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WATER RESOURCES SERIES
No. 61

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FOREWORD

This publication contains the report and documentation of the Regional Seminar on Systems Analysis for Water Resources Development, 12-23 November 1984, which was organized by ESCAP with the financial and technical assistance of the Netherlands.

The seminar consisted of lectures and a workshop, the material for which was prepared by experts from the Delft Hydraulics Laboratory and the Netherlands Ministry of Public Works and Transport.

The views expressed in the papers are those of the authors and do not necessarily reflect the views of the United Nations. Parts two and three did not receive formal editing.

ABBREVIATIONS

B:	broadcasted
B/C:	benefit/cost
Cl^-:	chlorine
cms :	centimetres
COTA:	Carrying Out The Analysis
CRF:	capital recovery factor
DHL:	Delft Hydraulics Laboratory
DO-BOD:	dissolved oxygen — biochemical oxygen demand
ETSPA:	estimating temporal and spatial pattern of activities
FCD:	flood control and drainage measures
g:	grammes
GNP:	gross national product
ha:	hectares
HYVs:	high yielding varieties
LT:	locally transplanted
m:	metre
m^2	square metre
m^3:	cubic metres
$m^{1/2}$/s:	$\sqrt{\text{metre}}$ per second
m^2/s:	square metre per second
m^3/s:	cubic metre per second

mm:	millimetre
m/m:	metre per metre
MPO:	Master Planning Organization
Mtons:	million tons
MTFPP:	Medium Term Foodgrain Production Plan
N:	nitrates/nitrites
NAP:	Normal Amsterdams Peil
NMP:	National Master Plan
NWP:	National Water Plan
O&M:	operation and maintenance
ORM:	operation, repair and maintenance
P:	phosphates
PAWN:	Policy Analysis for Watermanagement of the Netherlands
ppm:	parts per million
RWS:	Rijkswaterstaat
SFYP:	second five year plan
SUTA:	Setting up The analysis
SW:	surface water
TFYP:	third five year plan
WDM:	Water Distribution Model
WRM:	water resources management
WRS:	water resources system

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REPORT OF THE SEMINAR

Part one
REPORT OF THE SEMINAR

I. ORGANIZATION OF THE SEMINAR

The Regional Seminar on Systems Analysis for Water Resources Development was held in Bangkok, Thailand, from 12 to 23 November 1984. It was organized by ESCAP with the financial and technical assistance of the Netherlands.

Attendance

The Seminar was attended by 17 participants from Afghanistan, Bangladesh, Burma, China, India, Indonesia, Malaysia, Nepal, Pakistan, Sri Lanka, Thailand and Viet Nam as well as by experts from the Netherlands. The Secretariat of the Interim Committee for Co-ordination of Investigations of the Lower Mekong Basin was also represented at the Seminar.

Opening of the Seminar

The Seminar was officially opened by the Executive Secretary of ESCAP. In his opening address, the Executive Secretary stressed that he attached great importance to the Seminar because of the need in the developing countries of the region to use effective techniques for the development, management and use of water resources in view of the growing scarcity of water which is a principal input to their economic and social development. He urged the participants to take maximum advantage of the Seminar to further their knowledge and experience, and expressed the hope that the participants would find the Seminar useful for the efficient development, management and use of water resources in their respective countries.

The Permanent Representative of the Netherlands addressed the Seminar on behalf of the Government of the Netherlands, stating that the Netherlands was pleased to transfer the knowledge and experience it had gained during the Policy Analysis for the Watermanagement of the Netherlands (PAWN) study to other countries, and that this Seminar was one of the effective ways in which the transfer of knowledge and experience could be achieved. He also stated that the Netherlands was in a position to make further contribution towards the promotion of expertise in this field.

Officers of the Seminar

The director of the Seminar was Mr. Muang San Lin, Economic Affairs Officer, Water Resources Section, Natural Resources Division, ESCAP, and the co-director was Mr. E. van Beek of the Delft Hydraulics Laboratory, the Netherlands. The technical secretariat of the Seminar comprised representatives of ESCAP and the Netherlands experts.

Programme of the Seminar

The programme consisted of two and one half days of lectures, five and one half days of workshop and two days of group discussions. The lectures gave an overview of all aspects involved in planning for water resources management, the application of systems analysis to water resources planning and development, and some illustrative case studies. During the workshop, the participants carried out exercises on the practical application of a systems approach and systems analysis techniques to the setting up of the national master plan in a country, with emphasis on the formulation and analysis of alternative water resources management strategies. During the last two days the Seminar discussed the water resources management issues of the countries represented at the Seminar and the potential of using systems analysis to solve these problems. It also identified the extent of follow-up training required by various countries represented at the Seminar as well as the limitations of systems approach.

II. PROCEEDINGS OF THE SEMINAR

A. Lectures on the application of systems analysis to water resources management

The tasks of efficient planning and decision-making in water resources management is complex, because it has to deal not only with different sectors of public interest such as land use planning, environmental protection, food production, energy production, transport, etc. but also with other general areas of national concern such as social well-being, national economic development and public health.

The scale of complexity increases particularly in cases where there is keen competition for scarce natural and financial resources among conflicting interests and where the scope of water resources management changes from local to regional and/or from single criterion to multiple criteria and/or from supply oriented to both supply and demand oriented. In such cases, it is necessary to use advanced analytical techniques to ensure a systematic and consistent approach because conventional methods of analysis for water resources planning when applied to complex problems will require so many assumptions and simplifications that the accuracy or sometimes the validity of the results of analysis becomes questionable.

Systems analysis can provide an efficient analysis of water resources management problems through its analysis framework ensuring the co-ordination of the contributions of various disciplines and persons and also its computational framework which serves as a valuable tool in the formulation and analysis of water resources management strategies particularly with regard to impact assessment. The computational framework consists of a consistent set of mathematical models and techniques for the evaluation of alternative strategies. A computational framework for a water resources management study is composed of several models covering different disciplines such as hydraulics, hydrology, economics, statistics, agronomy, etc. Examples of some models used for a water resources management study were models to predict the demand of water by various sectors of the economy; models to simulate water levels and discharges in rivers; response or impact models to predict the effects of water resources management strategies on specific water users; and national or regional input/output models to predict the effects on national or regional economy. The use of modern computers provides decision makers with the opportunity to examine without much additional effort, the consequences of different conditions, assumptions and scenarios, thus providing the possibility of making more effective decisions compared to conventional methods.

Of the five stages involved in water resources management (planning, design, construction, operation and maintenance), systems analysis could especially play an important role in the planning and operation stages. The Seminar dealt in detail with planning aspects.

A systems analysis study required the carrying out of such tasks as (a) observation and analysis of water resources management systems; (b) development of models to simulate the behaviour of such systems and verification of their validity; (c) formulation of measures and strategies and assessment of their effectiveness; (d) comparison of alternative strategies, and (e) presentation of the results of analysis to the decision makers in a readily understandable way.

Systems analysis for water resources management studies consisted of two phases of analysis: setting up the analysis (SUTA) and carrying out the analysis (COTA).

The setting up the analysis phase, which is also called an inception phase, is concerned with the identification of planning objectives and criteria, and the specification of analysis conditions and the analytical approach. In identifying planning objectives, it is important that these are expressed in specific, and if possible quantitative terms, e.g., meeting certain water quality standards, maximizing food production, because systems analysis can be applied only if the objectives are quantifiable.

The necessity to set up criteria was explained by the fact that it provides a measure with which to assess the achievement of specific objectives by various alternative courses of action being considered.

Specification of analysis conditions comprises identification of time horizons and areal boundaries, selection of an appropriate discount rate and datum year, determination of hydrologic and meteorologic conditions, and forecasting of economic, demographic and technological developments.

Specification of the necessary analytical approach is also carried out during the setting up the analysis phase in which the type of data to be collected, the type of models to be developed, the type of computer facilities to be used, the number of personnel and disciplines required, their skills, and the required time and budget are specified.

Usually a preliminary analysis is carried out during the setting up the analysis phase in order to identify the relative importance of various water users as well as to determine whether the available water resources can meet present and future demands.

The carrying out the analysis phase comprises six elements: (a) estimation of temporal and spatial pattern of activities, (b) analysis of water using and water related activities, (c) analysis of natural systems, (d) formulation and analysis of water resources management strategies, (e) evaluation of water resources management strategies, and (f) presentation of results.

Information on future economic activities is generally available on a national level for major sectors of the economy such as agriculture and industry. These projections have to be broken down to regional levels as well as to different minor sectors within each major sector according to the temporal and spatial distributions used in the analysis.

The analysis of water using and water related activities involves estimation of quantities of water demand and wastewater discharge based on the levels of population and economic activities; development of relationship between water demand and wastewater discharge; and identification of factors which have an effect on water demand, costs and benefits.

The analysis of natural systems included the analysis of data for river discharges, precipitation, temperature, biochemical oxygen demand, soil characteristics, etc. as well as simulation of natural processes such as movement of water and sand, aeration of rivers and algal blooms in lakes. The outputs of this analysis are expressed in terms of physical, chemical and biological indicators.

Formulation and analysis of water resources management strategies is a repetitive process involving screening of individual measures based on criteria with regard to technical feasibility and benefit-cost ratios and on subsequent formulation of strategies and evaluation of their performance with regard to the fulfilment of various preset criteria. In this iteration process several rounds of analysis might be required to reformulate strategies using the results of preliminary rounds. One of the important criteria in the screening process is the degree to which supplies meet the demand under the given hydrologic and meteorologic conditions. Generally, the first rounds of analysis are dedicated to meeting economic criteria with subsequent rounds to meet other criteria such as biomass production; national balance of payment; administrative considerations with regard to the implementation of proposed measures; etc.

The evaluation of water resources management strategies is carried out based on preset multiple criteria and the corresponding weights attached to each of them.

Presentation of the results of analysis is made in the form and content desired by the decision makers, including relevant information on the characteristics of the system, objectives, criteria and analytical approaches.

A computational framework for a water resources management study is composed of several mathematical models which could be classified according to the major analysis segments of the framework of analysis: estimating temporal and spatial pattern of activities; analysing activities; analysing natural systems; formulating and analysing water resources management strategies; and evaluating strategies.

The models of the first group are socio-economic models that translate economic and demographic developments on a national scale into a regional scale (or regional scale into a local scale). Examples of these models are input-output models and national and regional simulation models.

The activity analysis models can describe the behaviour and output of a specific water related activity (agriculture, shipping, water supply, etc.) as a function of other influences. A typical example of this type of model is the agricultural yield model.

The natural system models can be subdivided into five groups: physical oriented models such as those for rainfall-runoff, flood routing, sediment transport, erosion, etc.; chemical models such as dissolved oxygen models, nutrient models, groundwater quality models, etc.; biological and ecological models such as algae bloom models, fishery models, pathogen models, etc.; integrated models that are a combination of different types of models; and supporting models such as meteorologic and hydrologic database systems and synthetic streamflow generators.

Models for formulating and analysing water resources management strategies are integrated models that jointly consider the aspects of demand, supply and socio-economics on a regional/national scale. Examples of models in this category are river basin simulation models, financial analysis models, input/output models, economic ranking models and cost allocation models.

Models for evaluating strategies are those that can determine an overall measure of performance of alternative strategies that were analysed based on different criteria being adopted for the purpose.

An illustration of the practical application of systems analysis techniques to water resources planning was made during the Seminar with examples of planning studies both in developed and developing countries, namely, the Policy Analysis of Watermanagement for the Netherlands (PAWN) study, the Bangladesh Water Sector Master Plan Project and the Mekong study which is a joint study carried out by riparian countries, Lao People's Democratic Republic, Democratic Kampuchea, Thailand and Viet Nam.

Some of the lessons which can be learned from the PAWN study with regard to systems approach were to make a rough outline of the whole duration of the study and prepare detailed working schemes only for short durations (2-3 months) as policy analysis was a trial and error process; to carry out such studies with a small group of highly qualified personnel at the beginning in order to ensure effective co-ordination and communication; to use only full-time staff for the study and keep observers at a distance in order to ensure quick progress of work; to ensure participation of policy makers and other interest groups in the analysis; and to involve local experts in the study as early as possible during the study.

A study of the Bangladesh Water Sector Master Plan Project indicated that the systems analysis techniques could be used in developing countries for designing a master plan for integrated river basin development, establishing the most effective sequence of works and measures towards the achievement of objectives within the constraints imposed by flood control, irrigation, navigation, etc.

In the lecture presented by the representative of the secretariat of the Interim Committee for Co-ordination of Investigations of the Lower Mekong Basin, it was reported that the three simulation models currently utilized indicated that modelling techniques could improve the efficiency of water resources planning. These models were the Streamflow Synthesis and Reservoir Regulation Programme, the Hydro System Seasonal Power Regulation Programme and the Delta Mathematical Model which were all used in the formulation of the Indicative Basin Plan for the Lower Mekong Basin.

As one of the major constraints to the application of systems analysis to water resources development in developing countries is lack of trained personnel in this field, it was considered necessary that training courses and seminars be organized for the following three levels of personnel:

(a) Professionals or water resources specialists who will be actually carrying out the systems analysis studies;

(b) Technical directors or supervisors, under whose supervision systems analysis studies will be carried out; and

(c) Decision makers who will be using the results of analysis.

For the first group (professionals) in-depth training should be provided in the use of systems analysis techniques. The duration of the training course should be approximately 2-3 months.

Training for the second group (supervisors) may take place in the form of seminars which deal only with the general aspects (approach and use) of systems analysis in water resources development. The duration of the seminar should be 2-3 weeks.

Training for the third group (decision makers) may take place in the form of a group study tour which should provide them with the opportunity to acquaint themselves with the usefulness of systems analysis and case studies on projects implemented by systems approach as well as the opportunity to exchange knowledge and experience among themselves with regard to the decision making process in water resources development. The duration of the study tour should be 2-4 days in any developed country having wide experience in the use of systems analysis techniques.

B. Workshop

The main purpose of the workshop was to put theory into practice. The participants carried out a rough simulation of the analysis required for the water sector master plan of a hypothetical country.

In order to stimulate active involvement of the participants as well as to provide them with a better opportunity to interact with the computers, the Seminar was divided into three small working groups, each provided with a microcomputer and guided by a supervisor who ensured a systematic execution of the planning process by these working groups and close co-ordination among the groups. Each working group was assigned a different set of scenario assumptions upon which to base their strategy.

During the case study on the water sector master plan of the hypothetical country, the participants developed alternative water resources management strategies and assessed their impacts on the natural systems and different water users. The main objectives of the strategies were to attain self-sufficiency in foodgrain production in the country based on equity principles by region, as well as to achieve an overall economic growth.

The problems that were addressed in the case study were drought, flood and drainage, and salinity intrusion. The water users considered were agriculture, navigation and fisheries. The case study designed for the workshop gave particular attention to the influence of droughts, floods and salt intrusion on agricultural production.

The analytical framework of the workshop consisted of: (a) the setting up the analysis phase called the inception phase during which the objectives, evaluation criteria and analysis conditions for the study were specified; (b) the preparation stage of carrying out the analysis phase during which a thorough examination and discussion of the available models and compiled data were carried out; and (c) the integration stage of the carrying out the analysis phase during which formulation and analysis of alternative water resources management strategies were carried out.

The workshop made extensive use of the computational framework in the evaluation of impacts of alternative strategies on the natural system and various water users.

The computational framework prepared for the workshop consisted of a network model for a hypothetical river system, an agriculture-based regional/district water balance model, and impact models associated with the water use categories, agriculture, navigation and fishery.

As the computational framework for the workshop was intended to serve the main purposes of illustrating the interrelationships among various elements in a water resources system and demonstrating the usefulness of mathematical models in facilitating the analysis of complex situations, it was simplified to a large extent by making several assumptions.

On the last day of the workshop, various alternative strategies worked out by the three working-groups were put together and compared in order to narrow down the strategies to a few among which decision makers could select to arrive at the optimal master plan in terms of achieving the planning objectives based on the evaluation criteria defined in setting up the analysis.

III. PROSPECTS FOR THE APPLICATION OF SYSTEMS ANALYSIS TO WATER RESOURCES DEVELOPMENT IN THE ESCAP REGION

A. Identification of areas of potential application of systems analysis to water resources development

During the Seminar, the participants identified areas of potential application of systems analysis to water resources development in their respective countries. A summary of this information is presented in table 1. It will be observed from table 1 that almost all countries represented at the Seminar indicated their interest in the application of systems analysis to the following priority fields:

(a) Formulation of a master plan for national planning including integrated river basin development, impact evaluation of engineering structures, and prioritization of water resources development projects;

(b) Studies for rational utilization and management of water resources and evaluation of various operation and water allocation policies;

(c) Operation of water resources development facilities (hydropower stations, storage reservoirs, etc.).

Table 1. Areas of potential applications of systems analysis to water resources development

Areas of potential applications of systems analysis to water resources development	Afghanistan	Bangladesh	Burma	China	India	Indonesia	Malaysia	Nepal	Pakistan	Sri Lanka	Thailand	Viet Nam
Formulation of a master plan for national planning:												
(a) Integrated river basin development	√	√	√	√	√	√	√	√	√		√	√
(b) Evaluation of physical, economic and environmental consequences of engineering structures	√	√	√	√		√	√				√	
(c) Prioritization of water resources development projects	√	√	√			√		√			√	√
Studies for rational utilization and management of water resources and evaluation of various operation and water allocation policies	√	√	√	√	√	√	√	√	√	√	√	√
Operation of water resources development facilities (hydropower stations, storage reservoirs, etc.)	√	√	√	√	√	√	√	√	√	√	√	√

B. Potential of developing countries for the application of systems analysis techniques to water resources development

The Seminar ascertained the preparedness of countries to apply systems analysis techniques to water resources development. Table 2 indicates that all the countries represented at the Seminar had plans to adopt improved methodologies for achievement of optimum benefits in water resources development and that systems analysis techniques was applicable in this regard.

However, almost all countries had inadequate financial resources and lacked the trained manpower required for the application of systems analysis techniques to water resources development. All countries therefore desired to obtain training for their personnel in the field of systems analysis.

Some difficulties that were identified by a majority of countries represented at the Seminar as constraints to the successful application of systems analysis techniques to water resources development were lack of co-ordination among government agencies, inadequacy of reliable data and ineffective communication between professionals (water resources engineers, systems analysts, economists, etc.) and decision makers.

Table 2. Current situation concerning factors affecting the potential application of systems analysis techniques to water resources development

Factors affecting the potential application of systems analysis to water resources development	Afghanistan	Bangladesh	Burma	China	India	Indonesia	Malaysia	Nepal	Pakistan	Sri Lanka	Thailand	Viet Nam
Intention to use improved methodologies towards achievement of optimum benefits in water resources development	√	√	√	√	√	√	√	√	√	√	√	√
Applicability of systems approach to water resources development	√	√	√	√	√	√	√	√	√	√	√	√
Adequacy of financial resources	×	×	×	√	×	×	×	×	×	×	×	×
Availability of adequate number of local systems analysts to support consultants	×	√	×	×	×	×	×	×	×	√	×	×
Availability of trained personnel in the field of systems analysis	×	×	×	×	×	×	×	×	×	×	×	×
Availability of software for use in systems analysis studies	×	—	×	√	√	√	√	—	√	√	√	×
Availability of trained personnel for writing computer programmes/setting up of models	×	—	√	√	√	√	√	—	√	√	√	√
Adequacy and availability/reliability of relevant data	×	×	×	×	√	×	√	×	√	×	×	×
Effectiveness of communication between professionals and decision makers	×	×	×	√	√	×	√	×	√	×	×	×
Adequacy of co-ordination among government agencies	×	×	√	×	√	×	×	×	√	×	×	×

Legend: √ Yes
× No
— Not known

IV. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions were drawn as a result of deliberations during the Seminar:

1. Water resources play an increasingly important role in the socio-economic development of societies. Just as scarcity of water resources can act as a constraint to socio-economic development of countries, overabundance of water (flooding) can inflict considerable socio-economic losses.

2. Modern societies, developed or developing, are so complex that a multidisciplinary and systems approach may ensure the realization of optimum benefits from water resources planning, development and management.

3. The systems analysis technique serves as an effective tool in supporting decision makers in properly discharging their responsibilities. Systems analysis identifies a number of alternate, promising water resources management strategies as well as their probable consequences with respect to the achievement of various objectives such as increased agricultural production, increased power production, minimizing environmental impacts, etc.

4. Systems analysis provides the possibility of analyzing quantitatively many alternative water resources management strategies under different scenarios and assumptions and to carry out extensive sensitivity analyses. Moreover, its computational framework enables the decision makers to undertake planning as a continuing process (as opposed to fragmented planning) by allowing modifications and adaptations of the computational framework to accommodate changing needs, objectives and constraints.

5. The multidisciplinary approach of systems analysis generally has found wide application in developed countries. Under proper circumstances, it can also be applied in developing countries with considerable success.

6. The application of systems analysis requires skilled professionals to carry out the studies. Where such skilled professionals are not yet available in a country, training of personnel can be carried out in a relatively short time.

7. Decision makers should be involved (be kept informed) in a systems analysis study as much as possible in order to familiarize them with the main elements involved and enable them to influence the course of the study.

8. A full systems analysis application can require considerable data and be very sensitive to the quality of the data. In many developing countries available data on economic, social and natural conditions are still inadequate in terms of accuracy and length and breadth of coverage. However, even in cases of limited availability and reliability of some data, systems analysis can still be usefully applied.

9. Areas identified for potential application of systems analysis in developing countries are: setting up of water sector national and regional master plans; studies for rational utilization and management of water resources; and studies for the operation of water resources development facilities (hydropower stations, storage reservoirs, etc.)

The Seminar recommended that:

1. The proceedings of the Seminar should be published for wide dissemination.

2. Those developing countries which have not yet done so may consider taking necessary steps towards the introduction of a systems approach to water resources development.

3. The United Nations and other international organizations should provide the developing countries in the region with follow-up training courses in the field of application of systems approach to water resources development. In this connection, consideration should be given to the organization of three types of roving seminars which could be held in a number of countries for the benefit of professionals (water resources specialists), technical directors (supervisors) and decision makers.

V. ADOPTION OF THE REPORT

The Seminar adopted its report on 23 November 1984.

Part Two

LECTURES

Part Two
LECTURES

I. FOREWORD AND ORGANIZATION OF THE LECTURE NOTES

A. OBJECTIVE AND APPROACH OF THE SEMINAR

The objective of the Seminar as stated in the project document was to assist the countries in the region in the development of national expertise in the application of water planning techniques by all appropriate means, with a view to speeding up and enhancing developing in the region, with emphasis on the poorest areas. The Seminar aimed to create sufficient awareness, in the countries involved, of the advantages and possibilities of systems analysis, to produce a desire for follow-up training resulting in the application of these methods.

The Seminar tried to reach these objectives by giving an overview of all aspects involved in planning for water resources management (WRM). The planning process was followed from the very beginning of stating the objectives of water resources management up to the evaluation of alternative water resources management strategies. The seminar focussed on the use of *systems analysis* in water resources management planning. Systems analysis is defined as a systematic process of generating, analyzing and evaluating alternative strategies (courses of action).

Systems analysis provides a framework for planning and as such it includes:

- an analysis framework (co-ordinated sequence of steps); and
- a computational framework (coherent set of computational techniques).

The Seminar elaborated on these aspects in three different ways:

- lectures;
- a workshop; and
- group discussions.

The lectures (two days) presented an overview of all aspects involved in planning for water resources management and discussed the use of systems analysis in water resources planning and development. In addition some illustrative case studies were provided.

The core of the Seminar was formed by a six-day workshop in which the participants applied a systems analysis approach and systems analysis techniques to a national master planning study. An important feature of the workshop was its emphasis on the activity of the participants. It was a matter of "learning by doing".

The group discussions during the last two days of the Seminar focussed on: (a) water resources management issues in the countries in the region and the potential of using systems analysis to solve these problems; and (b) the identification of follow-up training.

B. ORGANIZATION OF THE LECTURE NOTES

The following lecture notes start with four introductions to different aspects of water resources management planning and the use of systems analysis in this planning. The first two lectures (sections II and III) give a description of water resources management and the role of planning in it. The third lecture (section IV) is the key lecture, giving an overview of the analysis approach for water resources management planning studies. In the last introductory lecture (section V) some basic aspects of the use of computer models and techniques are highlighted.

The fourth and fifth lectures (sections VI and VII) describe two case studies in water resources management planning. The first case study (section VI) is the Policy Analysis of Watermanagement in the Netherlands (PAWN). The other case study (section VII) is the on-going masterplanning study for the water sector in Bangladesh.

The last lecture (section VIII) gives a concluding overview of the application of systems analysis in water resources management planning and the constraints and pitfalls in applying this approach.

Following the lectures an extensive workshop was held in which the theoretical aspects of the above lectures were put into practice. Information about the workshop is given in Part Three of the seminar proceedings.

II. INTRODUCTION TO WATER RESOURCES MANAGEMENT

1. INTRODUCTION

Water resources have always played a major role in human activities. Centuries-old local water resources systems exist in many countries to meet the basic needs for drinking water and to provide inputs for the production of food and fiber (e.g., cotton). The continually increasing demand for and decreasing quality of water as a result of increased population and production activity, led to a situation where local systems were no longer sufficient and more comprehensive, complex and ambitious plans for new water resources systems were designed, constructed, and operated. Such plans include the construction of large reservoirs and irrigation works, often on a scale of a region, a river basin, or several river basins. The aim of these plans is to provide water of an adequate quality and quantity at the times and places where it is of sufficient value to justify the costs.

The shift from local water resources systems to basin-wide systems increased the distance between planners and the end users of the water. Complex institutional arrangements became necessary to manage and operate the systems. As a result, it was found that many developments did not produce the expected levels of output and serious negative environmental and social consequences occurred. These adverse consequences often arose because the planning of these schemes had not taken possible environmental effects into account, the plans were not adequately adapted to the local circumstances, and the necessary institutional arrangements got too little attention. Hence, to avoid these mistakes, present planning has to pay explicit attention to these social, economic, environmental and institutional aspects of water resources management (WRM).

Water resources planners are facing complex problems. They have to comprehend and quantify the many aspects of water resources management and the relations existing among them. Especially in basin-wide or provincial planning studies they have to choose between the infinite variety and variations of possible water resources systems and management strategies. This growing complexity of water resources management forced the analysts to seek methods to help them in their task. Systems analysis provides one means for improving analysis for WRM.

In this lecture an introduction to Water Resources Management will be given. This will be done by first describing the Water Resources System (WRS) as an inut-output system (section 2) and Water Resources Management (WRM) as the totality of tasks to produce the desired outputs of the WRS (section 3). Section 4 describes some aspects of WRM problems and section 5 briefly touches upon the subject of the seminar, the application of systems analysis in WRM, and serves as an introduction to the other lectures.

2. THE WATER RESOURCES SYSTEM (WRS)

2.1 General

Water resources refer to the supply of water and to the support of water-related human activities, in relation to both groundwater and surface water. *Water* in this sense includes all physical (e.g., silt), chemical (e.g., dissolved solids) and biological (e.g., algae and fish) components and serves as an input to, for example, agricultural and industrial processes, fishing, the production of drinking water, and sedimentation on flood plains. *Water-related human activities* refer to, for example, water-based recreation and transportation.

A Water Resources System (WRS) includes all elements required to produce water and water-related goods and services. These elements comprise natural elements such as rivers and lakes, man-made physical elements such as weirs and canals, and administrative elements such as regulations and organizational structures. Water and water-related goods and services, as outputs of such a WRS, serve as inputs to human activities and natural processes that produce goods and services required by society, e.g., agricultural products, electricity. These human activities are also indicated as water use categories.

2.2 Definition and description of a WRS

Setting up an analysis for a specific WRM problem includes the definition and description of the system (the WRS) to be analyzed. Such a definition and description has three essential components: the spatials dimensions; the elements to be considered; and the time dimensions.

Spatial dimensions (including an indication of system and subsystem boundaries.) These boundaries can be drawn from different viewpoints, e.g., topographic conditions, economic activities, institutional arrangements, political jurisdictions, and waste source and waste management situations. This implies that it is not always possible to define one system boundary. In fact, typically several different boundaries will be involved in an analysis for WRM.

Elements to be considered. The decision in this context is that of deciding which elements are to be considered explicitly, i.e., in terms of providing alternatives, and which elements are to be considered as having fixed values. For example, will alternative *on-farm* production and irrigation systems be considered, or will it be assumed that there is a fixed water demand at each farm headgate? Will alternative watershed management alternatives upstream from reservoirs be explicitly considered? Will the analysis consider explicitly how inputs other than water, e.g., seed, fertilizer, pesticides, technical advice, will be provided, or will it be assumed that these will be available and that only the water input will be analyzed explicitly? Will an analysis of transport, processing, marketing of outputs from the farms be included in order to be able to assess the "value" of farm outputs, or will the value simply be assumed, thereby implicitly assuming that the associated "systems" will be available? Will means for mitigating possible increases in schistosomiasis because of seepage from irrigation systems, be included in the analysis? Will explicit consideration be given to the allocation of tasks among levels of government be considered in relation to producing the desired outputs of water and water-related goods and services? For example, what agency will be responsible for predicting flood flows; what agency for warning individuals and activities; what agency for evacuating individuals from the flood plain; and so on?

Time dimension. There are two aspects of the time dimension. One is the selection of the time horizons to be analyzed, e.g., the present, 10 years in the future, and 20 years in the future. The other is to select HOW the time horizons are to be analyzed, once the time horizons have been selected. The objective is to analyze how the WRS behaves, that is, what outputs can it produce over time in relation to specified hydrologic inputs. The approach or approaches to be used depend on the question(s) to be answered. For example, an analysis of a WRS in relation to water quality management might utilize a single flow rate, or set of flow rates into the system at various points, perhaps the lowest flows of record, or the 10 percentile flows. This set of flows would be the inputs to the system in the analysis of the present situation, 10 years from the present, and 20 years from the present. Analysis of a WRS in relation to multiple outputs, e.g., hydro-electric energy generation, flood damage reduction, irrigation, might use a 500-year sequence of synthetic hydrology, divided into ten periods of 50 years each. Such an analysis is particularly relevant, and necessary, when there are large variations in climate and long, carryover storage in reservoirs. The same 500-year sequence would be applied to the present case, that is, the existing levels and spatial distribution of activities; to the estimated levels and spatial distribution of activities 10 years from the present; and to the estimated levels and spatial distribution of activities 20 years from the present. This approach might be characterized as a quasi-dynamic or quasi-static approach. That is, the hydrologic inputs are varied but the economic activities remain constant for any given "run". The most complicated approach would be to vary *both* hydrologic inputs and economic activities in any given "run". That is, the 500 years of hydrologic inputs would be used with the demand side changing each year from the present to 20 years from the present.

Note that, for both the second and third approaches indicated above, depending on the mix of outputs involved, there will likely be *different* time steps within any given run. That is, monthly flows would be used until a flood occurred, at which point the analysis would shift to, for example, 6-hourly flows. Alternatively, the analysis of floods and flood damage reduction and the assessment of the effects of urban storm runoff on ambient water quality might be made separately from the long-term analysis of the behavior of the system based on monthly inflows.

The choice of how to define the WRS with respect to system boundaries, elements included, and which time step(s) to use will be determined by the specific problem to be solved or analysis that has to be carried out. In general one should be very careful not to define the system too narrowly, and in this way leave essential elements out of the analysis.

2.3 WRS as an Input-Output System

From the viewpoint of the systems analyst, a WRS can be conceived as an input-output system producing water and water-related goods and services (figure 1). The system changes the quantity, quality, time and location characteristics of the surface water and groundwater resources into the quantity, quality, time and location characteristics of the desired outputs of water and water-related goods and services. These outputs include irrigation water, transportation opportunities, water-based recreation opportunities, fish biomass, water for industrial use, hydro-electric energy, assimilation capacity of residuals and river discharges. These outputs serve as inputs to what are called water use activities such as fisheries, industrial and agricultural processes, transportation, and flood damage reduction.

Similar to industrial or other production systems, the production of the desired output in the above terms involves as well a nonproduct output. For a WRS such a nonproduct output includes, for example, the silt accumulation in reservoirs, scouring of river beds, sludge from treatment plants, rural developments due to activities involved in construction, maintenance, operation of infrastructure, and reduced siltation in flood plains.

Inputs to the WRS are water from outside the system boundaries (river discharges, precipitation), residuals discharged into the water, the primary resources, i.e., the various kinds of land, labour and capital by which a WRS is built and operated, and the management strategies.

According to the concept described above, a WRS essentially consists of the following four components:

(1) the totality of water and its physical, chemical and biological components in and on top of the soil in an area considered;
(2) the *natural subsystem,* including river, lakes, groundwater aquifers, topographic structure, vegetation, soil, and geological structure;
(3) the man-made *infrastructural subsystem* such as canals, diversion dams, pipelines, pumping stations, water treatment plants, and monitoring networks;

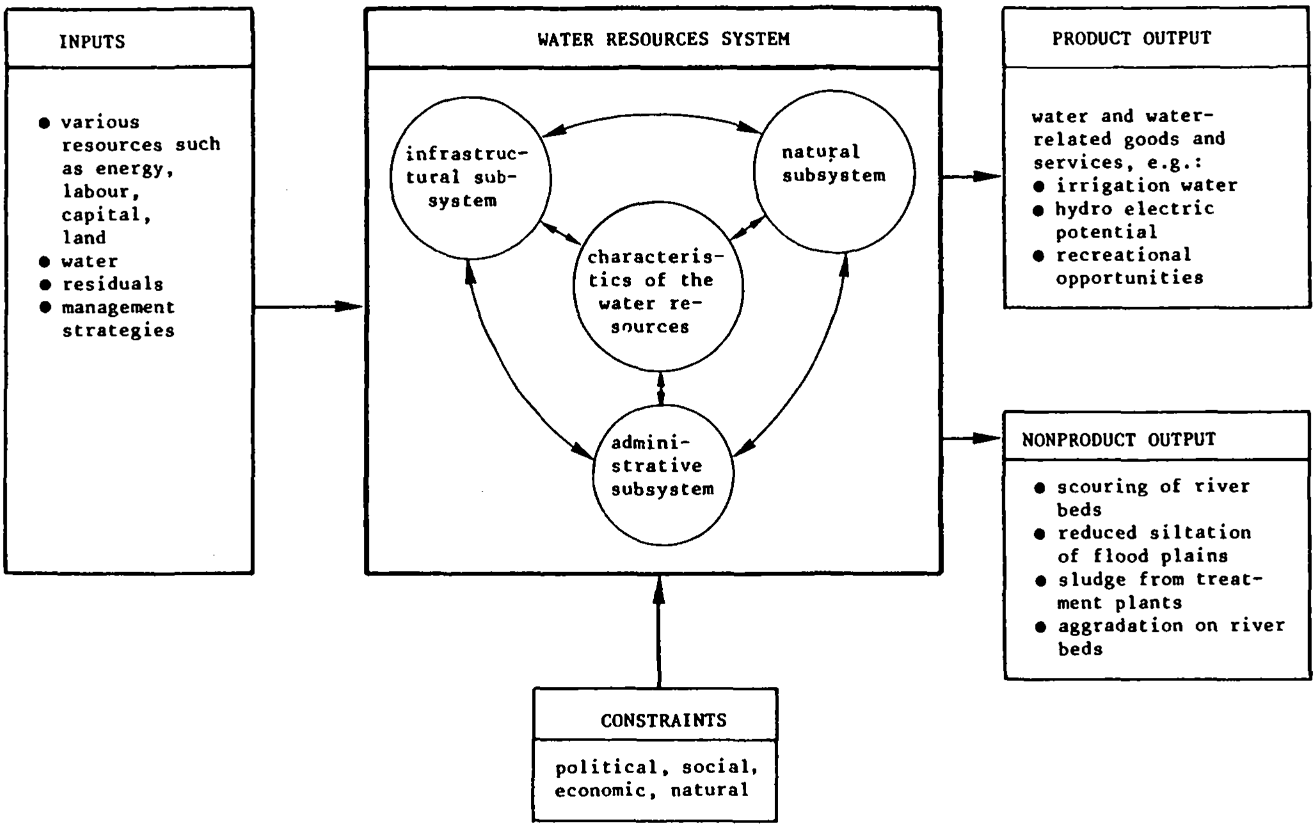

Figure 1. Water resources system as an input-output system

(4) the procedure(s) for operating the infrastructural subsystem; and

(5) the *administrative subsystem,* involving the existing legislation and regulations, charges, sanctions, taxes and subsidies imposed on users of WRS outputs, and the institutional framework comprising the agencies involved in quantitative and/or qualitative management of groundwater and surface water.

3. WATER RESOURCES MANAGEMENT (WRM)

3.1 General

Water Resources Management (WRM) is defined as the totality of tasks required to produce water and water-related goods and services. Figure 2 presents a general context of WRM.

