The terms and conditions under which individual rights to water use may be conveyed among the members or users of a common system;
VI. The terms and conditions under which the rights to a concession, or the use of surplus water, may be totally or partially conveyed to third parties;
VII. The procedures for dealing with complaints by members or users;
VIII. The terms and conditions to be followed in mergers, splits, dissolutions and liquidations;
IX. All other matters that stem from this Law and its regulations or are agreed upon by members or users.

Bylaws and amendments to them require a two-thirds vote in favour by a general assembly called expressly for this purpose.

Source: National Water Law, December 1992, National Water Commission, SARH

terms are taken from Mackintosh, 1992). An illustration of the meaning of these phrases is possible by comparing two recent laws for participatory irrigation management: that of Mexico and that of the State of Andhra Pradesh, India. Extracts from the two laws are given in Box 1 and Box 2.

The extracts from the Mexican law show that it is an enabling law. It creates a framework within which water users can design their own organisation and negotiate their own agreements and contracts with the water supply agency. Their only obligation is to pay for the water. In this way what the policy actually is, is determined on the ground, and it is likely that a considerable diversity of arrangements will occur. The law attempts to constitute the conditions for a process in which the different parties involved define their relationship and the internal rules and procedures of their organisations. Policy is seen as a social and evolutionary process.

Box 2: Extracts from the Act to provide for farmers' particpation in irrigation systems, Andhra Pradesh, India (1997)

3. (1) The District Collector may, by notification and in accordance with the rules made under this Act, in this behalf, delineate every command area under each of the irrigation systems on a hydraulic basis which may be administratively viable; and declare it to be a water users' area for the purpose of this Act.
(2) Every water users' area shall be divided into territorial constituencies, which shall not be less than four but not more than ten, as may be prescribed.

4. (1) There shall be a Managing Committee for every water users' association.
(2) The District Collector shall make arrangements for the election of President of the managing committee of the water users' association by direct election by the method of secret ballot in the manner prescribed.

5. (13) The Government may in the interest of a farmers' organisation in the command area by notification and in accordance with the rules made in this behalf,-
(a) form a new farmers' organisation by separating the area from any farmers' organisation;
(b) increase the area of any farmers' organisation;
(c) diminish the area of any farmers' organisation;
(d) alter the boundaries of any farmers' organisation; or
(e) cancel a notification issued under this Act for rectifying any mistake;
provided that no such separation, increase, diminution, alteration and cancellation shall be effected unless a reasonable opportunity is given to the organisation likely to be effected.

16. The objects of the farmers' organisation shall be to promote and secure distribution of water among its users, adequate maintenance of the irrigation system, efficient and economical utilisation of water to optimise agricultural production, to protect the environment, and to ensure ecological balance by involving the farmers, inculcating a sense of ownership of the irrigation system in accordance with the water budget and the operational plan.

17. The water users' association shall perform the following functions, namely:-
(a) to prepare and implement a warabandi schedule for each irrigation season, consistent with the operational plan, based upon the entitlement, area, soil and cropping pattern as approved by the distributory committee, or as the case may be, the project committee.
(e) to assist the revenue department in the preparation of demand and collection of water rates;
(q) to conduct general body meetings, as may be prescribed;

In contrast, the Andhra Pradesh law is highly prescriptive. It goes into great detail about the organisational characteristics of the water users associations and their internal procedures (only a few elements are reproduced in the box). It goes even up to the point that it specifies that a member of the managing committee should be a person with not more than two children! It is also clear that the government keeps a strong hold on the organisations established under the act. In terms of property rights, the limit is the inculcation of a `sense of ownership'. Policy is seen as prescription.

The question to be answered may now be rephrased as follows.

Does the introduction of PIM require a prescriptive or process approach to policy formulation and implementation?

Problems with prescriptive policies for pim: some examples

The characterisation of the two different approaches above is not yet an argument in favour of either of the two. A prescriptive policy approach for irrigation reform can work. Two important conditions for this are the following.

1) A strong government and administration, that is, well developed enforcement mechanisms and competent leadership, and legitimacy towards citizens.
2) Policies that address real needs, or put differently, policies for which there are strong incentives for farmers/water users to participate in.

These conditions are not always met.[3] In many cases there are different interest groups within the government itself (different departments, different cadres, field *vs.* office level, party political factions, etcetera). Established bureaucracies may resist institutional change and the adoption of other modes of work. Politicians may interfere with the administration to advance the interests of their constituents. These and other factors can seriously undermine the implementation capacity of governments and administrative institutions. The state is rarely the neutral, coherent and benevolent institution that the top-down model seems to want it to be.

Also on the farmers side there may be strong divergence of interests, between head end and tail end farmers, and along other lines of social division (class, caste, gender, religion). This may cause an unequal spread of the benefits of the policy and non-adherence or even sabotage of its implementation. Farmers may also have different priorities in their survival and accumulation strategies than the government's water-reform focus.

Some of these issues can be illustrated by giving examples of field level observations of PIM introduction efforts. I give examples from India, Indonesia and Pakistan. The examples all date from 1997 and were made by the author (India) and by students of Wageningen Agricultural University as part of their M.Sc. thesis fieldwork (Indonesia and Pakistan). The stories can be found in Boxes 3, 4 and 5.

The three examples present a gloomy picture of PIM implementation in practice. The examples may not be representative, and I make no claims to that effect. Also it is not my intention to point a finger at the persons and institutions involved. My interest is a broader one: what can we learn from such examples? Which general issues do they raise? What do they teach us about possibilities for the introduction of PIM in such cases? The following observations can be made about the examples.

[3]) The Andhra Pradesh case will be interesting to follow in this respect. It is a top-down approach to the introduction of PIM, and one that seems to be implemented with vigour and 'political will'. The prescriptive nature of the WUA characteristics and elections for example, explained a main responsible implementor, is to prevent dominant, head-end farmers to take control of the WUAs. The question then becomes, how long can the vigorous implementation be sustained (to make some aspects of decentralisation irreversible for example), and what are the field-level implementation characteristics?

Box 3: A PIM meeting in a tail end distributary, India

The Under Secretary to Government Irrigation Department (Command Area Development) in May 1997 issued guidelines for the implementation of PIM on a pilot basis to the Chief Engineers and CADA (Command Area Development Authority) Administrators of the different projects in the State. As the first step in the implementation of the PIM programme in the Karnap Project ten pilot villages *cum* command areas were selected. The selection criteria were, as far as we could ascertain, the size of the command area, and particularly the existence of a `cooperative attitude' of the farmers. For one case it was reported to us that the village/command area was included on the specific request of the local MLA (Member of the Legislative Assembly).

The CADA took swift action and organised meetings in the villages concerned in June and July 1997. We were able to be present at one such a meeting. The village/distributary command area was located in the tail end of the main canal. This was in contradiction with the intention at policy level that sites with not too problematic water supply conditions should be chosen. Furthermore, the meeting took place in the head end village, while the existing association was based in and had a chairman from the tail end village. The meeting place seemed to have been determined by the practical reason of accessibility by jeep. The meeting place was appropriate in so far that most farmers who irrigated in this distributary were from the head end village. The tail end village area hardly received any water. Apart from the chairman only head end farmers, about 20, were present at the meeting.

The farmers had been informed about the meeting a few days earlier. The Irrigation Department officer present at the meeting had heard about it the night before. The meeting was chaired by a CADA officer. Initially the meeting was rather one-directional. The chairman explained the contents of the new policy. It was clear that he was not very well informed about its content. This was hardly his fault because not all the details of the policy were decided at that point of time (one example was the composition of the management board of the new WUA).

The farmers were very quick to notice the problem of the quantity and the stability of water supply from the main canal. The Irrigation Department officer correctly argued that a stable supply could not be delivered because of interventions upstream in the system that his division was unable to influence. The chairman told him to determine a supply that he could guarantee, and thus more or less ignored the issue. The head end farmers had some fear that they would lose water in the new situation, but the head-tail issue was not appreciated and left undiscussed.

A large part of the discussion focussed on the most concrete aspect of the policy: the need to make an estimate of the costs of the necessary technical repairs and improvements of the canal system before the management would be turned over to the farmers. The only concrete result of the meeting was that the chairman told the Irrigation Department officer to prepare such an estimate together with the farmers within a few weeks.

At the end of the meeting we asked whether a copy of the guidelines could be provided to the farmers in the State's language. The chairman first reacted by stating that these guidelines were meant for the government officials and that farmers had no need for them. In the second instance he argued that there was a stationary problem in his office. He was clearly totally unprepared for this question. After the meeting we had some discussions with farmers that had attended the meeting, and it was clear that they had only very partially picked up the content of the PIM policy. Self-governance is a novel idea, and it takes time to explain it. However, when after the meeting we asked the CADA officers whether they would return to the village for further explanation and discussion, the answer was negative. They only intended to return at the occasion of a formally called meeting.

Box 4: A visit to a pilot village by a government and World Bank delegation, Pakistan

The World Bank urges the Pakistan government to make haste with giving farmers larger responsibilities *vis-à-vis* the Irrigation Department, which is reformed into a Provincial Irrigation and Drainage Authority. Part of the reform programme is that in the first 5-7 years pilot projects have to be implemented, in which specific distributaries (secondary canals) are privatised. The village where the student was doing his research turned out to be one of the selected villages for a pilot project. He reports the following.

> In March 1997 a mission visited the study village. It consisted of three officials from the World Bank, the Assistant Commissioner of the Irrigation Department, the Zilladar (divional revenue officer) and some Patwaris (land, water and tax record keepers) of the local Irrigation Department office. The Patwari told me more about the event. Three months before, officials from the World Bank asked the Zilladar for the names of the large landowners in the village. Those large landlords had been invited by the Irrigation Department to come to meet the mission. The proposal of the mission was to form committees in every watercourse around the village. One large village water committee would be formed in which all different watercourses would be represented. The water committee should agree on the division of water over the different outlets. If it would have the feeling that a new scheme was needed, like a tubewell or lift irrigation scheme, the World Bank and the government would provide for 80% of the costs. The committee would have to decide if the present system of water fee/tax collection should be maintained and if the Patwaris should remain in function or not. The officials of the World Bank suggested that the Village Development Organisation would take the responsibility of organising the committee on village level. According to the Patwaris, the farmers of the village were not enthusiastic about the proposal. They mentioned a lot of problems, but their main fear (at least according to the Patwaris) - that the large landlords would take all the benefits of the programme and all the water - was not expressed. The farmers said they were afraid for the fact that the project is an experiment and that they did not want to put their crops at risk. According to the Patwaris, the mission from the World Bank was left with the impression that a lot of problems existed in the village and that the enmities in the village would harm the forming of the committees. Nevertheless, the project would continue.

The mission must have assumed that by inviting large landowners it would get a good representation of the village and the irrigated area, or at least would group those with authority. However, not in all watercourses there were large landowners, and the person most active in organising farmers at watercourse level was not a large landowner. He was not aware of the meeting. The student had also found that organisation of irrigation was strongly linked with village politics, and that the lines of division within village politics did not coincide with the boundaries of watercourse command areas. For unknown reasons this possibly difficult village was selected for the pilot project, while nearby villages where the On Farm Water Management (OFWM) Programme had formed viable farmer organisations, which were waiting for legal recognition and handing over of responsibilities by the Irrigation Department, were not selected.

Box 5: The participation of farmers in turnover, Indonesia

The Government of Indonesia has recently expanded its irrigation management turnover programme to include not only systems smaller than 500 ha but also larger systems between 500 and 1000 ha. Pilot projects were set up to experiment with the turnover of the larger systems. In the implementation of the two pilot cases that were investigated foreign and local consultants were also involved. An important element of the turnover process is the `design system planning meeting'. In this meeting the WUAs that are formed negotiate with the consultants and government about the system upgrading that needs to be done as part of the turnover. The observation of one such meeting yielded the following results.

The meeting was organised by the DPW (Department of Public Works) and they also conducted and chaired it. In the meeting the objectives of the turnover process and this particular meeting were explained. The village and WUA heads heard about management transfer and the contents of the meeting for the first time at the meeting itself, and - thus -had come unprepared.

The local consultants presented the proposed infrastructural design to all attendants of the meeting. They introduced it as a combination of the farmers proposed design and design made by the local consultants themselves. Discussion was needed, they said, to define the priorities for the rehabilitation. These priorities should be defined by the WUA heads and village heads.