The major aspects of WRM are the *Water Resources System* and the *water use categories.* As indicated in the figure, there exists a demand-supply relationship between those aspects. The water use categories have a demand for water and water-related goods and services in order to produce their output (agricultural products, recreational opportunities, etc., called final demand). The WRS has to provide this water. The inputs to the WRS are: water; residuals from outside the system boundaries; other resources such as labour, soil, energy; and management (plans and regulations). To produce the outputs a set of tasks must be performed.

The physical, chemical and biological processes inside the WRS, the water use categories, their residuals and other natural inputs determine the *state of the natural system.*

The *perception of WRM problems* is based on: (i) the effects, caused by the state of the natural system, on human activities; or (ii) the situation that product outputs of the water use categories comply only to a certain degree with final demands, as a result of the fact that water-related inputs to the activities are less (in quantitative and/ or qualitative terms) than demands. Perceived problems may require *planning and analysis,* i.e. the formulation, evaluation and selection of strategies, resulting in management inputs. The management inputs affect the supply (WRS) and the demand (water use categories) and close in this way the loop of figure 2.

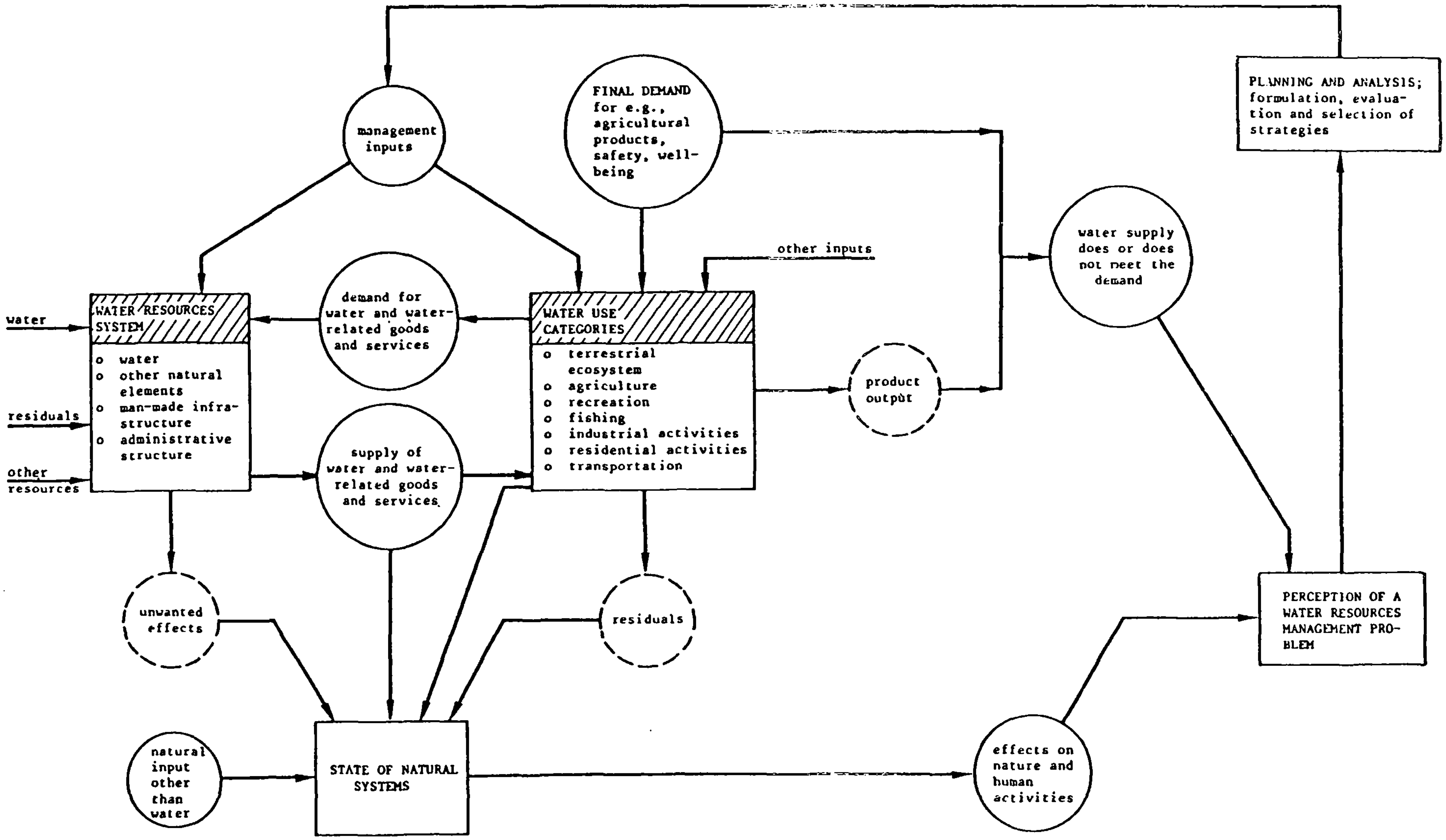

Figure 2. General context of water resources management

WRM generally deals with complex situations:

- Surface water, groundwater, quantity and quality aspects often are interrelated.
- Elements of time and space require a disaggregated, and sometimes a dynamic approach.
- A number of different water use activities may be involved, each with specific interests, some of which may be conflicting.
- WRM tasks generally are not executed by a single governmental body, but given the nature of the problems and the interests involved, are divided among a great many bodies and administrative levels, e.g., various departments, waterboards, provinces, environmental protection boards, irrigation and/or drainage districts, river basin authorities.
- Budget constraints and governmental policies with respect to related fields of national interest may create limiting "boundary conditions".

WRM is related to other sectors of public interest, for which the government has a primary responsibility. Relevant from the viewpoint of WRM are: land use planning, environmental protection, food production, residuals management, energy production, industrial production, transportation, and recreation. In addition to these sectoral areas, there are a number of more general areas of national concern, i.e., social well-being, national enconomic development, and public health.

The sectoral and more general areas can hardly be separated. In principle there are social, economic and public health aspects associated with all of the sectoral areas. In that sense a hierarchy in the national objectives can be distinguished. For example, a basic national objective such as "enhancing the level of prosperity and well-being in the country", can be translated into more specific objectives related to the socio-economic and public health situation. That in turn can be specified in terms of environment, food production, drinking water supply, etc.

Given the above observations, it becomes quite clear that the governmental tasks cannot be executed on an ad-hoc basis, but require a systematic and consistent approach. This applies not only to the actual tasks of water resources management, but also to the integration of WRM with other relevant fields of governmental concern. The latter requires explicit consideration of boundary conditions from interrelated fields/sectors.

Scientific research and analytical techniques have become indispendable aids to support the decision-making activities in WRM. In the following lectures the steps of analysis will be defined to provide the information required for the decision-making processes and the techniques that are available to support these analysis steps will be identified.

3.2 Aspects of WRM

The main aspects for WRM are *demand* and *supply* and the task to find a balance between them. Although the concept is not universally shared, water resources should be considerd as an economic resource and obey economic laws like other economic goods. Hence demand is never totally fixed but denotes the willingness of consumers to purchase the water and water related goods and services depending on prices to be paid. Demand can be influenced by implementation incentives to induce water users to a desired behaviour with respect to their water uses. Examples of such incentives are charges, quotas, taxes and subsidies.

Without being able to go into detail, a few remarks will be made about demand and supply:

Demand

- — demand has to be spatially and temporally defined;
- — demand generally refers to quantity and quality;
- — how much one can influence demand depends on the alternatives the user has;
- — demand for water by a given water user, e.g., an industrial plant, typically has several dimensions, i.e., intake demand, gross water demand, consumptive use demand, waste water disposal demand; and
- — to analyse demand one should understand the variables that determine that demand, e.g., economic, political, technological, and behavioural.

Supply

- — supply also refers to quantity, quality (physical, chemical and biological), time pattern, and location; and
- — supply has a stochastic nature that can be modified by technical means, e.g., reservoirs.

3.3 WRM as a process

WRM has to be considered as a process involving the stages indicated in figure 3: planning; design; construction; operation; and maintenance. In many cases an overemphasis is placed on the design and construction aspects of WRM at the expense of operation and maintenance. This overemphasis starts in the planning stage in which too little attention is paid to implementation aspects and measures, such as incentives to induce desired behaviour, and appropriate institutional arrangements. It is important to emphasize that in any given area, all five stages may be taking place at the same time. That is, different projects of a WRS are in different stages at a given point in time.

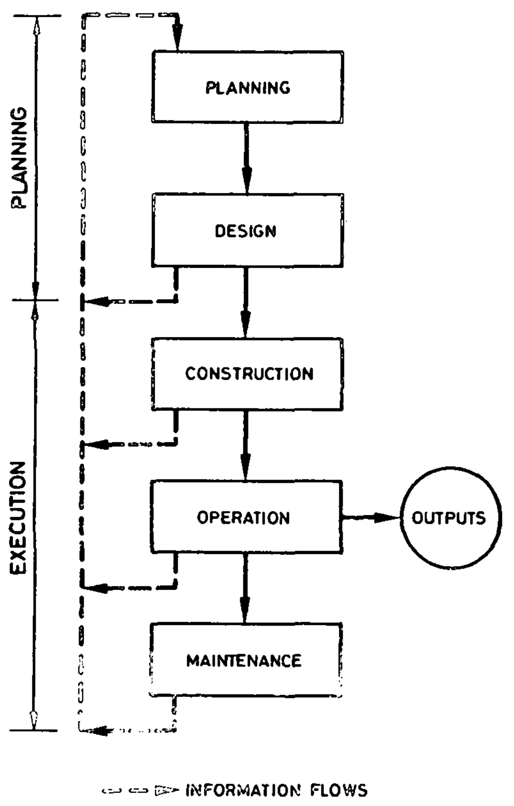

Figure 3. The five stages of water resources management

3.4 Hierarchical structure of WRM

The administrative and organizational components of the WRS reflect the complex nature of the natural and physical components, the variety of demands for water and water-related products and services, and the various interests involved. Because WRM involves decisions and actions on different geographical scales and with respect to different (a variety of) tasks, agencies at all levels of government — national, regional, local — plus user groups (private) are involved.

Given the national directions, more detailed planning and decision-making activities take place at the regional level, in turn providing a set of boundary conditions for local WRM tasks. Going from top down, the administrative involvement tends to be more concrete and more geared towards operation and implementation, as is the case with most governmental tasks. Given the different interests related to WRM, various governmental departments are usually involved, e.g., the ones responsible for environment, agriculture, transportation, and economic affairs. These departments may or may not have a hierarchical structure that facilitates their involvement at lower administrative levels. As a result of the more or less complex administrative structure, the operational tasks are not within the hands of a single government body within the same levels.

The allocation of the tasks of water resources management varies substantially from country to country, and often within a country. Some activities (tasks) are carried out by national governmental agencies, some by regional (provincial, state) governmental agencies, some by local governmental agencies, some by (private) user groups. The allocation is illustrated below by reference to flood damage reduction, provision of irrigation water, and water quality management. Note that governmental agencies at *all* levels may be involved (have responsibilities, may undertake activities) on the same body of water. For example, a national agency will operate navigation facilities on a river; the states (regional agencies) will issue discharge permits and be responsible otherwise for water quality management on the river; local agencies will carry out flood plain zoning along the river.

Flood damage reduction. National agencies are likely to do the following tasks: produce maps showing flood plains in major urban areas; develop a flood insurance program and subsidize insurance rates; do research on flood frequency analysis and compile data on flood probabilities/distributions for various streams; develop flood forecasting procedures and make flood forecasts; plan, design and supervise construction of dikes for protection from floods; help evacuate individuals, livestock, goods in flood periods; aid in reconstruction; and provide financial aid for rebuilding after flooding. *Regional agencies* may also make flood frequency analyses, plan/design/supervise construction of dikes, forecast floods, and so on. *Local agencies* are likely to zone flood plains and enforce regulations on construction in flood plains or any obstructions of stream channels, convey flood warning to those in flood prone areas, evacuate and resettle individuals, provide emergency housing,..... The national government will decide how much of the costs of providing flood damage reduction will be borne by regional and local governments.

Provision of irrigation water. Historically, at least in the United States, *private groups* — such as mutual water companies — planned, designed, constructed, and operated reservoirs, diversion works and canals, to provide irrigation water to their members. What is probably more typical at present, is that a *national agency,* such as the Bureau of Reclamation in the United States, or a *river basin authority,* plans, designs, and supervises construction of a dam and reservoir, diversion works, main canal and laterals, for an irrigation system. The national level of government decides what portion of the costs the water users (irrigation farmers) must pay. The farmers organize into some sort of association, such as an *irrigation district,* with which the national agency can negotiate a contract for repayment of costs allocated to irrigation. The irrigation district is responsible for delivering water to individual farm units, for maintenance of canals, pumps, and other distribution systems facilities. *The farmers* are responsible for maintaining the on-farm facilities, usually with technical — and sometimes equipment — help from the district. The national government carries out research on dam design and construction methods, methods of irrigation, scheduling of water deliveries. River basin authorities and state or provincial agencies may also carry out such research activities.

Water quality management. National agencies may carry out research on methods to reduce discharges, in conjunction with regional and local agencies or with private entities or with its own resources. A national agency may develop guidelines for discharge standards for various industrial activities; *regional/state agencies* and *local agencies* grant permits for discharges, monitor discharges, and impose sanctions. Local, regional/state, national, and private agencies design and construct waste water treatment plants, and monitor waste water discharges and ambient water quality. National and regional/state governments may make grants to local governments for some portions of the costs of construction and operation of waste water treatment plants. National agencies decide about subsidies for private sector activities.

4. CHARACTERIZATION OF WATER RESOURCES PROBLEMS

Water Recources Management, and especially planning for WRM, is related to actions or measures to eliminate or alleviate water resources problems. In general, the problems form the starting base for a WRM study. In this respect it is important to realize that a distinction should be made between the following aspects of a WRM problem:

- physical phenomena: flood, erosion resulting in on-site loss of productivity *and* downstream sedimentation
- their causes: occupance of flood plain, overgrazing
- their socio-economic impacts: economic losses.

Understanding the socio-economic impacts of the problems and not the physical phenomena or the causes is important because these impacts induce the decision-maker to undertake action. The socio-economic impacts are the actual incentives for the planning effort and the implementation of measures. Expressing water resources problems in relation to economic and social impacts (the final outputs to be achieved as a result of WRM) is the first improvement over simply identifying problems in physical terms.

The next step to be taken is to link these problems with their implications for WRM and for organizations and administrative arrangements. Inadequate institutions can lead to deficiencies in WRM that in turn lead to the water resources problems, as illustrated in figure 4. An example of such link is the following: a water resources problem, defined as a reduction in agricultural output caused by flooding, may be traced to inadequate WRM because upstream reservoirs are poorly operated with respect to reducing flood flows. This inadequacy in management may in turn be traced to the fact that the operation of the reservoirs is the responsibility of a drinking water agency.

In this kind of cases solutions to WRM problems can be found in improvement of organizations and administrative arrangements. In other cases specific infrastructural measures are required.

5. APPLICATION OF SYSTEMS ANALYSIS IN WRM — AN INTRODUCTION

The two major stages of WRM (figure 3) in which systems analysis can play an important role are planning and operation. This seminar focusses on the application of systems analysis in planning.

Planning involves the formulation, evaluation and selection of strategies for WRM. Systems analysis provides a systematic framework for this planning. As such it includes:

- an analysis framework (coordinated sequence of steps); and
- a computational framework (coherent set of computational techniques).

Based on the definitions of WRS and WRM in the previous sections, the other lectures in the seminar will pay attention to this planning and the use of systems analysis in the planning process. Case studies in the Netherlands and Bangladesh will illustrate its application. During the workshop a planning analysis will be carried out in which a systems approach will be followed and use will be made of systems analysis techniques.

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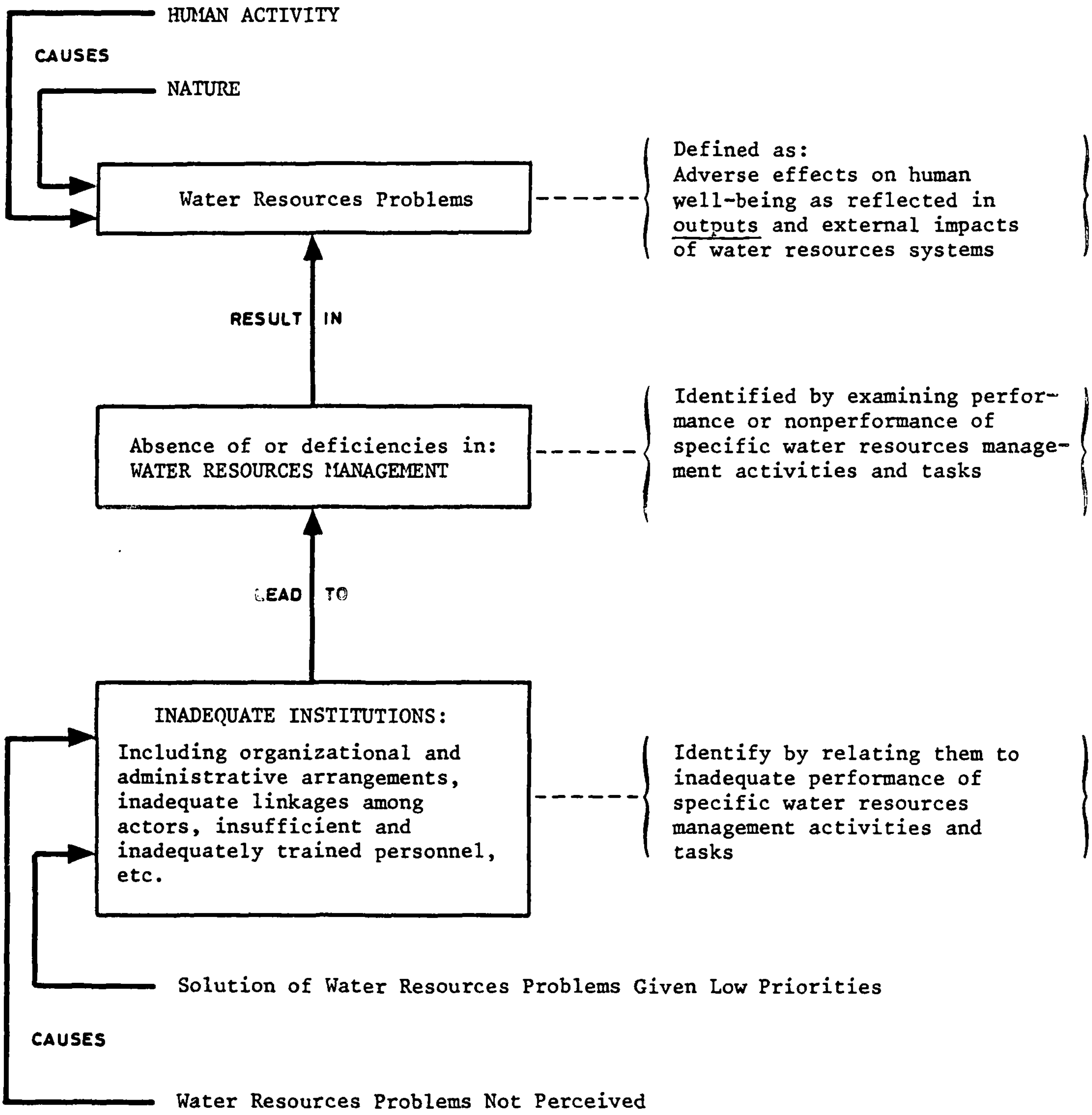

Figure 4. **Linkage of water resources problems, water resources management and water resources management institutions (Source [1])**

III. ANALYSIS AND PLANNING FOR WATER RESOURCES MANAGEMENT

1. INTRODUCTION

1.1 Definitions

Planning is the process of choosing how much water and water-related products and services to provide to whom, when and where, by what specific means. For example, what set of reservoirs and related operating procedures is necessary to meet projected increases over time in the demands for water and water-related outputs and services, e.g., water-based recreation opportunities, hydroelectric energy generation.

Analysis is the process of generating the information necessary for the planning decision. This is illustrated in figure 5.

It is important to distinguish two types of water resources planning, namely: (a) investment planning; and (b) operational planning. The former relates to planning for a decision to invest resources to produce desired outputs of water and water-related services. The latter relates to planning the day-to-day operation of an *existing* water resources system, e.g., reservoir releases, evacuation in times of flooding, responses to spills of toxic materials into a river upstream from water intakes.

1.2 Context of water resources planning

Water resources planning is carried out by governmental agencies at: the local/project level; the regional level; the sectoral level; and the national program level. Information in terms of water demands and project possibilities "flow" up the hierarchical system; policies and constraints flow down. The private sector can be involved in terms of: (1) undertaking specific projects, e.g., supplying water to municipalities, building and operating a hydro-electric energy project; (2) carrying out activities which affect the availability of water, quantity and/or quality, e.g., forest harvesting; and (3) using water as an input into production processes and as a means to dispose of liquid wastes.

At the national level, it is useful to recognize that water resources planning can be initiated as an "indirect" activity, or as a "direct" activity. By the former is meant that water resources planning is undertaken as a consequence of a proposed national development plan, such that the focus of the water resources planning is to determine if, and at what costs, the demands for water implied by the projected outputs in the national economic development plan can be met. The latter refers to the context in which the government asks how might developments in the water resources sector, such as a hydro project, contribute to national economic growth.

Government involvement in water resources planning stems from at least five factors:

- Some of the outputs of water resources systems are public goods. That is, in the provision of certain services, it is impossible to exclude individuals or activities. If flood protection is provided in a given

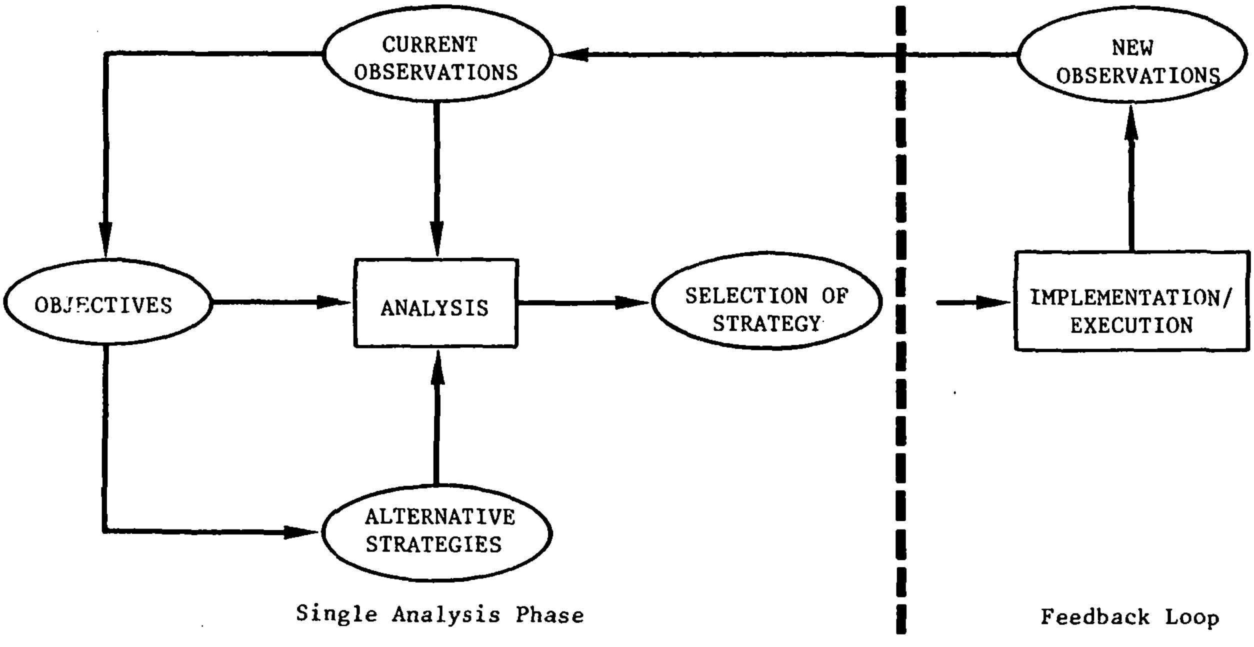

Figure 5. Planning for WRM as a continuous process

flood plain, all activities in the flood plain receive that protection, whether or not they want it.

- Some uses of water resources by a given activity result in adverse impacts on other activities, because the water user does not take into account the off-site or external damages (or benefits) when he makes his decision. Discharge of wastes into a river resulting in lowered water quality downstream, thereby increasing water intake treatment costs for downstream water users, is an example of such "externalities". Generally government intervention is necessary to reduce, or eliminate, externalities.
- Some outputs of water resources systems are difficult to market, such as water-based recreation opportunities on a reservoir or along a stream, and the increased fish yields made possible by actions to improve water quality. The diffuse nature of the recreational activities make developing a market difficult. Even more difficult is to determine willingness to pay for preservation of an aquatic ecosystem or a free-flowing stream. Only through the political process can a society decide how much it is willing to forego to preserve.
- There are complementarities among outputs from water resources systems. That is, the same volume of water can produce several outputs, under some circumstances. For example, one cubic meter released through the turbines in a dam can generate hydroelectric energy, then be used for irrigation downstream, with the return flow from irrigation being used to maintain streamflow in late summer for fisheries. A private entity is unlikely to be able to market all of these outputs; hence the need for government intervention.
- In many countries, some segments of the population cannot pay for water resources development to supply "basic human needs", e.g., potable drinking water, sanitary systems. The extent to which a government undertakes investments and O&M costs to provide these needs is a decision made by the political process.

Water resources planning is strongly related to other sectors of governmental planning, e.g., land use planning, transportation planning, energy planning. In both overall national planning and in sectoral planning, there are likely to be multiple *general* goals which are to be achieved by implementation of the plans for each sector. However, these *general* goals — such as improve living standards, maintain the marine ecosystem, make all rivers "fishable and swimmable" — must be translated into *specific objectives*, before rigorous analysis for planning is possible. Examples of specific objectives are: maximize net benefits; determine the least cost system to provide the 50 litres of drinking water per capita; provide "complete" protection from the 50-year flood at least cost. Or, there may be multiple objectives defined in specific terms, with a ranking among them by the political process. Or, any single objective can be specified as the basis for planning, subject to various constraints, e.g., capital budget, distribution of benefits.

A basic problem in water resources planning is achieving consistency between water resources planning and planning in other sectors, e.g., forest utilization, transportation, solid waste management. Boundaries of the planning (and management) areas for the different sectors do not always coincide (rarely coincide). Only if there is a governmental agency, such as a river basin authority, will the logical, natural boundary for water resources planning (river basin) coincide with the jurisdictional boundaries of a governmental agency. Because political decisions in terms of resource allocation are made by governments of general jurisdiction, water resources planning must be related not only to river basins but also to provinces, states, districts.

1.3 Time foci and outputs of water resources planning

Two types of water resources planning were identified in paragraph 1.1., operational planning and investment planning. The first involves the planning of the day-to-day operation of an existing water resources system. For example: at what level on a rising hydrograph should evacuation from a flood plain be initiated and who should be responsible for carrying out the evacuation and resettlement; how is information that a spill of toxic materials has occurred transmitted to downstream users; who checks snowpack density and makes forecasts of seasonal water available for irrigation; who monitors discharges from industrial activities and imposes sanctions for failure to comply with standards; who decides when to change the degree of intake water treatment for public water supply in relation to changes in water quality at the intake? Thus, the output of *operational* water resources planning is a set of operating rules, that is, specific criteria which set in motion (initiate) various activities, e.g., opening and closing valves and gates, transmitting warning of impending flood.

The time focus for *investment* planning ranges from 20-50 years. In general, the more capital intensive the proposed investment, the longer the time horizon of the planning. However, in periods of capital scarcity, the time horizon used tends to be shorter. Because most of the investments in major water resources systems are financed by intergovernmental loans, the output of the planning process must provide, in specific terms, the time pattern of demands for water and water-related outputs and the related benefits, and the time pattern of installation of facilities and measures, and their costs, to meet the demands. The plan will specify for example: the capacity of each reservoir; the number of megawats of capacity in the powerplant and the estimated firm energy generation each year; the sizes of the irrigation diversion works, main canal, and laterals; the seasonal pattern of irrigation water to be delivered; the time pattern of development of the new irrigated area, i.e., N1 hectares in year 1, N2 hectares in year 2, N3 hectares in year 3, and so on; the estimated time pattern of capital and O&M costs; and the estimated time pattern of revenues from sales of outputs from the system.

In the 1950s and 1960s, the output of water resources investment planning often was a set of facilities to be installed at points in time over a 50-year period to meet the growth in demands for water and water-related services over the same period, and the associated costs and benefits, respectively. However, as the dynamic context of water resources planning became increasingly recognized (dynamic as a result of changing social tastes and goals, changing technology, changing natural systems), the emphasis in water resources planning shifted to deciding on the "next" additions to the water resources system, i.e., over the next 5-10 years. However, the analysis for that decision included a longer time frame, e.g., 30-40 years, to ensure that the next increments to the system would be useful regardless of the directions in which demands might go beyond the first 5 to 10 years. Thus, the output of water resources investment planning would be comprised of: capital budget for 5 or 10 years; operating rules for the facilities; operation and maintenance costs in relation to the facilities in the capital budget for a 20-year period; short-run and longer-run data collection and research programs; estimated benefits from the outputs; distribution of costs; programs for monitoring discharges and ambient water quality; hectares to be irrigated in each year of the 20-year period;.....etc.

2. ANALYSIS IN WATER RESOURCES MANAGEMENT

2.1 Nature of management

Water resources management is a continuous activity, one which consists of a number of tasks which must be performed in order to produce the desired outputs each day. Therefore planning, and the analysis component of planning, must be done *continuously*, with the planning decisions being made at various points in time, based on outputs from analysis and taking into consideration changing conditions. This requires that feedback mechanisms be incorporated into the planning process, as suggested in figure 5. Examples of changing conditions are:

- Changes in demands:
  - economic developments, e.g., production levels, product mix, product characteristics;
  - changes in production processes;
  - population growth; and
  - land use developments, e.g., agriculture, urbanization, forest depletion.
- Changes in supply due to natural developments or human actions upstream, e.g., quantity, quality, and time pattern of surface and ground water bodies.
- Technological options with respect to *both* demand and supply.
- Societal changes regarding objectives and criteria.
- Changes in the relative prices of factor inputs and of the various products and costs.

From the above it is clear that, in view of the characteristics of water resources systems, planning must take into account a great many factors. Table 3 indicates typical examples of such factors.

2.2 Basic requirements for analysis for WRM

Analysis for WRM, as defined previously, is that activity which provides quantitative information for the formulation and evaluation of alternative WRM strategies, to make possible better decisions in the planning process. Given the varying contexts for planning water resources management, some basic requirements for the analysis for WRM are stated below:

- The analysis should be management oriented. The primary objective for the analyst should be to provide accurate and useful information for the decision-making process (the planning decision).
- Intensive interaction between the analyst and decision-makers should provide the former with insight into the decision-making process and problems, and the latter with costs and consequences of alternative WRM strategies and with the possibilities and limitations of the analytical techniques. One way to obtain this interaction might be the explicit formulation of subsequent rounds of analysis, each of these rounds encompassing a specific problem description, indication of the kind of results to be obtained, and specification of conditions of the analysis. Another way would be to have a "policy board" or steering committee for the analysis comprised of direct representatives of decision-makers.
- Demand for water should not be considered as a given boundary condition, i.e., a fixed requirement. Design of strategies as defined includes the formulation of incentives to induce behaviour resulting in changing demands for water and water-related products.
- The analysis should be sufficiently flexible: to study many alternative strategies; to make visible relevant costs and consequences; to quantify uncertain developments; and to consider, if rele-

- o Natural factors:
  - quantity and quality of water from surface and ground water (rain, river discharges, groundwater inflows);
  - geomorphological and geologic characteristics of the area (river basin) considered;
  - hydrographic characteristics of lakes, e.g., volume, area, depth, temperature properties; and
  - soil conditions and natural vegetation.

- o Technical factors:
  - hydraulic properties of reservoirs and canals;
  - storage capacity and surface area of reservoirs;
  - capacities of pumping stations, inlet works, treatment works;
  - location and characteristics of facilities, e.g., weirs, dams, pipelines, reservoirs, ship locks, canals, irrigation systems, water-based recreation facilities, power plants, design of ships, design of fishing equipment;
  - water utilization systems within activities, e.g., irrigation method, recirculation in industry, water conservation devices in households; and
  - possible sites for reservoirs, power plants, transmission lines, pipelines.

- o Socio-economic factors:
  - existing water use patterns;
  - water demand characteristics;
  - responses to changes in availability and cost of water and to changes in prices of other factor inputs to activities, e.g., energy; and
  - costs and benefits associated with water use.

- o Administrative factors:
  - existing laws and procedures in the field of WRM, e.g., water rights;
  - institutional organization, e.g., distribution of tasks, budgets, responsibilities;
  - decision-making procedures; and
  - relations with other governmental policy areas.

Table 3. Example of factors to be taken into account in planning for water resources management

vant, technical interactions between groundwater and surace water, and between water quality and quantity. The level of detail should depend on the "round of analysis" as defined above. The use of *mathematical models* can be most helpful to obtain the required flexibility, but is not to be considered as a requirement.

- Because planning is a continuous process, the analysis should be made in such a way that the applied analytical techniques fit into a consistent *framework for analysis* that is acceptable to the decision-maker and gradually can be expanded and improved, and that can be continually used to provide information for decision-making.

The last two items refer to an *analysis framework* and *analytical techniques*. These characteristics of systems analysis will be emphasized in following lectures.

3. ACCEPTANCE OF ANALYSIS RESULTS

In carrying out a planning analysis, one should be constantly aware that the results of the analysis have to be accepted. Quite a few good planning analyses have not resulted in a strategy which has been implemented because insufficient attention was given to this aspect of the planning process. The three major groups that have to be convinced that the results of the planning analysis are useful are:

- the decision-makers (mostly at political level);
- the implementing agencies (e.g. the public works department); and
- the interest groups (e.g. agriculture, shipping).

The first step is to have *the decision-makers* accept the results obtained in the planning analysis. This is especially tricky when the outcome of the study is not in agreement with the expectations of the decision-makers or when the results are controversial. Under these circumstances the conclusions of the analysis will be rejected if the decision-maker does not fully understand the approach which has been followed in the analysis. In order to prevent such situation from occurring, it is necessary that the analyst keeps the decision-maker informed during the analysis and seeks his opinion and advice at certain crucial points in the study. In other words the decision-maker has to commit himself to the analysis. That does not mean that he also has to follow all the recommendations that can be drawn from the results. It is essential that the assumptions, the analysis approach, and the results as such are no longer questioned. An involvement as meant here can be established by organizing extensive briefings on a regular basis, e.g. every three months, during the study period in which the analysts keeps the decision-makers informed about the progress of the study and also about assumptions, approach etc., and may ask for their ideas.

The second group that has to be convinced are the *agencies* that have to *implement* the resulting WRM strategy. It is suggested to incorporate the implementing agency in the planning and decision process as much as possible. Usually this group is different from the decision-makers, and they will be confronted with the conclusions practically on a day-to-day basis. If they are not convinced that the changes which are suggested by the analysis are real improvements, these changes will not be, or only reluctantly, enforced. Dictations from above without understanding why will usually not have the aimed effect. People have to be really convinced in order to get them to deviate from their usual pattern of behaviour. Therefore an extensive information campaign to the relevant users will be necessary. If no, or not enough, attention to this aspect is given, one can be left with a good analysis, a well accepted plan by the decision-makers. but the benefits counted upon will never be realized. Under these circumstances newly built facilities will not be used properly, there will be a lack of maintenance and constructions will deteriorate rapidly. If the suggested changes consist of a different management policy, it will not be carried out in practice.

The third group are the *interest groups*. They are in general the most difficult to cope with, especially when the planning analysis results in strategies that are disadvantageous for certain groups or regions. Even when the overall strategy is clearly beneficial from a national point of view it will be difficult for an interest group to accept a strategy that hurts its position. A careful presentation might smooth the sharp edges a bit. A redistribution of the primary benefits by a system of levies and subsidies can solve these problems. If there are reasons, e.g., political, for such redistribution, these measures should be incorporated in the planning analysis.

IV. SYSTEMS ANALYSIS IN PLANNING FOR WATER RESOURCES MANAGEMENT

1. INTRODUCTION

Analysis to support planning for Water Resources Management (WRM) has a simple aim: to provide quantitative information to decision makers to enable better decisions, or more specific, to make a better selection from among proposed alternative measures (strategies).

During the last twenty years the analysis for water resources planning has changed. These changes were brought about for one part by scientific and technological development, for another part by an increase in the complexity of WRM problems. Because of scientific and technological developments, we now have at our disposal powerful computers, models and analytical techniques, which enlarge our analytical capabilities enormously. However they do *nothing* to solve the problems of *obtaining* basic or primary data.

The increase in complexity of WRM problems manifests itself particularly in terms of conflicting interests competing for scarce natural and financial resources and in a change in the scope of WRM. This change in scope is reflected in changes from local to regional, from single criterion to multiple criteria, and from supply-oriented to both supply- and demand-oriented management. The changes described have their impacts on both the information required from an analysis and the set-up and execution of the analysis. Systems analysis tries to respond to these changes and new requirements by offering a framework for analysis (a coordinated sequence of steps) and a computational framework (a coherent set of computational techniques) to facilitate quantitative analysis.

The evolution of systems analysis as a method of analysis and its characteristics are discussed in some more detail in the next section. In the subsequent sections the framework for analysis and the related computational framework will be explained.

2. WHY SYSTEMS ANALYSIS AND WHAT'S NEW ABOUT IT

The art of engineering and planning may be defined as: to draw sufficient conclusions from insufficient data. This definition was valid in the past and still has its value. Drawing sufficient conclusions from insufficient data may also be understood as introducing the right assumptions and simplications into the analysis from which the conclusions are drawn.

If this interpretation is adopted there appears to be a distinct difference between past and present. In the past rather crude assumptions and simplifications had to be made because sufficient knowledge and computational facilities were lacking. At present, due to scientific and technological developments we are able to make better assumptions and introduce less severe simplifications. In short: we have the possibilities to approximate reality more closely. But "reality" has become more complex as we have learned more!!

Also, because of better computational facilities we are able to examine, without much additional effort, the consequences of different conditions or assumptions, leading to an improvement of the assumptions being made. For instance: changes of the systems configuration, of the operating rules of a reservoir or of the size of an irrigated area can easily be examined by changing the relevant input data and having the computer repeat the computations. This computational capability is important because planning is always related to an uncertain future. Any analysis for planning should treat the uncertainties in the future situation explicitly, either by examining different scenarios and by performing sensitivity analyses. A computational framework greatly facilitates such analyses.

In addition to better analytical capabilities, another important difference between present and past is that problems have grown more complex. In fact, it is no longer possible for a single person to understand all aspects and relationships involved in a WRM problem. Analysis for WRM has evolved into a multi-disciplinary activity. This increase in aspects and relationships to be considered, and the fact that several persons and disciplines contribute to the analysis sets a new problem. There is a potential danger that the different contributions to the analysis are not tuned to each other, making the results of the analysis less useful. To overcome this problem the analysis has to be structured in a sequence of steps or a set of procedures in which the contributions of various disciplines and persons are coordinated and tuned to each other.

To summarize, changes in analysis for WRM manifest themselves as:

- — a need for integration of the contributions of various disciplines and persons; and
- — a need to make proper use of increased analytical capabilities in order to realize an effective and efficient execution of a planning effort.

As stated in the introduction, systems analysis responds to these changed circumstances by offering a framework for analysis and a related computational framework. As such, *systems analysis* can be defined as:

> a systematic process of generating, analyzing and evaluating alternative strategies (courses of action).

Through the design and application of a coordinated set of procedures and a coherent set of computational techniques, systems analysis can reveal the multiple consequences of such strategies.

Some of the tasks to be performed by analysts in a systems analysis study are:

- to observe and describe the behaviour of complex systems;
- to develop models to explain the observations to test their validity, and to enable predicting behaviour under alternative sets of conditions;
- to formulate measures and strategies and assess their consequences;
- to compare the alternative strategies; and
- to communicate the results to the decision-makers in a readily undestandable way.

If applied properly systems analysis will contribute to an efficient analysis of WRM planning problems. It is however not a universal remedy for all kinds of problems one may encounter during an actual analysis. Some of the pitfalls one may encounter in applying systems analysis will be summarized at the end of the seminar. It goes beyond saying that sound engineering and economic judgement and a good understanding of the decision problem remain essential ingredients for a succesful analysis.

It is important to emphasize that "systems analysis" is fundamentally a "way of thinking" about problems, rather than some formal, mathematical method of analysis. Systems analysis is sometimes confused with the term, operations research, which does connote a set of mathematical techniques. Systems analysis as a way of thinking about, and framing analysis of, problems, is particularly relevant to analysis for WRM, because of the increased complexity of water resources problems and the necessity for linking (integrating) the economic, technologic, ecologic and institutional aspects of WRM. It is this capacity to integrate which is critical to producing useful results for decisions.

3. FRAMEWORK FOR ANALYSIS

3.1 Introduction

A framework for analysis structures the analysis procedure to provide the required information for the formulation and selection of WRM strategies. The framework presented in this lecture describes the necessary steps to be carried out, regardless of the specific problem. It is recognized however, that there will be differences in the way the actual analysis will be carried out depending on the decisions to be made and on practical constraints like available time and money. Nevertheless the general framework can be used as a reference for the design of problem-specific frameworks.

A framework for analysis should meet certain requirements.

- It should be flexible to apply and easy to change in order to be useful for continuous analysis for planning for WRM.
- All steps in the framework, and especially those steps that include the application of computational techniques, should be tuned to each other. They should produce no more and no less information than required in view of the total procedure, the accuracy of the different components of data, and the objectives. In many situations this internal consistency appears to be a dominant factor in the efficiency of the analysis.

The framework presented in figure 6 consists of two phases of analysis: SUTA (Setting Up The Analysis) and COTA (Carrying Out The Analysis). Both the SUTA and COTA phases are explained in more detail in the next sections.

3.2 Setting up the analysis (inception stage)

The SUTA phase is dedicated to the description of the problem(s), the identification of the objectives and criteria, and the specification of analysis conditions and the analytical approach. The SUTA phase may be described as the process which determines what types of analyses have to be undertaken in the COTA phase and in what order, to produce the desired information in relation to the questions to be answered and within the available time. In figure 6 some of the major steps of the SUTA-phase have been depicted. These steps are discussed below.

Triggers

Triggers that initiate a WRM analysis can be divided into direct and indirect stimuli. Direct stimuli pertain to, e.g., mandated planning or a specific WRM problem or event such as drought and floods. Indirect stimuli have to do with WRM analyses carried out as a secondary but required analysis in the framework of some other planning effort, such as or land use planning, energy planning, agricultural developments planning.

Identification of planning objectives and criteria

One of the fundamental premises underlying analysis for WRM is that the analysis will be quantitative where possible. Therefore the WRM objectives to be achieved must be defined in specific, quantitative terms. Objectives such as "WRM has to aim at protection of public health and welfare" are *non-operational* in an analytical sense. Examples of *operational objectives* are: to meet certain ambient water quality standards or to produce a specified quantity of food grains or to maintain a specified minimum flow in a river at all times.

Analysis for WRM is directed to the generation of alternative strategies. Criteria are needed to enable a comparison of alternative strategies, with respect to the extent by which they could achieve certain objectives. Criteria form a measure with which the achievement of specific objectives can be assessed.

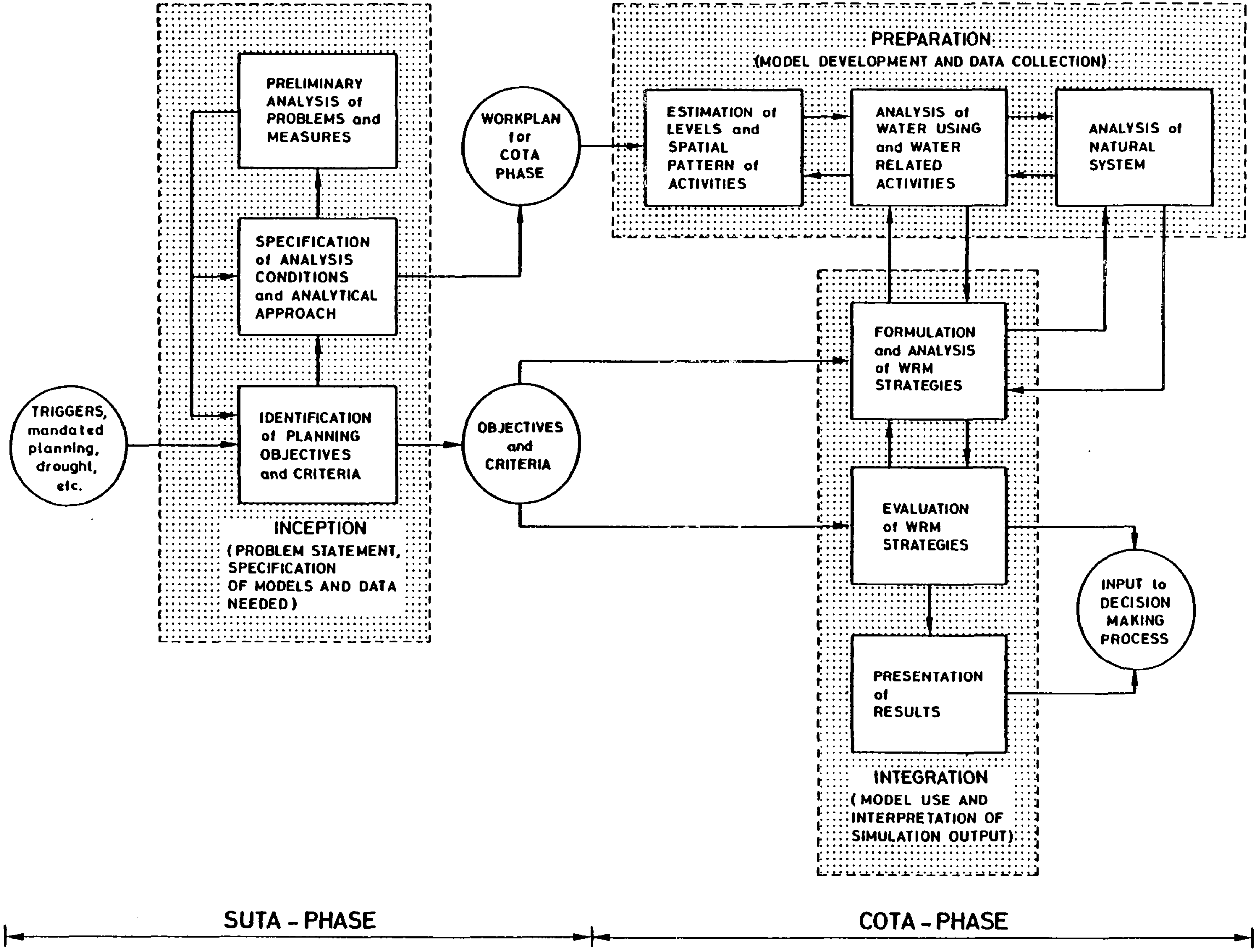

Figure 6. Framework of analysis for WRM studies

Specification of analysis conditions

Analysis conditions refer to the complete set of conditions and assumptions under which an analysis for WRM is undertaken. They include amongst others:

- ***Time horizons and areal boundaries.*** Usually an analysis is to be made for present conditions and for one or more points in time in the future. Rarely is it feasible or necessary to analyse each year of the complete time period. Also the boundaries of the region to be analyzed need to be established.
- ***Discount rate and base conditions.*** Strategies involve capital, and operation and maintenance, costs over time. In an economic evaluation of alternative strategies the time streams of costs and benefits need to be converted to some comparable measure, such as the present value. For that purpose a discount rate needs to be selected. Similarly a decision must be made on how changes in prices will be handled. Often it is decided to use constant prices, expressed in monetary units for some specified base year.
- ***Hydrologic and meteorologic conditions.*** These conditions are important for both the water supply and the water demand characteristics (e.g. agriculture). As hydrologic and meteorologic conditions are stochastic in nature, strategies should be analyzed for various sets of hydrologic and meteorologic conditions. In the SUTA phase it should be decided how much of the stochastic nature should be taken into account in the analysis.
- ***Scenarios.*** There is always some uncertainty associated with forecasting of economic, demographic, political and technological developments. Although such developments are exogeneous to the system to be analyzed they do exert an influence on the behaviour of the system. To account for this fact, alternative developments or scenarios are developed and analyzed.

Preliminary analysis of problems and measures

The purpose of the preliminary analysis is to identify the relative importance of the various water-using and water-related activities and to find out whether or not the water resources can meet the demands for water and water-related outputs in the present or future situation. The demands for water include both quantity and quality as well as the temporal and spatial distribution. Also, an inventory of potential measures or strategies is relevant in this context.

The preliminary analysis aims to focus the efforts during the COTA phase on the most important problems and the most promising measures. The specifications of the analytical approach will, to a large extent, be based on the results of this preliminary analysis.

Specification of analytical approach

Based on the previous steps the output of the analysis can be specified, e.g., agricultural production, costs of measures to whom. The level of disaggregation (the amount of detail) is an important element in this specification. Given the required output the analytical approach can be specified, that is, what data are to be collected and what models are to be developed. Also, other required resources should be specified, such as computer facilities, number of personnel and required disciplines and skills, time and budget.

Finally the outcomes of the various steps should be combined and summarized in a workplan for the COTA phase.

Feed back in SUTA phase

The previous parts of the SUTA phase must be checked with the decision makers. Although such checking should be part of the process of SUTA, nevertheless the final output of SUTA must be one to which the decision makers agree. Particularly important in that respect is the work plan for COTA. If the time and budget required for COTA as proposed in the output of SUTA are not consistent with the available time and available resources, revision will be necessary or additional time and resources will have to be obtained.

3.3 Carrying out the analysis

The COTA phase in its general form comprises six segments (see figure 6). The segments pertain to:

- — estimation of levels and spatial pattern of activities (segment 1);
- — analysis of water using and water related activities (segment 2);
- — analysis of natural systems (segment 3);
- — formulation and analysis of WRM strategies (segment 4);
- — evaluation of WRM strategies (segment 5); and
- — presentation of results (segment 6).

A short explanation of each segment is presented below.

Segment 1: Estimation of the levels and spatial pattern of activities

Any analysis must begin with an estimate of levels of population and economic activities, such as households, agriculture and industry, for the specified time horizons. The levels and spatial distributions of these activities should be in accordance with the required detail (level of disaggregation) of the analysis.

Information on economic activities for future conditions pertains to the final demand of society for the production of goods and services. In general this information is available on a national level for aggregated sectors, e.g., agriculture and industry. These projections of national activity levels need to be disaggregated to regional levels accompanied by a further disaggregation into sectoral activities. The classification of sectoral activities should reflect the different characteristics of these activities, e.g., the disaggregation of total national agricultural production to regional hectares of specific crops, produced in specific ways. Similarly, the projected national total of tons of steel must be disaggregated to regional totals of *specific* types of steel produced by specific processes in specific locations.

Segment 2: Analysis of water-using and water-related activities

In this segment the "translation" is made from levels of population and economic activities into quantities of water demanded and of residuals discharged. Included are: the development of relationships between water demands and generated residuals, the various factors which determine such demands and the benefits and costs involved. Examples of such factors are: production technology, alternative farming practices, internal water recirculation costs, prices of water and energy, intake water and sewer charges, flood damage reduction measures and drainage improvements.

The output of an activity analysis is input into: (i) the analysis of natural systems; and (ii) the formulation and analysis of WRM strategies. Input into the first analysis concerns e.g. the estimations of the demand for water and the residuals generated, which affect water quantity and quality in various bodies of water. Examples of inputs into the formulation and analysis of strategies are benefit/loss functions or tables and price elasticity curves for water use in industrial processes. It is important to note that the activity analysis should not only yield the average time pattern of water demand, but also variation around that pattern.

Segment 3: Analysis of natural systems

Analysis of natural systems includes the analysis of how the demands for water and water-related goods and services and the measures to meet those demands affect natural processes. Data comprise river discharges, precipitation, temperature, biochemical oxygen demand, soil characteristics, etc. Processes include physical, chemical and biological processes, such as the movement of water, sediment and nutrients, aeration of rivers, algal blooms in lakes and productivity of ground water aquifers.

The amount and accuracy of available data are predominant factors in the overall accuracy of the analysis of WRM strategies. Collecting, evaluating and processing natural systems data require a good knowledge of the represented phenomena as well as of the purpose of the analysis. For example, recorded extreme values of river levels may be due to sampling errors; however, leaving them out may have serious consequences for the development of design criteria for such structures as dikes and spillways of reservoirs.

Inputs into natural system models involve the outputs of the activity analysis, i.e., the demand for water and quantities of discharged residuals, both at specific locations and in specific time patterns, and when relevant the formulated physical measures and their operating procedure as part of WRM strategies.

The linkage between analyzing activities and analyzing natural systems merits emphasis. The former *must* result in data inputs in the proper form for the natural system models used. Conversely, these models must be chosen and/or formulated in relation to the outputs which the analysis of activities can provide, the available data, and the desired outputs in terms of physical, chemical and biological indicators.

Segment 4: Formulation and analysis of WRM strategies

This segment includes various rounds of analysis. The first steps in this segment include a screening of individual measures, often based on criteria related to technical feasibility and benefit-cost relations. Subsequently, strategies are formulated and, in accordance with the posited criteria, other impacts than costs and benefits are estimated. These steps may include an environmental impact statement. Finally, segment 4 results in a set of promising strategies and their impacts or consequences in terms of the posited criteria.

Screening of measures

Screening of physical measures mainly is oriented to the technical characteristics and costs of such measures. Such measures may consist of collective facilities, such as reservoirs, pipelines, and treatment plants. Calculated costs should include capital costs, annual operation and maintenance costs, and replacement costs as well as administrative costs for monitoring of, e.g., discharges and ambient water quality. Typical examples of results of such an analysis are: cost/capacity relationship for a reservoir; relation between investment and maintenance cost (dredging) for river regulation works; and the relation between costs and efficiency of removal of certain contaminants by waste water treatment plants. The screening of possible physical measures may result in a first selection procedure: measures may appear to be not technically feasible at a given point in time or too costly. However, rejections of proposed measures should not be done too quickly without further analysis of a more complete strategy.

Screening of implementation incentives and institutional arrangements is mainly oriented to the definition of combinations of these measures, in relation to the proposed physical measures. The activity analysis (segment 2) provides information on the responses of individual and collective activities to possible governmental actions in relation to factor input prices, waste water charges, new technology, etc. Given the economic, administrative and political context of planning and implementation of WRM strategies, the feasibility of combinations of implementation incentives and institutional arrangements should be investigated and decided upon in close interaction with elected officials and/or representative governmental authorities and interest groups.

In some cases there will be potential measures which are technically feasible and economically desirable, but which — at the given point in time — are not legally possible. Ideally in such cases, the analysis would proceed by first, including such measures and determining the net benefits from the strategy. Second, the analysis would be made excluding those measures which presumably would result in substantially lower net benefits. These results can be presented to the decision-making process so that the decision makers can determine whether or not the increase in net benefits is worth the political problems of changing the legal/institutional structure to permit adoption of the more efficient measures. Too often, potentially excellent measures have been arbitrarily excluded by the analysis because they believed they were not politically feasible. But determination of political feasibility is a prerogative (responsibility) of the decision makers and the political process, not of the analysts.

Formulation and selection of promising WRM strategies

Strategies are formulated given: specified levels of demand of actual and future activities; levels of natural system indicators which are to be achieved; and identified measures and operating procedures for infrastructural works. The level of detail of the measures investigated should be consistent with the level of disaggregation of demand and natural system indicators.

An important selection criterion is the degree in which supplies meet the demands under predefined hydrologic and meteorologic conditions. In addition, direct costs and benefits play an important role in the selection procedure for promising WRM strategies. Operationally this means that the first analysis rounds will be dedicated to the determination of direct economic effects. In subsequent rounds gradually other impacts, related to the defined criteria, will be determined.

Analyzing impacts

The decision on WRM strategies presents a multi-objective decision-making problem. Decision criteria that may be involved are produced in the SUTA phase. Examples include: physical, chemical, biological effects and their distribution over time, such as water levels and biomass production; economic effects such as costs and benefits and their distributions, national balance of payment; and administrative considerations in relation to the implementation of proposed measures and political considerations such as required new legislation. Most of these criteria are expressed in non-comparable units (total costs or benefits per year, tons per hectare, cms above mean sea level), or are of a qualitative nature.

It should be mentioned that the procedure for formulating and analyzing strategies is a strongly iterative one. Consequently, several rounds of analysis may be used to reformulate strategies using the results of preliminary rounds. Iteratively, the total number of strategies may be reduced while the level of detail increases.

Segment 5: Evaluation of WRM strategies

Decision-makers use multiple criteria in making decisions. Costs represent a major criterion but not the only one. The decision-makers should indicate the relevant criteria and give relative weights to the individual criteria. The analyst plays an important role in providing the framework for making explicit criteria and related weights.

Analytical methods exist to contribute to the evaluation of strategies, such as cost/benefit analysis and multi-criteria analysis.

A cost/benefit analysis represents a systematic enumeration and evaluation of all relevant, direct and indirect social benefits and costs of a given strategy. Benefit/cost analysis can be done in ways which provide information on objectives in addition to national economic efficiency. For example, the analysis can track the costs to whom, both in terms of geography of political jurisdiction and in terms of economic classes, and the benefits to whom, in the same terms. Benefit/cost analysis can be done with various types of constraints. For example, the objective function can be to maximize net benefits subject to preserving a particular free-flowing stream. If the analysis is repeated without the constraint, what is produced is the net economic benefit lost to society by preserving the stream. This does not represent the value, as such, of the free flowing stream; what it does represent is the *minimum amount* that society would have to be willing to pay in order to preserve the stream. In analogous fashion, benefit/cost analysis can be done with other constraints, such as specification of maintenance of some level of employment in a given region, or the provision of so much water to a reservation. Doing so thus indicates the tradeoff between economic efficiency and the other objective. All of these benefit/cost analyses can be done with multiple sequences of hydrologic events, in order to produce "expected values" of the outputs.

Multicriteria methods, such as expected value methods, permutation methods and concordance analysis aim to provide an instrument for a systematic evaluation characterized by the presence of multiple criteria or multiple attributes. The basic idea of these analyses is the fact that some of the project impacts are not necessarily translated into monetary units as is the case with cost/benefit analysis.

A critical part of evaluating strategies is the financial analysis. The results of the financial analysis represent important inputs into the decision process for selecting a WRM strategy.

Segment 6: Presentation of results

Explicit consideration is given to the kind of participants in the decision process and the nature and forms of information needed or desired by those participants. Apart from the results of the analysis, information on the selection and definition of the characteristics of the system considered, on objectives and criteria, and on analytical approaches are also presented in this phase.

Interaction with decision-makers

During the SUTA and the COTA phases of the analysis a close interaction is required between the analysts and the decision makers. Each individual segment requires this interaction.

4. COMPUTATIONAL FRAMEWORK

The SUTA phase includes an outline of the analytical techniques to be used in the different segments of the COTA phase. A computational framework aims to tie together those different analytical techniques. At present a variety of techniques and models exists and more are being developed. The selection from this variety and the subsequent implementation should be:

- internally consistent (matching inputs/outputs);
- tuned to the objectives of the analysis;
- adequate in relation to the required level of detail; and
- consistent with the fact that planning for WRM should be considered to be a continuous procedure.

In Water Resources Management analytical techniques from many different disciplines are needed, e.g., from hydraulics, hydrology, economics, statistics, agronomy. Some examples of possible analytical techniques that may be included in a computational framework are the following:

- models to predict the demand for water (irrigation, drinking water);
- models to simulate water flows and levels in surface waters (flood routing);
- models to simulate water and contaminant movements in ground water aquifers;
- response or impacts models to predict the effects of WRM strategies on specific water users (e.g. crop yield, industrial production, shipping movements);
- national or regional input/output models to provide the economic base data on national and regional economies for the analysis.

A more elaborate overview of available techniques is presented in the following lecture.

As is the case with a framework for analysis, the computational framework also has to be problem specific. When carefully designed and rigourously applied such a computational framework may add considerably to an effective and efficient execution of an analysis. In particular, during the execution of the segments 1, 2 and 3 of the framework for analysis described in the previous section, the development of a computational framework can be of great assistance in the integration of the individual contributions to the analysis. Moreover, the computational framework provides a valuable tool in the formulation and analysis of WRM strategies, in particular with respect to impact assessment.

V. INTRODUCTION TO MATHEMATICAL MODELS AND ANALYTICAL TECHNIQUES IN PLANNING FOR WATER RESOURCES MANAGEMENT

1. INTRODUCTION

The main characteristics of systems analysis are: (1) it provides a framework for analysis; and (2) it uses a computational framework to produce quantitative information. A computational framework consists of a consistent set of mathematical models and techniques that helps the analyst to evaluate alternative strategies. Not all of the segments of analysis in the framework for analysis can be analyzed in terms of mathematical models, e.g., legal and institutional questions.

The complete set of tools that may be used in analysis for WRM includes: (i) very general methods, such as the Delphi method for systematically developing and expressing the views of a group of individuals by questionnaires and written responses; (ii) very specific models and analytical techniques, such as algorithms for mathematical programming, input-output analysis, and finite elements methods to solve groundwater flow equations; and (iii) analytical methods for accessing benefits, such as contingent valuation and travel costs. This lecture deals with the second kind of tools: models and analytical techniques.

Three expressions will be used to indicate quantitative tools:

- — computational framework;
- — mathematical models; and
- — analytical techniques.

Although these expressions are closely related and are sometimes used interchangeably, they are different and form a kind of hierarchical order. A *computational framework* for a WRM study is composed of several *models* and their corresponding input data bases which represent different aspects of the system, such as groundwater models, agricultural production models, etc. An example of a computational framework and the models in it is given in figure 7, which shows the computational framework (system diagram) of the PAWN study. Each box represents a model. The analyst will use various *analytical techniques* to solve the individual models.

A computational framework is used to increase the

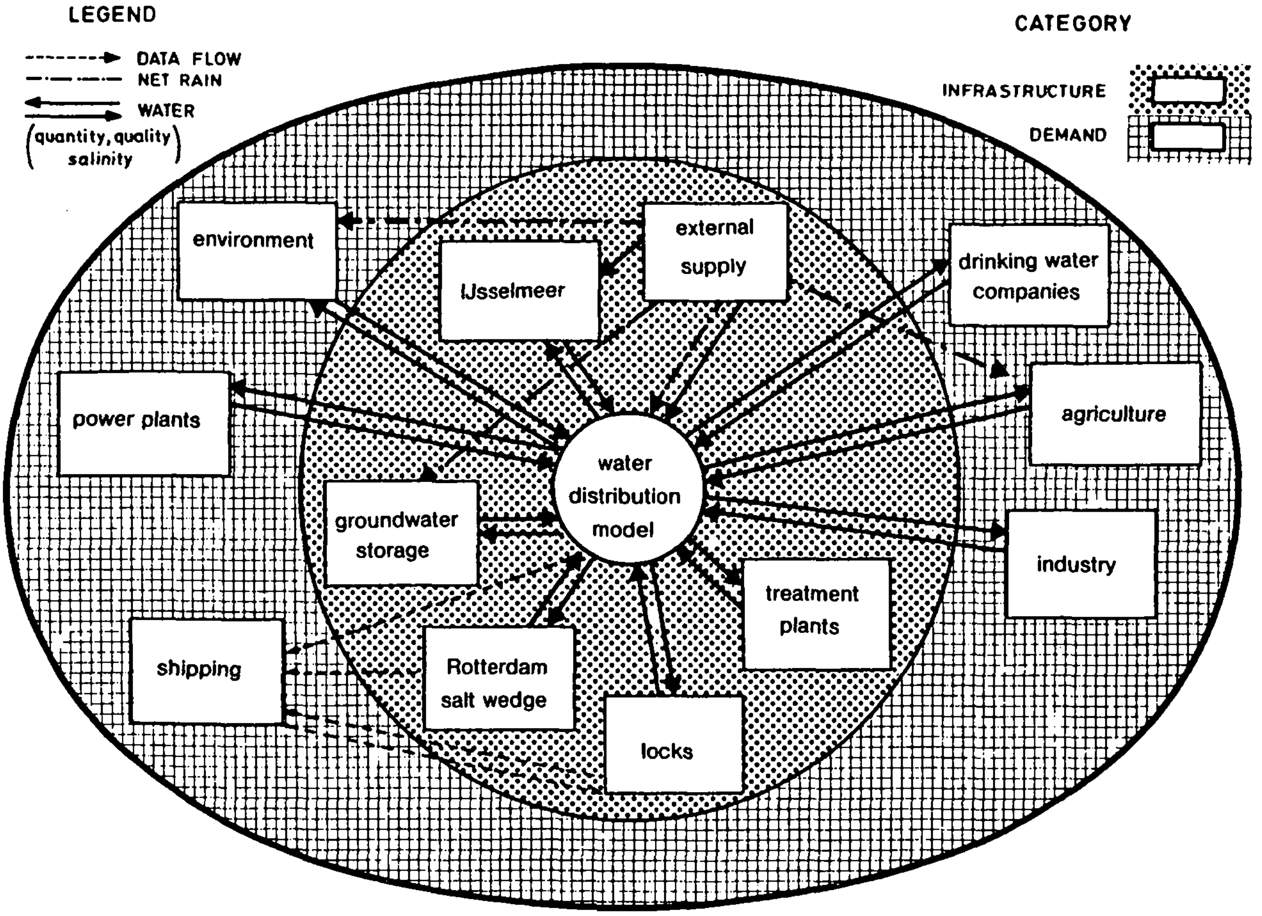

Figure 7. System diagram of the PAWN-study

efficiency of the analyst in planning for WRM; problems can be solved that otherwise couldn't be solved. But it is not only the technical detail that benefits from the use of a framework. Once a computational framework is developed it will be possible:

- to analyse many different situations, scenarios, system assumptions, alternative strategies, sensitivity of proposed strategies, in other words, to carry out a more comprehensive analysis (if necessary) and to repeat the analysis with new data over time, as part of the continuous planning process; and
- to use the computational framework and structural forms of models for other problem areas, e.g. other river basins.

In the following paragraphs some of the basic aspects of the use of models and analytical techniques will be highlighted. For more detailed information one should refer to the many good textbooks on these subjects.

2. WHAT IS A MATHEMATICAL MODEL?

In its simplest context, a mathematical model is a representation of a functional relationship between certain inputs and certain outputs. The initial data are referred to as *the input*, the end result is *the output*, and the translation of input into output is performed with prescribed mathematical equations, sometimes referred to as *transfer functions (s)* (see figure 8 (a)).

A simple model is demonstrated in figure 8(b), with a specific example in figure 8(c). In this rather trivial example, there is one input variable, x, and a single output variable, y. The translation of x into y is performed by the functional relationship:

$$y = f(x)$$

The relationship $y = 2x^2 - 12$ is a specific example. In this case, the input value $x = 3$ will produce a corresponding output value $y = 6$.

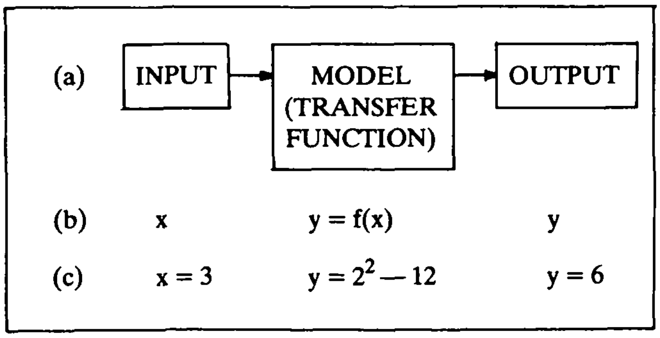

Figure 8. Conceptual representation of how a model yields output

It is clear that this example would not normally be solved with the aid of a computer (although it could be). As the functional relationship $y = f(x)$ becomes more and more complicated, it will be evident that the manual effort to compute y increases. At some point it simply becomes more practical, i.e., quicker or cheaper, to write a set of instructions (or computer program) for the computer and to obtain the solution in that manner.

The foregoing example was developed with only one input variable, one output variable, and a simple functional relationship. Normally, models are more complex; they can have many input variables, many output variables, and a complex functional relationship. An example is a model which estimates how much electrical energy can be generated at a series of power plants in a river system.

When representing the behavior of a system, it is necessary to examine its response at specific intervals of time and over varying periods of time. A river system used for energy generation, for example, is usually subdivided into monthly time intervals with the simulated time ranging from several years to 50-500 years. Analysis of flooding conditions may use hourly intervals, with the total simulation time ranging from a few days to one or two months.

A distinction between models can be made on their descriptive or predictive role. *Descriptive models* describe the way the system being modeled (being represented) works, and help to understand the behavior of the system. Many traditional physical science and ecologic models belong to (are in) this category. *Predictive models* are for the purpose of estimating what the system would do in response to a different set of inputs, i.e., predicting the behavior of the system. The distinction between descriptive and predictive models is not always clear; the former can — and often do — grade into the latter. The analyst may begin with a model, i.e., mathematical or statistical relationship, which purports to describe the behaviour of the system at some point in time. That descriptive model may then be modified in one or more ways in order to be able to predict the behavior of the system at other points in time, i.e., under different conditions. A basic problem in all cases is that a model of a given system is likely to be calibrated and validated for a finite range of conditions. If the set of conditions for which a prediction is to be made is beyond the range of the conditions for which the model was calibrated and validated, the model may not yield an accurate prediction.

Note: The output of a model should NEVER be thought of as being "prescriptive". That output is one item of information into the decision-making process. For example, a linear programming model that yields the least cost "solution" to achieve some goal, e.g., ambient water quality standards, will not necessarily be the solution selected. The distribution of costs or the distribution of benefits or the legal problems involved with that solution may well lead the decision makers to *reject* that option.

3. SYSTEM REPRESENTATION (CONCEPTUAL FRAMEWORK)

A key aspect of systems analysis is the representation of the "real-world" as a well-defined system. A "system" consists of a series of components and linkages. Each *component* represents a specific entity, such as a water treatment plant, stretch of river, one trophic level of a food chain. *Linkages* define interactions between components, such as flow from one power plant to the next and energy exchange between two trophic levels.

Any representation of a real world system is imperfect. This arises because the real system is always more complex and detailed than the system being represented. The art in a systems approach, therefore, is to produce a representation consistent with the nature of the problem and the available analytical resources and to define boundaries explicitly so that cross-boundary flows can be considered explicitly in the analysis if necessary. The more significant variables of the system are treated in detail, while less important features are treated in a more aggregate fashion.

Two points merit emphasis. *One*, it may be that the nature of the problem is such that a highly sophisticated model of a natural system would be required to answer the question in the specified level of detail. However, the available analytical resources are insufficient to make that possible. Therefore, the decision makers either have to provide more analytical resources, or modify the question to a level requiring a less sophisticated model, one consistent with the available analytical resources. *Two*, in terms of management, if there are no implementation incentives which can affect activities at a disaggregated level, there is no point in analyzing at such a level of detail. If water is not metered in individual apartments in an apartment house, there is essentially no way to relate water use to individual apartments and therefore to apply incentives to individual households in the apartment house. Therefore, the apartment house rather than the individual household will be the focus of implementation.

After completing the conceptual representation (*conceptual framework*) of the system, the next step is to translate it into mathematical form, i.e., to develop the *mathematical model* or set of mathematical models (more likely), and the supplementary analyses. This requires that each component and linkage be defined mathematically. The model will then be the total assemblage of these mathematical relationships.

4. ANALYTICAL TECHNIQUES

A variety of analytical techniques exists which allows or requires different degrees of schematization. As a consequence, models based on these techniques differ considerably with respect to, for example: the amount of input data required; calculation effeciency; and accuracy of output. The analyst will apply this variety of techniques to provide the required information at least cost within the given constraints of time, personnel, and budget. Within the scope of this seminar it is not possible to discuss these techniques in detail. Reference is made to textbooks on these subjects (see the references in section 8). Below, only general remarks will be made about certain techniques.

4.1 Mathematical Programming (Optimization) Techniques

This set includes the optimization methods using *classical calculus* and *Lagrangian multiliers* as well as *mathematical programming* and *control theory*. These modeling techniques are both descriptive and predictive. They are descriptive because they usually incorporate quantitative relationships between variables of the system and describe their interactions. The predictive characteristics stem from the analytic structure of these models which contain a procedure to seek out the maximum or minimum value of a specified objective function. Mathematical programming techniques like linear and dynamic programming are discussed in more detail in section 7, as these programming techniques have numerous applications in water resources planning.

4.2 Probabilistic Techniques

This group of techniques includes and builds on the elementary techniques for describing stochastic system elements with appropriate statistical parameters. That is, they can develop information concerning the probabilities of different *levels* of outputs into different degrees of certainty, i.e., different percentages of time.

Important techniques in this set are those associated techniques of *queuing and inventory theory* which are concerned with the study of queues or waiting times and inventory stocks. Such studies are associated with decisions regarding service and storage capacities. Queuing theory itself is strictly descriptive; it does not produce decision solutions, rather, it contributes important information required for decision-making by predicting such characteristics as waiting time means and variances for various processes. Often queuing models are combined with optimization methods and utilize search simulation approaches. Many reservoir problems are inventory problems of a sort and a number of them have been solved using approaches that combine various techniques. All water resources problems have probability aspects because of the stochastic nature of hydrologic events.