Before this discussion the local consultants gave the list of the proposed design to farmers representatives. While they gave it to the farmers representatives, they whispered to the representatives (in dialect) that they had already marked (with a blue circle) which work should be given higher priority than others. This was mainly done to convince the foreign consultant that negotiations with farmers had already taken place. The consultants had used the signature of a single WUA head as evidence for farmer involvement in the proposed design.

During the discussion the farmer representatives obediently identified the priorities for the rehabilitation as it had been prepared. However, when the foreign consultant asked why they considered that work as more important than other work, the farmer representative could not answer and got confused. The DPW staff said that the the WUA head was not used to speaking in Indonesian, and proposed to translate the explanation in Indonesian for the foreign consultant. What really happened was that the WUA head admitted (in dialect) that he did not understand a thing about these drawings, while the provincial design officer `translated' the explanation of the technical drawing to the foreign consultant.

It also turned out that the priorities of the DPW in rehabilitation were not those of farmers. The DPW wanted to build the still unconstructed secondary canals in this system in the natural drains (also used for re-use of drainage water and diversion by village weirs), while the farmers wanted the secondary canals on the ridges. According to one source there were no more funds for land acquisition because they had been used for other purposes by the DPW, and therefore construction on the ridges was financially impossible.

1) In all three cases the PIM initiative did not originate in the group of farmers/water users, but came from outside. PIM was an idea of the government, the World Bank and consultants. Farmers were confronted with it, but they had not asked for this confrontation.

2) In neither of the three cases a serious effort was made to understand even the basic features of the local situation with regard to water management and distribution and social relations in the community. There is also a strong tendency to discuss with large farmers and local leaders only. This ignores differential interests and perceptions within the group of farmers/water users. That priorities of farmers were different than those of government remained unobserved.

3) In all three cases the primary interest of the irrigation agency was the physical interventions that were part of the reform process. Construction remains the main orientation of irrigation agencies. It may even be speculated that institutional reform programmes' main, but hidden, objective may be the mobilisation of new funds for physical works.

We can hardly be surprised that PIM policies will achieve little when they are implemented in this way. What are the implications of this for the design of policies and programmes to introduce PIM in such situations? I have three suggestions to make.

1) Ways need to be found to enrol irrigation agency staff in the reform process. There are 'negative' ways to do this, meaning the adoption of policies and procedures that force irrigation agencies to work differently and change their priorities. There are also more 'positive' ways to do this: by education and training, by creating incentives (or removing disincentives) for different modes of work and forms of organisation. An underemphasised way to enrol irrigation engineers in reform, and the one that I want to highlight in this paper, is to provide engineers with professional technical challenges that will contribute to the reform process. I elaborate this point in section 4.

2) Policies and programmes have to be designed from farmers' perspectives and priorities. In this it should be recognised that irrigation is just one the elements of a farmer's livelihood strategy. Goldensohn, in a review of programmes for the establishment of WUAs in six countries has concluded something similar.

> The sociologists and anthropologists who joined the irrigation bureaucracies to help create and strengthen WUAs concentrated on how to organise. They paid far less attention to what to organise for. They generated effective internal management and administrative structures to help establish organisations as good as the irrigation infrastructure itself. But they failed to look carefully enough at why water users would want to organise and what purpose WUAs would serve after the construction was over. They aimed for simplicity and efficiency in their organisations and gave little thought to the complications that politics and economics could introduce.
> Farmers cannot be expected to limit their objectives to those of engineers and sociologists, but unfortunately, until recently, this assumption has governed most efforts to organise WUAs in Asia.
> (...)
> The members of WUAs (...) earn their living from their farms, not from their irrigation systems, which admittedly provide a crucial input but one that is no more important than land, labour, capital, seeds, and other inputs. Without these agriculture cannot thrive, even if the irrigation system is working perfectly. WUAs principally are organisations of water-using farmers, whose final concern is the living they earn from agriculture.
> The participatory approach to WUAs stops at the entry to the farm. The WUAs thus become irrelevant to farmers after construction or rehabilitation is over. Farmers want water. But they want water as a means to an end, not as an end in itself. The WUAs are conceived with water management as their sole objective, whereas farmers want more than to manage the water and to perform O&M. They

> know that efficient and effective water delivery is a sine qua non for agriculture. They are not opposed to what the engineers have in mind. On the contrary, their almost universally enthusiastic response to efforts to organise WUAs for system construction, rehabilitation, or expansion shows that they share the engineers' goals. However, they want to go beyond these goals because they see a holistic system, not just an irrigation system, at work. (Goldensohn, 1994:11-12)

The implication for reform policies and intervention programmes is in my view that these should be less canal and water focussed than they have been so far. I elaborate this point in section 5.

3) At the most general level it can be concluded that policy formulation and implementation in practice often are complex processes of formal and informal, legal and illegal, open and hidden interaction and negotiation of different interest groups. Policy formulation and implementation need to be treated as political processes in which many interests are at stake. Reform processes tend to be slow and difficult in such circumstances[4)], and require strategic political action to be successful. This is elaborated in section 6.

Technical challenges as part of pim initiatives

Any reform initiative in canal irrigation needs to take cognisance of the fact that these systems are designed and managed by civil/irrigation engineers. When irrigation management is to be done differently, these professionals and the institutions they work in will have to change. There are as yet very few examples of successful bureaucratic reform of irrigation agencies, certainly in South Asia. There seems to be insufficient pressure of governments, from society in general, or from the possibility of financial and other crises, to induce processes of institutional change within these bureaucracies. Irrigation departments tend to take an extremely defensive attitude towards reform. It has not been possible to enrol their staff in the desired process of change.
Without wishing to suggest that there are simple solutions to this problem, I would like to put forward the idea that one of the most obvious ways to interest the engineering community for reform has not been used very much. That way is the translation of the different elements of the reform into professional, technical challenges for the engineers. When the devolution of rights and responsibilities, and self-governance of part of the canal systems by farmers are considered as elements of PIM, many technical challenges emerge. I give a number of examples.

1) The first is the issue of intermediate storage in canal systems. `Live' examples of these can be found for example in some irrigation systems in South India where tanks are part of canal systems. Intermediate storage facilitates `hydraulic decentralisation'. It decreases fluctuations in the supply from the main system, and creates small buffers. It may also create the possibility of night storage.

4) Those who want to argue that only radical decisions can provide solutions in such cases, have to answer the question when, how and by whom such radical decisions can be taken. The magical formula of `sufficient political will' can hardly suffice as a strategy.

Intermediate storage can make the use of canal systems much more flexible, and local self-governance more realistic. They involve many design issues with regard to size and number, location, siltation and other factors.

2) The type of outlet structure that connects the government-managed part of the system and the farmer-managed part of the systems is a second challenge. The features of this device are crucial for how and how much water is delivered to farmers. Our research in South India suggests that field level engineers are quite creative in trying to respond in their designs to problems in water management. However, they are heavily constrained by the rules and procedures in the irrigation agency, in which design standards actually mean standard designs. Instead of getting rewards for their creativity, they fear that their digressions from the standard design are detected.

3) Another technical challenge lies in the provision of drinking water for the people who live in the irrigation command areas, and more generally in the health and sanitation dimensions of irrigation. Particularly in areas where there is no good quality groundwater (like in the vertisol `black cotton soil' areas on India) the canal systems are essential for drinking water provision, but often the systems are closed for several months in the summer. For farmers and their households water is not just irrigation water, but has other functions and values as well, which require particular infrastructural provisions.

4) Perhaps the greatest technical challenge lies in the integration of soil and water conservation technologies and irrigation technologies. These disciplines and their projects are often implemented separately. In the irrigation system where I worked the soil and water conservation was not even allowed to undertake activities in the area that was the jurisdiction of the irrigation department! The increasing emphasis on integrated water resources management provides many technical challenges for irrigation engineers.

5) Yet another area is the use of local materials in for example canal lining and small dam/weir construction. These materials may be cheaper and allow more sustainable use of the infrastructure (for examples, see Gore, 1998).

6) The last area that I just want to mention, is that of drainage, which acquires increasing prominence with mounting problems of waterlogging and salinisation.

The biggest challenge however perhaps does not lie in the technical questions as such, but in the way that they are addressed. I would like to advocate an approach of participatory technology development in this respect. Models for this have been developed for and used in the context of farmer managed irrigation (and in other sectors like agriculture, forestry and soil and water conservation), but they have found very little application in canal irrigation. However, they could very well be part of PIM initiatives. A participatory approach to technological innovation would provide professional challenges to engineers, and establish different relations and interaction patterns between farmers and engineers, which could also help institutional change.

A rural development approach to irrigation reform

In most cases irrigation reform policies of governments have not met with great enthousiasm from farmers. At the same time many local experiments with farmer organisation suggest that there is great interest of farmers in different types of irrigation management. However, these positive local experiences never seem to replicate themselves. The reasons for this are partly the prescriptive nature of government policy and the unwillingness to devolve real powers to local organisations. Partly also it is related to the limited focus of the policies: they tend to limit themselves to irrigation water and canals, and do not look at water from the perspective of farmers livelihoods. It is this latter point I want to elaborate in this section. My argument is that irrigation reform initiatives like PIM need to be made part of broader efforts at integrated water resources management and rural development to be able to speak to farmers' needs and gain more explicit support.

To illustrate my point I briefly discuss the main elements of an approach that has been published under the title `banking on biomass' (see Paranjape and Joy, 1995; Datye, 1997).

The first element of that approach can be derived from the following quotation.

> It is generally found that in watershed development schemes local groups as well as development administration tend to concentrate on the *in situ* measures to the exclusion of water source development for water application. On the other hand irrigation projects give scant attention to local resource management and exogenous water is seen not as supplement to primary ecosystem productivity that it should be but as a substitute for it. The need is to integrate them both within a coherent perspective. (Datye, 1997:57)

The dichotomy between rainfed agriculture and (canal) irrigated agriculture needs to be transcended. In this approach the sustainable management of local resources is a precondition for the availability and use of `exogenous water' like that provided by a canal irrigation system. Such an integrated approach to water resources development can lead to substantial increases in resource use efficiency.[5)]

The second element of the approach refers to the social dimensions of sustainable resource use. It can be derived from the following quotation.

> Equitable access to water necessary for ensuring livelihood needs to be treated on par with employment guarantee and the right to work as part of the larger right to an adequate livelihood. (...) water necessary for drinking and domestic use, for regeneration and for the livelihood component including special measures for the disadvantaged sections represents a priority claim on water resources in the area, and only after these claims have been met can the water be available for commercial use. The policy is to ensure a minimum livelihood for all and to regulate all resources necessary for this, and leave the rest of the resources to be freely utilised by the enterprising. (*ibid.*:58)

[5)] The author claims that "by the integration of external sources of irrigation water with `local' water harnessed from the watersheds and conserved *in situ*, it is possible to raise the productivity level of total available water for productive use to levels three times that of `external' irrigation water." (Datye, 1997:142) These and other statements are backed up by empirical evidence and calculations on the basis of existing technologies.

The approach defines a basic water right for all, and delinks water rights from land rights. In strategic terms the approach wants to allocate `new water', that is water that has become available through efficiency gains and ecosystem development, to the resource poor. The approach is a positive-sum variant of hydraulic property creation (Coward, 1986a&b). Those who have (collectively) invested in the generation of new resources by optimising existing resource use, gain rights in these new resources.[6)]
The third element is the ecological sustainability-with-growth element. Characteristic of the approach is that it not only advocates ecologically sound techniques for agricultural production, but conceptualises agriculture as a system of `regenerative biomass production' that provides the bio-energy not only for sustainable agriculture but also for dispersed industrialisation.[7)] The production strategy emphasises production of crops that can serve as the inputs for small industries, like tree crops. The approach wants to `move beyond subsistence' and wants to provide an agricultural *cum* industrial perspective of sustainable growth.[8)] Part of the approach is an argument for non-subsidised prices for external inputs in agriculture, subsidies that help the detrimental effects of high external input agriculture to pertain. The approach proposes the (gradual) removal of subsidies on electric power and the introduction of a progressive tariff system, volumetric water supply and cost recovery, while price support for coarse grains is advocated.
The fourth element is the methodological one. There is a strong emphasis on decentralised and interactive planning and decision-making, including an emphasis on elements like people's science, participatory technology development, and resource literacy.[9)]

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6) The authors recognise that the acceptability of equitable access to water is a "most troublesome point" (Datye, 1997:130), but several examples are cited where this has been achieved in practice. The general finding in the cases reported is "that where access to water resource is seen to come about clearly to collective action, and where there are no previous entrenched water rights, farmers are not averse to equitable sharing arrangements." (*ibid.*:132) In terms of social reform the approach chooses to move away from a primary focus on land reform as a precondition for agrarian change. "The alternative paradigm presented here suggests another route -- that of augmenting the subsistence base by harnessing and generating new productive assets and ensuring access to them in the course of development in building up common resource pools through the development of wastelands and water, and by a policy of tying availability of public funds with the conditionalities of creating rights and access for the rural poor to the common pool resources of water and biomass. Combined with an overall improvement in the availability of water and efficiency of water use along with increased productivity of land and water, conflicts can be minimised though, of course, not entirely eliminated." (*ibid.*:261) This aspect of the approach is likely to spark a lot of discussion, particularly from a gender perspective. For the importance of control over land for gender equality see Agarwal (1998). Also see NEDA (1997).

7) The publications referred to contain descriptions and calculations of biomass based power generation, in relation to the power required for lift irrigation that is part of the agricultural system for example.

8) In this respect it goes one step further than approaches like those described in Chambers, Saxena and Shah (1989) for example, though many of the individual elements are similar. There is also a greater emphasis on the technological prerequisites in Datye *et al.*'s approach.

9) The publications referred to do not discuss these methodologies in detail. For more elaborate treatment see for example Chambers, Saxena and Shah (1989), Shah (n.d).

Elements of Datye *et al.'s* approach can certainly be questioned. However, it makes an in my view highly original attempt to combine the concepts of integrated water resources management, ecologically sustainable agriculture, agro-industrial growth, equity/poverty alleviation/social security and decentralisation/democratisation. It broadens the debate on canal irrigation reform in the following way.

1) It situates canal irrigation reform in a broader rural development strategy, and doesn't look at canal irrigation as a self-contained phenomenon.
2) It links canal irrigation development and watershed development (it takes an integrated water resources management perspective), and links this to decentralised and democratic forms of planning and decision making.
3) It emphasises the importance of water rights (and property rights in resources in general) as central for a development strategy that targets the resource poor.
4) It gives detailed attention to the technological dimensions of the development strategy.

Coalition politics

Despite the statement that (in India) "the policy framework and implementation of the post-Independence programme in the water, energy and infrastructure sectors lack all the components of the policy frame proposed here" (Datye, 1997:266), the approach described above contains no description of a strategy to achieve the policy reform and/or broad-based social activism that is necessary to create more favourable conditions for large(r)-scale implementation of the approach. Are we discussing Utopias?

I don't think so. Interesting about the approach is that it incorporates elements of several other reform perspectives: an emphasis on productivity growth, employment creation, resource use efficiency, and non-subsidised pricing. This implies that it can possibly speak to the concerns of a number of different political constituencies.

This introduces the general question how to build a political support base for policy reform in the irrigation sector. Bottrall (1992) is one of the few attempts that I know of a strategic political analysis with regard to canal irrigation reform in the South Asian context. He argues that

> "there could be a possibility of [an irrigation reform] agenda being incorporated into - and thereby reinforcing - broader-based movements for democratic reform." (Bottrall, 1992:245)

According to him major changes on three fronts are necessary:

1) reduction of the excessive powers of the Irrigation Department and other agencies responsible for
   large-scale canal irrigation,
2) the formation of agencies for long-term integrated water resources planning, and
3) launch programmes in regions that were neglected in the past.

He argues that support for such an agenda might be found in different corners.

> "Those currently opposed to the *status quo*, or with good reasons to oppose it, include finance ministries (concerned about IDs' never-ending demands on public funds); politicians and their constituents in regions disadvantaged by present patterns of water development (either through direct damage, as in waterlogged areas, or through

> long neglect, as in tank areas); environmental action groups; local issue-based groups (such as opponents of state water policies in Maharashtra); and non-agricultural water users, including urban domestic and industrial users, who suffer from the absence of efficient methods of inter-sectoral water allocation." (*ibid.*:244)

What Bottrall argues is that political coalitions have to be forged of non-governmental and governmental groups in society to create a demand for reform. He also suggests that the agenda of such a coalition should be broader than the sectoral interest of better management of canal irrigation systems, but focus on irrigation as part of integrated water resources management.

Conclusion: The role of inpim

To conclude this paper I would like to look at the possible role that INPIM can play in an approach like that advocated above.

Let me begin with a sketch of the policy reform situation in the South Indian state where my research work is located. What we have seen in this state is that over the past few years there has been an initiative within the government to formulate a policy for PIM. A High Level Working Group was appointed, which prepared an interim report and later a final report which contained proposals for reform. These proposals were approved in principle, and all the necessary amendments and rules to implement them have been put on paper. A start with implementation was already made by the selection of pilot projects and conducting meetings with farmers (see Box 3). The amendments and rules only needed formal political approval to go ahead. That situation has existed for a year. Up to a few months ago the approval had not come. The momentum that was there seems to be drifting away.

My understanding of this course of events is the following. The policy initiative had a number of different sources. There is a history of management problems in existing canal irrigation systems and general policy declarations that something needs to be done about it. There was a case of a World Bank assisted construction project in which the World Bank had put conditions for policy reform in relation to WUA formation and other items. There was pressure from the Central Government to take initiatives for policy reform. There was the influence of reports on successful experiments in other States which academics and NGOs brought into the debate. And there was a fair number of individuals within and outside the government that had ideas about the changes that are necessary. At a certain moment in time a number of these individuals were occupying positions in the government influential enough to allow the active pursuit of a PIM policy initiative. A working group could be formed, and the process of mobilising support for the ideas started. Why did it stop - hopefully temporarily - shortly before the finish?

The main reason for this in my view is that it was a group of *individuals* that was lobbying for the policy change. When one of them was transferred (for reasons nothing to do with the PIM initiative), the momentum was lost. There was no back up. There were no groups in society that were actively demanding a new PIM policy. There is no coalition of social forces as envisaged by Bottrall that has made irrigation reform an important item on its agenda. When such a support base does not exist, the acceptance of particular policies

becomes a matter of chance and circumstance. And one can wonder, when the policy is accepted, what the commitment to implementation will be.
Here possibly lies an important role for a network like INPIM, and particularly for its national chapters. As an independent organisation an INPIM chapter can play an advocacy role in the reform process. It can document problems in existing irrigation systems and positive experiences with reform, and bring these into the public debate. It can take initiatives to bring together the different stakeholders, and try to identify common agendas. It can organise training sessions and other activities to redirect the professional orientation of engineers to field-level problems. And it can do many other things.

To conclude my paper I would once again like to rephrase the question with which it started, into a discussion question for this seminar.

> *How can INPIM and INPIM chapters contribute to the emergence of an interactive or participatory policy process that provides professional challenges for engineers, that looks at irrigation in the context of IWRM and rural development and that can build social and political networks and coalitions to support irrigation policy reform?*

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WETLANDS FOR FOOD SECURITY: BUILDING CAPACITY FOR WETLANDS MANAGEMENT

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Summary

Around the world large sections of populations subsist on direct exploitation of the natural resources. Wetlands provide many of these important resources as well as a range of life support functions. In the drier regions wetlands are the only sites where people can get water, varieties of food and other basic supplies. Sustained good and effective management of the wetlands is therefore the most achievable and practical way to ensure food security for such communities. This calls for various forms of institutional capabilities - within the communities, at national and international levels. This case study, developed by Wetlands International, shows how through appropriate networking and capacity building good management of the wetlands can help to ensure food security for many of the communities.

Wetlands International is an international non-governmental conservation organisation active across the world. It promotes the conservation and sustainable development of wetlands and related resources. It does this through an extensive international network of programmes. The sustainability of the programme results is ensured through networking and capacity building with partner institutions. An emerging area of concern being addressed by Wetlands International is the use of wetland resources to meet the growing needs of local communities. Through programmes, Wetlands International works at establishing processes to facilitate mechanisms through which potentials of the resources can be sustained in the long-term. The needs for food and water by communities are real and will need to be addressed systematically. Most past global programmes to improve food security have relied heavily on modern technology and market forces. Consequently, the programmes have benefited largely only people who are already active within the market economy. To ensure food security for large sections of the communities not yet part of the market economy there is therefore a need for complementary programmes. These would need to build on and enhance the existing subsistence mechanisms of such a people. There are many examples which illustrate how networking and the sharing of experiences of people in similar circumstances help promote successful solutions to conservation and food supply problems. An expanding network of communities and institutions able to properly plan and manage their natural resources promises food security for the most deprived sections of populations.

CAPACITY BUILDING IN IRRIGATED AGRICULTURE

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Introduction

Capacity building contributes to a better functioning of staff and institutions and therefore to the society in which these institutions operate. Capacity building includes both human resource development (training) and institutional strengthening (RAWOO, 1993).

In this paper, first the work field of irrigated agriculture will be presented and an overview is given of activities that are supportive to capacity building. Subsequently, the activities of ILRI on training and institutional strengthening are discussed, followed by two examples of capacity building programmes in Indonesia and Pakistan. Finally, some new priorities in capacity building are mentioned.

Irrigated Agriculture

In irrigated agriculture, one can distinguish between many institutions. The institutions influence the performance of those involved, e.g. farmers, the private sector, and governmental agencies, in a direct or indirect way. These institutions can be responsible for a specific part of the water system or for one of the levels in the water hierarchy, or they may represent an interest group. The institutions typically differ in perspective and approach.

Basically, a water system for agriculture consists of an irrigation system and a drainage system. Water is an input in agriculture, but it is also used for drinking water and sanitation, industry, traffic and nature. Some of the users are concerned with the quality of water. Others are more interested in quantity and water depth issues. Requirements for water are time and place specific. Thus, people rely on water to fulfil different needs; they built their institutions around them.

Water control systems in agriculture are organised at different levels: field or farm level, outlet or village level, main system level, and even watershed level.

Both users and managers have to deal with issues, which are not only technical in nature, but also socio-economic, legal, organisational and cultural. Users are usually farmers. Farmers depend on water control systems, but at the same time are involved in production systems, agricultural service systems, and markets. Moreover, they are confronted with taxes.

Institutes concerned with irrigated agriculture find their target groups and problem fields in the above domains. Changes in one element of the complex system will affect others. In irrigated agriculture the sources land and water become increasingly scarce. This requires the participation of all involved in working out sustainable solutions to problems. In general, thus far investments in water control systems for agriculture did not result in sustainable conditions.

Capacity Building

Capacity building could play an important role in the development of sustainable irrigated agriculture. Even more so if capacity building programmes are tailor-made to an institution, its conditions, and to the problems it faces. In order to achieve this, capacity building must be built up from different elements. Main elements are *human resource development* and *institutional development* (RAWOO, 1993).

Human resource development takes place through *training*; it is an activity which is directly concerned with the capability of individuals. Training can be offered through regular or tailor-made courses, as well as through programmes of distance learning. On-the-job guidance, co-research and attachment training are other ways of training people. They can be most effective. Usually they are less formal. In these latter approaches, learning-by-doing is prevalent. Also, the content of the training can be more easily adopted to the demand (DGIS, 1998).

Problems with training include problems of quality and ensuring long-lasting effect. The training process passes through individuals who do or do not pick up new information and skills. After they have returned at their duty stations, they may or may not apply what they have learned. Trainers can usually not control the after-training situation, as the trainer is not in contact any more with the trainee. This is even more a problem if the trainee has to go overseas to follow a course. Institutional development helps to overcome this last problem (see below).

The development of *training infrastructure* helps to create appropriate training conditions and tools. Training infrastructure includes buildings, computers, vehicles, and class room equipment. The risk exists that the tools provided do not function under the local conditions, are not intensively used, or are badly maintained.

Through *project/programme support,* assistance is given in a more integrated way. It helps an institute to perform a certain task. The support usually combines advice, physical support and training. This is a most delicate process, as the transfer of knowledge should be well-balanced and responsibilities should gradually move towards the host organisation.