4.3 Statistical Techniques

Statistical techniques represent a class of techniques that includes such methodologies as *multivariate analysis,* *statistical inference,* and *decision theory.* These techniques are primarily descriptive. However, many of the techniques are useful in decision making, in terms of selecting appropriate system elements, data sets, and functions to describe a system. The techniques of multivariate analysis, including factor-, principle component-, and discriminate-analysis, have been applied in water resources planning, primarily to describe hydrologic phenomena associated with river basin or watershed runoff problems.

4.4 Search Simulation Techniques

Search simulation is a descriptive technique. A simulation model incorporates the quantifiable relationships among variables and describes the outcome of operating a system under a given set of inputs and operating conditions. Some simulation models contain criteria for moving toward "better" solutions, such as steepest ascent. Simulation models usually permit far less drastic simplification and approximation of the real problem than is required when using a mathematical programming (optimization) model.

Often a simulation model is run many times with various input and parameter data. The output of these runs describes the response of the system to the variations in inputs and parameters. If the simulation model includes an objective function, the values of the objective for the several runs generate a "response surface". The model can be used in various search techniques that explore the response surface and seek better solutions.

5. OVERVIEW OF MODELS

5.1 Classification of Models

In recent years many models have become available and, as the state-of-the-art of modelling continues to advance rapidly, many more can be expected in the future. This chapter will not try to provide a comprehensive overview of available models but will be limited to brief comments on some major types of models. The described models will be classified based on the major analysis segments of the framework of analysis:

- — estimating levels and spatial pattern of activities for specified time horizons;
- — analyzing activities;
- — analyzing natural systems;
- — formulating and analyzing WRM strategies; and
- — evaluating strategies.

This classification is neither unique nor complete. As will be shown later, several models can be placed in more than one of these groups.

5.2 Estimating levels and spatial patterns of activities

Analysis for WRM in a region will begin with projections of economic activities at the national level, using one or more of various econometric, input-output models. Each application of the projection model involves assumptions about final demand, including government investment, foreign trade, "consumption" patterns domestically. These projections are typically made in monetary terms, not in terms of physical units, and are consistent with demographic projections at the national level.

The major types of models and techniques in this category are:

- — "shift-share" techniques;
- — input-output models; and
- — national and regional simulation models.

The first task in this sequent is to "translate" these national projections into projected levels and spatial pattern of activities within the region being analyzed. One analytical procedure for doing so is the *"shift-share" technique.* This technique in effect projects future levels within regions of a country based on trends each region has of the share of the activities of a given sector at the national level. Other procedures are based on exploitation of a particular resource in a region, such as iron ore or coal, and various economics base (multiplier) approaches. In some cases the regional levels are "determined" as a part of central government's regional development or regional redistribution strategy.

The most difficult problem is to translate the regional levels into locations of the activities within the region. Although there are a few mathematical models which have been applied to this task, they are strictly limited. For some industrial activities and for agricultural activities, the important variables affecting location within a region are known, and can be applied in a given case. Urban development is likely to occur or increase around existing urban nodes. Basically the approach is to apply judgment to empirical data.

The use of *input-output models* (I/O) has been one of the most significant developments in economic modelling. In essence, these models are structured as a series of equations which capture economic interactions in a region or nation. Each equation simulates the flow of commodities from one production sector to all other production sectors, as well as satisfying external demand. By altering final demand for a particular commodity, the likely effects on all production sectors can be estimated.

Input-output models can be effective in capturing the various interactions in a region or nation. However, they are expensive to develop and to use. Data collection and collation in particular may be very time-consuming. In addition, the coefficients in the model may not provide an accurate prediction of future changes — because they do not necessarily reflect the effects of improved technology and economies of scale. However, "dynamic" input-output models have been developed and applied which *include* changed technologic coefficients.

In recent years, several *national and regional simula-*

tion models have been developed to simulate national and regional socio-economic trends. Such models are usually designed to capture interconnections among demography, industrial activity, employment and income. Often they include dynamic and feedback considerations and tend to be relatively detailed. The use of regional simulation models is a subject of considerable debate. Many of the socio-economic relationships developed (such as interactions between unemployment and migration, or rates or investment by occupation), can be very subjective. This type of model is developed by national and regional (general) planning agencies and are not specifically oriented to water resources planning. Most of these models are econometric models, using an input-output model of the national economy as the core.

5.3 Analyzing activities

Activity analysis models describe the behaviour and output of a specific water related activity, such as agriculture, shipping, industrial water supply, as a function of exogenous and endogenous factors. These models can be used to predict the demand for water as well as to predict the consequences of certain WRM strategies for that activity. A typical example of that type of model is an agricultural yield model that computes the amount of required irrigation water and the crop yield (or damage) based on projected levels of activity, e.g., crop area under cultivation, use of irrigation, prices of other factor inputs, and the particular WRM strategy under consideration, e.g., availability and quality of supplied water and constraints on soil loss and/or discharges of N and P. Other activity models concern, for example, industrial water use and shipping, the latter in terms of required water levels.

5.4 Natural systems models

This category contains a wide variety of models from simple water balance models to very complicated ecosystems models. During the last 15 years hundreds of models have been developed and described in the literature. Some of these models are generally applicable and can be purchased from the developer, including the necessary documentation and user manuals. However, many of the models have not been calibrated or validated and many of them lack documentation and user manuals.

Natural systems models simulate the physical, chemical and/or biological behaviour of natural systems. The following gives an overview of the different types of models available. Within the framework of this note and the seminar it is not possible to be more specific.

Physical models

Physical models include:

- rainfall-runoff models: predict river runoff based on meteorological conditions and areal properties, such as Sacramento model, Stanford watershed model;
- hydrologic routing: calculate water levels and velocities through river systems; mainly used for simulation of flood waves and as input for sediment transport models;
- sediment transport models: calculate scouring, transport and deposition of sediment in river systems;
- erosion models: predict sediment load to rivers as a function of climatological conditions and land use;
- lake and estuarine models: calculate water and constituents movement within individual lakes (or reservoirs) and estuaries; these models are two- or three-dimensional and include sometimes multiple layers and density currents; and
- groundwater models: calculate groundwater flow and levels.

Chemical models

Chemical water quality models are concerned with reactions amongst constituents in water bodies. These include the effects of discharges such as acids and bases, dissolved solids, heavy metals and other materials. In some cases these models include the interaction between chemical and biological regimes. The most widely known models of this type are:

- dissolved oxygen models for rivers based on the DO-BOD Streeter-Phelps formulation;
- nutrient models (nitrogen and phosphate) for rivers, estuaries, lakes;
- chemical equilibrium models for lakes; and
- groundwater quality models.

Ecological models

Ecological models include analytical representations which describe interactions of ecosystem components. These models have been developed primarily for lake and estuarine systems. Important models for WRM planning are, among others:

- algae bloom models: modeling of nutrient, phytoplankton and zooplankton to predict eutrophication phenomena as a result of nutrient discharges and watermanagement strategies;
- fishery models which are concerned with population and location of various fish species, the effects of introducing new fish species, changing water patterns and water quality, food supply, fish stocking and fishing activities; and
- pathogen models used to simulate the concentrations of disease-carrying bacteria associated with effluent discharges or storm-water overflows.

Integrated models

In recent years models have been developed that combine several components described above. For example, models are available that include aspects of rainfall-runoff, flood routing, erosion, sediment transport and water quality. These models are complex, require large amounts of data, and are often inflexible in that sense that they are difficult to adapt to the specific problem that has to be analysed.

Supporting models

There are some models that are used in analyzing natural systems but which do not belong to one of the specific categories mentioned. Examples are data storage and processing systems for meteorological and hydrological time series and synthetic streamflow generators.

5.5 Analyzing WRM strategies

In this stage of the analysis demand and supply are compared, measures to improve the situation are evaluated, and the effects of WRM strategies are determined in terms of economic, environmental, and social criteria. The models used in this stage contain demand models (paragraph 5.3) and supply/natural systems models (paragraph 5.4) and socio-economic analysis models. Typical models for this stage are integrated models that jointly consider these aspects (demand, supply, socio-economics) on a regional/national scale. They are in general based on a water and mass balance approach followed by socio-economic evaluation techniques. Some models in this category are:

- river basin simulation models; these are the integrated models as indicated above, followed by:
- financial analysis models determine the effects of a WRM strategy on a financial unit, e.g., an industrial plant or a farmer;
- input/output models determine the secondary effects of WRM strategies in terms of employment and additional services required;
- economic ranking models (cost-benefit models) including economic criteria such as Net Present Value, Internal Rate of Return, and Capital Recovery Factor; and
- cost allocation models.

5.6 Evaluating strategies

In this last category models are found that estimate an overall measure of performance of the alternative strategies that are analysed. Because in most cases the different criteria on which the strategies are evaluated do not have a common unit (money, ppm, per cent, employment, etc.), these models contain techniques to combine the criteria in some other way. Moreover, because not all criteria are equally important in the decision making process, different weights can be attributed to the criteria. Many methods exist under the common term, *multicriteria evaluation methods.* The use of these methods is a subject of considerable debate. Many subjective elements are introduced by employing these methods. Decision-makers often prefer more straight-forward evaluating techniques, e.g. the score-card technique used in the PAWN study, or net benefit analyses with constraints, to show the trade-offs between net national (or regional) economic benefits and various physical or social outputs, such as ambient environmental standards, preservation of unique ecosystems or free-flowing streams, and provision of water to a particular low income group or region.

In addition, there must be semi-quantitative models, e.g., ranking high/medium/low, or qualitative models, to assess such aspects as legal feasibility, impacts on existing institutions, administrative capability.

6. CONSIDERATIONS IN MODEL DEVELOPMENT AND MODEL USE

The foregoing sections described the general background of mathematical models. Which model to select for a particular analysis for WRM will depend on many considerations. These include:

General considerations

- basic purpose, e.g., planning, operation;
- prime discipline, e.g., socio-economic, technologic, environmental;
- system or problem definition;
- ease of understanding;
- mode of use. e.g., one time run, interactive;
- data requirements;
- availability of personnel;
- cost;
- accuracy; and
- credibility.

Model Structure Considerations

- comprehensiveness;
- flexibility;
- modularity; and
- computer language.

Model Technology Considerations

- principle of formulation, e.g., fundamental, empirical;
- simulation or optimization;
- numerical methods;
- computing efficiency;

— steady-state or dynamic;
— deterministic or probabilistic; and
— feedback effects.

It will be immediately apparent that these considerations are not necessarily independent. For example, there is overlap between "cost" and "comprehensiveness", and between "ease of understanding" and "modularity". Nevertheless, each of these items is independently important and worthy of careful consideration at the outset of a modelling exercise.

In preparing this list, the progression has been from the general to the specific. In a planning team, it would be expected that the chief planner or water resources manager (whose knowledge of modelling is often limited) would be primarily concerned with the first group of considerations. On the other hand, the modelling specialist (who would have prime responsibility for selecting, formulating, developing and applying the set of models) would give greater attention to model structure and model technology considerations, i.e., the second and third groups. However, the best chance for modelling success will occur, of course, when all twenty items are carefully considered jointly.

7. OPTIMIZATION MODELS

7.1 General

A major distinction is often made between "simulation" models and "optimization" models. Actually, one should not speak of simulation models versus optimization models, as optimization models are simulation models too, in the sense that they also describe, i.e., simulate, the behaviour of a system. It is theoretically more correct to speak of mathematical programming simulation ("optimization") and search simulation ("simulation"). For simplicity, in the following the more commonly used terms optimization and simulation are used.

A *simulation model* will simply compute the system response for a particular set of specified conditions. The conditions may then be altered, the model rerun, and another set of responses obtained.

Optimization models, on the other hand, are designed to explore alternative combinations to obtain an optimum response for a specified set of conditions. For example, long term planning of a power system may be performed with the objective of minimizing cost while satisfying growing energy demand. In such a case, the model objective would be to minimize cost and the model will examine, i.e. simulate, the possible alternative sequences of investment and operation and maintenance which would meet growing energy demand. The least costly alternative would then be selected automatically by the model. However, as in "simulation", the conditions may be changed — and usually are changed — and the model rerun.

In principle, the idea of rerunning a simulation model under a variety of conditions, to obtain the best (or optimal) response, is simple. In practice, however, the number of alternatives quickly becomes enormous, and the associated time and cost can become prohibitive. As a result, there has been a rapid development of optimization models which are particularly efficient in analyzing various alternatives to maximize or minimize an objective function. They include:

— linear programming;
— dynamic programming;
— integer programming;
— quadratic programming;
— geometric programming; and
— non-linear programming.

A characteristic feature of all optimization models is their breakdown into:

— an optimization function;
— a set of constraint conditions.

The optimization function is simply the mathematical statement of an objective to be achieved, e.g., minimize costs, maximize net benefits. The constraint set is normally a large number of equations or inequalities which define the requirements of the problem or system. For the power system referred to above, the constraints could define:

— energy demand on a time and location basis;
— physical conditions such as the principle of continuity, availability of water, size of existing facilities, capacity limits;
— operational conditions, such as variability in demand (daily, weekly, monthly);
— limits on financial resources;
— other demands for water, such as water supply and flow augmentation.

The most commonly used optimization techniques for water resources management are linear and dynamic programming.

7.2 Linear programming

For the class of problems solved by linear programming, the optimization function and all constraint equations must be expressed as linear combinations. An example of a very simple linear WRM problem is the maximization of the output of a reservoir over two time steps, described in figure 9. This example is only illustrative and not very realistic as it assumes an independency of irrigation and power output. Of course, this simple problem can also be solved without the help of linear programming. In reality, when more time steps, interests and constraints are involved, the problem gets very complex and linear programming becomes a useful tool.

The most known method for solving linear programming problems is based on the use of the simplex method. This method has been programmed into a relatively standard code which exists on virtually every major computing facility.

The objective is:

$$\text{Maximize } Z = b_1 * Q_1^p + b_2 * Q_2^p - a_1 * (Q_1^{ad} - Q_1^a) - a_2 * (Q_2^{ad} - Q_2^a)$$

under the constraints:

$$\left.\begin{aligned} Vol_1 &= Vol_o + I_1 - Q_1^a - Q_1^p - Q_1^{fp} \\ Vol_2 &= Vol_1 + I_2 - Q_2^a - Q_2^p - Q_2^{fp} \end{aligned}\right\} \text{reservoir continuity equations}$$

$$\left.\begin{aligned} Vol_{min} &\leqslant Vol_1 \leqslant Vol_{max} \\ Vol_{min} &\leqslant Vol_2 \leqslant Vol_{max} \end{aligned}\right\} \text{reservoir capacity constraints}$$

where: Z = total benefits from a reservoir

Q_i^{ad} = irrigation demand in timestep i

Q_i^a = irrigation release from reservoir in time step i

a_i = unit damage of irrigation shortage in time step i

$Q_{i,min}^{fp}$ = firm power release during time step i (that has to be provided at all times)

Q_i^p = additional power release from reservoir in time step i (on top of firm power power release)

b_i = unit benefit of additional power release

Vol_i = reservoir volume at end of time step i

I_i = inflow in reservoir during time step i

Vol_{min} = minimum volume of reservoir

Vol_{max} = maximum volume of reservoir

Figure 9. Example of reservoir release optimization problem

7.3 Dynamic programming

Dynamic programming is designed to solve any class of problems which can be translated into a sequential decision process. For this class of problems, the objective and constraint equations can be more general than those associated with linear programming. The equations can be of any form, linear, nonlinear, continuous, discrete, etc., without increasing computational time.

The essence of dynamic programming may be better appreciated as a generalized approach than as a formal mathematical procedure. First, the problem is decomposed into a series of sequential subproblems. Optimization at each stage of calculation is performed by incrementing the effect of that subproblem on the total combined effect of all previous subproblems. The process is thereby oriented to having the solution grow in a series of stages from optimizing a single component, i.e., the first subproblem to eventually optimizing the entire system.

There are, however, shortcomings in using dynamic programming. One, no general computer codes are available, and consequently this technique usually requires quite some development effort. Two, the nature (or structure) of some problems can create an enormous number of combinations which all require investigation. This is commonly referred to in dynamic programming literature as the "curse of dimensionality".

7.4 Optimization versus simulation

In effecting a choice between simulation (i.e. search simulation) and optimization (i.e. mathematical programming simulation) models, several factors need to be considered. First, every optimization model contains the essence of simulation. However, the extent to which such simulation can be included is limited by the type of the particular optimization model. As a consequence, there is greater opportunity to provide more comprehensive, detailed, and accurate representation in search simulation models, especially when significant non-linearities and/or economies of scale and/or discontinuities are involved.

A second factor is the defining of the objective function. In many cases, this is particularly difficult. Translation of the objective stated by the decision makers in general terms into an operational, quantitative objective, for example, may be difficult. The perceived objective may also have a highly qualitative (or subjective) component. In such cases, it is normally preferable to proceed via the "simulation route". The results of alternative simulation runs can then be used as a basis for iterating towards the more nebulous objective, through a process of interpretation, increasing perception, and subjective assessments in which preferences are established.

A third consideration relates to the degree of understanding of the particular problem area. For classes of problems where modelling has been used as a direct planning aid and where the represented system is well understood, optimization models have been popular. Examples include power system planning, irrigation, waste abatement. For other situations in which problem understanding is still relatively undeveloped, continuing reliance is still being placed on the use of simulation models.

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VI. Illustrative case study: Policy Analysis of Watermanagement for the Netherlands (PAWN)

1. INTRODUCTION

During the last centuries scarcity of good quality water seldom was a problem in the Netherlands. Usually there was more than enough water to meet all the demands and getting rid of the incoming water has been the main issue of Dutch watermanagement. However, over the past few decades demands have grown, while the quality of the water has deteriorated. Agriculture has become highly productive and at the same time more vulnerable to sudden change in its supply of fresh water. Other large users of surface water such as shipping, power plants and drinking water companies are claiming their shares of the same source and competition among water users has grown. As a consequence, the Dutch have become aware of their dependance on a good water supply system. On top of that, in 1976 a severe drought occurred in Europe and the lack of a good understanding on what to do under these circumstances became painfully apparent.

These events, coupled with Dutch awareness that the present watermanagement problems are nolonger local in scope, obliged the Dutch government to conduct a major policy analysis of the country's watermanagement. The word "major" in this connection, means that something in the order of 125 man-years of direct contributions have been invested in the study. The study lasted from 1977 to 1982 and was performed by the Rijkswaterstaat (the Dutch governmental organisation concerned with national water management) together with the Rand Corporation (Santa Monica, California, United States of America) and the Delft Hydraulics Laboratory. It has delivered an insight in the size of the problems, their relative importance, and in the ways to solve them. More specifically, this PAWN study (PAWN = Policy Analysis of Watermanagement for the Netherlands) provided the information needed to draft a new national watermanagement master plan for the Netherlands.

In the first part of these lecture notes a general description of the watermanagement system of the Netherlands and the problems related to it will be given. Later on the PAWN project itself will be discussed. The description of the PAWN study will be subdivided into some general aspects (such as the history of the project, the objectives, etc.), the approach of the analysis and the computational (modelling) approach. Finally the main results and the policy conclusions drawn from the study will be discussed.

2. GENERAL DESCRIPTION OF THE NETHERLANDS

The Netherlands (see figure 10) cover an area of about 37,000 square kilometres including the present fresh water reservoirs of the IJsselmeer (Lake IJssel). It is located at the downstream end of two rivers, the Rhine and the Meuse. Its present population amounts to 14 million inhabitants; the gross national product is the seventeenth largest in the world.

Of the total area, about 25 per cent is located below mean sea-level and more than 50 per cent has to be protected by embankments from storm surges in the North Sea and from flood conditions of the rivers Rhine and Meuse. The lowest point is in a reclaimed lake near Rotterdam, where ground elevation is more than six metres below mean sea-level, i.e. 11 metres below the design storm-surge level.

The low-lying areas, some of which are won form the sea by inpoldering, are situated in the western and the northern part of the country. Most of the population is concentrated in this area and it is here that cities like Amsterdam, Rotterdam and The Hague are found. The soil is of recent geological origin (holocene). The low-lying regions are subdivided into "polders", i.e areas isolated from the external hydrologic system in which the water-level can be controlled. Excess water from rain and seepage is drained off, mainly by pumping, into a system of canals ("boezems") with a high waterlevel, from where it flows or is pumped into the sea.

The higher regions in the east and the south of the country are entirely different in character. They consist mainly of sandy fluviatile terrace deposits (pleistocene) and lie well above sea-level. There are no polders; drainage of the arable land is effected via a network of ditches, rivulets and small rivers, flowing into the Rhine and the Meuse.

2.1 The main watermanagement system

As long as man has lived in these territories he has performed a constant struggle against inundation. This story is one of successes and defeats. Many times areas were flooded and reclaimed.

The large water surface in the heart of the country was a small lake in the early Middle Ages; after the sea broke in, it became a huge, though shallow, estuary, the "Zuiderzee", fed by one of the Rhine branches, the river IJssel (10 per cent of the Rhine flow). After a severe flood in 1916 the enclosing dam (Afsluitdijk) with discharge sluices was built (closing: 1932). This created the fresh water IJssel Lake of which large areas were reclaimed by constructing polders. The IJssel Lake now functions as a reservoir from which the northern part of the country can be supplied with fresh water; the lake also receives excess water from these areas. Its levels are kept between NAP -0.20 m in summer and NAP -0.40 m in winter, thus creating a fresh-water reservoir with a capacity of over 0.5 x 10^9 m^3. (NAP = Normal Amsterdams Peil, the national reference level; almost equals mean sea level).

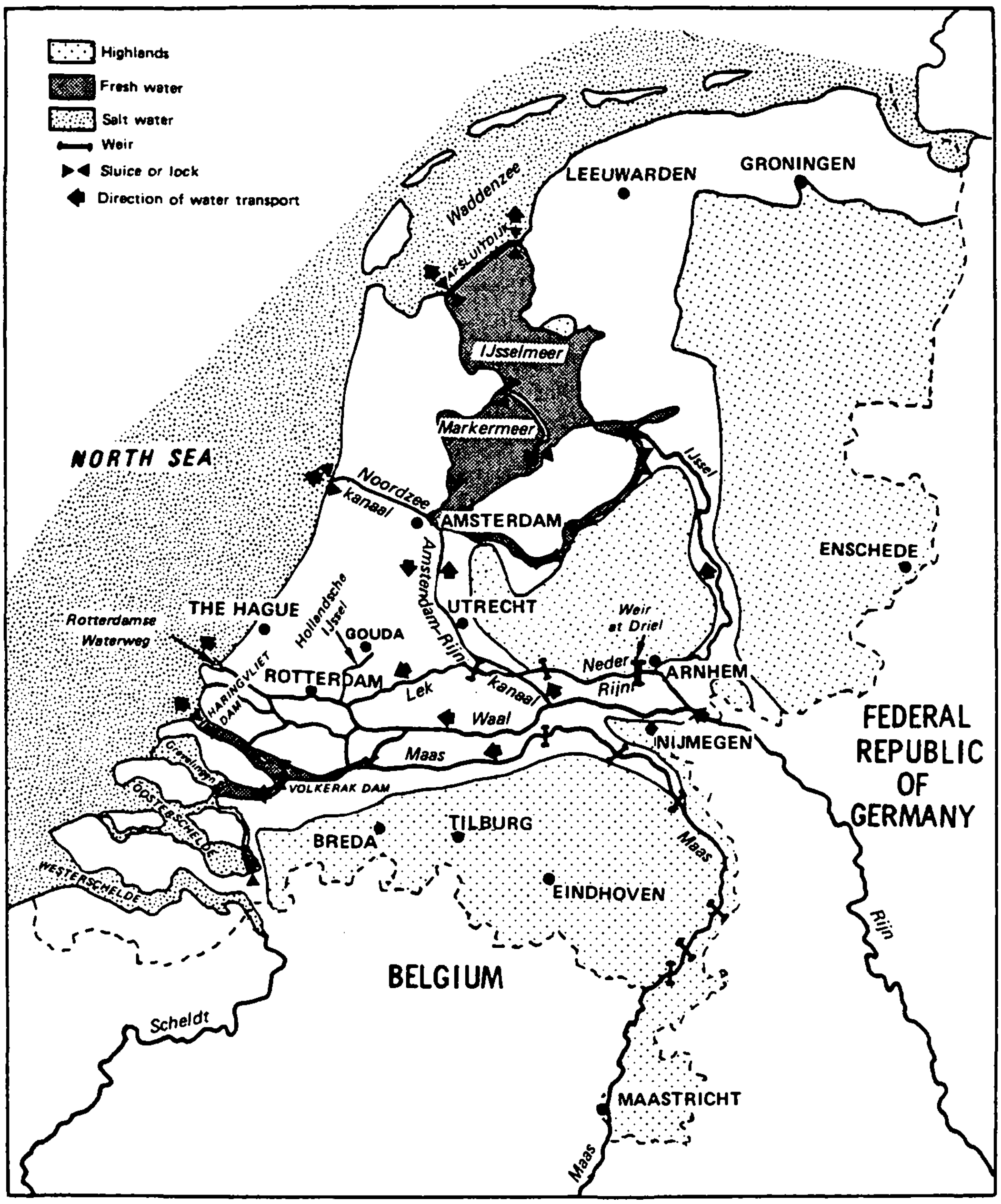


Figure 10. The Netherlands: principal elements of the watermanagement system.

Islands, surrounded by deep estuaries, constitute the south-western part of the country. Into these estuaries the Scheldt and the Meuse debouch, as well as 90 per cent of the Rhine flow. Here, the fresh river water mixes with the salty tidal waters of the North Sea. Most of these estuaries have been or are being closed by huge dams, in the framework of the Delta Plan, following the disastrous flood of 1953. For the subject under consideration it is important to know that:

a) the entrance route to Rotterdam harbour will not be closed and so remain open to tidal action and salt intrusion; and
b) in the "Haringvliet" the dam contains very large discharge sluices. These sluices are utilized as an instrument to control the water level and all the waterflows in the (now fresh water) northern Delta basin.

The large river of the south-eastern part of the country — the Meuse — was canalized for inland shipping reasons. So was the Lower Rhine, one of the tributaries of the Rhine; but this canalization is also an instrument to control water flow. At low flows of the river Rhine the weir near Arnhem will be partly or entirely closed so that more water will flow down the IJssel to improve depth for navigation, and to enhance the supply of the IJssel Lake.

Two major canals are also part of the main watermanagement system: the North Sea-Canal and the Amsterdam-Rhine Canal. Amsterdam harbour lies at the eastern end of the North Sea-Canal, the western end of which is separated from the sea by locks. Operating these (and other) sea-locks constitutes an important source of salt intrusion into the low-lying area. Amsterdam is connected to the Rhine by the Amsterdam-Rhine Canal, for which plans have been designed to make it suitable for substantial water transport in both directions, thus improving the flexibility of the system. In the present situation only a relatively small amount of water can be transported from the rivers to Amsterdam.

2.2 The watermanagement problems

In an average year the total fresh water supply to the Netherlands is 110 x 10^9 m^3 of which 20 x 10^9 m^3 evaporates. Of the supply 67 per cent is provided by the river Rhine, 8 per cent by the Meuse, 3 per cent by the small rivers crossing borders in the east and south and 22 per cent by local precipitation. Under these average conditions the Netherlands as a whole has sufficient water to meet all demands. However in dry years the supply may amount to less than a quarter of the figure mentioned above. Under these circumstances the consumers are faced with serious cut-backs in their demands. In 1976, one of the driest years ever recorded, this became very apparent. Agriculture losses that year exceeded 5 billion Dutch guilders; low river levels caused serious damage to shipping and the cut-backs in waterflows created cooling-water problems for power plants at various locations.

On top of the quantity problem the Netherlands have a serious water quality problem. Apart from the harmful industrial pollution, the low-lying part of the Netherlands is confronted with a salt problem. This is caused by the following factors:

- The salt load of the main water supply, the river Rhine, is high and amounts to some 340 kilogrammes of ions of Cl^- per second, which with a minimum discharge of 600 m^3/s would correspond to a chlorosity of some 570 p.p.m. of Cl^-.
- In the deeper subsurface layers of the low-lying parts of the Netherlands water is found with a very high salt content. Owing to the low groundwater table in the polders below mean sea-level, this salty ground-water tends to flow into the polders (seepage).
- Salt water also enters the canals where they communicate with the sea and where sluices and locks have been constructed for discharge of water and for navigation purposes.
- The Rotterdam Waterway is an open waterway to the sea. This means that, under the influence of the tides, sea-water is able to penetrate inland. In order to prevent this saline water from penetrating into an important inlet-point for a vast agricultural area in the Mid-west of the Netherlands, a substantial amount of water (a minimum amount of 700 m^3/s) has to be diverted through the Rotterdamse Waterweg.

In the higher parts of the country the problems are of somewhat different nature. Here large parts of the country cannot be supplied with surface water from the main watermanagement system. The necessary infrastructure is missing. Plans for extending the surface water system have been made but up till now these areas are mainly relying on groundwater. However this source is scarce; agriculture, drinking water companies and industry are competing for its use. On the other hand these substantial withdrawals have their draw-backs on the environment.

In order to get some insight in the relative importance of these problems, their interrelations and the ways to solve them, the PAWN study has been undertaken.

3. THE PAWN-STUDY

3.1 General characteristics of the study

The objective of PAWN was to investigate the *national* watermanagement of the Netherlands. The study had to:

- indicate the coherence and the ranking between the various interest-groups related to the Dutch watermanagement system;
- show the limitations of the existing watermanagement system and suggest solutions for these problems; and finally
- indicate the consequences of these solutions for all parties concerned and in as many aspects as possible.

The study had to be objective and no implicit policy choices had to be made. These conditions have defined the course of the study for a great deal. In paragraph 3.3 this will be further elaborated.

The next paragraph (3.2) will deal with the PAWN-study and the Masterplan for the Netherlands. The history of the study is not discussed in order to give an insight in the Dutch planning process as such. Although it does that, it is not the main purpose of this paragraph. By discussing some of the problems that were encountered during the PAWN-study, lessons can be learned so others might avoid the same pitfalls.

Paragraph 3.4 gives some information about the models involved. More information can be found in the PAWN-documentation: Policy Analysis of Water Management for the Netherlands Volumes I-XX; and in the Rijkswaterstaat Communications no. 31/1982 about PAWN.

3.2 History

The work for the Dutch Masterplan can be distinguished in four phases (see figure 11):

i. Reconnaissance
ii. Preliminary examinations
iii. Research and analysis
iv. Analysis and policy formulation.

The *first phase* was characterized by a trial search for solutions of an unclear defined problem. In this phase various external consultancy agencies were visited and tested on their possibilities and capabilities with respect to the Dutch watermanagement problem and some rough ideas about what had to be done were obtained.

In August 1976 the actual work on PAWN was started with *phase 2*. This part of the study was meant to make a project plan in which the various steps in the whole study should be laid out. Although this part of the study still is considered vital for its success, a project plan as mentioned above was not established. These months (roughly half a year) were used for the various parties concerned (Rand, DHL and RWS) to get to know each other's expertise. Quite some time was spent for the formulation of the actual problems (e.g. is salt intrusion a problem or is the salt damage to the crops the real issue?). Although these kinds of discussions may seem trivial on the first hand, these clarifications turned out to be important. It forces the line of thinking away from the usual paths and a lot of new solutions to various problems were discovered.

The reason why an overall plan for the whole study was not made were the following. As will become clear during the course, policy-analysis is a trial and error learning process. One tries to solve some parts of the problem. With the information obtained by solving that part the original plans are adjusted. It will be clear that such a process cannot be planned in advance. This, however, does not mean that there should be no planning at all. One of the main lessons which were learnt from

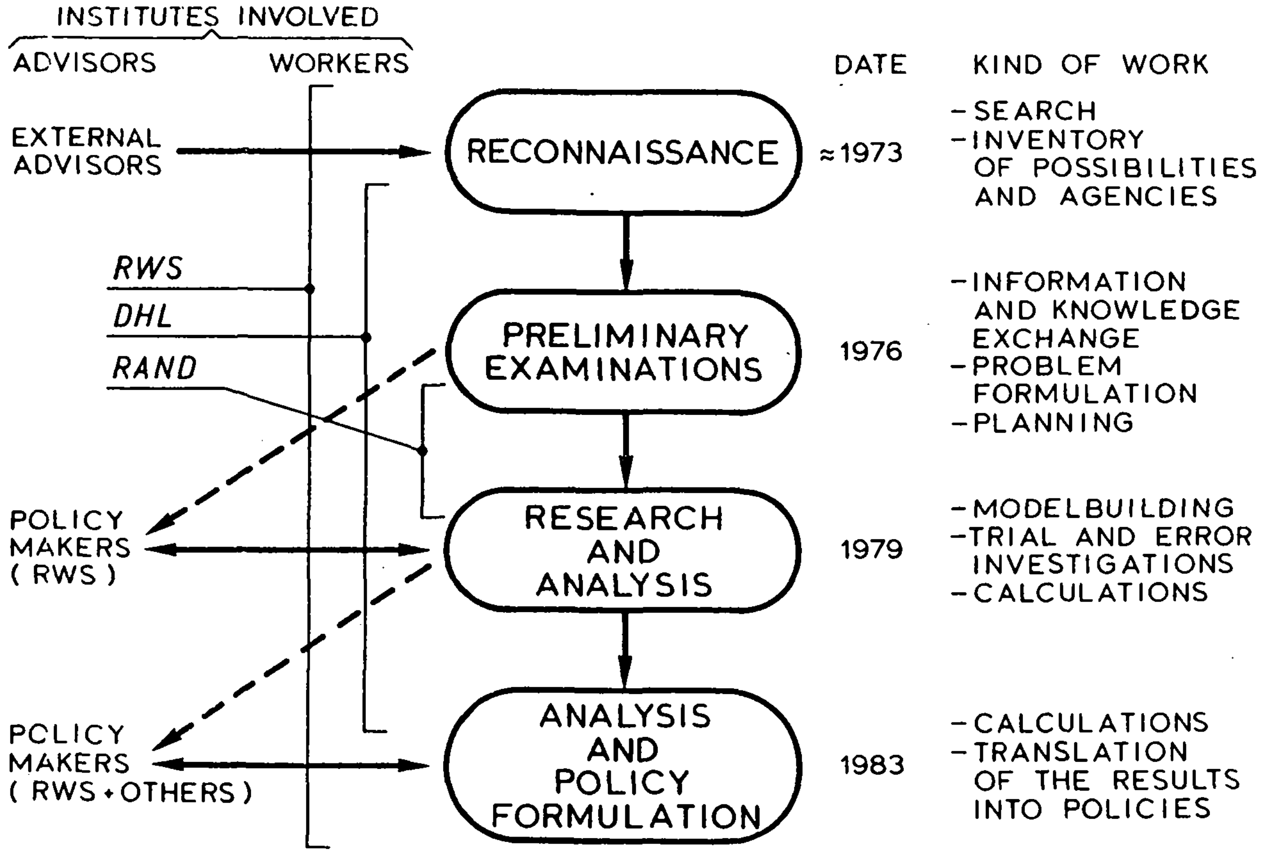


Figure 11. Phases in the preparation of the Dutch Watermanagement Masterplan

PAWN was that too little planning was done. Therefore, at the end of the third phase of the study, serious time problems occurred. The approaches followed by the various analysts will diverge when a proper planning is lacking. So short term plans should be made. These plans have to be adjusted continuously during the course of the study.

In the beginning the study started with a small group of people (four to five on the Dutch side and roughly the same number on the Rand side). Later on, at the end of the third phase, the number of people grew to 27. The start of this kind of a project is a delicate phase. In order to keep the communication and coordination problems to a minimum, the number of people involved should be as small as possible in the beginning. But even more important was that those people which were involved were fully available for the project. Apart from the PAWN-project they had no other work. This is crucial; lots of manpower was offered by people who could make only a few per cent of their time available for the project. These people only wanted to see what was going on, and their offers were turned down. During the whole project a strict separation between the workers and the spectators was maintained. This separation turned out to be crucial. A lot of Dutch projects have never left their early stages because too many people were involved. They confused the early discussions, slowed the workers down and by that these projects never took off.

On the other hand, at a certain stage of the PAWN-study (end 1977-begin 1978), it became clear that the work on the project could not be successfully accomplished without the help of some of these people (mostly policy-makers). Cooperation and information was needed from them and the institutes they were working for. This was solved by establishing two guiding groups, one with only RWS-members and a second where various other interest-groups were invited. In these groups the progress of the project was discussed, information was exchanged, meeting with specialists were made possible, advices were solicited, ideas were tested and administrative solutions provoked. By this way of organisation, the above mentioned problems could be avoided, while the policy-makers were kept posted with the various developments of the study. They were also extensively informed on the various models involved. This aspect turned out to be especially very valuable when the Masterplan itself was drawn up. In the discussions about the Masterplan with the various interest-groups, such as the Department of Agriculture, the power companies and the shipping industry, the models were not at stake any more, not the basic model assumptions. The discussions could be concentrated on the various solutions and the policy conclusions, which were drawn from the model calculations.