Another element of capacity building is *institutional co-operation*. Institutes are working together in several fields (research, advisory services, and training), and attention is given to methods of problem solving and organisational aspects (RAWOO, 1983). Usually the relation between institutions is long term and includes exchange of staff and support to attend international meetings. Long term relations allow trainers to learn in more detail the actual training needs in sister institutes, which contributes to the value and effectiveness of trainings.

Ideally, *institutional support* consists of a package of activities (grants, training, specific projects) to improve the functioning of an institution. This can be done only after an overall strategic vision of the institution's expected role and development has been formulated. In practice funds for inter-institutional co-operation are often channelled to a few institutions only, with the risk of creating over-dependency on external financing within these institutes (Schute, 1989).

Networks are increasingly important in capacity building programmes. In networks, information is transferred and contacts are made with relevant individuals and institutions. It can lead to the formation of peer groups of researchers and managers. Networks can link similar institutes in different regions, or institutes covering complementary issues.

A programme for capacity building can consist of several of the above mentioned activities. In the process of development the relative importance of the capacity building components may gradually change.

ILRI activities in capacity building

ILRI is involved in capacity building programmes since its establishment in 1955. An important activity is the implementation of regular and tailor-made training courses in the Netherlands and overseas. In addition most of the ILRI projects contribute directly to strengthening of research institutions through capacity building activities (ILRI, 1996, 1997).

ILRI's staff operates in research, training and advisory work. This gives an additional value to each of the activities and facilitates the more integrated approach required for capacity building.

Because of the experiences in advisory work, ILRI research focuses on local problems in developing countries. Research is implemented in close co-operation with the host institutes and invariably concentrates on land and water development issues.

Human resource development

ILRI offers training courses on a regular basis, like the 16-weeks International Course on Land Drainage (ICLD), and shorter courses, like the course on computer applications in irrigation (ICCAI), the course on drainage (ICMALD), and the course on execution and maintenance of drainage systems (ICDEM). ILRI also offers tailor-made courses, like the ICIW, on institutions in water management (in preparation), and the ICWIS, on water management in irrigation systems.

ILRI also organises refresher courses in overseas countries for the nearly 1000 alumni of the ICLD. And IlRI organises courses that are tailor-made to the needs of projects. These projects allow also for research guidance and on-the-job-training in the respective institutes. In special cases, attachment training can be organised at specialised institutes in Wageningen or elsewhere, depending on the support required.

Institutional development

Most projects implemented by ILRI focus on the strengthening of drainage-related research and education. Long-term co-operation exists between e.g. research institutions, like the Drainage Research Institute (DRI), Egypt; the Central Soil Salinity Research Institute (CSSRI), India; and the International Waterlogging and Salinity Institute (IWASRI), Pakistan. Each institute is linked to ILRI through a Memory of Understanding (MOU). Institutional development can only have result if it concerns a long-term relation.

In some countries ILRI supported more than one single institute at the time. In Egypt, for example, different activities have been developed with different institutions over the last decade:

- in co-operation with the Drainage Research Institute and EPADP: co-research, fellowships for training, organisational support, library support, computer hardware development, drainage machine introduction, networking;
- at the same time: support to the Advisory Panel on Water Management and Drainage.

In India support is given to CSSRI through:

- co-research, fellowships for training, library support, physical infrastructure development, and networking support,
- strengthening of institutional co-operation between CSSRI and Indian universities working on the same issues of waterlogging and salinity but under different conditions.

Since 1988, ILRI works together with IWASRI, Pakistan. The following activities are developed:

- co-research, fellowships for training, library support, networking, institutional support;
- guidance to the process of formulating a National Research Agenda (NRA);

- assistance to the co-ordination of the research programme of the National Drainage Programme (separate from IWASRI).

Similar forms of co-operation are in preparation with institutes in other countries, like with the Wuhee University at Wuhan, China; with the Faculty of Agriculture of the San José University, Guatemala; and with Spa Saniiri at Tasjkent, Uzbekistan. Starting-up activities can be multiple, like assistance in project management, library support, curriculum development, etc.

The Indonesian example

In the period from 1986-1994, the Indonesian government implemented an on-farm water management development programme at farmers level in Java, West-Sumatra, Aceh and South Sulawesi (FAO, 1993). For this purpose, the government of Indonesia received support from FAO, which contracted ILRI to render technical advice to the Indonesian government. It was a capacity building programme focusing on a new approach to deal with farmers in irrigation management. The programme was effectuated in the water management sections of the Department of Agriculture at all three levels: central, provincial, and district.

The programme used the rehabilitation of village and tertiary irrigation systems as a tool for institutional development. The new approach was a participatory way of local development of irrigation systems: the improvement and management of irrigation systems was based on requests, needs, commitments, and possibilities expressed by local communities. Water management sections at district levels and "line agents" at the sub-district and village level were facilitators in this process.

The programme included training of staff at all levels of the water management sections of the Department of Agriculture. The objective of the training was to improve the staff performance in co-operation and development activities. The active role of staff in the process lead to a two-way learning system: higher-level staff trained and guided the sub-ordinates, and by implementing the programme all officers learned from the experience gained at lower levels.

Training methods were adapted to the needs of the different levels. Farmers were trained through extension activities, short training sessions, and farmer-to-farmer visits. The training of the district officers existed of a combination of formal classroom training, in-the-field guidance, and workshops. In these sessions they exchanged field experiences and discussed interim reporting issues. Central and provincial staff participated in workshops and on-the-job training. Training issues were presented according in an order parallel to the development of the irrigation system.

The programme enhanced co-operation with local universities (responsible for training materials and lecturers), the Agriculture Extension Service, the Irrigation Department, and local government agents. The most intensive and decisive co-operation was realised at the sub-district level: the lowest level of governmental representation in

Indonesia. Civil servants at this level are usually well-acquainted with farmers needs and conditions.

Important elements in the capacity building programme for Water Users' Associations at local level were:

- respect for local initiatives;
- use of informal leaders;
- local commitment;
- co-ordination at a strategic level, the sub-district level;
- involvement of line agents of other services;
- training attuned to the project activities.

Through training and development, 670 farmers' organisations and related government agencies in the sub-sector were trained with attention to their specific functions. The project also succeeded in strengthening the relation between the line agents of three departments: irrigation, agriculture and local government. The number of staff who in this way gained practical experience in irrigation system development with farmers after 8 years was: 28 people at provincial level, 122 people at district level, and 673 at sub-district level. Through the programme, central government level officers were better able to formulate adequate policies on water management at local level.

The Pakistan example

The International Waterlogging and Salinity Institute (IWASRI) in Lahore, Pakistan, developed from a more technical-oriented research institute into a research institute with a focus on operation and maintenance of drainage systems by users. This change was supported by the Netherlands Embassy. The initial programme of co-operation between IWASRI and ILRI was formulated in 1995. This programme had 2 goals (IWASRI/NRAP, 1997):

1. to develop guidelines and procedures to realise the direct role of farmers in the operation and maintenance of drainage systems;
2. to develop institutional linkages for IWASRI to ensure the incorporation of non-technical issues in research on drainage, waterlogging and salinity.

In order to reach the first goal, three types of activities were developed:

- social impact assessment in large scale drainage systems;
- action research in a farmers' implemented drainage system;
- advise to national services and consultants on the involvement of farmers in the planning, implementation and operation and maintenance of drainage systems.

To achieve the second goal two types of activities were developed:

- the organisation of "Expert Platform Meetings" on participatory methods in drainage;
- an inventory of expertise available in Pakistan on non-technical issues related to farmers' participation on drainage, waterlogging and salinity.

Social and technical research programmes were formulated. This approach clearly strengthened the institution's capacity to undertake research in socio-technical aspects of drainage. Another objective was to strengthen local institutions in water management.

The action research took place in an area suffering from waterlogging and salinity near Bahawalnagar, Punjab Province (IWASRI/NRAP, 1997). This gave the opportunity to develop a process with farmers' participation from the very start. The farmers had the intention to contribute directly to the improvement of their lands.

An NGO was contracted to take care of socio-cultural aspects. The NGO contributed to site selection, communication with the farmers, and the strengthening of a Community Management System (CMS) at village level. IWASRI staff was responsible for the technical aspects. Line agents were involved to advise on operational aspects and training. In every stage of the project an effort was made to have the community involved as much as possible, both in sharing information, decision making, and the execution of the work.

Close observation of the progress made and of the impact of the project on the community helped to adjust the programme and contributed to a better understanding of the social and institutional aspects related to the implementation of drainage systems.

A site of about 100 ha was selected where waterlogging and salinity was considered a major obstacle for development. Because of unfavourable soil characteristics, a complex subsurface system had to be constructed to drain off excessive water and salts. Tailor-made training modules were developed to assist farmers. Farmers formed a Farmers' Drainage Organisation (FDO) to take care of operation and maintenance. The drainage system made it possible to pump up groundwater and to use it for supplementary irrigation or to evacuate it from the area. In spite of the efforts to obtain full participation of the farmers, farmers' involvement appeared difficult. One reason is believed to be the attitude of farmers, who wished the project to take care of all that needed to be done. This supports the idea to insist from the first moment onwards on initiatives by local institutions.

A lesson learned formulated after the initial phase of the project is that this kind of projects has to start with an awareness programme to stimulate communities or social groups to take the initiative. Farmers themselves should start reclaiming their land; they should apply for support if they cannot do by themselves whatever needs to be done. Solutions will have to be small scale and tailor-made to the needs and potential of the local community.

Priorities in Capacity Building

From the examples it may be clear that capacity building is an integrated approach directed towards the improved functioning of the institutions in society. It consists of a combination of activities designed for the specific needs and local conditions.

Policy
Capacity building programmes should be effective and functional. The goals to be achieved will be based on the analysis of institutional constraints (DGIS, 1998; NEDA, 1998). To realise such programmes, long-term commitments will be needed. Because funds are usually limited and the capacity to adopt change is equally limited, such an intensive approach is possible only for selected areas (region or countries), or on a defined sector. One could choose between the most promising, the most deprived sector; or the sector with the highest impact on society.

Programming
The focus must be on a more integrated approach. This asks for a longer duration of the programme and for phasing in steps, with specific benchmarks and approaches. Indicators are needed to check progress and to adjust means and approaches when appropriate.

Tools
Participatory approaches imply that initiatives lay with the future users of the systems and the "owners" of the institutions. More attention needs to be put on decision-making processes in which information management and institutional networks will get full attention. Interval-guidance may be a means to guarantee the "distance" required, leaving the initiative at the proper side of the co-operation.

Capacity building will become increasingly more important in irrigated agriculture as a means to improve the performance of water control systems. A close co-operation between institutes in Wageningen, like those present on this workshop, can contribute effectively to future capacity building in irrigated agriculture.

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Economic instruments for sustainable integrated water resource management

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Abstract

This paper starts with a brief introduction on water use, the characteristics of water, and the difference between water as a renewable and as a non-renewable resource. The general economic principles with respect to water are mentioned, but only as an introduction to the main topic of the paper: economic instruments for managing water scarcity. Although both supply and demand management is important, the focus of this paper is primarily on demand management, i.e. water use management. After describing the enabling conditions, three types of policy measures are analysed: market-based incentives, non-market-based incentives, and direct interventions. The emphasis is on market-based incentives. Water pricing, water markets and tradable water rights, water auctions, water banks, pollution charges, subsidies, and taxes are described and their likely effects outlined. Examples of implementations are given where possible. Some remarks on implementation costs and enabling conditions with respect to developing countries conclude the paper.

Introduction

Water is increasingly becoming scarce. Agriculture is using as much as 70% of global fresh water consumption. This is however changing. To illustrate this it is sufficient to compare e.g. the European Union and Africa. Whereas in the European Union 55% of water use is for industrial purposes, this is only 5% in Sub-Saharan Africa. For many years increasing demand for water could be met by equal increases in supply. This however has reached its limit. Large rivers like the Yangtze, the Colorado, the Nile and the Elephant River are almost completely dried up because of human water use by the time they reach the ocean. Lester Brown, director of the World Watch Institute, recently stressed the importance of competition for water as a scarce resource. At a meeting in Paris he talked about the effects on world grain prices and world food security. He predicted a serious decline in irrigated area, because of alternative (especially industrial) and more profitable use of water resources. Competition for water has to lead to a more efficient water use. This however is not an obvious process, as markets for water are often missing or highly imperfect and characterised by market failure and lack of competition.