The *third phase* of the study was characterized by model-building. This model-building was done by trial and error. First a simple version of a model (mostly computer models) was built. From the results of this model conclusions for improvements were drawn. Sometimes this led to changes in the model, sometimes a completely different approach was chosen. Comparisons with the real world were made, which led to changes. During this process a close contact between the analysts and the experts was kept. Major problems were avoided in this way, although problems still occurred, underlining the necessity that the one who has the problem works in close contact with the people who try to solve it. Policy analysis is not a kind of study where one instructs some institute to carry out the investigations and waits a couple of years for the answers. Several iterations with the policy-makers are necessary and a close contact with local experts and with people who have knowledge about the area involved is a must. In a number of cases it is observed that the ideas put on paper turned out to be completely unfeasable in practice due to the lack of insight of the local circumstances.

This learning process extended from the beginning till the very end of the third phase of the study. At the end of the study in 1979, models were still being improved and hardly any concrete results were available. The main reason for this was that the scope of the problem was much larger than was expected at the beginning of the study. At that stage the analysis contract with Rand terminated and the documentation phase for them started. In the beginning of 1980 the various models were transferred from Rand to the Netherlands and the necessary analysis for the policy formulation started over there. From the point of view of the one who is responsible for drafting the Masterplan, it is preferred that he makes the necessary calculations himself. As he is responsible for formulating and executing the policies, it is much better that he is fully aware of all the ins and outs and the underlying basic assumptions of these calculations. If a conclusion depends heavily on one assumption and that assumption is questionable he will formulate the policy differently than he would have done if it was not. Also he will be more careful when executing this policy in practice.

The main lessons from the execution of the PAWN study can be summarized by the following:

i. Do not try to plan the whole programme of the study in advance. Instead, make a rough outline for the whole study and prepare detailed short-term working schemes (2-3 months) and adjust those on the way.
ii. Start with a small group of highly qualified people.
iii. Limit this group to workers. Keep the spectators out.
iv. The one with the problem should be involved as much as possible in the analysis.
v. Do as much as possible yourself, especially the stage of policy-formulation. Do not leave it completely to external consultants.
vi. Ensure the involvement of policy-makers and other interest groups. This is the only guarantee for acceptance of the formulated policies.

vii. Ensure the involvement of local experts as early as possible during the study.

3.3 The analysis approach

As mentioned in the objective statement of Paragraph 3.1, PAWN had to investigate the problems, which the various interest-groups have with the existing watermanagement. This implied that sectors such as agriculture, drinking and industrial water supply, shipping, power plants and the environment had to be investigated. Consequently both water quality and quantity and surface and groundwater had to be considered. Further the study had to be directed at determining the multiple consequences of a large number of alternative watermanagement policies. Such a *watermanagement policy* is constituted by a coherent mixture of tactics, where a *tactic* is defined as a single measure to improve the watermanagement. Four different kinds of tactics were considered:

- *technical tactics:* adding new elements to or changing the watermanagement infrastructure (e.g. building a new canal or increasing the capacity of inlet structures); applying some form of treatment to the water;
- *managerial tactics:* using managerial measures to change the distribution of water among competing regions and users;
- *pricing tactics:* imposing taxes to affect the quantity or quality of the water extracted or discharged; and
- *regulation tactics:* imposing quotas to affect the same.

In PAWN roughly 120 technical tactics, 10 managerial tactics (each with their own variations in capacity and amounts) and lots of pricing and regulation tactics were identified. From the last group, five types of pricing tactics and four types of regulation tactics were studied in more detail, including lots of variations within the type of tactic itself. According to the problem statement all of these tactics and their numerous combinations had to be investigated for their consequences for the various sectors such as agriculture, shipping, etc under different natural and economic circumstances. Moreover, national aspects had also to be considered such as direct and indirect effects on the employment, gross national product, balance of trade, public health and social-distributional aspects.

It goes without saying that it was not possible that all these tactics and their numerous combinations could be studied in detail. Hence an analysis approach was developed that enabled the analysts to combine the different tactics into coherent (alternative) policies and analyse those. This analysis approach is given in figure 12. Three major stages can be identified:

- screening;
- policy design; and
- impact assessment.

The *screening stage* reduced the large number of possible individual tactics. In this stage the various single tactics were analysed on their own. They were investigated with a broad brush evaluation in terms of a very limited number of impacts. For the technical tactics it was usually their effect on agriculture. The output of screening was a relatively small list of promising tactics, i.e. tactics that were considered sufficiently sensible to warrant a further investigation of their merits.

In the next stage, the *policy-design stage,* individual promising tactics were combined in different ways to obtain a number of alternative promising watermanagement policies. Attractive policies indentified during this process were evaluated in the third major stage called *impact-assessment.* Here a more complete and detailed analysis was carried out to determine the multiple consequences of the selected policies (for all relevant sectors of the national economy). This was done by comparing the performance of the water management system and the impacts on the relevant use-groups with and without the policy considered for a number of different conditions. Essential in this process is that although the analyst makes the comparison, he does not make the choices. This is left to the policy/decision-maker (usually the politicians). Hence the analysts has also to provide the decision-makers with the basic information on which he has made the comparison. During this process other ideas may come up and the analysis is repeated.

Two more steps are to be discussed which have preceeded the above mentioned stages of analysis. These steps were the analysis of: (i) the existing situation; and (ii) a future situation, both under the existing watermanagement policy. From the first analysis, a clear picture was obtained of what the problems in the current watermanagement system are. The second analysis indicated what problems could be expected under future circumstances, if the existing ways to handle the national system is not changed. For this latter analysis assumptions had to be made on how the future might look. Therefore scenarios were made, scenarios for the growth of the various sectors involved and scenarios with respect to developments the neighbouring countries are planning. These analyses helped identify the real problems and at the same time provided some ideas on how to solve them.

With respect to the impact assessment stage some remarks have to be made. In most cases it is not possible to express all the multiple consequences in the same comparable units. For example, increased agricultural production and infrastructural costs will be expressed in money terms but environmental quality in concentrations of pollutants. How does the decision-maker in spite of that come to one preferred policy? The common practice is to combine impacts into a single measure of performance, but such an approach usually looses information and may substitute the analyst's values for those of the decision-makers. In the approach of PAWN, the various impacts

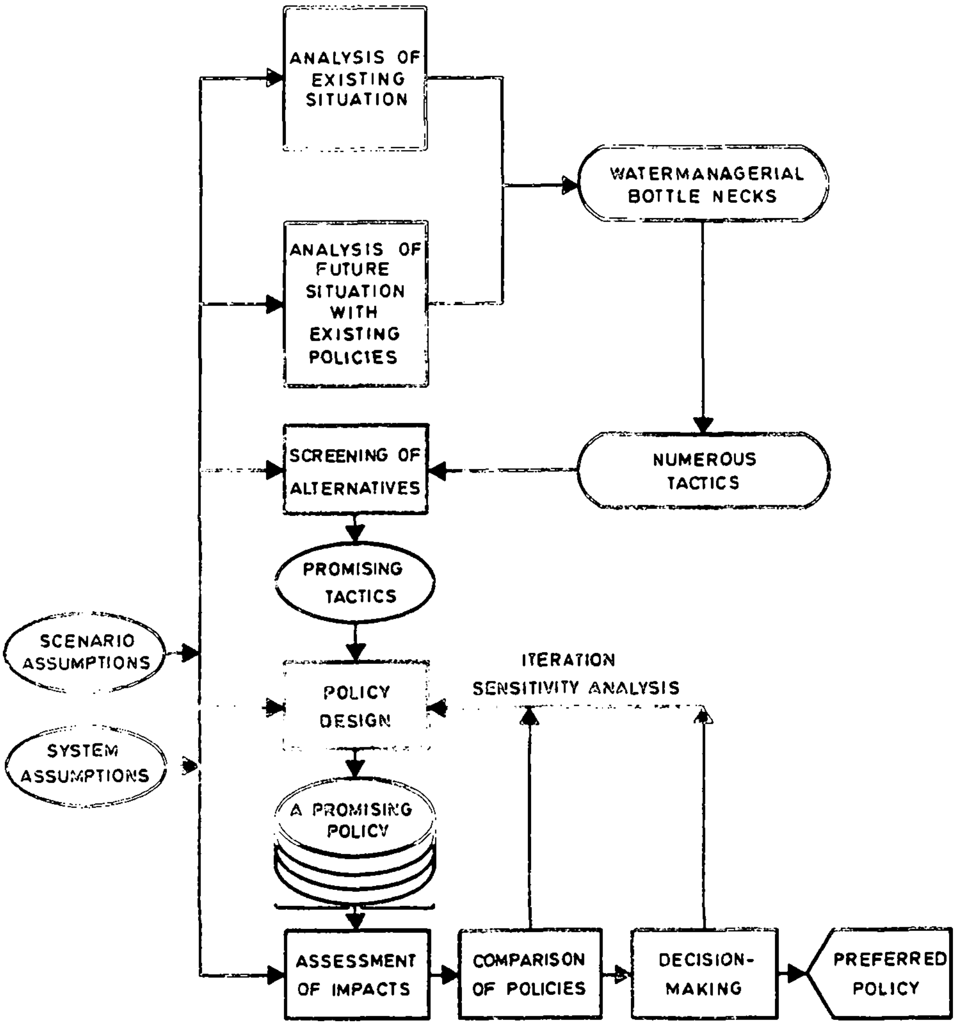
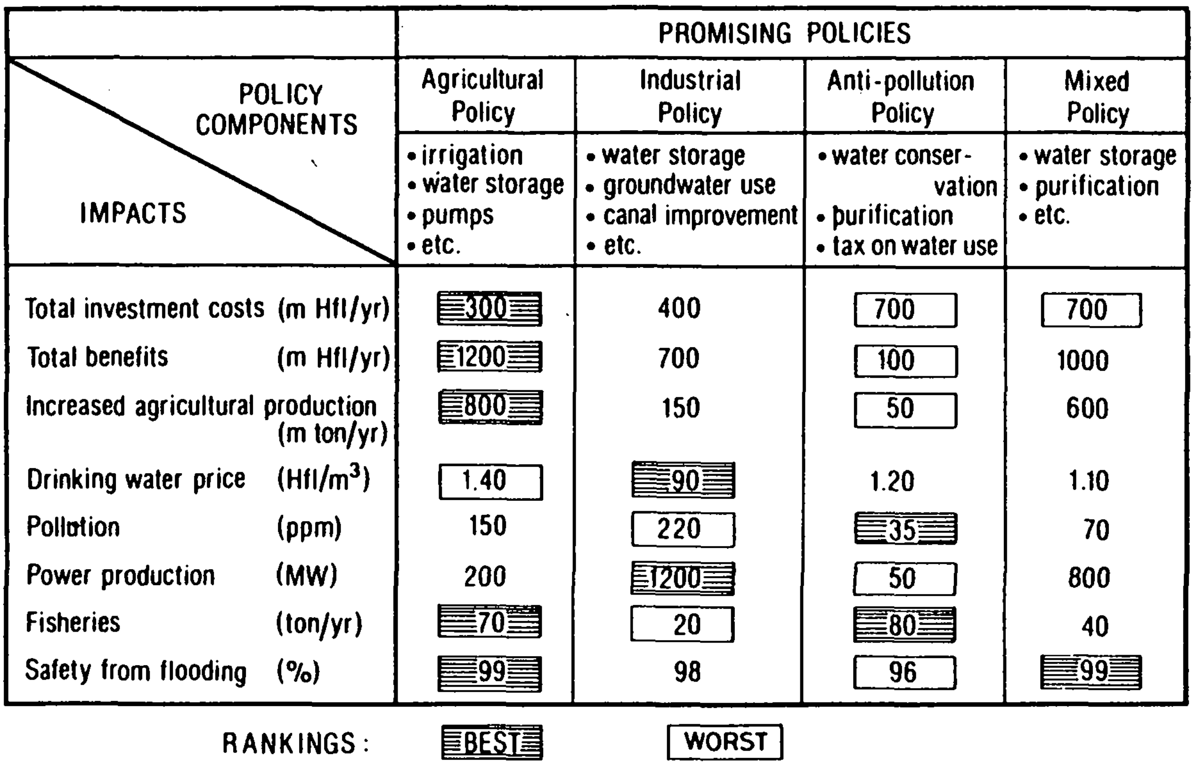


Figure 12. Stages of policy analysis in PAWN

are displayed on a *scorecard*. Impact values are summarized (in natural units) in a table, each row representing one impact and each column representing an alternative strategy. The scorecard is the table of impacts with color or shading added to indicate each alternative's *ranking* for a particular impact. A sample scorecard from a hypothetical comparison of alternatives is shown in figure 13. Colors are employed to show rankings in the scorecards used in the PAWN final briefing: blue designating the best value, yellow the worst and gray the intermediate. In figure 13 shading is used instead for reproduction reasons.

For PAWN, the scorecard has several advantages. It presents a wide range of impacts and permits a decision-maker to give each impact whatever weight he deems appropriate. It helps him to see the comparative strengths and weaknesses of various alternatives, to consider impacts that cannot be expressed in numerical terms, and to change his subjective weighing and note the effect this would have on his final choice. To this factual knowledge, the decision-makers then add their value judgements about the relative importance of the different impacts, thereby weighing and trading off the impacts to select a preferred alternative — that is, to make "the decision". When there are multiple decision-makers, the scorecard has the additional advantage of not requiring explicit agreement on weights for different social values. It is generally much easier for a group of decision-makers to agree on a preferred alternative (perhaps for different reasons) than on weights to assign to the various impacts.



POLICY COMPONENTS / IMPACTS	PROMISING POLICIES			
	Agricultural Policy	Industrial Policy	Anti-pollution Policy	Mixed Policy
	• irrigation • water storage • pumps • etc.	• water storage • groundwater use • canal improvement • etc.	• water conservation • purification • tax on water use	• water storage • purification • etc.
Total investment costs (m Hfl/yr)	▨ 300	400	☐ 700	☐ 700
Total benefits (m Hfl/yr)	▨ 1200	700	☐ 100	1000
Increased agricultural production (m ton/yr)	▨ 800	150	☐ 50	600
Drinking water price (Hfl/m³)	☐ 1.40	▨ 90	1.20	1.10
Pollution (ppm)	150	☐ 220	▨ 35	70
Power production (MW)	200	▨ 1200	☐ 50	800
Fisheries (ton/yr)	▨ 70	☐ 20	▨ 80	40
Safety from flooding (%)	▨ 99	98	☐ 96	▨ 99
RANKINGS:	▨ BEST	☐ WORST		

Figure 13. Sample scorecard

3.4 The computational approach

The complicated structure of the problem determined the approach to be followed to a large extent. The many components to be considered, the aspects of space and time and the often complex relations existing between the components of the watermanagement system forced PAWN to make extensive use of mathematical modelling. This was done with a coherent set of models of different sizes.

In the PAWN system diagram the main components and their interrelations are presented (figure 14). Each box in the diagram represents one or more different models or substudies. In the outer ring the models for the various sectors involved have been indicated. These models are mainly concerned with the demand side of the problem. The models in the inner ring represent the physical components of the watermanagement system.

Roughly 40 models were built. As agriculture is the most important consumer of water in the Netherlands quite some attention was given to this sector. Models were developed which calculated the water demand and the agricultural losses due to water shortage and/or excess salt in the root zone. Furthermore analyses have been done in order to get projections for the future irrigated area (sprinkling) and the way the sprinkling equipment was going to be employed. For the drinking water companies and the industry, models were built which described their behaviour if they had to refrain from the use of groundwater and had use surface water instead. With respect to the power plants, a model was made which calculated the power production costs given the available surface water flows while complying with the thermal standards of the water bodies that are used to receive the cooling water.

In addition, sub-studies were carried out for:

- — navigation and shipping locks (shipping losses caused by non-optimal water-management situation);
- — salt wedge in the Rotterdam Waterway;
- — IJssel Lake;
- — external supply (supply of rain and river discharges); and
- — the aquatic and terrestrial environment.

Central to the modelling structure is the Water Distribution Model (WDM) that by comparing supply and demand and applying built-in allocation rules simulates the distribution of water and certain pollutants over the country. It is based on a network of links and nodes, representing the main rivers, canals and lakes. The models simulates the water distribution for discrete timesteps of 10

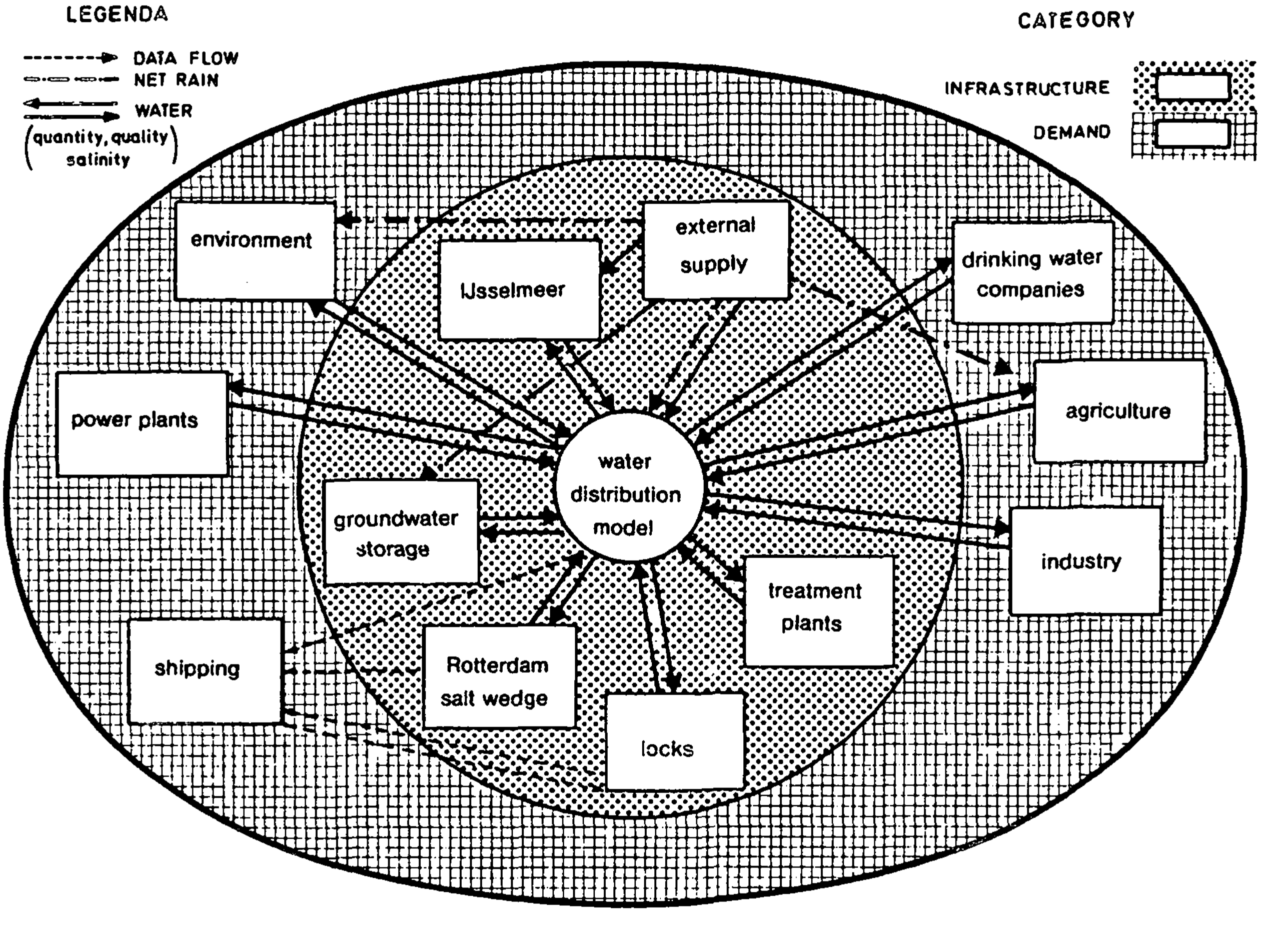


Figure 14. PAWN system diagram

days. As it makes use of the information supplied by sectoral models it also calculates the damage to each sector induced by that particular water distribution.

The models and sub-studies related to specific categories of water usage were integrated with the WDM in one of the following three ways:

- one line connection with the WDM (e.g., agriculture and groundwater storage);
- pre-processing: use of results of the model or sub-study in the WDM (e.g., navigation, shipping locks, drinking water companies and industry); and
- post-processing: use of WDM results in the model or sub-study (e.g., power plants).

By comparing different runs of the distribution model, the effects on the different user-groups caused by the measures under investigation could be determined.

Figure 14 indicates the approach the analysts had in mind at the beginning of the study. In reality it turned out somewhat different. For instance:

- the groundwater-storage model: no separate model was built, this aspect was included in the agricultural model;
- the section treatment plants never has been finished due to all kinds of administrative reasons;
- for environment no separate model was built, only the effect of other sectors on the environment have been indicated;
- drinking water companies and industries were combined into one model; and
- the IJssel Lake (flooding) study turned out to be a completely stand alone study.

An overview of the actual output of the models is:

Agriculture: — gross and net benefits (prevented crop damages); and
— fixed and variable costs of sprinkling.

Industries: — use of surface water, groundwater and drinking water; and
— change in costs of water used in industries.

Drinking water companies:
- use of surface water and groundwater;
- change in costs and revenues of drinking water production; and
- change in price of drinking water.

Shipping:
- change in costs of shipping due to low water levels;
- change in costs of shipping due to delay at locks; and
- dredging costs.

Power plants:
- extra costs of power generation, in order to meet thermal standards.

Environment:
- extent and frequency of violation of water quality standards;
- changes in groundwater; and
- distribution of the Rijnwater over the country.

To the system diagram three more aspects have to be added. This is illustrated in figure 15. Here the national economic, public health and social/distributional aspects come into the picture. For the first and the last items separate models were made. The impacts for the second category came from the drinking water and industry models (a simple criteria was used: percentage of groundwater in drinking water). Calculated model output for the first and the last category were:
- total net benefits realized in the Netherlands;
- direct and indirect effects on employment;
- breakdown of net benefits by producers, consumers, government; and
- breakdown by region.

4. THE MAIN RESULTS AND POLICY CONCLUSIONS FROM THE PAWN-STUDY

Within the scope of this paper it will only be possible to give an overall impression of the most important results of PAWN and of the policy conclusions derived from them. The main items are:

a) The Netherlands remain very dependent for their watersupply on the rivers Rhine and Meuse. An international agreement is of highly importance.

b) A considerable increase in the use of sprinkling installations for agriculture in the Netherlands can

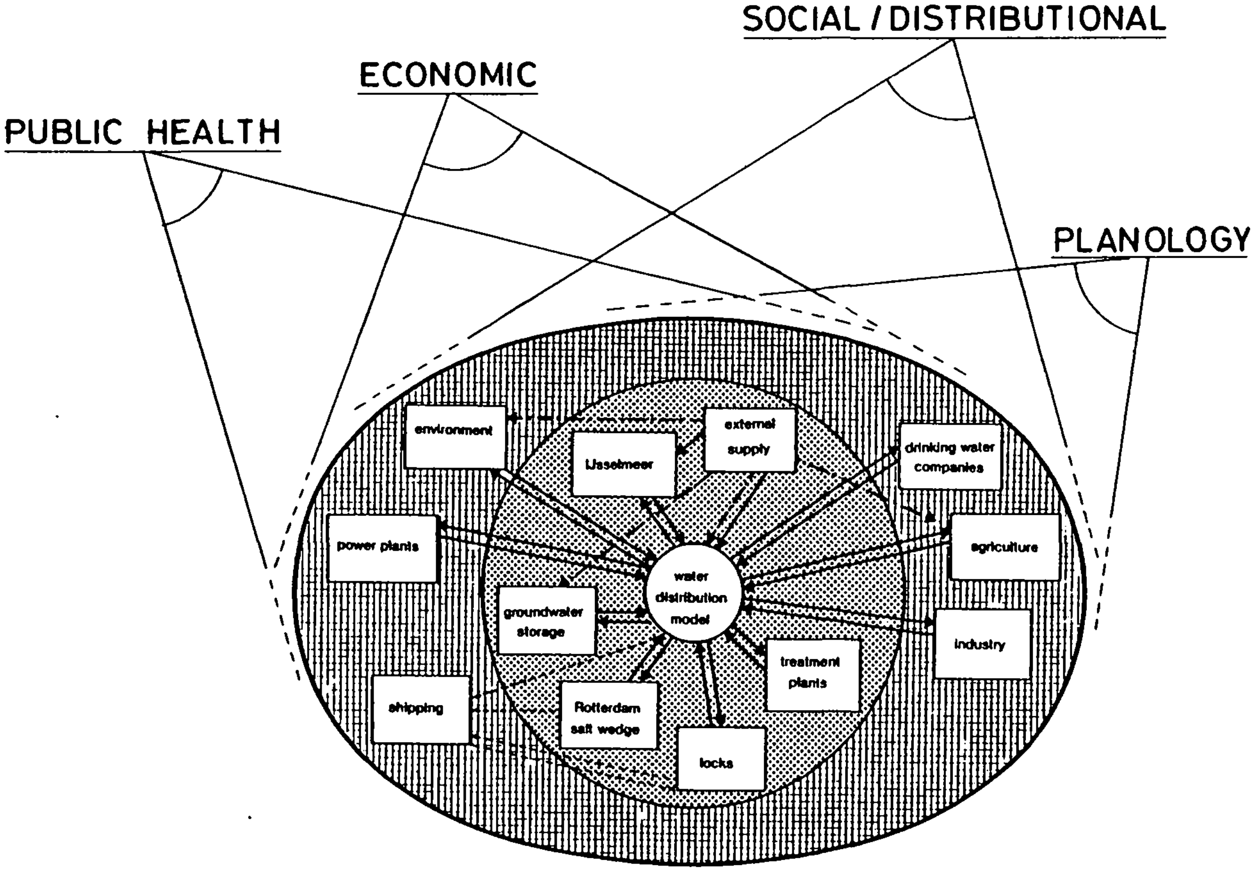


Figure 15. Other aspects of the system diagram of PAWN

be expected because additional sprinkling of crops seems to be a cost-effective measure.

c) As a result of the increase in sprinkling with groundwater and the growing withdrawals by drinking water companies and industry, a considerable decrease of the groundwater level can be expected. Taxing the groundwater use by agriculture seems to be a cost-effective measure. This tactic however is politically unfeasible; instead the growth of the groundwater withdrawal will be regulated with legislative measures (licenses).

d) The Netherlands have considered a large number of infrastructural works to improve the national watermanagement system (costs 3 billion Dutch guilders = $US 1 billion). Of the larger, more expensive projects only one (an enlargement of the storage-capacity of the IJssel Lake) has been shown to be potentially cost-effective. A number of smaller projects, such as a small alternative supply-route for the agricultural area near Rotterdam, have been recommended for further consideration.

e) The different improvements of the watermanagement for other sectors like shipping and agriculture have no important effects on the costs to the power companies.

f) It is possible to decrease the costs to the power companies by changing the water distribution in the network. However, the decrease in benefits for agriculture and the increase in costs for shipping are much larger than the decrease of power plant costs.

g) For the distribution points in the main watermanagement system specific management guidelines have been established. Apart from that, some general priority order which can be used for the distribution at other locations in times of water shortages have been derived. This priority order is roughly:
   - The withdrawal for industry and drinking water supply due to their relative small amount and their high economical and sanitary importance will not be cut back.
   - High priority will also be given to level control in the low-lands. If levels are not maintained shrinkage of the subsoil and damage to pile foundations might be the result.
   - The demands for sprinkling will be met as long as possible. However if serious shortages occur they will be cut back accordingly.
   - Low priority will be given to the demands for flushing of the "boezem" system, the supply of cooling water for power plants and the water demand for shipping at locks.

h) The total net benefits of the new policy for the country as a whole are on the average 200 million Dutch guilders ($US 70 million) per year. Almost all economic sectors benefit from this policy. Only the power companies are left with a negative benefit of 10 million Dutch guilders per year. Apart from the above mentioned positive effects, other indirect effects such as a stronger position on foreign markets, are obtained.

5. CONCLUDING REMARKS

The results and conclusions from PAWN have played an important role in the drafting of the Watermanagement Policy Note (Masterplan). In this note the official policy of the Dutch government with respect to the watermanagement is embodied. This note was sent for discussion to the Netherlands Parliament at the end of 1984. After approval by the Parliament the document will be used by various agencies of national, provincial and local government as a guideline for their watermanagement.

More indirect results of PAWN that are considered as important as the specific results above are:

- PAWN has highly stimulated an integrated way of thinking about watermanagement. Explicit attention was given to the many relations between the different aspects of watermanagement.
- PAWN has improved co-operation between the different governmental departments related to watermanagement.
- A general methodology (models and corresponding data base) was created to assess the impacts of changes in watermanagement on various usage categories. Such a tool can be used in subsequent studies and given the fact that watermanagement is a continuous process rather than a one-time effort, this is certainly to be considered a most valuable result.
- PAWN has indicated where data were missing or of insufficient quality. In this way PAWN structured the data gathering and processing activities related to watermanagement in the Netherlands.

Much more can be said about PAWN and the potential of using systems analysis in water resources management. This lecture is meant as an introduction. For further information reference is made to the PAWN reports and available literature on this subject.

Obtaining these concrete results is not the end of the PAWN-project. At the moment steps are being taken to improve and extend the obtained models. Furthermore quite some effort is spent to keep the large economical data-bases up-to-date. With these adjustments the Netherlands will be able to adapt their watermanagement policies to future, now unforeseen, developments. PAWN has created a capacity in the Netherlands to solve complicated watermanagement problems, a capacity which can also be used abroad.

VII. ILLUSTRATIVE CASE STUDY: MASTERPLAN BANGLADESH

1. INTRODUCTION

This lecture note describes the background, objective and approach of the Bangladesh Water Sector Master Plan Project. This project has been started in 1983 and will continue till 1985/1986. As the project is still in execution it will not be possible to discuss its final results. Although the objectives of the Bangladesh project and the other case-study that is considered during the seminar — the PAWN study — are the same (to formulate a national watermanagement plan), the scope of problems, availability of data etc. of the two studies are clearly different. In the Bangladesh project the main elements of systems analysis can be identified as the systematic approach (analysis framework) and the use of a computational framework.

The purpose of this part of the seminar is to illustrate a planning study in a developing country and to discuss the possibilities of using systems analysis in such a study. This will be done by a short lecture on the information described in this note, followed by an extensive discussion about the applicability in this case of the systems analysis approach and techniques presented in the previous days.

Most of the information described in this note is taken from existing project documents and hence represent the way the Bangladeshi themselves perceive their problems and the path they think should be followed to solve them.

2. BACKGROUND

2.1 General

Bangladesh suffers from the twin problems of floods and droughts. Nowhere in the world does water pose such a contrast of its abundance in one season and its scarcity in another. During the monsoon season (May to October), the combined discharges of the rivers total about 140,000 m^3/s, but this dwindles to only about a 7,000 m^3/s during the dry season. The rivers carry an annual total runoff of about 1,350 billion m^3. For six months during the dry season (November to April) the country suffers from drought. Low topography, cyclones, storm surges, high sediment discharge, high concentration of rainfall during the monsoon (about 90 per cent of the 2,000 mm annual average), saline water intrusion, and high tides in the coastal areas aggrevate the problems.

Development of water resources is vital for increased agricultural production, and for the economy of Bangladesh. Agriculture dominates the Bangladesh economy accounting for nearly 54 per cent of the gross national product (GNP), 75 per cent of all employment and, directly or indirectly, nearly 90 per cent of the country's exports. Bangladesh has a gross area of 14 million ha of which about 9 million ha are under cultivation at a cropping intensity averaging 140 per cent at present. Rice, by far the most important crop, accounts for about 80 per cent of the cultivated area; jute, the principal export, for 6 per cent, and a variety of other crops, such as wheat, pulses, oilseeds, sugarcane, and vegetables, account for the remaining area. Agricultural productivity in Bangladesh is among the lowest in the world; the average paddy yield of about 1.2 tons per ha is barely half of the average yield for the South Asia Region. Over the last two decades, agricultural production has fallen far short of the needs of the nation and, as a consequence, Bangladesh suffers from a chronic shortage of foodgrains. Foodgrains imports rose from about 0.6 Mtons in 1961 to about 1.5 Mtons by 1970 and to about 2.2 Mtons in 1982.

Agricultural development in Bangladesh is constrained by scarcity of cultivable land, climatic hazards, lack of irrigation facilities, and above all, floods and poor drainage conditions that normally affect one-third of the country's cultivable area of 9 million ha. Flood protection has, therefore, been a major national objective. Bangladesh has large areas of highly fertile deltaic soils, and a climate suitable for year-round cropping. The development of high yielding varieties (HYVs) of rice and wheat, suitable for cultivation in large areas of Bangladesh even under rainfed conditions, has opened up the prospect of substantial increase in production that can be brought about quickly and inexpensively. However, the main rice crops, *aus* and *aman* that are grown in the monsoon season, are frequently constrained by flooding to depths which severely reduce yields and diminish the incentive to increase production by shifting to HYV-fertilizer technology. Increases in cropping intensity, by expanding the acreage of *boro* rice (dry season rice crop), wheat, and other *rabi* crops during the dry season, depends upon the provision of irrigation. The monsoon season rice crops are also frequently affected by erratic rainfall during the monsoon, and by a late onset or early cessation of the monsoon rains.

2.2 Presently existing plans

The Government noted in the Second Five Year Plan (SFYP, 1980-1985) that although the short-term strategy for water resources development during the SFYP will lay emphasis on small and medium projects, the ultimate solution of water resources development problems in Bangladesh lies mainly in long term basin-wise development of surface and ground water. Therefore, the long-term strategy incorporated in the SFYP plan included investigations, surveys, and studies so that a balanced program for long term development of water resources is implemented during the present and subsequent plans.

The core investment programme for the SFYP is the Medium Term Foodgrain Production Plan (MTFPP, 1981). The Government stated that the plan represents an effort to shift the emphasis of planning and implementation from the ad-hoc management of a still largely subsistence-oriented agriculture sector, to an orderly administration and implementation of a consistent and forward looking development strategy in the agriculture sector. The plan identifies, as the primary instrument to achieve this objective, water resources development, namely the rapid expansion of irrigation, improved drainage, and flood control. The basic short-term strategy for water resources development emphasises the completion of on-going projects, and the implementation of low cost per acre, quick-yielding, short-gestation projects that contribute directly to increase foodgrain production.

At present the country has no up-to-date overall national water resources plan. The last Master Plan, prepared in 1964, covered a 20-year programme with little or no provision for small-scale irrigation systems that are vital for the development of irrigated agriculture and emphasizing flood protection along the major river system. The Government has not been able to implement the 1964 Master Plan for a variety of reasons, chief among them are escalating costs and the shortage of funds.

2.3 Need for a new Master Plan

Under these circumstances, it has become increasingly difficult to effectively achieve the objectives of the SFYP, even if the financial allocations in the plan had not suffered their recent drastic reductions. The reasons for this are primarily that many of the projects and programs in the plan have been supported only by generalized hydrologic analysis rather than engineering analysis of the local resource pattern, and there has not been adequate comprehensive planning to provide a sufficiently large project portfolio specially suited to the plan strategy.

Pre-investment studies for water resources development must focus on agriculture because agriculture dominates the economy, and the satisfaction of basic foodgrain requirements is the core issue. Other water uses cannot be neglected however. Improved domestic water supply and sanitation (resulting in improved health and therefore contributing indirectly to increased productivity) and other important objectives of the Government also have a high priority. Under the International Drinking Water Supply and Sanitation Decade Bangladesh has prepared a country program of investment projects in domestic water supply and sanitation. This country program reflects the recent rapid advances in the development of appropriate technology in this subsector of water use (much the same can be said for other key subsectors of water use such as fisheries and transportation). What has been lacking is a sound basis and framework for the implementation of projects and programs in these subsectors, that is consistent with the basic resource pattern. The resource assessment to be carried out under the project will provide the framework necessary to enable these subsectors to accelerate their planning and implementation.

3. OBJECTIVES

The project basically has two objectives that may be summarized as follows:

- to prepare a new masterplan for the water sector; and
- to establish a permanent Master Planning Organization (MPO) and train its staff so that the organization will be capable of continuing planning independently.

3.1 Preparation of a New Water Sector Master Plan.

The project will have three sub-objectives:

(a) The project should provide an assessment of the water resource base and pattern, and a hydrologic framework including surface/subsurface simulation modeling for water development planning, and project design, implementation, and operation. The resource assessment and hydrologic framework should directly serve the development objectives of all water use subsectors.

(b) For the near term, and prior to the end of 1984, the project should carry out pre-investment studies to prepare a project investment portfolio that:
   (i) contributes to the acceleration of programs for water development under the SFYP and the achievement of water sector targets;
   (ii) provides an adequate project pipeline for the TFYP; and
   (iii) emphasizes low cost flood control, drainage, and irrigation schemes, and the identification of the highest priority capital intensive projects for agricultural development. The priorities reflected in the investment schedule and the project pipeline should represent a rational and efficient construction sequence from an economic and financial view point.

(c) The project should prepare a long term frame work plan that provides a sound basis for planning and managing the water resources, and future project selection. The long term framework plan should be based upon:
   (i) the identification of surface and groundwater resources;
   (ii) the quantification of water resources in each hydrologic area and sub-area;
   (iii) the determination of the best use of these resources in each hydrologic area and subarea;
   (iv) the determination of the proper modes of development, project types, and the sequence or order of development;
   (v) the formulation and evaluation of alternative long-term development plans;
   (vi) the identification of potential conflicts in

water use and modes of development among different water users and subsectors of water development, and the formulation of policies and measures to resolve these conflicts.

The project will prepare a masterplan having two basic components: a near term investment schedule and project portfolio for the Third Five Year Plan period 1985-1990; and a long term framework plan for the period 1990-2005. The last two sub-objectives are concerned with the preparation of the masterplan.

3.2 Establishing a Continuing Master Planning Organization.

National water resources planning is a continuous process that must be responsive to development progress, increased knowledge of resources, and changing economic conditions, objectives, and priorities. The planning process should evolve as implementation progresses, and low cost per acre investment opportunities are gradually exhausted.

An objective of the Government is to develop a unit capâble of the continuous preparation and updating of the master plan. To accomplish this objective the following three sub-objectives are also included:

- Develop a sufficient number of local professional staff who possess the various required disciplines and backgrounds, in the perspective and methodology of national water planning.
- Establish a permanent organization at an appropriate level and location within the Government that is dedicated to the independent continuation of the national water planning process.
- Develop a programme of priority and long term studies and investigations including improvements and expansion of the data base, and provide it with adequate techniques of analysis and investigation.

4. WORK PROGRAMME AND SCHEDULE

This section gives an overview of the indicative work plan of the project as formulated in the project document. The work plan was intended as a guide for the initiation of the project and as a framework for the development of a detailed work plan to be presented in the Inception Report, three months after the actual project is initiated.

Project Activities

(i) Assessment of present achievements (studies and projects).

(ii) Assemble and compile existing data and determine data collection needs:
- Surface water and groundwater (quantity and quality), rainfall and related meteorological and climatic data, sediment, salinity, and tidal data.
- Engineering field data such as river cross-sections and topography.
- Current and planned water use.
- Soils and land capability and suitability to various crops.
- Completed and planned infrastructure affecting water development.
- Inventory of previous and ongoing planning studies in the areas of water resources, agriculture, domestic and industrial water supply, fisheries, and inland water transport, etc.
- Carry out supplemental field surveys as needed on efficiency and problems of water use and management, and socio-economic and agro-economic conditions in selected planning areas.

(iii) Assessment of available surface and ground water resources.

(iv) Determination of flood protection and drainage criteria.

(v) Compile and analyze available agriculture and agro-economic information.

(vi) Determine and summarize the demands for water use, water management needs and constraints to growth in agricultural production, including non-water factors, in each planning area.

(vii) Assessment of modes of development.

(viii) Carry out economic studies focusing on Government economic policy, prices, subsidies, and cost recovery.

(ix) In each planning area identify and formulate projects based on alternative investment criteria and development strategies.

(x) Plan formulation and evaluation:
- Establish objectives, priorities and levels of financial resource availability.
- Formulate and evaluate alternative development strategies and investment plans to meet these objectives and priorities.
- Identify institutional adjustments or developments needed for policy and plan implementation.
- Recommend a schedule of steps and actions to be taken by the Government to implement the plan.

(xi) Establish the functions and responsibilities of the unit that is to continue the national water planning program at the conclusion of this project.

5. TRAINING PROGRAMME

A prime objective of the Master Plan Organization, during the preparation of the National Water Plan, is to develop an independent unit capable of continually updating the water sector master plan. The MPO seeks to develop a cadre of trained local professionals skilled in the various disciplines and methodologies necessary to provide leadership in the area of national water-planning. To achieve this objective an extensive multi-component training programme has been conceived. It commenced before the technical planning work actually began, and it will extend beyond the completion of the National Water Plan. The four major components of this training programme, scheduled in sequence, are as follows:

(a) ***Orientation Training Course.*** This three-week course was organized immediately after the MPO professional staff was selected and posted. The course which was presented in Bangladesh from 28 February to 17 March, 1983, was designed to: (i) develop an understanding of the interdisciplinary nature of the planning process; (ii) familiarize participants with contemporary approaches to national and river basin planning; (iii) offer refresher courses on various engineering topics; and (iv) prepare the MPO staff for an intensive foreign training programme. All the 25 participants subsequently attended an intensive training course in Holland.

(b) ***Intensive Foreign Training.*** This 11-week programme was jointly implemented by the International Institute for Hydraulic and Environmental Engineering, the Delft Hydraulics Laboratory, and the Public Works Department (Rijkswaterstaat). The programme was presented at Delft, Holland, from 11 April to 23 June, 1983 and focussed on analysis techniques for water resources planning.

(c) ***On-The-Job Training.*** This major component of training is presently being carried out and will continue until submission of the NWP reports.

(d) ***Advanced Technical Training Programme.*** After the preparation of the NWP reports, there will be opportunities to send selected staff abroad for further advanced professional training.

6. ACHIEVEMENTS

The actual work on the project started in July 1983 when the 25 participants of the Intensive Foreign Training returned from the Netherlands. Aided by some foreign consultants MPO submitted its first interim report (the inception report) in November 1983. The first five months of the project were used to define a detailed work programme of the MPO for the next two years. This work programme is based on the definition of some 36 issues, and an initial attempt to develop a planning process. This process of planning (analysis framework) follows seven standard planning steps:

- define national and sectoral objectives, identify issues and formulate criteria;
- inventory of data, developments and conflicts;
- analysis of inventoried materials;
- identify plan elements (facilities, projects, programmes);
- combine plan elements to form alternative plans;
- evaluate and select a plan; and
- identify requirements for implementation.

In addition to this analysis framework MPO is currently developing a computational framework. The three major models that will be used are:

- Investment Analysis Model: maximizes the net present value of income generated in the agriculture sector from a given level of investment in water resource development.
- Crop Enterprise Model: calculates net income from project induced changes in crop production.
- Water Balance Model: stimulates streamflow and groundwater level conditions.

Other models will be used or developed if there is a need for computerized analysis.

The computer models are (or will be) implemented on powerful microcomputers (TRS-80 and IBM-PC) and are available in the MPO-office.

7. CONCLUDING REMARKS

The Bangladesh National Water Plan Project is still being carried out and no final results are available. From the point of view of this Systems Analysis seminar these results are not important anyhow. This note was meant to give an example of a planning study in a developing country and to show that the principles involved are the same for other developing countries as well. Approaches for PAWN and the Bangladesh project and the terminology used will be different. The basics of systems analysis, the analysis framework and computational framework, however, remain the same. It is this point that will be the subject of the discussion that follows the lecture.

VIII. CONSTRAINTS AND PITFALLS IN APPLYING SYSTEMS ANLAYSIS IN WATER RESOURCES MANAGEMENT

1. INTRODUCTION

In the previous sections an overview is given on what systems analysis is about and what its potential is in planning for WRM. In summarizing the role of systems analysis in WRM planning, the following remarks can be made.

- It offers an explicit method for generating, analyzing and evaluating alternative courses of action in WRM.
- It forces the analyst to make the objectives, criteria and underlying assumptions of the planning study explicit and hence discussable.
- It makes it possible to analyse quantitatively many alternative WRM strategies under different scenarios and assumptions and to carry out extensive sensitivity analyses.
- It provides a framework of communication among the many disciplines and between the analysts and the decisionmakers and may enable the integration of their inputs in a comprehensive analysis.
- It expedites the continuing planning process (as opposed to a "start-stop" or fragmented planning) by allowing modifications and adaptations of the computational framework to accommodate changing needs, objectives and constraints.

It is important to note that systems analysis is an aid to decisionmakers and does *not* replace them.

Realizing the above, it seems logical that systems analysis has a bright future in planning for WRM. However, a successful application of systems analysis depends on many factors and several constraints should be surmounted before systems analysis will have become common in planning for WRM. This section touches upon some of these factors and constraints and summarizes some of the most common pitfalls in systems analysis studies.

2. CONDITIONS FOR SUCCESSFUL APPLICATION

To be able to carry out a successful (= accepted by the decisionmakers) systems analysis study there are several general conditions that should be fulfilled.

The *first* one is rather trivial and requires that the subject of the study has to be of the right topic. That is:

- the problem situation should be real and felt that way by the decisionmakers;
- the problem(s) should be urgent;
- there must be alternative solutions for the problem(s); and
- there must be implementation possibilities which are considered explicitly.

The *second* condition is that the decisionmaker/responsible agency should be of the right attitude:

- the analysis should be supported up to the highest level;
- "moderate risk/high pay-off" methodological research must be acceptable (e.g. model building);
- the objective of the study should be clearly defined and open to discussion;
- regular discussions between the decisionmakers and the analysts should be possible.

The *third* condition is that the analysts should be of the right background. A systems analyst should:

- be a specialist in one or more fields and have an overview of other fields;
- know the basics of systems analysis approach and techniques;
- be flexible; and
- be able to communicate effectively with other team members and decisionmakers.

The *fourth* condition is that in an early stage of the project the confidence and understanding of the decisionmaker for the study should be gained.

3. CONSTRAINTS TO THE APPLICATION OF SYSTEMS ANALYSIS

Although the potential of using systems analysis in improving Water Resources Planning and Management has been generally accepted, there are several constraints that hamper a rapid increase in applying system analysis in WRM.

One of the main reasons has been (and still is in many countries) *the lack of specially trained skilled professionals* to carry out the studies. Actually this is not a real problem or it is at least a problem that can be solved by providing training. The situation in European countries and in the United States proves this. The lack of trained personnel in water agencies was also present in these countries but was improved greatly within 10 years by providing training and by simply starting systems analysis projects and learning "the trade" by doing it (of course based on a certain level of basic knowledge of systems analysis).

More fundamental is the constraint caused by the fact that the *top managers and decisionmakers* are too far removed from the analytical aspects of systems analysis and that it has become very difficult for them to assess the utility of the new approach. Of course this problem will disappear over time when younger professionals take over their positions but in the meantime solutions have to be found to get around this situation.

Ineffective communication. Systems analysts have communicated chiefly with each other rather than with other professionals and decisionmakers in the area of water resources planning. Sometimes in communication with decisionmakers, undue emphasis is placed on the complexities of mathematical techniques. The success in the application of systems analysis techniques is enhanced by clear presentation of the framework for analysis and project alternatives to decisionmakers. Systems analysts need to be sensitive to the above mentioned lack of receptivity on the part of senior personnel.

Availability and accuracy of data. Systems analysis applications can be very data intensive and sensitive to the quality of data but are not necessarily so. In many countries and especially developing countries the data on economic, social and natural resources are poor in the sense of time series, breadth of coverage and accuracy. *This however need not prevent the use of systems analysis.* On the contrary, systems analysis can be adapted to the limitations of data availability and better results can be obtained by applying systems analysis than could otherwise have been possible. Furthermore, systems analysis can assist in directing data collection processes. For example, sensitivity analyses can point out which variables are important for management, and hence which data should be collected. It could also point out the frequency with which such data should be collected, assuming that accuracy is a function of frequency. Moreover, through such means as assisting in data evaluation, sensitivity analysis may prevent the all-too-prevalent temptation to collect data on any variable relating to the project which could conceivably be relevant in the future.

In-house capabilities. When systems analysis studies are carried out by consultants it is required that there be a certain minimum in-house systems analysis capability in the agency for which the study is carried out. Often, especially with respect to the more technical requirements of mathematical model building and other specialities, it may be more efficient for agencies to utilize consultants. This is especially true for smaller agencies, whose needs for certain systems analysis talent may be more periodic. But even in these cases in-house capabilities are necessary to monitor and utilize contract work. But more importantly, it cannot be over-emphasized that the systems approach to continuous planning means continued use and revision of the computational framework. This requires in-house personnel who can use and interpret the models. Additional consultants help can be utilized when necessary to update, revise, or build new models.

To date it appears that the product requirements are often inadequately described when consultants conduct systems analysis studies for agencies. There is too much emphasis on delivering a model and manipulating data, and too little effort on building analytical capacity within the agency. Too little attention is paid to the continuing nature of problems. Studies tend to be terminal in nature rather than becoming continuing analytical and management tools. Not enough attention is paid to ensure that the model and computer programs, if any, can be carried forward by staff. If necessary, staff training should be part of the task. This need should be recognized and become part of the task of the consultants.

Availability of standard computer programs. As systems analysis is still developing there is, as yet, no set of generally applicable models readily available, in spite of recurring problems with similar characteristics. While the same techniques are often applied, new models and programmes are generally written each time. This involves delays and unnecessary extra costs in applying the systems approach. The high costs of model development will even sometimes prevent the use of systems analysis. It should be helpful if a stock of flexible software packages became available for general use. These standard models and programs can then be used as a base for the (in most cases necessary) adaptation of the models to the specific problem situation.

4. PITFALLS IN APPLYING SYSTEMS ANALYSIS IN WRM PLANNING

In this section some concluding comments will be made with respect to the most common pitfalls in applying systems analysis as presented in the seminar. The order of listing does not imply order of importance.

- Analysts are often obliged to "interpret" national goals by transforming them into operational objectives, given that typically national goals are expressed in such general terms that quantitative analysis of alternatives relating thereto is not possible. The result of this "interpretation" by analysts is often different from what decisionmakers had in mind.
  PRINCIPLE: This "interpretation" should be done in close interaction with the decisionmakers to ensure that the "interpretation" is what the decisionmakers actually had in mind.
- Failure to draw the boundary of the WRS sufficiently widely to ensure consideration of all the factors affecting the outputs of concern. For example, an irrigation project is typically to produce food and/or fiber outputs. To produce outputs water is only one of the requisite inputs, the others being, e.g., credit, pesticides, fertilizers, energy. These inputs must be included in the analysis of the system.
  PRINCIPLE: The boundaries of the system (to be analyzed) must be defined so as to include all relevant variables on the demand and supply sides, to ensure that the desired outputs could be achieved.
- Failure to consider the relative importance of the different variables affecting demands for water and water-related products and services, thereby leading to non-optimal allocation of available analytical resources.
  PRINCIPLE: The available analytical resources

should be allocated in a systems analysis in proportion to the relative importance of the variables affecting the outputs of the analysis.

- Failure to consider explicitly in setting up the analysis the level of sophistication to be used, where the level of sophistication depends on the questions to be answered; the available analytical resources; and the relative importance of variables.

  PRINCIPLE: Never use any more sophisticated analysis than is necessary to answer the question.
- Failure to reallocate available analytical resources when the quantity of those resources changes during the analysis activity.

  PRINCIPLE: Application of systems analysis must be sufficiently flexible so as to enable reallocation of resources as problems are uncovered and new data become available, during the analysis.
- Failure to recognize explicitly the uncertainties associated with the variables involved in the analysis — demographic; economic; technological; political; social, e.g., behavior of water users; and ecological (only hydrologic uncertainty is often recognized).

  PRINCIPLE: Uncertainty of results of analyses of water resources systems must be described explicitly and conveyed to the decisionmakers.
- Inadequate attention is given to the development and selection of scenarios to be analyzed, where a scenario is defined in relation to variables whose values are determined exogenously from the WRS. The government needs to know what the costs and consequences would be for the water sector under alternative possible future sets of conditions.
- Failure to consider a sufficiently wide range alternative physical measures and alternative implementation incentives, particularly possibilities of change within activities, e.g., on-farm, in industrial plants. In particular, there often has been a failure to consider those alternatives which are simple, easy to maintain, and use indigenous resources.
- Failure to consider the implications of government decision on subsidies/cost recovery rules, with respect to:
  - responses of water users in terms of their water demands, e.g., the efficiency of water use; and
  - financial feasibility of projects and strategies.
- Inadequate attention and analytical resources are given to consideration of financial feasibility of plans/projects. Where capital is scarce and borrowing from external agencies is required, it is essential that sufficient attention be given to development of the financial aspects of the proposed projects, e.g., cash flows to and from the government, and their sources.
- Simply, failure to plan the analysis (SUTA), typically leading to incomplete reports, missed deadlines and untouched questions.
- Failure to give adequate attention and allocate sufficient resources to the preparation of the final report. The problem is, what data and results are to be presented; how and to whom? The best systems analysis may not be utilized if the presentation is inadequate.

  PRINCIPLE: The final report is a critical and an essential part of a systems analysis; and, the preparation of the final report always takes longer than anticipated

Part Three

WORKSHOP

Foreword

This part of the seminar proceedings gives an overview of the workshop that was carried out during the seminar. It consists of material that was issued to the participants during the workshop and contains the information necessary to carry out the workshop. Although it does not include new "theoretical" issues other than those presented during the lectures, it serves the purpose of providing the practical illustration of the theory already discussed. As the workshop itself made intensive use of micro computers, reading the following information only cannot replace the exercise of carrying out the workshop. It does however give a general idea of the necessary steps involved in the analysis process, the set-up of a computational framework and the data required for such a framework.

This part of the seminar proceedings is organized as follows: Section I: An introduction with the objective and set up of the workshop;Chapter II: Description of the case study — a master planning analysis for a country — including all data necessary to carry it out;Chapter III: Modelling structure of the computational framework used in the workshop, including some illustrative indication of solution techniques and data structure; and Chapter IV: Results of the workshop as produced by the participants.

Part Three
WORKSHOP

I. Introduction

1. INTRODUCTION AND CASE STUDY

In the following, the set-up of the workshop is described. The theoretical lectures of the first days of the seminar will be put into practice in the workshop and a rough simulation will be carried out of the required analysis for a water sector masterplan of an imaginary country.

This and the next sections specifically deal with:

- the case study that will be analysed during the workshop (this chapter);
- the stages that are distinguished in the workshop and the corresponding time schedule (section 2);
- the organizational set-up (the division into working-groups, section 3); and
- the type of models and accompanying data that will be available for use in the analysis (section 4).

The case study that will be analyzed during the workshop concerns the analysis for a masterplan for the water sector of an imaginary country*. The country, with its major river system, is schematically shown in figure 29. The main objective of the case study is to develop alternative WRM strategies and to assess their impacts on the natural system and the different water users. In carrying out this task the participants will follow a systems analysis approach and make use of a computational framework prepared in advance by the course organizers.

The problem statement of the case study includes drought, flooding and drainage problems and salinity intrusion. The water users considered are agriculture, drinking and industrial water supply, shipping and fisheries. Of these water users agriculture will get the most attention. Agricultural production as influenced by drought and flooding situation as well as by salt intrusion will be analysed.

In the following sections more information will be presented on the problem statement. This will include:

- A description of the country's natural system (information on climate, river system, topography etc.); the water users (cropping patterns and crop area, critical location with respect to water depth etc.); and the socio-economic situation. This information will be illustrated with graphs, figures etc.
- A description of the problems as they exist in the present situation as well as a description of the expected developments. To solve or alleviate existing or anticipated problems, several measures are possible. An outline of these potential measures will be included, together with cost estimates of the different measures.
- Some guidelines for the execution of the case study particularly with respect to the application of systems analysis.

2. STAGES AND TIME SCHEDULE

Reference is made to the lecture on "Systems Analysis in planning for WRM" in which the framework for analysis has been explained. This framework distinguishes between an inception stage called SUTA (Setting Up the Analysis) and an actual analysis stage called COTA (Carrying Out The Analysis). The COTA-stage may be further divided into a preparation stage and an integration stage.

During the workshop this framework for analysis will be applied. Within the limited time available (about 5½ days) the emphasis of the workshop will be on the integration stage of COTA (3½ days). The inception stage SUTA (1 day) and the preparation stage of COTA (1 day) do get due attention. Most of the work to be carried out in these stages, however, had to be prepared in advance by the course organizers. In the following, an indication is given of the tasks the participants have to perform in each stage.

SUTA (inception stage)

Many of the results of the SUTA-stage are already included in the problem statement. During the first day of the workshop the problem statement will be discussed, objectives and criteria will be identified, and the analysis conditions and analytical approach will be specified. Use will be made of the computational framework to simulate the present conditions in order to quantify the problem statement. Finally a workplan will be devised for the COTA-stage. Time devoted to the inception stage will be approximately one day.

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* Much data describing the "imaginary" country is taken from a previous training course on the analysis for a water sector masterplan of Bangladesh

COTA (preparation stage)

This stage consists of three segments:

- estimating temporal and spatial pattern of activities;
- analyzing water using and water related activities; and
- analyzing natural systems.

In a "real-world" analysis these three segments always consume the major part of the total effort. Activities carried out in these segments include among others, data collection and model development, which are both very time-consuming tasks.

In the case of the workshop the major share of the preparation stage of COTA has in fact been carried out in advance by the course organizers. The results, a data base and the computational framework, have been included in the problem statement. During the workshop this preparation stage of COTA will be simulated by a thorough examination and discussion of the available models and the compiled data. In this way the participants will be prepared for the tasks to be performed during the integration stage. Time available: approximately one day.

COTA (integration stage)

The integration stage will get the most attention; approximately 3½ days will be devoted to this stage. The major task in this stage is the formulation and analysis of alternative WRM strategies to attain the objectives of the masterplan as defined in SUTA. In the case study one of the major objectives is to bring about an increase in the production of foodgrains.

In this stage an integration of the results of the former two stages will take place. Extensive use will be made of the computational framework to assess the impacts of alternative strategies on the natural system and the various water users. This stage will be concluded with an evaluation of the developed strategies and a discussion on the implementation aspects of these strategies.

3. ORGANIZATIONAL SET-UP

The participants will be divided into three small working-groups to stimulate their involvement and initiatives. Each working-group will be guided by a member of the course-organizers ("supervisor").

The prime responsibility of the workshop supervisor concerns the procedural and organizational aspects of the workshop. They will not "lecture" during the workshop. The input of the supervisors will focus on:

- a systematic execution of the planning process by the working-groups;
- the tuning and coordination between groups; and
- the maintenance of a tight time schedule.

Moreover the supervisors have prepared the problem statement and are familiar with the capabilities and limitations of the computational framework, and thus will be able to assist the groups in the actual execution of their task.

Although self-activity and initiative of the participants is invited as much as possible, the workshop supervisors may assign the group members with specific tasks to ensure progress in the execution of a certain stage.

In principle each group will work independently of the other groups during the execution of the case-study (parallel sessions). However on the last day of the workshop the alternative strategies from the three working-groups will be put together and compared in a plenary session. To ensure a good comparability of the strategies the supervisors may give some instructions during the development of alternative strategies.

4. COMPUTATIONAL FRAMEWORK

A computational framework aims to tie together the different analytical techniques and models that are used during the analysis.The course organizers have developed a problem specific computational framework, dedicated to the masterplanning problem under consideration. This framework will be available to each workgroup for use on micro computers. The use of a computational framework may contribute considerably to an effective and efficient realization of a project, such as the analysis for a water sector masterplan. During the workshop the computational framework will play a role in:

- the quantification of the problem statement (through simulation of the present and future conditions); and
- the assessment of the impacts on the natural system and the various water users of alternative WRM strategies.

The computational framework prepared for the workshop consists amongst others of:

- a network model for the national river system;
- an agriculture-based regional water balance model (district model); and
- impact models associated with the network model or the regional water balance model.

The network model includes flooding and salt intrusion. The district model takes into account drainage, drought, groundwater and flooding. The network model and the district model interact at specific locations, i.e. at the nodes of the network. The schematization adopted for this seminar is shown in figure 33.

The impact models pertain to the most important water users in the case study: agriculture, fisheries and shipping. Moreover, economic evaluation techniques will be available to determine the internal rate of return or benefit-cost ratio of a specific strategy.

II. Description of the Case-Study

1. INTRODUCTION

The greater part of the seminar will be devoted to a workshop in which the theoretical lectures of the first part of the seminar will be put into practice. In the workshop a case-study will be carried out concerning the set-up of a masterplan for the water resources system of an imaginary country. The execution of this task will be based on a systems analysis approach, using a computational framework and a related data-base that was prepared in advance by the course organizers.

The objectives of the case-study are (i) *to identify a number of Water Resources Management (WRM) strategies;* and (ii) *to assess their impacts* in order to develop a masterplan for the development of the water resources of the country in the most "desirable" way.

The problems to be taken into account include water shortage (drought), flooding and drainage problems and salt intrusion. The water users to be explicitly considered are agriculture, navigation and fisheries.

The planning problem in general is to find the "optimal" masterplan taking into account:

- the planning objectives and evaluation criteria;
- the costs and benefits of the plan;
- trade-offs between:
  - water users;
  - various parts of the country;
  - water quantity and quality, surface water and groundwater;
- uncertainties in future developments, e.g. related to population growth, changes in technologic and economic situation, hydrologic and meteorologic inputs.

The problem in general is illustrated by the simplified system diagram shown in figure 16. The surface water system and the interconnected land and groundwater system are fed by cross boundary inflows and net rainfall. All water users taken into account depend on the availability of surface water, while agriculture also depends on groundwater. If surface water quantity or quality, or groundwater quantity are insufficient, damages to the various water users will occur. In dealing with shortage situations trade-offs among the various users may play an important role. Damages may also occur due to flooding and drainage problems. Measures to improve the performance of the water resources system will lead to damage reductions. Damage reductions (benefits) should be compared with the costs of the measures to judge the desirability of such measures.

This part of the proceedings deals with the set-up of the case-study to be dealt with in the workshop. Section 2 contains a description of the imaginary country. Specific attention is given to the description of the natural system, the various water users (especially agriculture) and the socio-economic situation. Section 3 deals with the identification of problems (in the present and future situation) and the potential measures to improve the water resources system. Finally, section 4 deals with the actual application of systems approach to carry out the planning exercise. Attention is given to the main two phases distinguished in the framework of analysis: setting up the analysis (SUTA) and carrying out the analysis (COTA). Moreover, the section provides the basic information for computing costs and benefits of measures during the workshop.

2. DESCRIPTION OF THE COUNTRY

2.1 Natural system

In this chapter information will be presented on the natural system of the imaginary country Eldoran. The information is compiled for the following aspects:

(i) topography (general and regional);
(ii) climate (rainfall, evapotranspiration);
(iii) soil and groundwater system;
(iv) river system.

Subsequently the schematization of the natural system will be briefly discussed. More detailed information on the schematization is presented in chapter III, of Part Three which deals with the computational framework.

Topography

Figure 17 provides a general overview of the country Eldoran[*]. The country measures some 500 kms from south to north, and some 400 kms from east to west. Eldoran is bordered by two other countries: Lindon to the west and Estolad to the north and east. On the southern side the country is bordered by the Balar Sea. To the north the country is bordered by a mountaineous area (Dolmed Mountains). From north to south Eldoran gradually descends from some 20-50 m above sea level down to sea level. The elevation of the different parts of the country is shown in figure 18 by contour lines with an elevation interval of 3 m.

To account for regional differences (in topography, in available water resources, in climate and in existing water uses) the country has been divided into eight districts. These are shown in figure 19; the names of the different districts are also shown in this figure. In addition, the country is divided into four regions (North-West, North-East, South-East and South-West, respectively); each of the regions consists of two districts. This division is also shown in figure 19.

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[*] Names of districts, rivers etc. have been derived from the book Silmarillion of Tolkien.

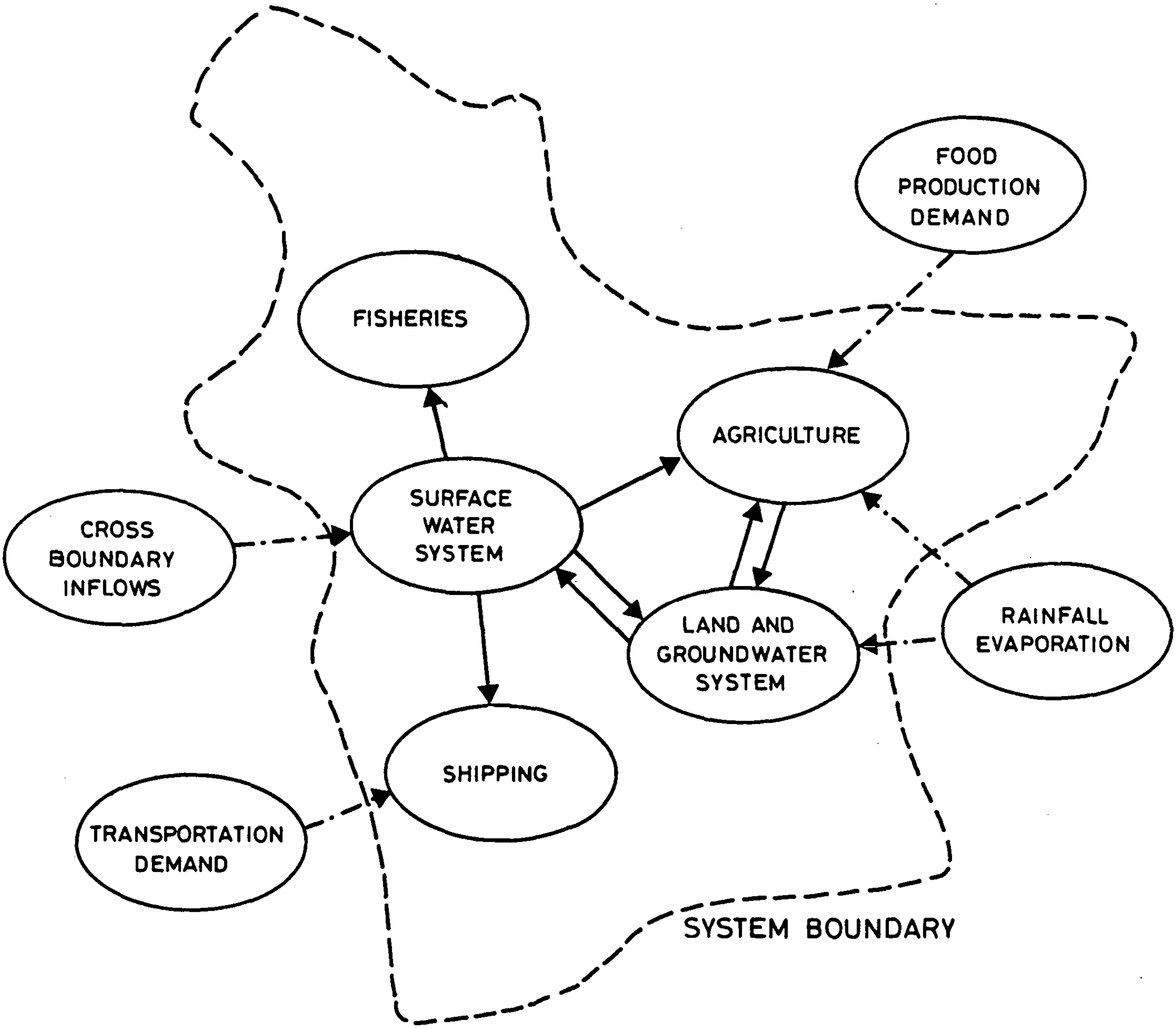


Figure 16. Water resources system of Eldoran

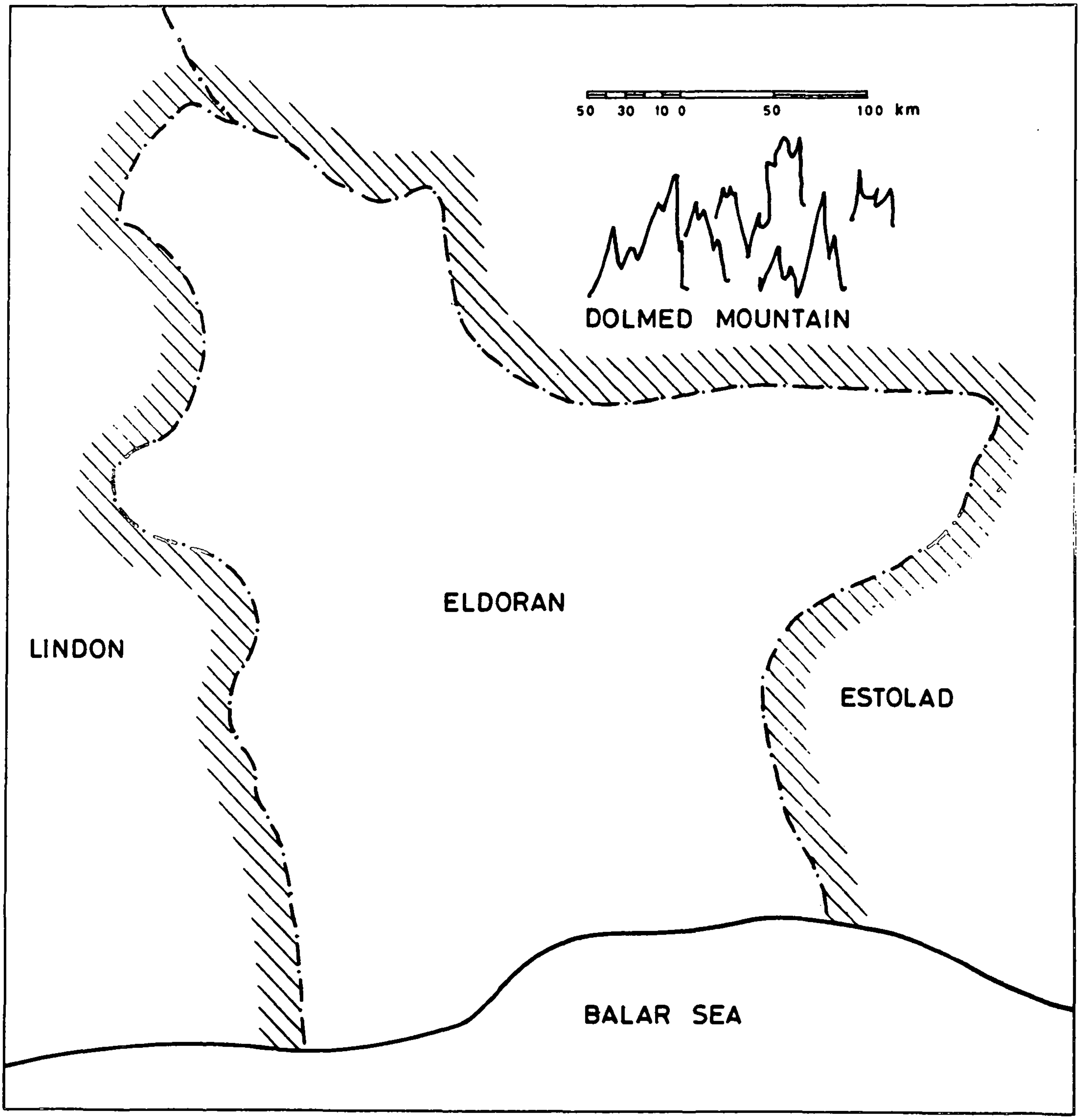


Figure 17. General overview of country Eldoran

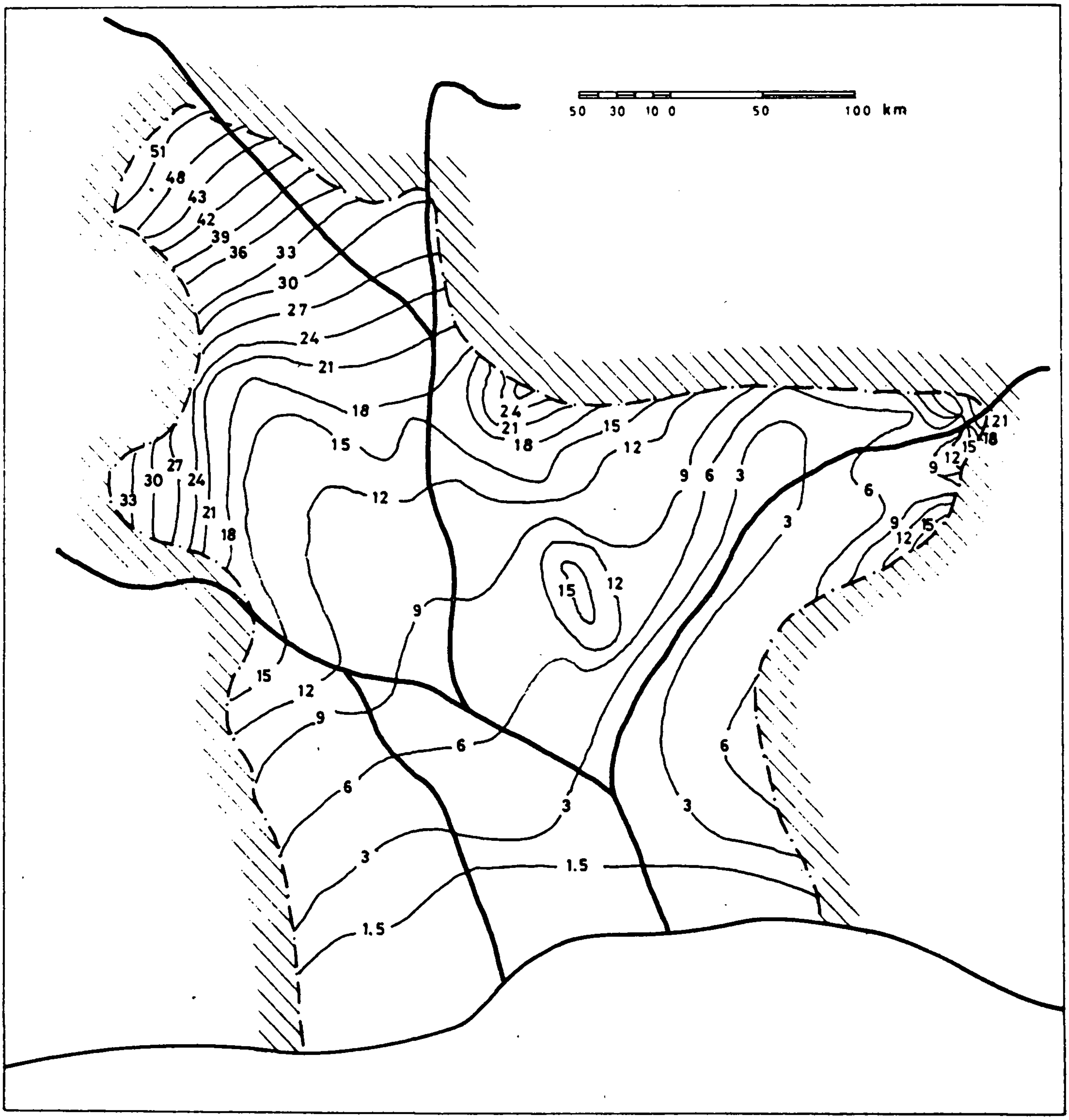


Figure 18. Land surface contours (in m)