This paper provides on overview of the economic instruments that can be applied to manage water use and water distribution. Before discussing these instruments the various functions of water and its characteristics are given and criteria that can be used to evaluate water policy are listed. Also the economics of water supply and demand as well as the topic of optimal water allocation are briefly discussed.

Different functions of water

Although this study is focusing on water quantity items it has to be stressed that an economically efficient water management system has to integrate quantity as well as quality issues (Howe *et al.*, 1986). Figure 1 shows the different user groups that benefit from water (Ministry of Transport and Public Works, 1996). The dashed lines between the categories of use are supposed to indicate their overall interrelationship meaning that every activity has effects on other activities.

Nature
The category *nature* represents all functions that are important for the continuation of bio-diversity and the preservation of the natural composition of water, soil, and air (see de Groot 1992 for a further specification of the ecological functions of water). Because all other categories are originated by human activity which is never without consequences for the natural material cycle it can be stated that *nature* is the main opponent of all other categories.

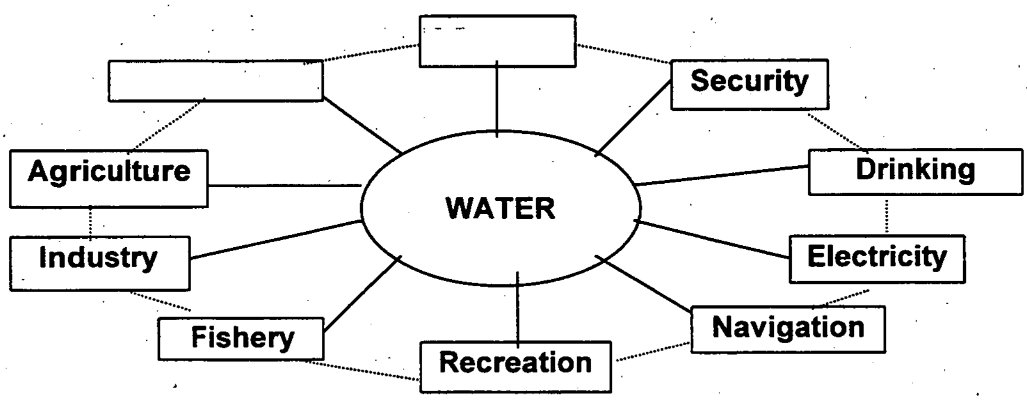

Figure 1 Different user categories of water

Security
In order to protect people from floods and extreme high tides it is necessary to take measures that use water. At certain times fast enough run-off of superfluous water is required. So security is also a water user, albeit an awkward user.

Urbanisation
Urbanisation contributes to water scarcity problems because rainwater that runs away through the sewage system does not have enough time to percolate through the soil to replenish the groundwater reservoir.

Agriculture
Agriculture makes use of water in nearly all-possible ways. Firstly, it demands special management of water control to prevent flooding. Secondly, water is needed for irrigation in order to save the crops from drought damage and for the cattle. This two purposes demand high quality water especially with respect to salt contents and toxic elements. Thirdly, *agriculture* is putting pressure on water quality by leftovers of fertiliser and pesticides that are washed out of the soil into groundwater reservoirs or that end up in ditches.

Drinking Water
The main competitors of *agriculture* on quality level as well on quantity level are certainly *drinking water companies, nature*, *fishery*, and *recreation*. All of them are interested in water of good quality. *Drinking water* has to be purified. The cost of this is partly determined by pesticides and nitrate pollution.

Industry
Industry needs water for in-stream uses such as for production processes, for the products themselves, and for cooling and for off-stream uses such as for the dilution of wastewater. Groundwater extractions of many industrial firms, especially in food industry, are to large extent responsible for desiccation on a local scale. This is because large amounts of groundwater are extracted from the same spot.

Electricity
Electric power plants and *industry* use most of the surface water they use for cooling purposes. The pollution of surface water with warm water can have considerable effects on the living conditions of local water life and therefore be harmful to *nature, fishery* and *recreation.*

Fishery
For *fishery* quantity and quality of water are the most essential inputs. Water pollution from *agriculture* and *industry* has negative effects on the health condition of the fish stock. The straightening and deepening of rivers and streams deteriorates the settlement possibilities of migratory fishes such that they became very scarce or that they disappear totally from their original habitats. On the other hand irrigation canals, artificial lakes, and irrigated rice fields are providing new habitats for various species.

Navigation
Navigation makes demand of an appropriate wide and deep enough waterway with a water flow that should neither be too high or too low. Although *navigation* is by comparison with road and air transport regarded as being a rather clean way of conveyance, the water pollution, especially of oil discharge and antifouling coating should not be underestimated. These negative effects for *fishery, recreation* and *nature* have to be taken into account while planning integrated water management.

Recreation
Recreation is an increasing sector all over the world. Water is needed for swimming, diving, sailing, rafting, fishing, and water skiing or just as an element that cannot be missed in the landscape and is enjoyed by walkers or bikers. Water quality aspects are certainly the most important items in recreation because it directly effects the health of human beings enjoying water activities or because an abnormal smell would be inconvenient for people. Quantity only becomes a point of discussion when talking about the extension of protected area for special animals and plants that would be harmed by recreational activity in such areas.

Welfare maximisation

For social welfare to be maximised, an economically efficient resource allocation requires marginal net benefits to be equal across all different users. The marginal net benefit curve is defined as the vertical distance between the demand curve for water and the marginal costs of extracting and distributing that water as it is depicted in Figure2 (Tietenberg, 1992).

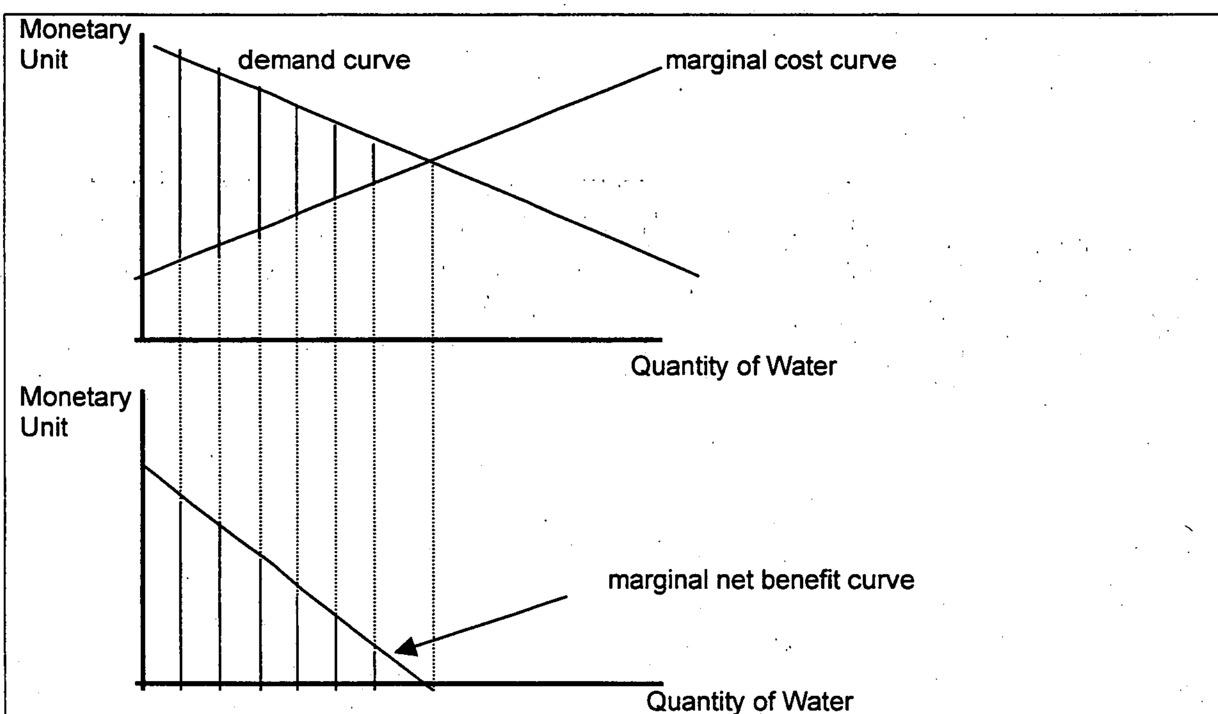

Figure 2 Derivation of marginal net benefit curve

Water use can be classified in different economic terms. On the one hand, water offers benefits through direct use in final consumption such as in households or for environmental and recreational purposes. On the other hand, it is used as an

intermediate good in a production process, e.g. irrigation, hydropower or cooling (Gibbons, 1986). In the latter application the value of water has to be derived from the value of the final good. An optimal allocation of water in different production processes requires the value of the marginal product to be equal over all processes. Hence, the demand for water is a derived demand and depends on the value of the good produced (Bogess *et al.*, 1993).
It should be noted that for convenience water is treated as a homogenous good in this welfare analysis. In practice water is heterogeneous, so a kind of quality weighted water unit would have to be used.

While talking about the optimal allocation of water it is important to distinguish between surface water and groundwater. Surface water has the characteristics of a renewable resource and its future supply depends mainly on natural phenomena, whereas the future supply of groundwater is dominantly influenced by current withdrawal and the aspect of intertemporal allocation has to be taken into account as well (Tietenberg, 1992). Depletion of groundwater occurs when the extraction rate continuously exceeds the recharge rate. A groundwater aquifer can become irreversibly used up if the geological pattern of its supply channels is such that they need a certain minimum water level to keep on functioning and the provision of this minimum level is not guaranteed because of excessive withdrawal (Neher, 1990). Also antique acquifers exist that are not recharged at all. This difference between surface water and groundwater is of great importance. For surface water a steady-state has to be reached, where the rate of extraction should equal the rate of recharge at some level. For groundwater this is not true. A non-renewable resource will become increasingly scarce as stocks are depleted, which will be reflected by an increasing price. It is optimal if this price rises at a rate equal to the social utility discount rate, which reflects intertemporal substitution. However, optimal water use is hard to establish, as water belongs to the common property resources. This prevents an optimal allocation, as market forces can only attain an optimal allocation if property rights are fully assigned and if all goods and services are private. Furthermore, the use of water produces externalities whose costs are not incorporated in the price and are therefore passed on to society. The social costs of water use are therefore higher than the private costs. This is portrayed in Figure 3 at the hand of an example of a private producer who is using water as input for production.

As mentioned above the private producer will demand the quantity of water that corresponds to a situation where the price of water is equal to the private marginal costs. Say that the water price is established at P*, then the producer will demand the quantity Q^P. If the same condition shall hold for social marginal costs (P* = SMC), the quantity demanded has to be reduced to Q^S. The triangle a-b-c is the amount of external environmental costs that have to be borne by the society. The implications for the introduction of the optimal environmental tax will be discussed further down.