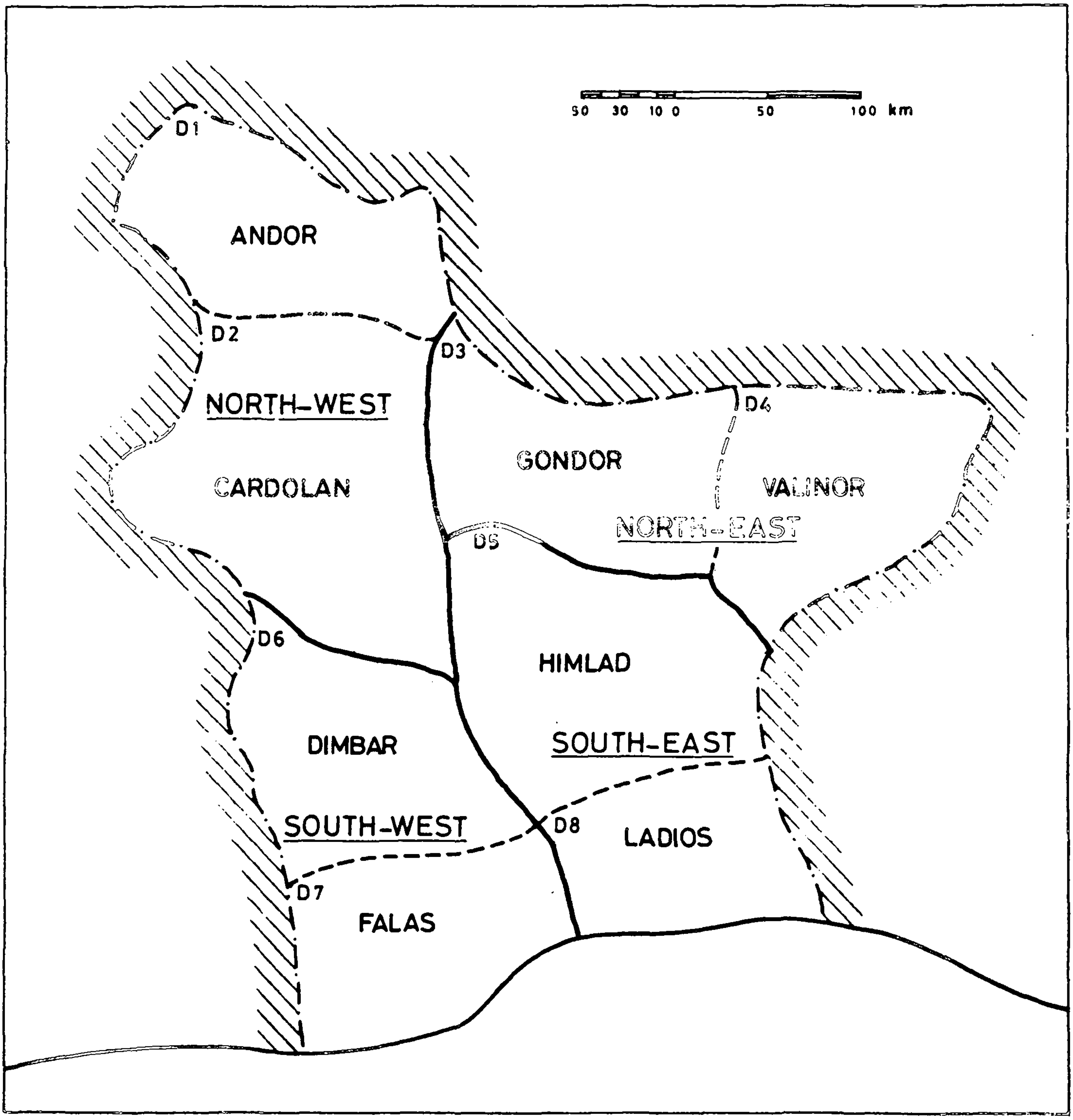


Figure 19. Division into districts

The topography, i.e. the landlevel, in each district varies, leading to differences in flood susceptibility for different parts of a district. Based on these differences in flood susceptibility the area within a district is divided into four landlevels with different elevations. The lowest level has an expected flood depth during an average wet season of over 2 m and the highest level has an expected flood depth of zero. The total area occupied by each of the four landlevels in a district has been derived from maps indicating the flood depth. The location of the various landlevels within the district has not been specified. Different parts of the district with the same flood susceptibility have simply been combined into one area. Besides these four landlevels a certain area of surface water is considered in each district. This area of surface water accounts for lakes and minor streams which are not incorporated in the major river system. The area that is occupied by each landlevel and the surface water area by district is shown in figure 20.

Climate

The climate (rainfall and evapotranspiration) shows distinct differences across the country. Rainfall is most severe in the northeastern part of the country. There is also a distinct wet and a dry season in a year. Almost all rain falls in a period of a few months, while almost none occurs during the remaining months. Evaporation is much more homogeneously distributed over time and regions. The average evaporation amounts to 80-100 mm/month. To account for differences from year to year data have been compiled for what is assumed to be a dry, an average and a wet year. The compiled time series for rainfall and evaporation by district have been arranged in three separate data files. An overview of the rainfall and evaporation data by type of year and region is shown in figures 21-23.

Soil and groundwater system

The different physiographic regions are shown in figure 24. Included are: pleistocene uplands, piedmont plain, flood plain, deltaic plain and tidal plain. To account for differences in soil characteristics like soil-moisture retaining capacity and permeability three different soil types have been distinguished:

(i) fine textured soils;
(ii) moderately fine textured soils; and
(iii) medium textured soils.

River system

Eldoran is located at the delta of two major rivers: the Sirion river and the Salmar river. The major part of the catchment area of these rivers (approximately 90 per cent) is located outside the country. Besides these two rivers there are two other major rivers entering the country: the Legolin river and the Upper Thalos river. The cross boundary inflows of the four rivers are presented in a graphical form in the figures 25-28. The three graphs in each figure pertain to the inflows for a medium, a dry and a wet year, respectively. These three years correspond to the same historic years as the ones used for the rainfall and evaporation data.

The major rivers are by the confluence and separation at several locations. Figure 29 presents a schematic overview of the major rivers together with their respective names. In addition, figure 30, presents an overview of the names of the most important locations (nodes) in the river network. Nodes are found at the cross boundary inflow points and the confluence and separation points. As indicated in figure 29 the rivers finally flow into the Balar sea as the rivers Celon and Lower Thalos.

Besides these major rivers, numerous small streams and rivers exist; these have been included in the surface water area of the districts. A schematic overview of these minor rivers is shown in figure 31. This figure also indicates the prevailing drainage direction of the small streams within a district. This information is used to schematize the surface and groundwater system of the country Eldoran into a district-network concept.

Schematization of natural system

The natural system of Eldoran is schematized into a district-network system. The districts represent the land and groundwater system as well as the regional surface water system, while the network represents the major river system. The division into districts together with the major river system is shown in figure 32. A more schematic presentation is given in figure 33. In this figure also the interaction between the districts and the network (withdrawals, drainage) has been indicated. These interactions are in agreement with the prevailing drainage direction as shown in figure 31.

2.2 Water users

Three important water users have been explicitly distinguished: agriculture, navigation and fisheries. On each of these water users some information is presented in this section. Agriculture will receive the most attention during the workshop: a more or less thorough activity analysis will be carried out for agriculture, while the other two water users will only be dealt with more briefly. For the latter two, the attention will merely focus on the transportation opportunities(navigation) and fish production as affected by water resources management strategies. As a result, most of the information presented in this section is devoted to agriculture.

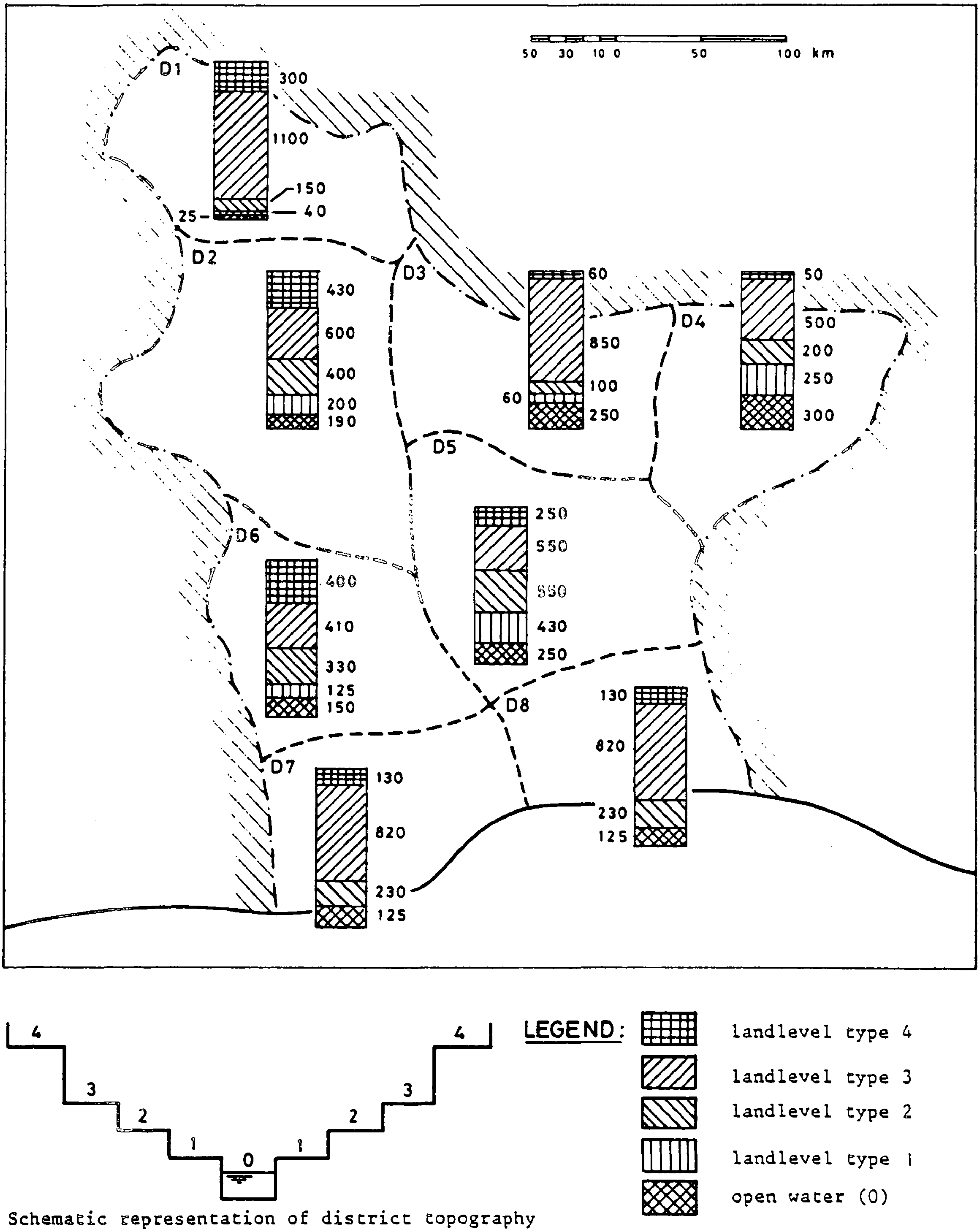
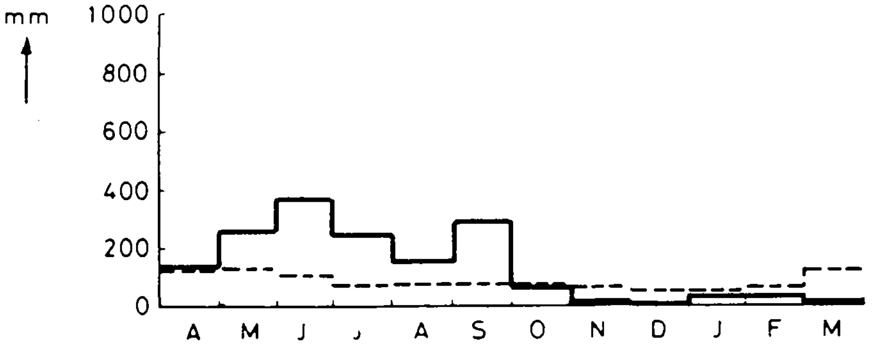
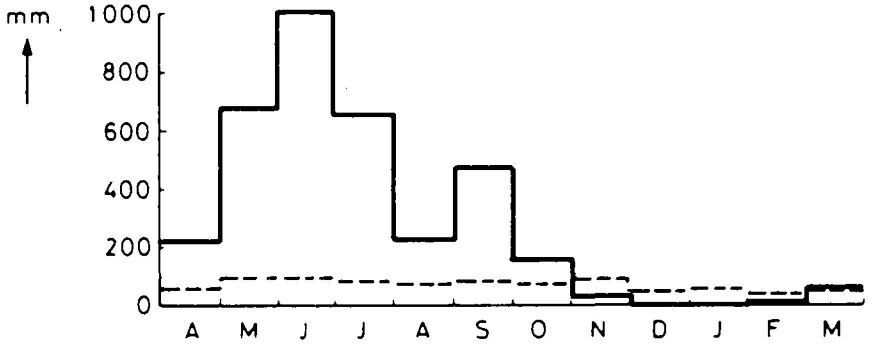


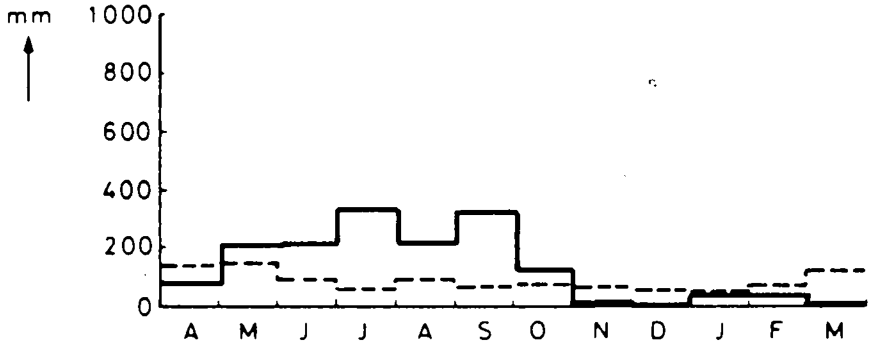
Figure 20. Overview of regional topography (in 1,000 ha)



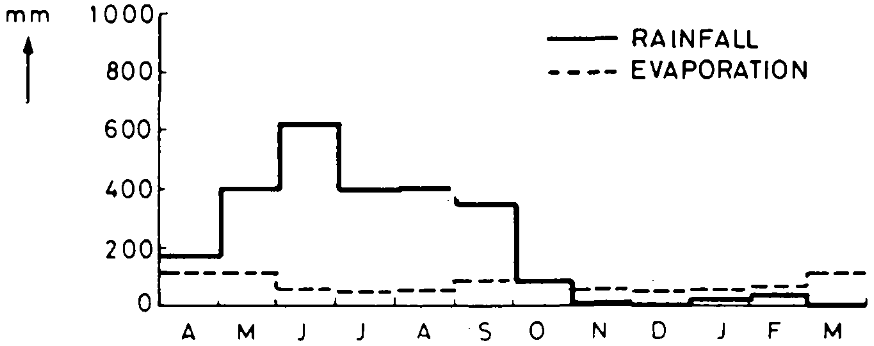
NORTHWEST (D1, D2)



NORTHEAST (D3, D4)



SOUTHWEST (D5, D8)



SOUTHEAST (D6, D7)

Figure 21. Rainfall and evaporation (medium year)

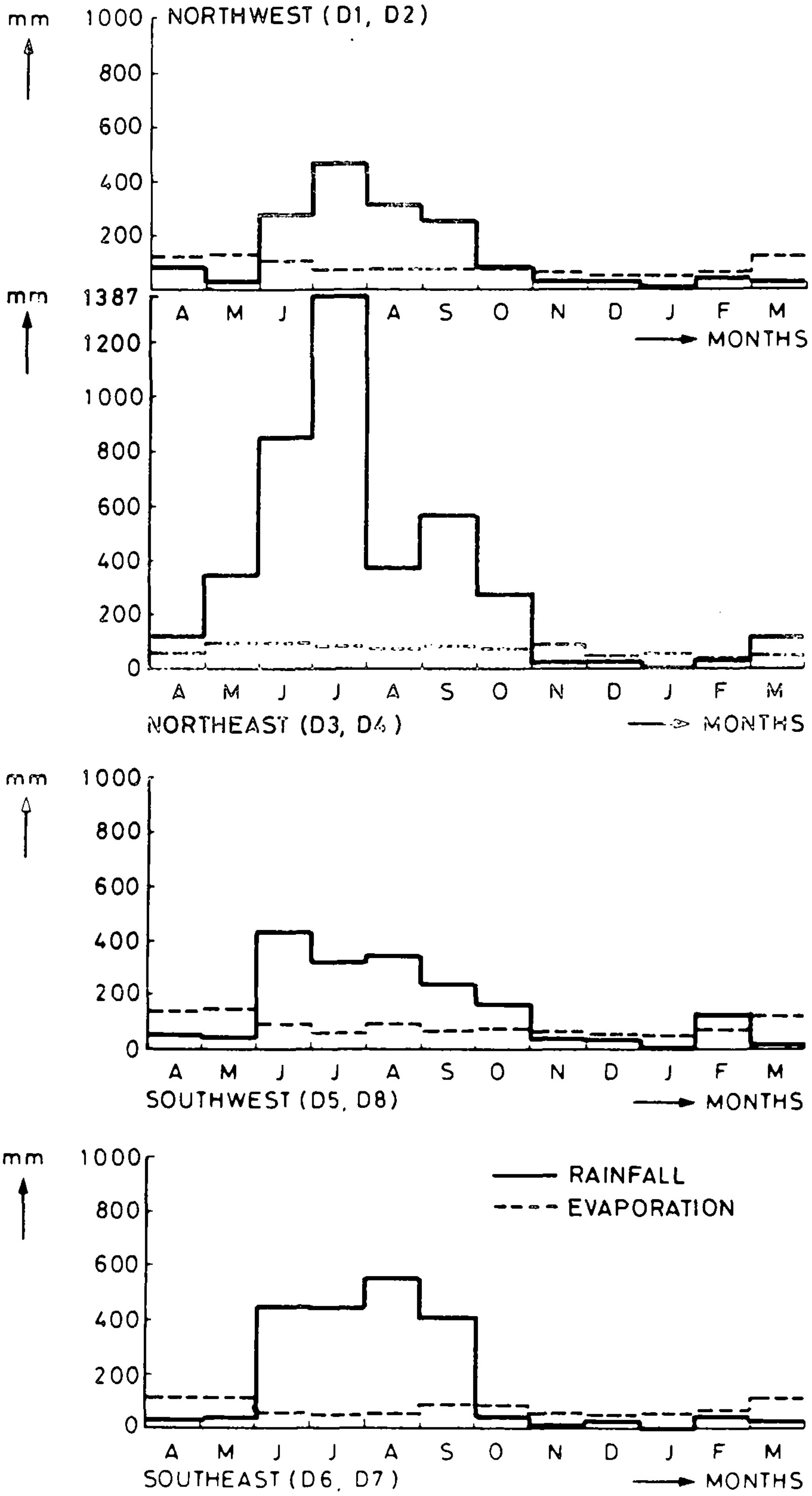


Figure 22. Rainfall and evaporation (dry year)

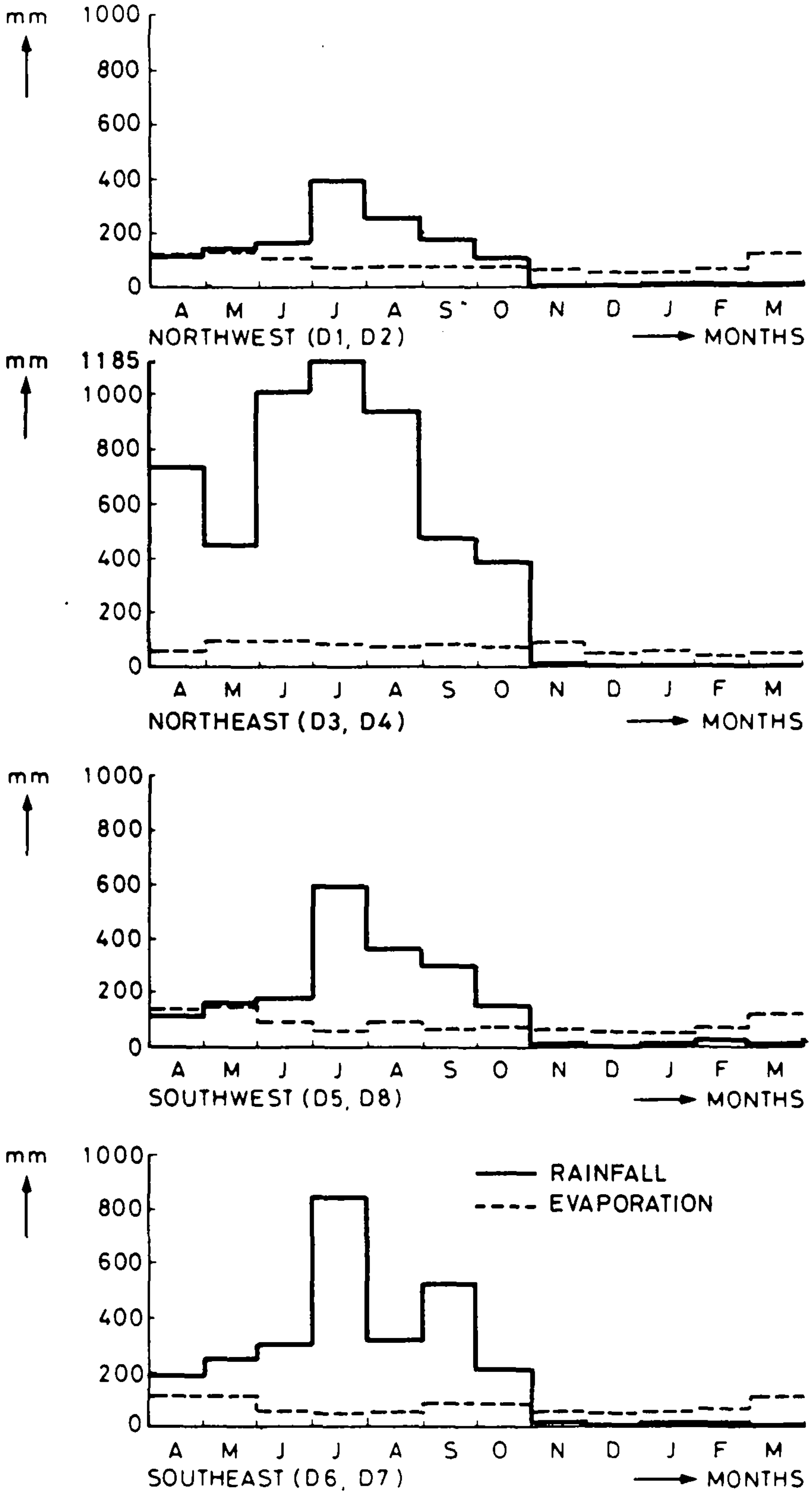


Figure 23. Rainfall and evaporation (wet year)

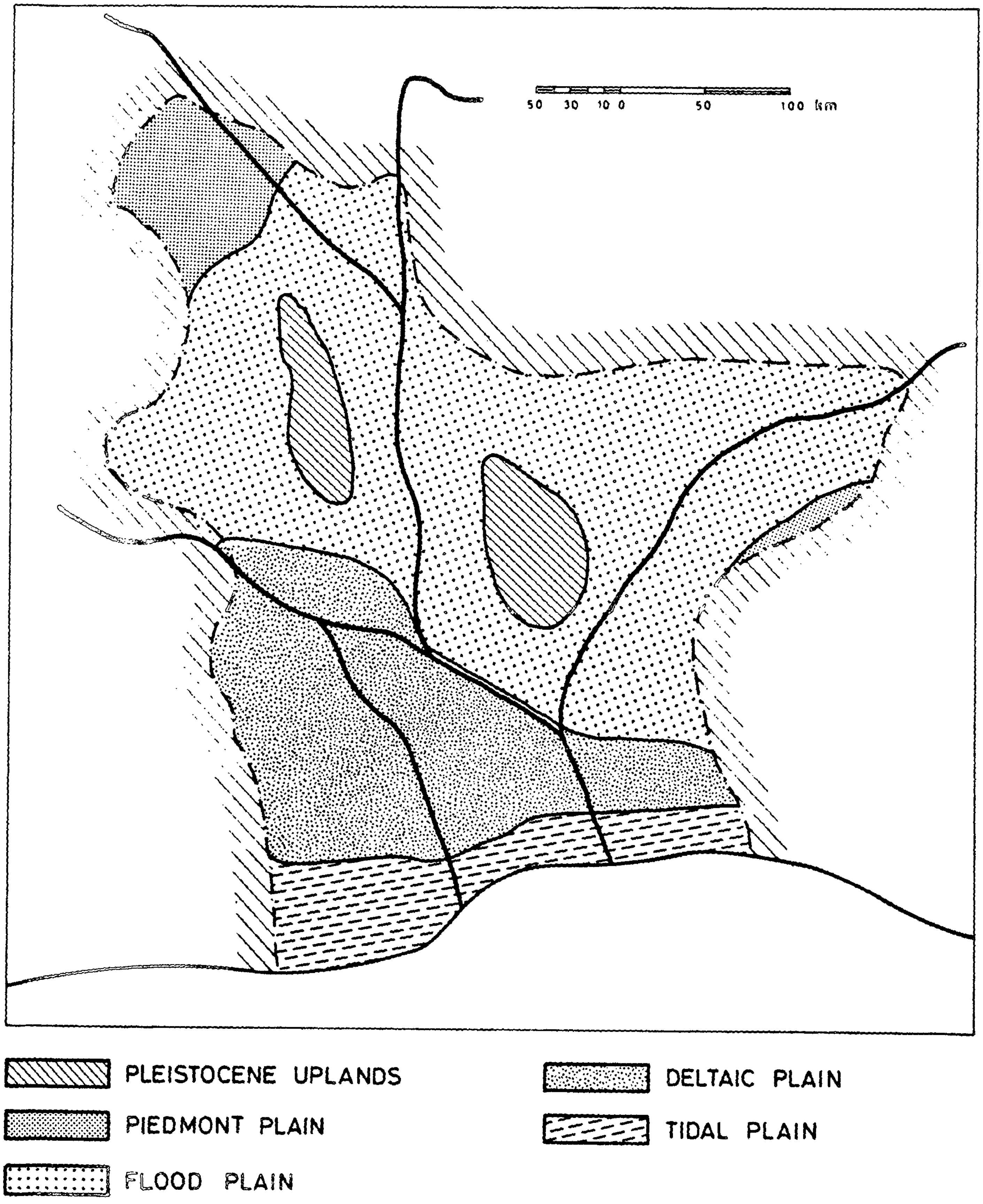


Figure 24. Overview of physiographic regions

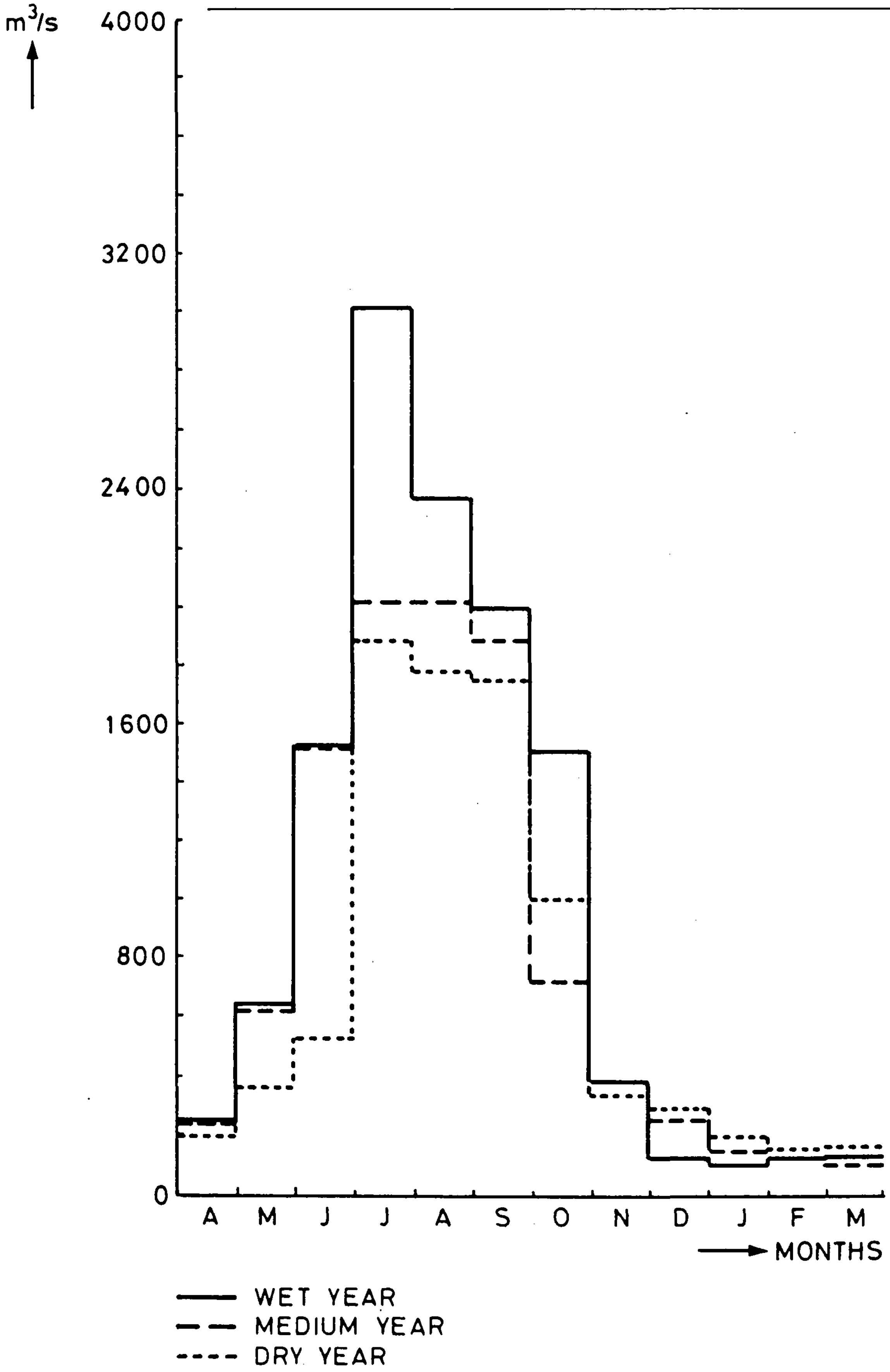


Figure 25. Cross-boundary inflows River Legolin at Nivrim (N1)

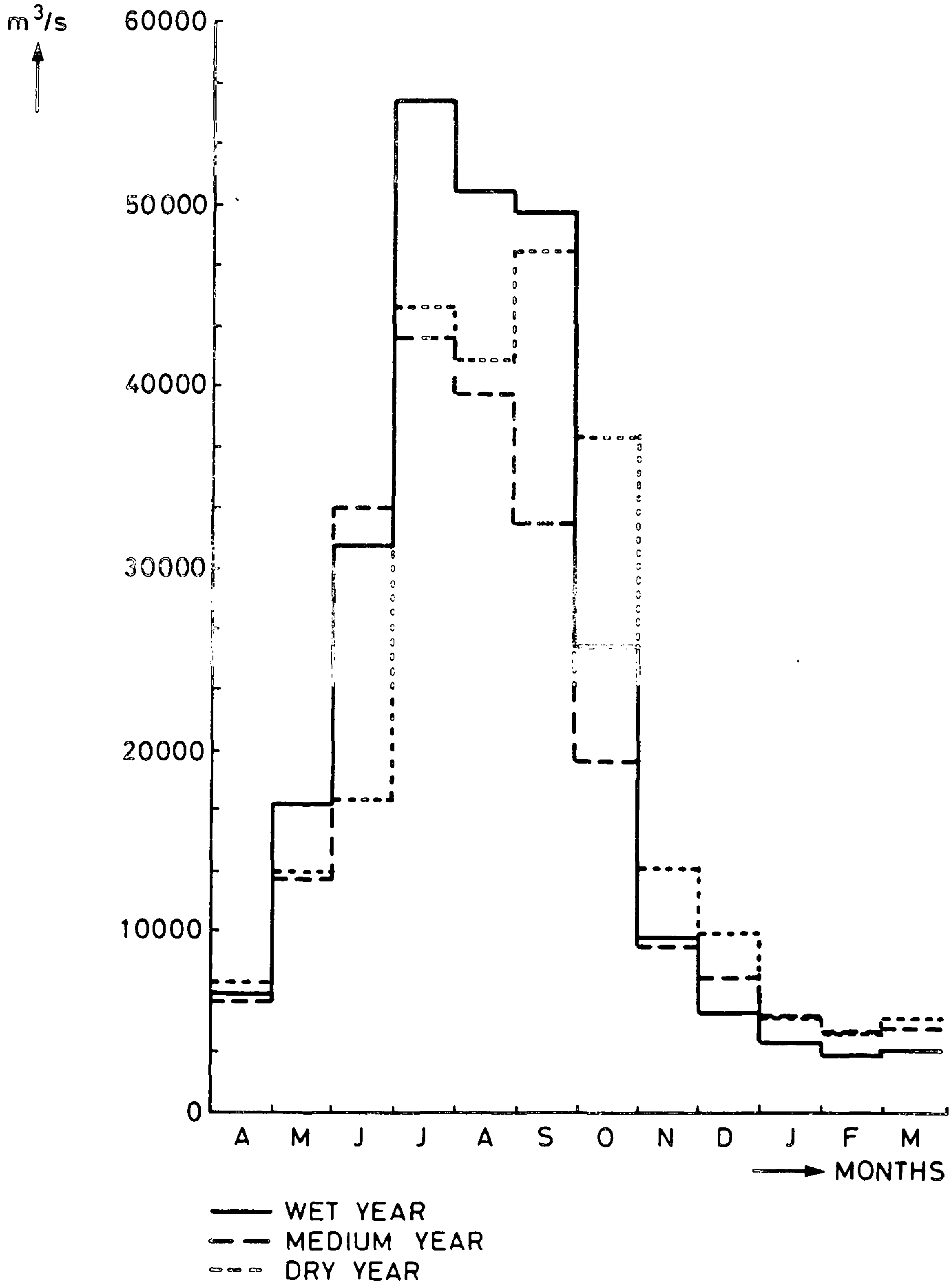


Figure 26. Cross-boundary inflows River Sirion at Mandos (N2)