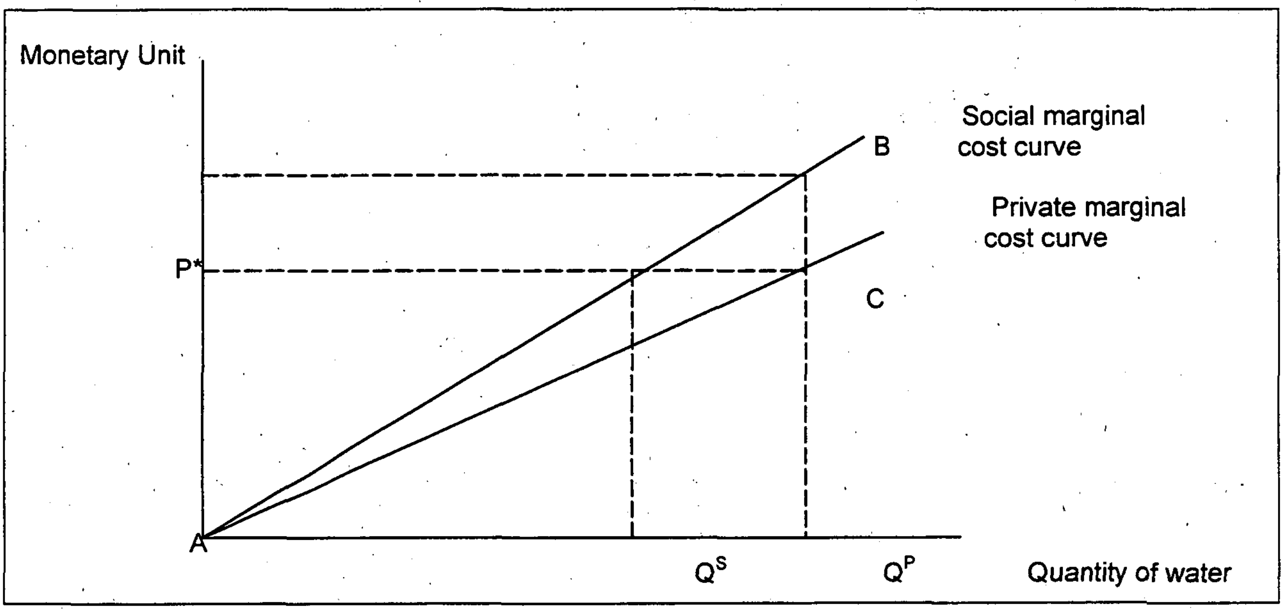

Figure 3 Social and Private Marginal Costs

Characteristics
Young (1986) summarises some supply and demand characteristics that distinguish water from other commodities:

- *Mobility:* Since water flows, evaporates, seeps, and transpires it is difficult to identify and measure. This makes the establishment of property rights problematic.
- *Economies of large scale:* Due to large storage and distribution systems water supply has a large fixed costs component and is hence predestined for being a natural monopoly.
- *Uncertainty in supply:* Water supply depends on stream flows and precipitation and is variable in time, space and quality. It is therefore not foreseeable in a precise way. In general, supply peaks do not coincide with periods of high demand.
- *Assimilating and absorbing capacities:* Water does also serve as a host for wastewater and pollutants. The assimilative capacity of a water body could therefore be seen as an additional commodity itself. This characteristic reminds that quality and quantity items are very close connected to each other.
- *Diversity of use:* Water is used for numerous purposes in different user categories. For some uses it is difficult to establish an economic value, which complicates the derivation of utility that different users gain from different forms of water application.
- *Diversity of exclusiveness:* water can be reused to a certain extend, depending on the function it was used for. For recreational use, e.g., this is straightforward.

Water pricing
In accordance with Randall (1981) water can be defined in terms of resource costs, opportunity costs or social costs. Resource costs reflect the provision of water as, for instance, pumping or distribution costs; opportunity costs represent the value of that

water in its best alternative use; and social costs are costs that society has to bear such as costs arising from externalities. In an efficient situation the three marginal costs are equalised and at the same time they are pointing out the proper price. Randall's recommendation corresponds to the fundamental concept of economically efficient use of resources, the marginal costs pricing system (Frederick and Kneese, 1995).
Because of increasing marginal costs in most common situations the marginal costs pricing system needs a progressive tariff structure which implies higher charges at higher units of consumption (Winpenny, 1994). At present however, the opposite, namely special-offer charges for bulk users, is in many cases a matter of course.
The OECD (1987) suggests that marginal cost pricing under the User-Pays Principle (UPP) would be the proper charging system to prevent inefficiency. The UPP is analogous to the well-known Polluter-Pays Principle (PPP). Whereas under the PPP the polluter has to pay for the external costs that he/she enforces upon society, the UPP prescribes that the users of the services have to bear the full costs of the service collectively. Subsequently a charging system that reflects quality and quantity items will divide full costs among all users. The UPP certainly implies the abolition of subsidies to users of the water service.
Unfortunately, the marginal costs pricing system is not found in practice. In general, water companies apply a system to recover the costs of treatment and delivery (Randall, 1981; Tietenberg, 1992; Winpenny, 1994; Rosegrant, 1997), which means that they only take into account the resource costs (see above). The system by which water rates are determined often takes the form of average cost pricing, whereby the water service is charged at average costs or flat rate tariffs. This means that the price is not directly based on the quantity of water used, but on, for instance, number of residents, number of tabs, size of inflow pipe, or the property value. (For details see OECD, 1987). Thus the price for water use paid by the different users does not enclose the full costs. As a consequence, the market fails to allocate water in an optimal way and overuse and waste of water are inevitable.
Tietenberg (1992) mentions the consequences of inappropriate water pricing for migration. He notes that tariffs that are set too low would make arid regions financially more interesting to new residents than they really are. An increase in population in such areas would put even more pressure on the limited water resources. The question arises if this statement counts for independent private people and if they would make the price of water as an important criterion of their decision to move to an arid region. In most cases people migrate because of reasons of employment. Therefore, irrigation and the settlement of industries and big employers should be aggravated in such areas.

Water belongs to the common property resources and experiences the tragedy of the commons. An important characteristic of water is its diversity of use. Water fulfils numerous functions for different economic activities. Externalities that arise from the use of water by these activities indicate that the price for water use paid by the different users does not enclose the full costs. As a consequence, the market fails to allocate water in an optimal way and overuse and waste of water are inevitable.
The following Section describes several economic instruments that assist in internalising external effects and correcting market failure.

Economic instruments for managing water scarcity

This Section presents several economic instruments that are applied to economise water use in countries where water shortage has become a serious problem. The objective of economic instruments is to influence the demand behaviour of water users. They are hence aimed at the demand side of the water chain. However, putting more emphasis on demand management does not mean that supply management should be totally ignored. According to Alfred Marshal who is cited by Winpenny (1994), "*supply and demand are the two blades of a pair of scissors*". In many situations new supply schemes have to be introduced, but it is always important to take the demand management policies equivalently into account in order to avoid the mistakes from the past, where supply side approaches dominated water resource practices (FAO, 1995). In the following sub-sections different policy measures for tackling the problem of water scarcity are described. The focus is put on the demand management side because this is where efficiency improvements through economic instruments can be achieved.

Different policy measures: An overview and criteria

Based on Rosegrant (1997) and Winpenny (1994) the following scheme of policy instruments for managing the demand of water has been developed.

Table 1 Different policy measures for water management

Enabling conditions	***Market-based incentives***	***Non-market-based incentives***	***Direct interventions***
• Institutional and legal changes • Reform of water rights • Privatisation of utilities • Macroeconomic and sector policy	• Pricing reform • Tradable rights and Water markets • Effluent or pollution charges • Water banks • Auctions • Subsidies • Taxes	• Restrictions • Quotas and licenses • Public information and education	• Conservation programs • Leak detection and repair programs • Water efficient user appliances • Industrial recycling

Source: Winpenny, 1994; own adaptations

Before describing the market and non-market based policy measures in detail it should be mentioned that every control mechanism could be subject to criticism for many reasons because of conflicting interests in society. Bressers (1989) recommended that instruments should consider the purposes, the information and the power of the government agency and should regard the addressed target group. Instruments are only able to contribute to efficiency improvements if they are adjusted to the circumstances under which they are applied. The different instruments are therefore not different options but have to be combined in order to reinforce each other. This implies that an optimal policy mix has to be constructed conforming to the particular circumstances and economic situations in the various countries, such as the level of economic development, institutional capability, relative water scarcity and level of agricultural intensification (Rosegrant, 1997).

Furthermore there are some criteria that have to be taken into account while choosing the best way of water planning (Winpenny, 1994). These criteria, which will be used in the remainder of this section are:

Efficacy/Effectiveness
This criterion can be seen as the elasticity of response to different instruments. A combination of measures, such as higher charges joined with campaigns of public information and education and subsidies for the introduction of water saving technologies, will be in most cases the most effective.
Efficacy is associated with the criterion of acceptability because policy measures will have the highest pay-off if society accepts them.

Economic efficiency
For a policy measure to be efficient it is required that its discounted economic benefits exceed its discounted costs. The efficiency principle was already discussed but it is worth to mention again that the re-allocation among users such that water moves to higher-value uses is essential to gain an optimal solution.

Equity and distribution effects
Equity can be reached in an undistorted market through trading from lower to higher-value applications. As soon as the market gets distorted through for instance subsidised inputs or protectionism in crop prices, equity is not guaranteed any longer. Instruments should be fair with respect to their impacts on the various socio-economic groups. It is often recognised that groups with less influence get low priority in the provision of public water services. The equity criterion is often contradictory to the economic efficiency criterion, which is only concerned with the magnitudes of benefits and costs and not their distribution (Colby Saliba, 1987). Although, in theory, efficiency improvement through reallocation should lead to a higher net social benefit, some groups that do not have anything to trade with (money, water rights, political power and legal power to impose transaction costs) will suffer losses if no compensation payments are taking place.

Public health and nutrition
The World Bank warned that over one thousand people are in need of safe water supply and proper sanitation (FAO, 1995). Hundreds of million of people who suffer from intestine diseases due to lack of hygiene would benefit if a general improvement in water supply and sanitation would take place. Especially in developing countries where the infrastructure of the water system is not as obvious as in the developed countries, this criterion is very important.

Environmental impact
Consideration of the environmental criterion got more importance in recent years only. The increasing significance of environmental impacts is the reason why demand

management measures are getting more popular. They reduce the environmental costs arising from the development of supply projects, which used to be favoured in water management decision making.

Fiscal impact
It is beyond question that the sum of all policy measures should have a non-negative net impact on the finances of the central or local government, the water utilities and the irrigation agencies. For instance, positive effects such as taxes, higher water prices and charges should outweigh negative effects such as subsidies or tax relief.

Political and public acceptability
As already mentioned, acceptability is combined with efficacy. The factors that determine acceptability are the distribution of costs and benefits, the severity of the problem, the educational level of the population, the role of prominent political and community figures, and the readiness for behavioural change in society. A policy measure that gets support from the target groups involved is more likely to be implemented than one that runs into severe resistance of the affected parties.

Sustainability
The most sustainable policies are those that have an increasing positive long-run effect. They consist of elements that reinforce each other such that their impact is continuos and growing over time.
Short-term measures have a strong instantaneous effect. They are introduced in a case of emergency such as a drought when quick action is required. They loose their impact when emergency is over.

Administrative feasibility
This criterion refers to the government's capability to administer, enforce and monitor its chosen policy measure. In the case of water pricing for instance, it has to be kept in mind that it requires quite a lot of staff and organisation that is connected with the metering and the collection of revenues. Moreover, there must be a willingness and ability to prosecute non-payers.

Macroeconomic environment
Agricultural and food policy measures on macroeconomic level can be supporting as well as discouraging for water conservation policies. If, for instance, prices of water intensive crops are subsidised and protected, it will be more difficult to let farmers' behaviour change towards crops that use water more efficiently. Therefore, liberalisation could have in many cases a positive effect on water policies.

Enabling conditions

The term 'enabling conditions' or 'enabling environment' describes the creation of a general basis for encouraging a more economically rational use of resources through a change in the institutional, legal and economic framework within which this resource is supplied (Winpenny, 1994). According to Young (1986) the surrounding circumstances

should not be underestimated. He proclaims that the choice of institutions to co-ordinate economic activity is among the most fundamental of social decisions. Enabling conditions build the conditions that are necessary for the introduction of other instruments. For instance, in the literature about the introduction of water markets in several countries it becomes obvious that the government has to check in what way its new policy conforms to the existing legislature and to what extent a law making process has to be carried out. Some examples of legal issues that are important for water markets are: the security of water rights, certain rules in case of a conflict, the question whether water rights may be transferred separately from land, and the management of third party effects. The latter includes e.g. return flows, changed groundwater levels, and changed water quality (FAO, 1995). A further explanation of water markets can be found below.
Another example is on privatisation of water supply. Since water supply systems have a high fixed-costs-component, they have the characteristics of a natural monopoly and are therefore predestined to be in public hands. However, different forms of privatisation are implemented to increase efficiency. An often-used example of privatisation is the French water sector (Dijkgraaf *et al.*, 1997). In the French model two different forms of contracts between the authority and private firms exist. One is the *lease contract* where only the operational tasks such as extraction, purification, wastewater treatment and discharging are privatised but the waterworks system and the installations are still property of the authority who is also responsible for necessary investments. Lease contracts are short-term contracts and are the most common. The other form is called *concession contracts*. They are long-term contracts and can last up to 50 years and the private company is fully responsible for maintenance and investments. After expiration of the contract all property rights go to the government and the private owner gets a compensation payment if the investments are not depreciated.

Market-based incentives

Pricing Reforms

As already mentioned, a marginal cost pricing system would contribute to an efficient allocation of water. The introduction of marginal cost pricing implies that users have to pay a higher price, which is also reflecting opportunity and social costs. The effect of a price increase on water demand depends on its price elasticity. Pricing measures can only have a positive influence on water conservation if the elasticity of demand is significantly different from zero and negative. Several estimates of the price elasticity can be found in the literature. They vary widely according to sector (industry, agriculture and municipalities), utilisation (indoor or outdoor), country and season (Gibbons, 1986; OECD, 1987). They are mainly situated in the inelastic range of the demand curve, which means that they have values between zero and minus one. It is a wide spread opinion that the pricing instrument is not very effective because of the low price elasticity of water demand. The problem is that the low price elasticities are based on estimations calculated from existing water prices, which are obviously too low. Estimation based on higher prices that reflect the real costs of supply would probably show that the demand curve would become more elastic.

Metering is required in order to be able to register and control consumption of the different users, which is an essential condition for the implementation of water tariffs being as an instrument for water conservation. Estimates of irrigation water use in Mexico by Schramm and Gonzales (Young and Haveman, 1985), and of urban water use by Hanke and Gysi, point out that the introduction of a metering system combined with volumetric charges had significant impacts on consumption. A similar result is found by the OECD (1987) in its examination of pricing of water and related services. They find that the introduction of volumetric charges creates notable reductions in demand and consequently economic and environmental benefits. However, the OECD (1987) concludes that the final decision of introducing a metering system will depend on its costs and benefits.

With respect to *equity* the pricing instrument can be approached from two sides (OECD, 1987). On the one hand metering is recognised as fair because everyone pays exactly the amount that he/she used. On the other hand it is criticised that poorer members of the society are at a disadvantage, because they have to spend relatively more of their income on water, which is, as stated by the United Nations, a basic need and everyone should have the right to its provision. To guarantee *equity* it is important to develop a charging system that considers income classes, disadvantaged regions and user categories (OECD, 1987). The danger of the complexity of such a charging system is that it may become too difficult for consumers to understand. This may have consequences on *public acceptability* with negative effects on the *effectiveness* of price measurements. Public acceptability is directly related to the costs of control and the extent of theft and fraud. These costs should not be underestimated. Water theft is a common feature in developing countries.

Without a doubt, the introduction of an effective metered charging system needs a lot of research, planning and investment. But for an efficient market where prices are supposed to be a signal of real scarcity, the effort that has to be made in the beginning can be worthwhile in the future.

Tradable rights and water markets

Tradable rights and water markets emerged in areas where water scarcity became very severe and new supplies were not easy to discover. Becker (1995) reports from Israel that the stimulus to introduce a water market arose from the fact that investments in institutional changes that are necessary for a proper functioning of the market appear to be cheaper than investments in developing new supplies such as import or desalination installations. The most important condition to be introduced for a successful working of a water market is that property rights are secure and well established (Gazmuri Schleyer and Rosegrant, 1996).

If water becomes a marketable good, a transfer of water from lower to higher value application will be set in motion. It will stop if the marginal benefits of all applications are equal.

In a simple example with e.g. only two participants overall benefits can be maximised by trading. In reality, however, there will be negative effects on third parties. The problem of the third party effects was already taken up while discussing the *equity* criterion. It should be mentioned that especially instream uses that are difficult to evaluate are often neglected because its interest groups do not have enough purchasing power.

Gazmuri Schleyer and Rosegrant (1996) who investigated the Chilean water market describe an example of a good functioning water market. They emphasise that the positive picture of the Chilean water market owes much to its legal and institutional framework. It is found that there are strict laws for the protection against adverse third-party effects, for water user organisations and for solving conflicts if these cannot be solved by the organisations themselves. Another success supporting item is the decoupling of water from land. This regulation makes it possible for the farmers to sell water to urban users. This is a lucrative trade for the farmers and it stimulates them even more to increase efficiency in their production processes.
Water markets have to be diversified with respect to different qualities and different purposes of use. Spulber and Sabbaghi (1994) state that water can be seen as a group of differentiated products for different purposes traded in different markets at different prices. Ideally a water market would give complete information on all these aspects to all market participants and authorities. Colby *et al.* (1993) also enters upon price dispersion in water markets. Based of empirical evidence they conclude that the price of water rights depends on: a) the geographic area, and the characteristics of the local market, b) the size of the transaction, c) the number and size of potential traders, and d) the information and search costs that are involved in the transaction.
The high demand for regulatory and administrative institutions is often mentioned as a major disadvantage of water markets. However, if a supporting institutional framework is guaranteed, water markets with secure property rights can be a good approach to achieve an efficient allocation and to stimulate investments in water-saving technologies (Gazmuri Schleyer, Rosegrant, 1996).
In order to bring water markets into line with modern forms of communication, the internet and e-mail can surely not be left out of consideration in the future. Olmstead *et al.* (1997) report about the application of WaterLink, the first electronic water market system. This pioneer system has been established in the Westlands Water District in California and it enables water users to buy and sell water rights with their home computers. WaterLink contains weekly and seasonal market statistics on the number and volume of transactions, the average trading price, rainfall summaries and water storage levels. Olmstead *et al.* conclude that electronic water systems will definitely improve the efficiency of water markets because they are able to reduce the high information, search and negotiation costs that are often claimed to be major obstacles in water trading.

Effluent or pollution charges

Although this instrument is actually placed in the category of water quality improvement it has also influence on the quantity of water used. Effluent and pollution charges are imposed to internalise the costs arising from the environmental damage caused by the discharge of (industrial) wastewater. If these charges are set high enough, industries are encouraged to invest in their own wastewater treatment and recycling plants in order to reduce costs. Recycling and reuse of wastewater consequently implies that the demand for fresh water decreases. If this measure were combined with higher water prices for industries or subsidies for the installation of recycling plants the incentive to reuse wastewater would be even stronger.

Water banks

A bank is an institution where goods that are abundant at present can be stored for future use. Water banking in its simplest form means that surface water that is not needed now is conducted to an area where it can percolate to recharge an aquifer. In times when surface water is scarce this groundwater can be pumped up again in order to meet demand (Winpenny, 1994). A well known example of water banking is that of the establishment of a water bank in California in 1991, after a major drought during which the state was responsible for water transfers. According to Keller *et al.*, who is cited by Winpenny (1994) a water bank is an effective short-term emergency instrument. The long-term effects of water banking are not very clear because there is not yet enough experience in this field. The observations made in California show that next to the state-controlled water banks there are also a lot of private-controlled water transfers taking place which may appear to be more appropriate ones (Isreal and Lund, 1995).

Auctions

Water auctions are not very common. Some examples can be found in the USA (Victoria State), Spain and Australia (Winpenny, 1994). It is exclusively used for the distribution of water among farmers. For an auction to be sensible it is necessary that the water under consideration is fully controlled by the water authority and that no other users can dispose it. In an auction a minimum price is established and subsequently the person who can bid the highest price for a specific amount of water will have it at his/her disposal. Theoretically, this mechanism could lead to an efficient allocation of that water but in practice it is often realised that part of the bidders made engagements with each other beforehand such that the allocation mechanism was undermined by monopsonistic behaviour (Winpenny, 1994).

Subsidies

In the framework of water management measures there are two ways of dealing with subsidies. Firstly, there are the subsidies on water consumption that fail to give a clear sign of real scarcity to consumers with the result of excessive consumption and secondly there are the subsidies that intent to support firms in the investment of water saving technologies. Beyond dispute, the subsidies in the first case have a negative effect on an efficient allocation of water. Subsidised water can be found in all user categories. Especially in developing countries the basic-need criterion of water causes that municipal water facilities are highly subsidised, such that water can be provided at a lower price. Subsidised irrigation water in agriculture leads to uneconomic applications on low value crops and it raises the possibility that farmers irrigate just to calm their conscience. This will be worse if farmers have invested recently in high cost irrigation installations (fixed costs) and variable costs are low due to the subsidisation of water.

The second application of subsidies is a bit ambiguous. On the one hand they are supposed to have a positive effect on water conservation because they should encourage firms to invest in water saving technologies (including wastewater treatment facilities for recycling and reuse as mentioned earlier). On the other hand there is also substantial criticism attached to this kind of subsidies. Baumol and Oates (1975) point

out that uncontrolled granting of subsidies would attract new firms into a business which would more than off-set the reduction of water use that is attained by single firms. Another issue, pointed out by Hommes and van 't Hof (1989), is that the subsidised technologies are in many cases end-of-pipe technologies that only shift the environmental problem to another level. In the example of wastewater treatment plants, unwanted substances are accumulated in the sludge. Instead of investing in end-of-pipe technologies, more effort should be spent on solutions that try to avoid environmental problems before they actually arise. Anderson *et al.* (1977) state that these subsidies cause a shift of investment from improvement of process related innovations to investment in wastewater treatment facilities only.
However, it cannot be concluded that subsidies in water management should not be introduced in general. It is only a warning that attention has to be paid to the negative side effects that can come up if a subsidy scheme is not well planned and difficult to control.

Taxes

Taxes have to be levied to equate social and private marginal costs in order to internalise external effects that arise from water use. The optimal tax level can be added to Figure 3, which is depicted in Figure 4.

At the existing price P*, the distance t is the optimal tax level because this amount has to be added to private marginal costs to incorporate social marginal costs.. The tax revenue that is received by the government is equivalent to the shaded rectangle D-E-F-G. Originally, the costs that had to be borne by society were shown by the triangle A-B-C. After the introduction of the tax these costs are internalised. The remaining area E-B-C-F can be divided into two parts: one is the triangle E-C-F that describes part of the forgone benefit to the private producer and the other is the striped triangle B-C-E that expresses social welfare gain.

The theoretical framework of the optimal tax level is clear but some difficulties emerge if a proper tax level has to be determined in reality. In most cases it is hard to attach an objective monetary value to the damage arising from the excessive use of a natural resource. The perpetrators of the externalities usually evaluate the damage less severe than other interest groups. Whether the imposition of a certain tax is accepted by the society, depends heavily on the provision of information, and on the influence, and lobbying capacity of interest groups.

Non-market-based Incentives

Restrictions

A common situation in which restrictions are imposed is at times of unusual dry periods such as droughts or seasonal water shortages. The restrictions may consist of

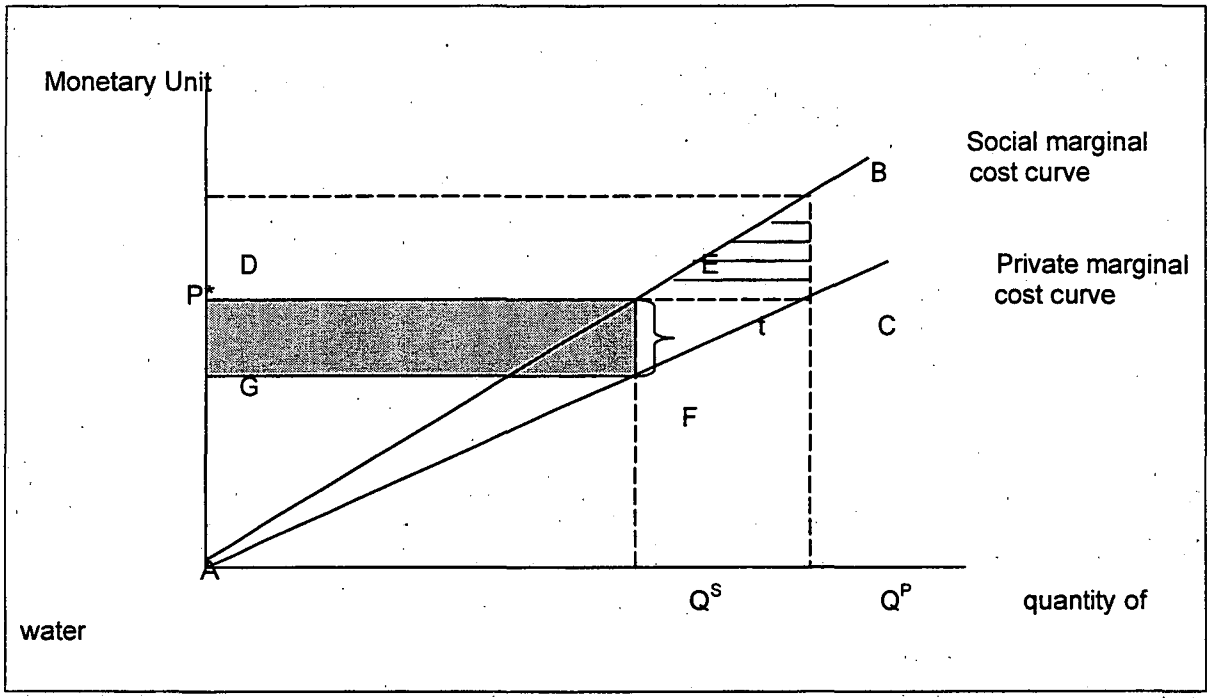

Figure 4 Social and private marginal costs and the optimal tax level

prohibiting irrigation, municipal outdoor uses (lawn sprinkling or car washing) or of industrial production constraints. A major disadvantage of this instrument is its dependence on monitoring and execution, which may turn out to be too expensive. In cases where the administration is subject to corruption and bribery performed by bulk users even more pressure is put on small-scale users. A restriction scheme can only be successful if it is fair to all groups of the society and the need of it is clear to all consumers.

Quotas and licenses

Quotas and licenses are based on quantity control. They are divided among different users with the intention to allocate a restricted amount of supply in a most efficient and equitable way (Winpenny, 1994). Penalties have to be introduced for those users who exceed their assigned quota. This, in turn, means that it is dependent on monitoring and control. Although intended to restrict supply in an efficient way, it is obvious that quota hardly ever lead to an optimal allocation.

There are different ways to determine the distribution of quota among the different users. Rosegrant (1997) mentions two possibilities. Firstly, the assignment of the quota in proportion to the water that was extracted by each user in a certain base period. This is called a grand-fathering system. Secondly, in the case of groundwater extraction in agriculture, appropriation on the basis of the amount of land owned above an aquifer. In many developing countries water user groups are being set up. This is ideally done on a (sub)catchment basis. Upstream and downstream users then negotiate on entitlements. As all kinds of social and historic issues play a role in these negotiations, the resulting quota or water rights are often not proportionate to a well quantified,

measurable entity. However, the system works as long as consensus is reached, and it is not difficult to think of circumstances where it will be more efficient than applying a straightforward proportionate rule.
According to Arlosoroff, cited by Winpenny (1994), quotation and licensing attained great success in the Israeli industrial sector. Within 20 years, between 1962 and 1982, the average water consumption (per unit value of output) was reduced with 70%. In that case, quotas were delivered according to norms of best-practice technology in combination with the specific circumstances of each firm.

Education and persuasion

It is doubtful whether the instrument of education and persuasion has influence on consumer behaviour if it is introduced on its own. Winpenny (1994) notes that it could be used as an announcement for a price increase to "soften up" consumers. Martin and Kulakowski (1991) concluded on the base of an empirical research on urban water use in Tucson, Arizona, that without an increase in price at the same time, information and education do not seem to have a significant effect on water consumption.
Nieswiadomy (1992) found a positive effect of education programs, conservation and education on urban water demand in the United States. His calculations show that only in the West, public education has a significant effect on the reduction of water consumption but not in other parts of the country. As a possible explanation of this phenomenon he mentions the already existing awareness of water scarcity in the West which makes education programs more effective.

Direct interventions

In the case of direct interventions, the government plays an active role in the development and execution of the programs, whereas in the case of market and non-market based instruments the government's main duty is to provide an enabling environment, in which the individual users behave in their own best interest (Winpenny, 1994). Measures of direct intervention can have a supporting and reinforcing effect in combination with the other economic instruments discussed above. For instance, conservation programs, water efficient user application, and industrial recycling projects are useful if they are introduced together with price increases, because it makes users more keen on the possibilities of saving water.
Important direct intervention measures are leak detection and repair programs. The costs of these measures are rather high and an involvement of the government is hence necessary. Especially in developing countries technical losses due to leaks and deteriorated infrastructure can be quite substantial, such that the costs of the programs are lower than the value of the water saved and lower than the costs of the creation of new supplies (Winpenny, 1994).
Another typical situation for a direct involvement of the government is in cases of emergency such as droughts or floods. These measures are mainly short-term interventions and will stop when the state of emergency is over.

Concluding remarks

The instruments that were discussed in the previous section do not provide a blueprint for integrated water resource management in arid and semi-arid developing countries. In many of these countries the government does not have the capacity or the means to implement the suggested measures. The rule of law in these countries is often so weak that is also not possible to have enough control and enforcement to prevent fraud, theft, favouritism, and corruption. Yet there are success stories to be told.
In many large cities, e.g. in Mexico and in Marrakesh, water metering has in fact reduced water consumption and more importantly induced the water authorities to repair leaks.
But also in rural areas there are systems in place that seem to work. Tunisia e.g. is one of the few countries whose approach in water resources management has been successful. The National Water Operation and Distribution Board (SONEDE) guarantees fair and independent distribution of water among different user groups by means of a progressive pricing system. Publicity campaigns have increased public awareness of the scarcity of water. Industry is taxed for industrial water disposal according to the polluter pays principle (VROM, 1996).
Another example of a major improvement is the decentralisation of Sri Lanka's National Water Supply and Drainage Board into five regional service centres with progressively increasing managerial authority. Within five years billing had increased by 125%, non-payment was reduced from 75% to 17%, recovery of Operation and Maintenance costs had increased from 31% to 99%, complaints were reduced by 70%, and productivity per employee had doubled. This is an example of improved revenue. It is a prerequisite for effective water resource management. If your neighbours do not pay the bill why would you? And if you do not pay for the water, why bother about the quantity used? (VROM, 1996).
Haouz irrigation district in Morocco applies volumetric pricing. Farmers can get discounts if they participate in maintenance of the canals. The Haouz office spends about 35% of the annual budget on monitoring, regulation and enforcement. Investment in measuring equipment is not included in that amount. That illustrates the cost of a pricing system (Tsur and Dinar, 1997) .
The high cost of monitoring volumetric pricing is the probably the reason for various other pricing systems throughout India. Examples include: area charges that vary by crop or across season, area charges that vary according to method of irrigation, and flat area rates. Only in a few areas with pumped irrigation and tube wells can volumetric pricing be found (Tsur and Dinar, 1997).
These are a few examples that developing countries do ponder the pros and con of different economic instruments to regulate water use. However the effectiveness of the instruments depends to a very large extent on the quality of governance. And that is probably one of the few things that instruments that enhance technical efficiency and instruments that enhance economic efficiency have in common.

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DISCUSSIONS: RESULTS OF THE WORKSHOP

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The following summarizes the main positions taken during the discussions at day 1 and day 2 of the WWW98. Sometimes the positions are contradictory; in those cases the discussions did not lead to final conclusions.

regarding the question of the relevance of field scale water flow and salt transport models for extrapolations to river-basin level:

- as field-scale models are developed to represent larger, physical-geographically homogeneous areas, extrapolation is possible in theory at least
- instead of extrapolating field scale models to river-basin level in one step, divide river basins in homogenous units (hydrological, but also social, economic, and agricultural)...
- ...subsequently the results of the models representing homogenous units are to be combined into a model representing the larger area
- ... alternatively the field scale model can be run with a set of "average" input data representing the larger area
- it can never be certain whether field scale models that in themselves generate convincing results can be extrapolated to larger areas
- much data have been collected that are not being used (the problem of 'data grave yards'[1])
- it remains difficult to meaningfully incorporate the needs of farmers in a field scale - water flow and salt transport - model
- river basin scale models should be based on crop demands at field level
- models should be based on the principle 'what you measure is what you simulate'; this allows for direct verification of results;

regarding the question of the role of WWI[2]

- to create a platform of Wageningen-based researchers in the field of water resource development
- to stimulate the access to and exchange of data, including data that are stored away and that are not available to users

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[1] The problem of 'data graveyards' was also extensively discussed during the WWW97 (A. Schrevel, 1997, Groundwater management: sharing responsibility for an open access resource, Proceedings of the first Wageningen Water Workshop, 13-15 October, ILRI, Wageningen)
[2] WWI stands for Wageningen Water Initiative; it is a platform for co-operation between Wageningen-based institutes with a focus on water issues

- to initiate the formulation of objective criteria for model performance; this is essential to make progress in the field of modelling
- to invite others to participate in the (further) development of the models;

regarding the relation between water and food security

- in general increases in food security should come from increased efficiencies in the use of water, not from the development of new water resources
- increases in food security should also come from increased water use efficiencies in unirrigated areas; knowledge how to do so is available, the problem lies in implementing this knowledge
- in addition to water, nutrients are a limiting factor to increases in agricultural production
- increasing production is one thing; ensuring entitlements to sufficient food for all and questions related to the distribution of food supplies are equally important
- food security, or rather the lack of food security, is a problem felt at different levels (household – global); in discussions one should be specific regarding the level

regarding the relevance of drainage

- understanding the basics of drainage technology only is not sufficient; one should understand the impact of drainage on the hydrology and the ecology of an area, even before implementing drainage
- ILRI's International Course on Land Drainage should be continued; the course includes attention for the ecological and environmental effects of drainage
- in a number of situations agricultural production is not possible without drainage; the cases of banana cultivation in Costa Rica, and in general those of India, Pakistan, and Egypt, were mentioned
- drainage is also important in the sense that a sensible use of existing water and land resources is important for the food security of future generations;

regarding a vision for the future

- when developing a vision for the future, one should forget the problems of the present and do some creative "out of the box" thinking.

List of participants WWW 1998

Name	Organization	
G. Aguilar	ICLD, Peru	
M.S. Arain	ICLD, Pakistan	
M. Arshad	ICLD, Pakistan	
E.F. Barakat	Egypt	
W. Bastiaansen	IIM	
Ahmad Khan Bhatti	NDP, Pakistan	speaker
P.S. Bindraban	AB-DLO	speaker
H. Blaas	ILRI	
J. Boonstra	ILRI	
J. Bouwhuis	Ministery of Agriculture	
L. Bouwman	RIVM	
J.C. Cavelaars		
R. Chaverro	ICLD, Colombia	
J.C. van Dam	LUW DOW	speaker
H. Denecke	ILR	
A. Diallo	Embassy Dakar	
W.H. Diemont	IBN-DLO	speaker
B. Dolfing	ILRI	
H. Donkers		
E. Estrado	ICLD, Cuba	
A.R. Ganta	ICLD, India	
R. Geelhoed		
Dr. C. Grashoff	AB-DLO	
M.L. Gupta	ICLD, India	
H. Hoeve	ILRI	
G. de Jager	Wageningen Agricultural University	speaker
A.M.J. Jaspers	ILRI	
S.M. Kamundia	ICLD, Kenya	
J.H. Kauffman	ISRIC	
A.H. van Keulen	ILRI	
B. Khalil	ICLD, Egypt	
T.J. Kelleners	ILRI	
E.H. Kloosterboer	ILRI	
F. Konukcu	ICLD, Turkey	
A.K.A. Kordjie	ICLD, Ghana	
R.A.L. Kselik	ILRI	
H.P. Li	ICLD, China	
A.H. Manlunas	ICLD, Philippines	
U. Mannan	NDP, Pakistan	
P.P. Mollinga	Wageningen Agricultural University	speaker

H.J. Nijland	RIZA	
H.P. de Nooy	DLO	
P.O. Obimbo	ICLD, Kenya	
L.R. Oldeman	ISRIC	
K. Oltmer	LEI-DLO	speaker
M. Oneka	Wetlands International	speaker
G.A. Oosterbaan		
R.J. Oosterbaan	ILRI	
R. Rabbinge	Theoretical Plant Production	chairman day 1
H.P. Ritzema	ILRI	
B. Roelofsen	DHV	
C.W.J. Roest	SC-DLO	speaker
A.H. Saleh	ICLD, Egypt	
T. Salimov	ICLD, Tajikistan	
S. Schot	ILRI	
A. Schrevel	ILRI	chairman day 2
E. Schulze		
D. Segura	ICLD, Costa Rica	
M.N. Sharma	ICLD, Nepal	
J.J.L. Sluijsmans	ILRI	
G. Sterk	EBWC/WAU	
L. Stroosnijder	EBWC/WAU	
R. Villalobos	ICLD, Colombia	
J. Vos	ILRI	
G.H. van Vuren	Wageningen Agricultural University	
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W. Wolters	ILRI	
D. van Zaane	DLO	
A.N. van der Zande	SC-DLO	
T. v.d. Zee	DLG	