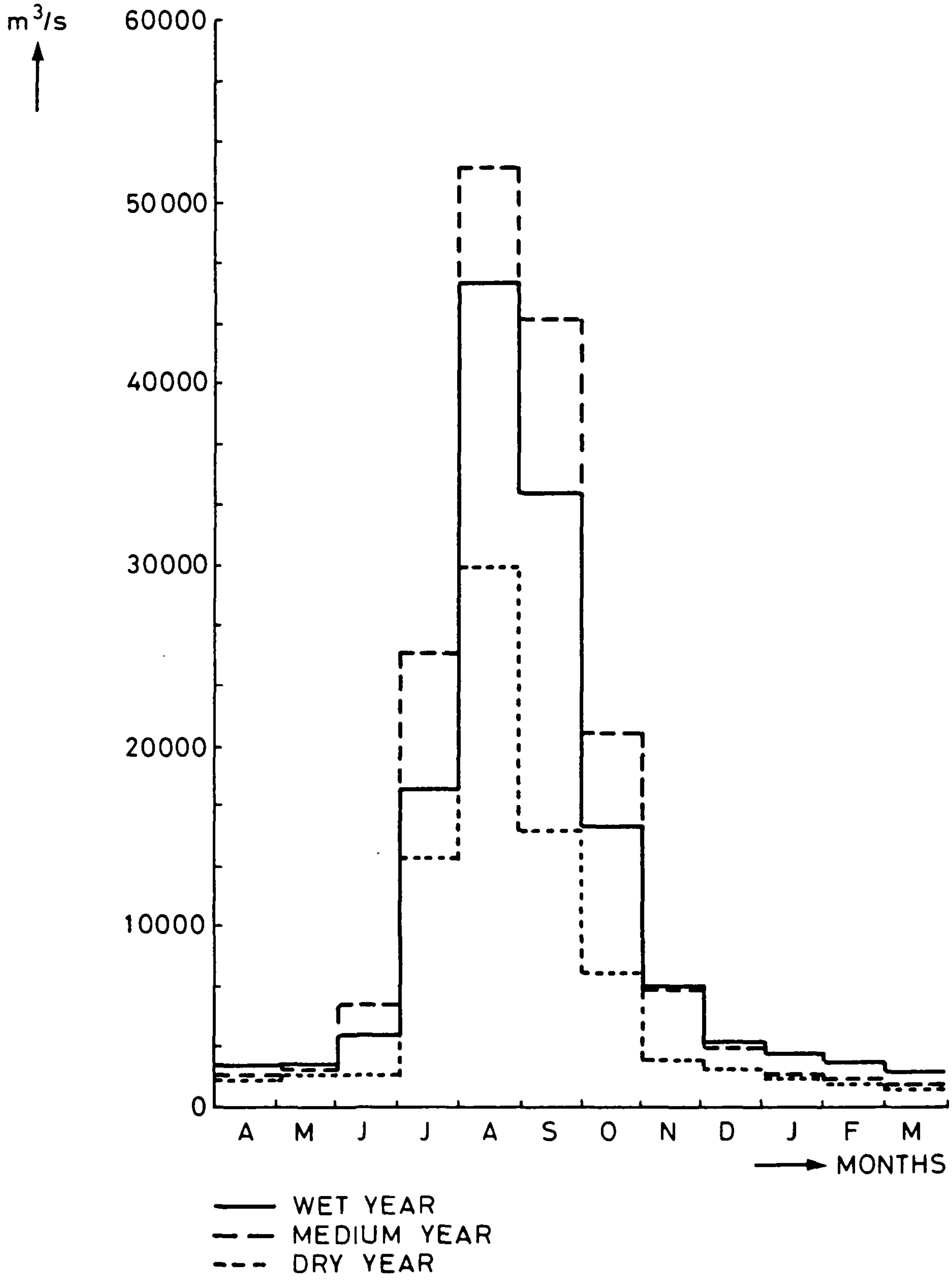


Figure 27. Cross-boundary inflows River Salmar at Ulmo (N3)

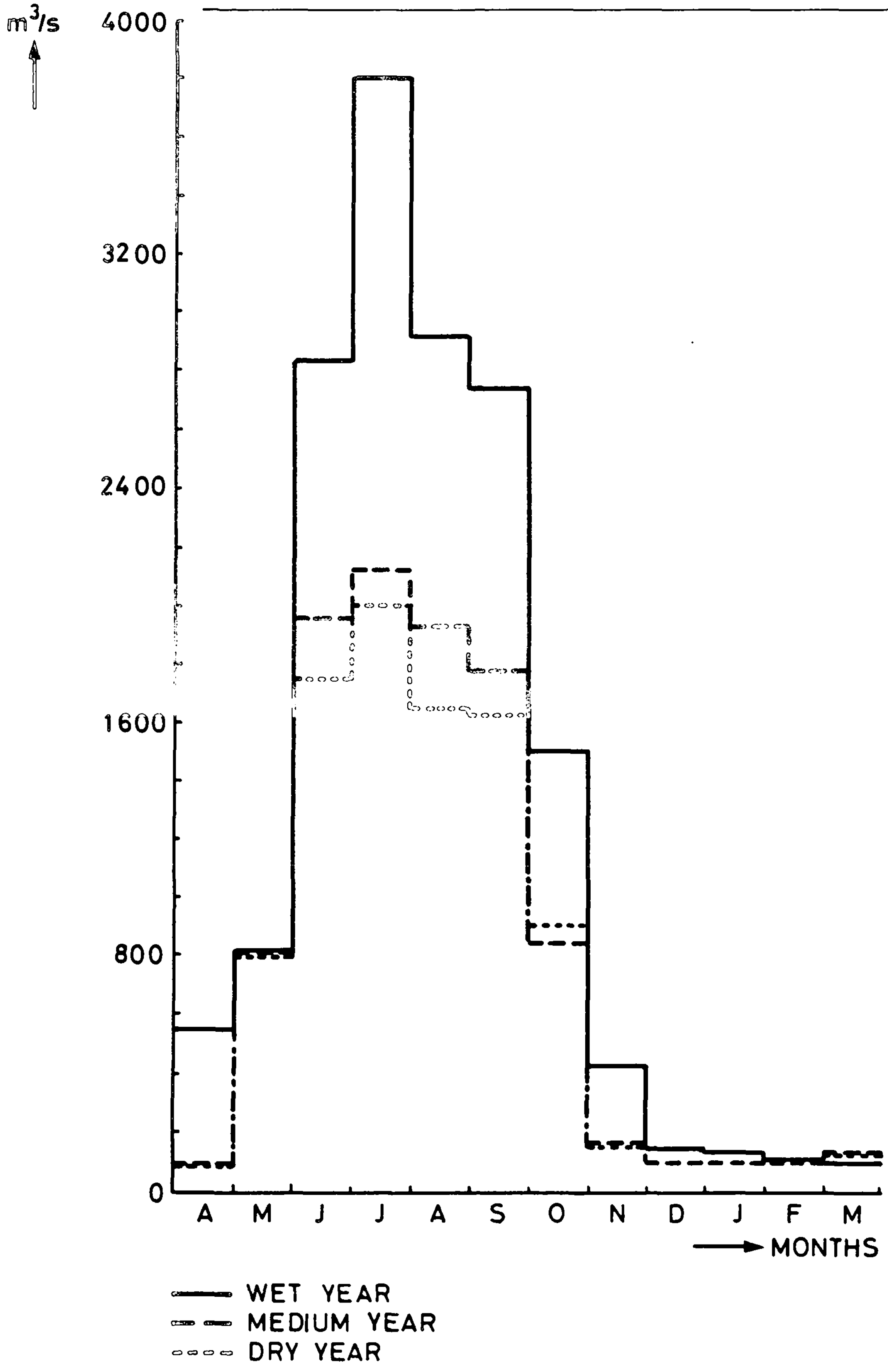


Figure 28. Cross-boundary inflows River Upper Thalos at Bragol (N6)

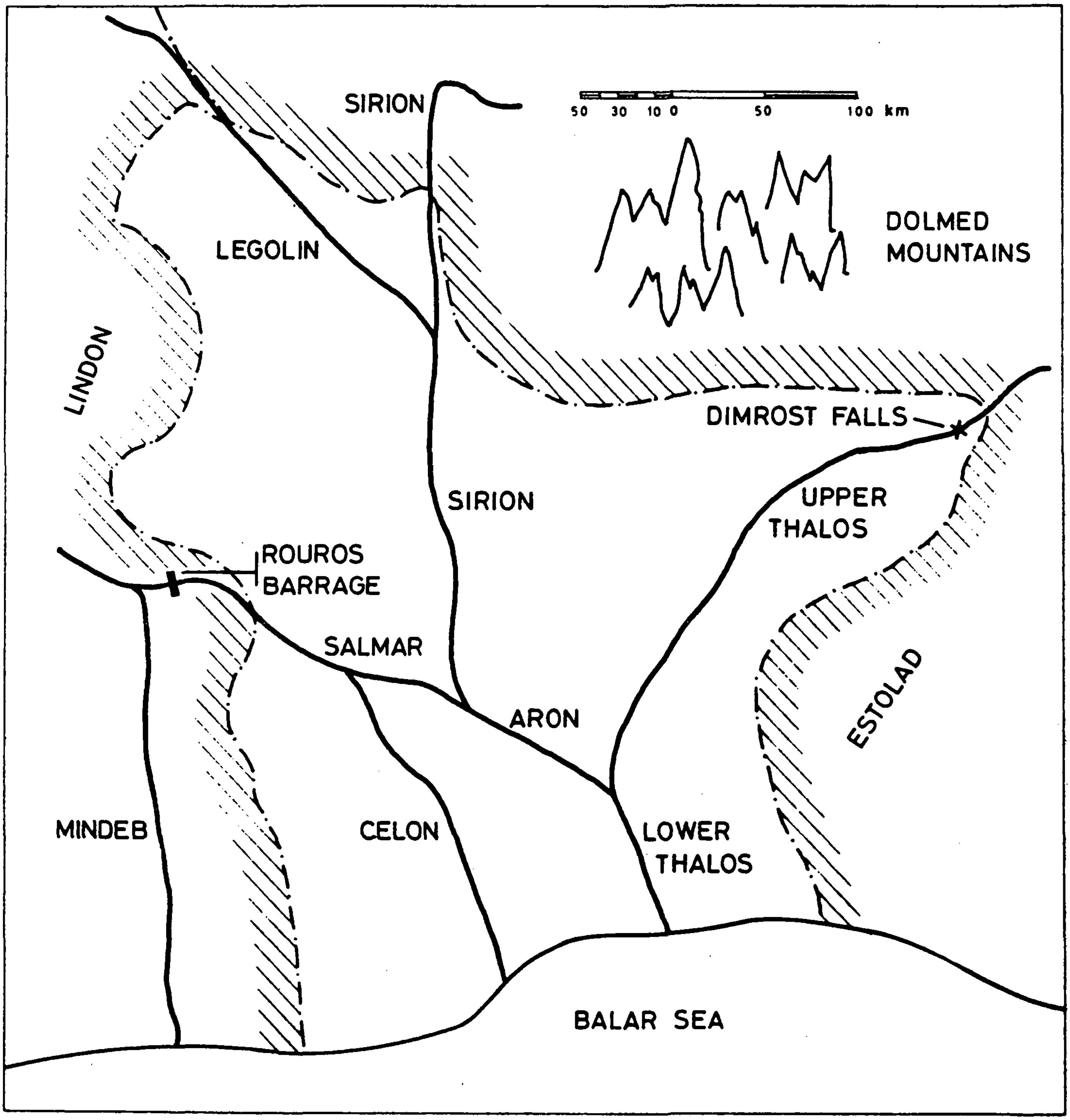


Figure 29. Major river system

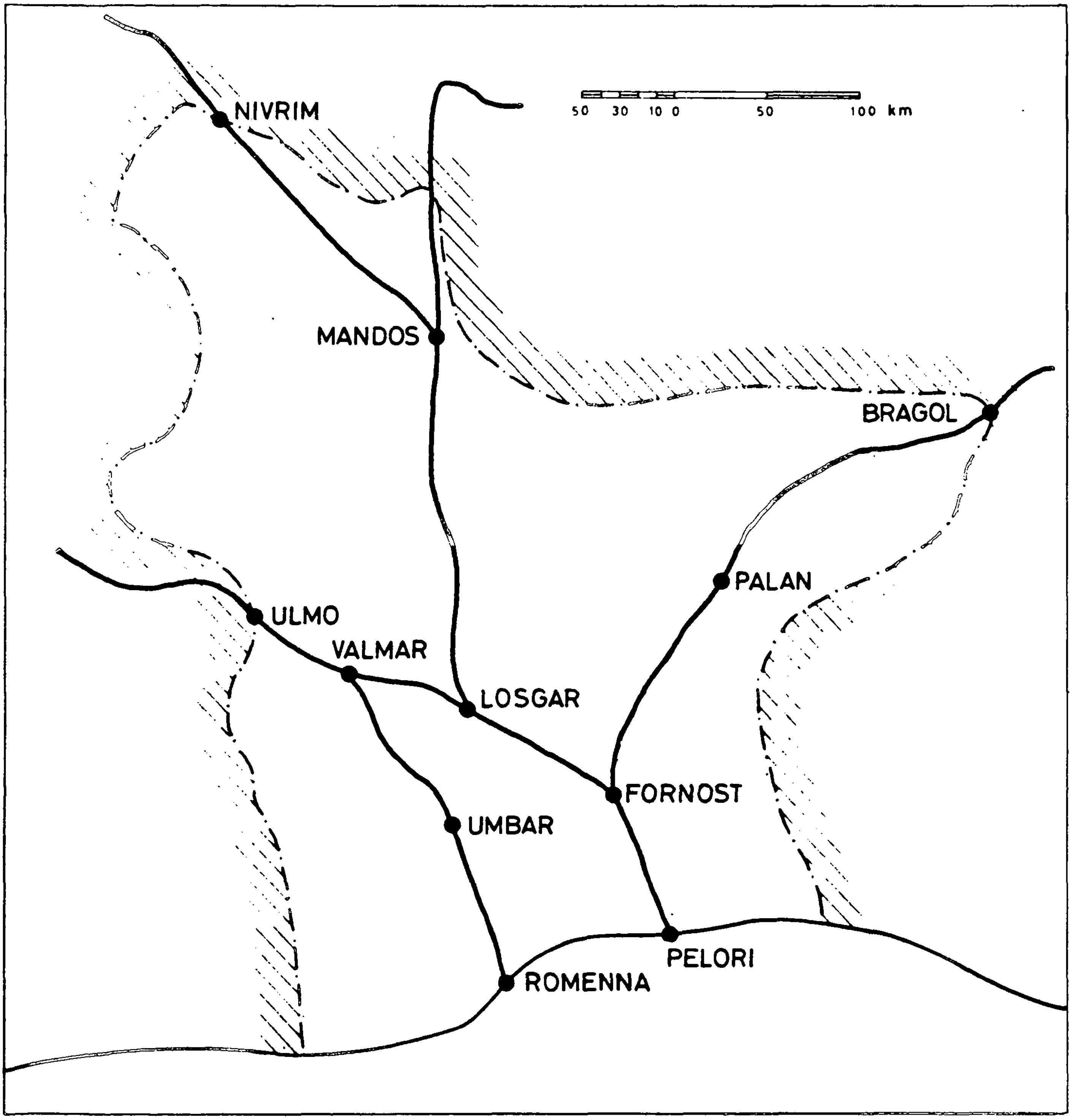


Figure 30. Nodes in major river system

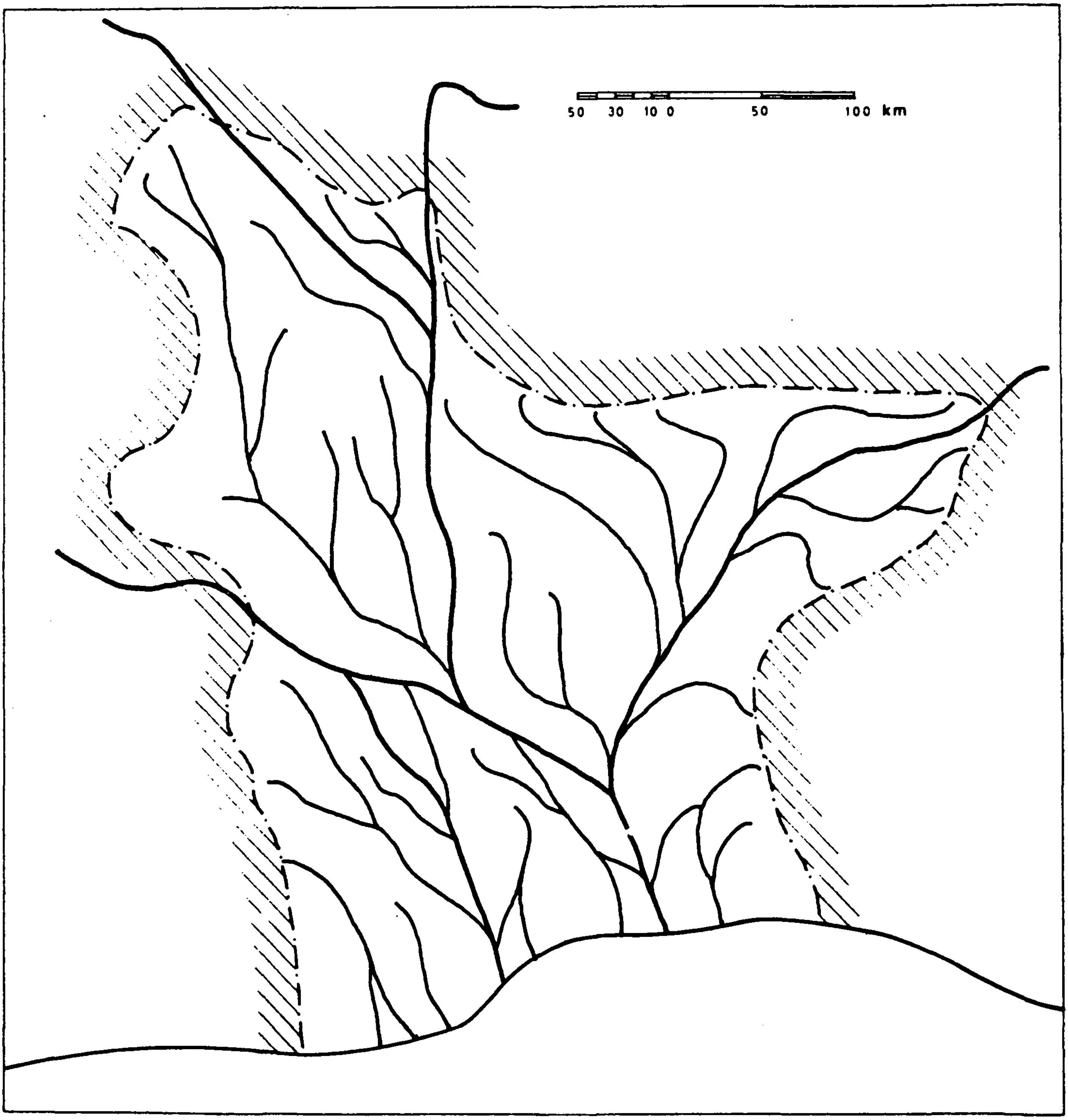


Figure 31. Minor river system together with major river system

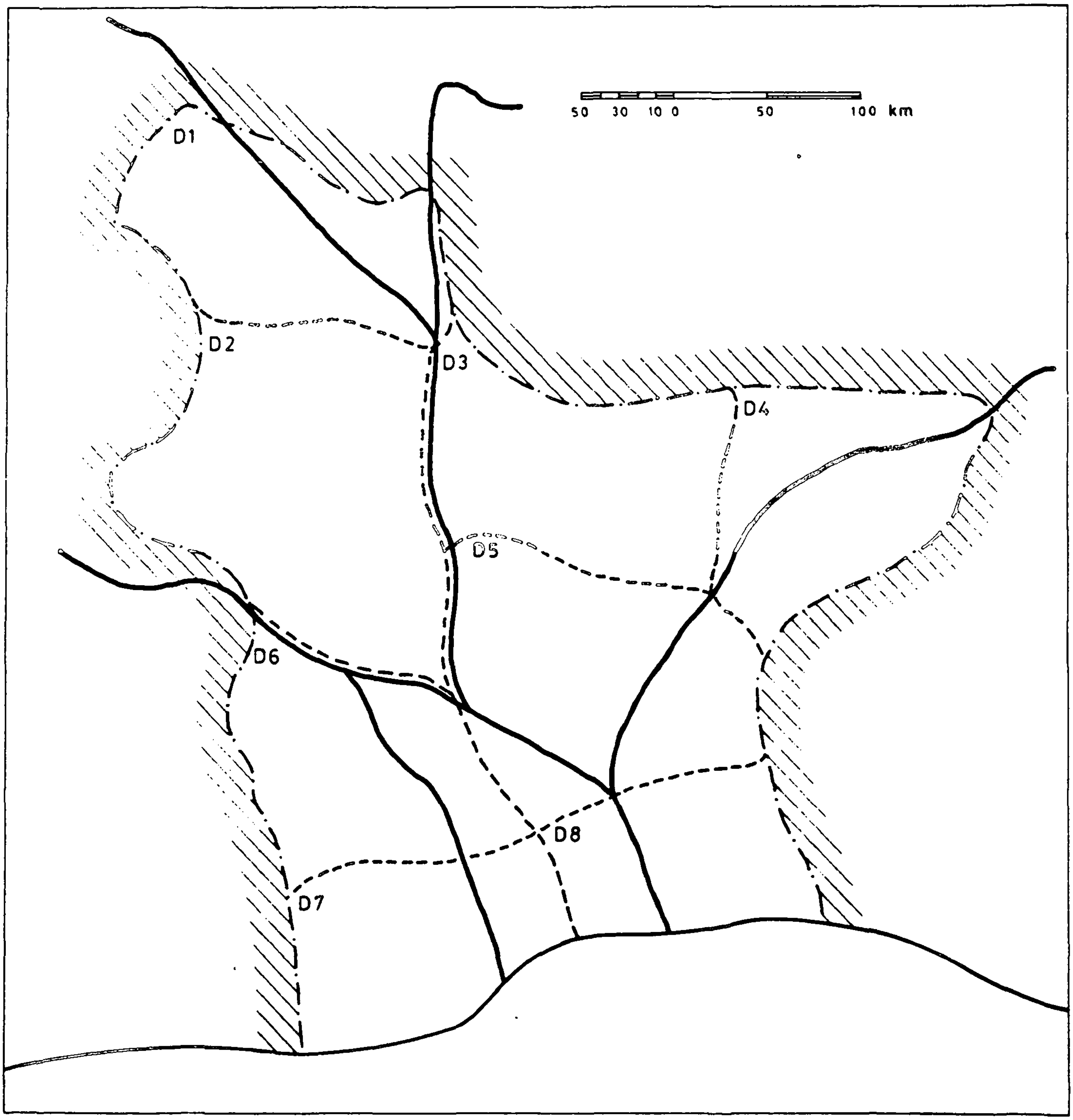


Figure 32. District division together with major river system

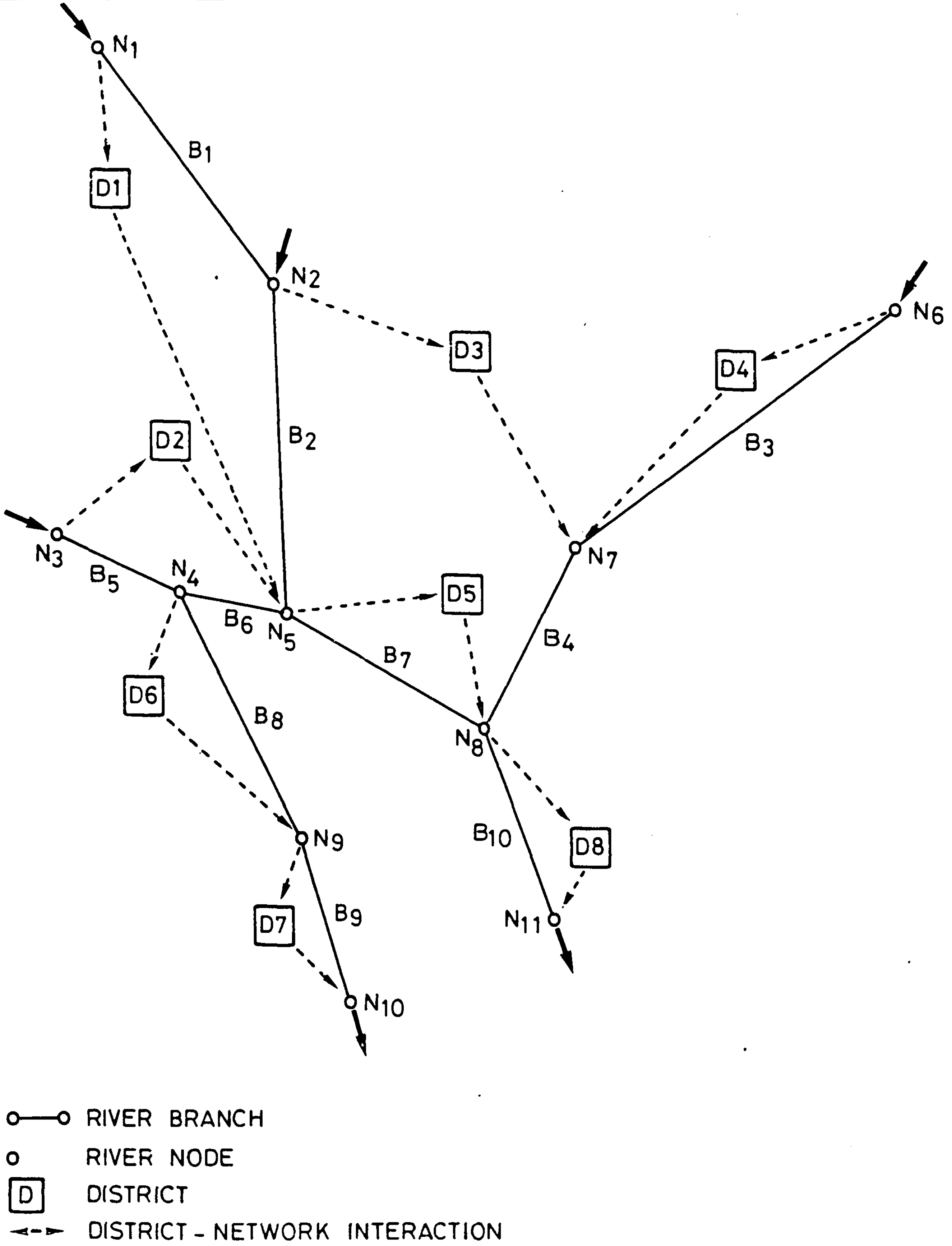


Figure 33. Overview of network and district schematization

Agriculture

The information on agriculture concerns the following items:

a) crop types, cropping patterns and growing season;
b) crop water requirements;
c) potential yield and damages;
d) existing agricultural production system.

a) Crop types, cropping patterns and growing season

The main objective of the water sector masterplan for Eldoran is to establish the water resources conditions necessary for an increase in the production of foodgrain. For that reason several foodgrain crop types have been distinguished. Rice is by far the most important foodgrain in Eldoran. Three main types of rice exist: *Aus*, *Aman* and *Boro*. Of these rice types 2 or 3 different varieties are considered: a locally transplanted (LT) or broadcasted (B) variety and high yielding variety (HYV). Besides rice one other type of foodgrain is considered: HYV Wheat.

In addition to foodgrain only a limited number of other crop types have been distinguished. These are: jute (an important export crop), sugarcane, pulses and oilseeds.

The crop types considered are presented in table 4 together with their growing season. It is important to note that the growing season of most crops is approximately four months which creates the opportunity to raise three crops in a year from the same area, provided that the other conditions are favourable. The three rice types considered *(Aus, Aman, Boro)* each grow in a different part of the year as is shown in table 4.

Table 5 presents the cropping patterns which have been distinguished for this study. The number of croptypes within a cropping pattern ranges from one to three. The existence of different cropping patterns depends to a certain degree on landlevel and soil type. Landlevel is important because of flood susceptibility and the potential for capillary rise. With the higher landlevels the groundwater is deeper and hence the contribution of capillary rise to the water supply of the crops is less. Also the soil type is important in relation to the water supply of the crops. The relationship between cropping pattern, landlevel and the corresponding soil type is also indicated in table 5.

b) Crop water requirements

With the help of the district model (see Chapter III: computational framework) the crop water requirements are determined for each timestep (10-days period) during the growing season. For that purpose, in each timestep a water balance is calculated for the rootzone. Variables considered in the calculation of the water balance are: rainfall, potential evapotranspiration, rootzone storage and capillary rise. Of these variables two depend on crop type: the potential evapotranspiration and the rootzone storage. The potential evapotranspiration (E_p) is determined by multiplication of the open water evaporation (E_o) with a time dependent crop factor (C_{fac}):

$$E_p = E_o \; C_{fac}$$

These crop factors are presented in table 6. The rootzone storage depends amongst others on the root depth of the crop type. In table 7 the root depths have been specified for each crop type.

c) Potential yield and damages

The potential yield of each crop type (in tons/ha) has been specified in table 8. A distinction is made between present non-water inputs (use of fertilizer, pesticides) and an increased use of these inputs. For both inputs a separate data file was compiled in which the information in potential yield has been collected.

Actual yield may deviate from the potential if the water resources conditions are not optimal. Three types of potential damages are considered: drought damage, salt damage and flood damage. For each of these damages an impact relationship has been derived.

The damage due to drought is related to the ratio of the accumulated actual evapotranspiration over the growing season and the accumulated potential evapotranspiration. The impact relationship and the parameter values for each crop type are shown in table 9 and the corresponding figure.

The determination of flood damage takes into account both the flood depth and the flood duration. A critical flood depth is introduced for this purpose. If this critical depth is exceeded the extent of exceedance is determined and accumulated over the flooding period. Finally the accumulated exceedance is entered into the impact relationship to determine the yield reduction. Table 10 and the corresponding figure present the impact relationship and the parameter values for each crop type.

Salt damage is related to the salt concentration of the rootzone. For this purpose a salt balance of the rootzone is determined for each timestep. Salt can only enter the rootzone by applying surface water irrigation. This implies that salt damage will only occur in the southern districts where salt intrusion from the sea may be considerable during low flow periods of the major river system. The calculated salt concentration of the rootzone is compared with a critical level and the average excess over the growing season is determined. Based on this average excess of the critical salt concentration the yield reduction is determined. In table 11 and the corresponding figure the impact relationship is shown as well as the parameter values for each crop type.

Crop type	Number of timesteps	Period in calender months
1. B. Aus	1-11	(begin April - end July)
2. HYV. Aus	1-11	(begin April - end July)
3. B. Aman	1-24	(begin April - begin December)
4. LT. Aman	12-24	(end July - begin December)
5. HYV. Aman	12-23	(end July - end November)
6. L. Boro	24-35	(end November - end March)
7. HYV. Boro	25-36	(begin December - begin April)
8. HYV. Wheat	24-35	(end November - end March)
9. Jute	1-11	(begin April - end July)
11. Sugarcane	1-36	(year around)
13. Pulses	24-34	(end November - mid March)
14. Oilseeds	24-36	(end November - begin April)

Table 4. Period of growing season by crop type
(in number of 10-days timesteps)

N.B. The hydrological year starts in April. In the model the first timestep coincides with the first 10 days of April.

	Cropping pattern			Land level	Soil type
1.	B. Aus	LT. Aman	Pulses	3	III
2.	B. Aus	HYV. Aman	HYV. Wheat	3	III
4.	B. Aus	LT. Aman	Local Boro	3	II
5.	HYV. Aus	HYV. Aman	HYV. Boro	3	II
6.	HYV. Aus	HYV. Aman	Pulses	3	II
7.	HYV. Aus	HYV. Aman	HYV. Boro	3	II
9.	Jute	LT. Aman	Pulses	4	III
11.	B. Aus	Oilseeds		4	III
13.	B. Aus	HYV Wheat		4	II
14.	B. Aus	HYV. Aman		3	II
16.	B. Aus	HYV. Boro		3	II
17.	B. Aus	Local Boro		3	II
18.	Jute	HYV. Wheat		4	III
19.	Jute	Pulses		4	III
20.	Jute	Oilseeds		4	III
21.	Jute	HYV. Boro		3	I
22.	Jute	Local Boro		3	I
24.	B. Aus	HYV. Aman	HYV. Boro	3	II
25.	HYV. Aus	HYV. Aman		3	I
26.	HYV. Aman	HYV. Boro		3	I
27.	LT. Aman	Local Boro		3	I
28.	HYV. Aman	HYV. Wheat		3	II
29.	B. Aman	HYV. Wheat		2	I
30.	Sugarcane			4	II
31.	B. Aman			2	I
32.	LT. Aman			3	I
33.	B. Aus			4	III
34.	Local Boro			1	I
35.	HYV. Boro			1	I
36.	B. Aus	Pulses		4	III
37.	-	-	-		

Table 5. Overview of cropping patterns with related landlevel and soil type

month croptype	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Febr.	March	Average
Aus	1.10	1.15	1.30	1.00									1.15
Aman					1.10	1.15	1.30	1.00					1.15
Boro									1.00	1.15	1.25	1.00	1.10
Wheat								0.50	0.75	1.15	0.70	0.70	0.75
Jute	0.90	0.90	1.20	1.20									1.05
Sugarcane	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Pulses								0.60	0.70	0.70	0.70	0.60	0.65
Oilseeds								0.60	0.70	0.70	0.80	0.70	0.70

Table 6. Crop factors to determine crop water requirements
(by crop type and by month)

Crop water requirements = (crop factor) x (open water evaporation)

Crop type	Root depth
Rice	25 - 30
Wheat	30 - 36
Jute	50 - 60
Sugarcane	60 - 70
Pulses	20 - 25
Oilseeds	30 - 35

Table 7. Root depths of crop types (in cm)

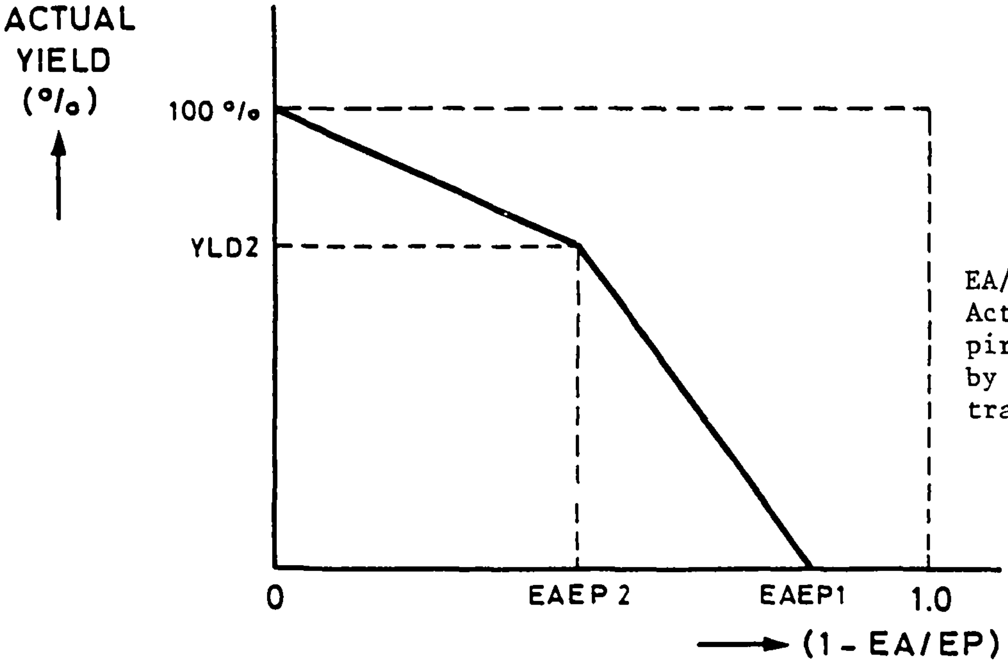
N.B. In the model implementation a fixed value has to be specified. The average value of the indicated interval has been used.

Crop type	Present input	Increased input
1. B. Aus	0.74	0.81
2. HYV. Aus	2.20	2.42
3. B. Aman	0.93	1.02
4. LT. Aman	1.26	1.39
5. HYV. Aman	2.20	2.42
6. L. Boro	1.34	1.47
7. HYV. Boro	2.20	2.42
8. HYV. Wheat	1.75	1.93
9. Jute	1.50	1.65
10. Sugarcane	37.00	40.70
13. Pulses	0.80	0.88
14. Oilseeds	1.20	1.32

Table 8. Potential yield by crop type for different non-water inputs
(in tons/ha).

Croptype	EAEP1	EAEP2	YLD2
1. B. Aus	0.80	0.30	80
2. HYV. Aus	0.65	0.30	80
3. B. Aman	1.00	1.00	100
4. LT. Aman	0.70	0.30	75
5. HYV. Aman	0.70	0.30	75
6. L. Boro	1.00	0.50	75
7. HYV. Boro	0.70	0.30	70
8. HYV. Wheat	1.00	0.50	75
9. Jute	0.80	0.30	80
11. Sugarcane	0.85	0.30	80
13. Pulses	1.00	0.40	85
14. Oilseeds	1.00	0.50	80

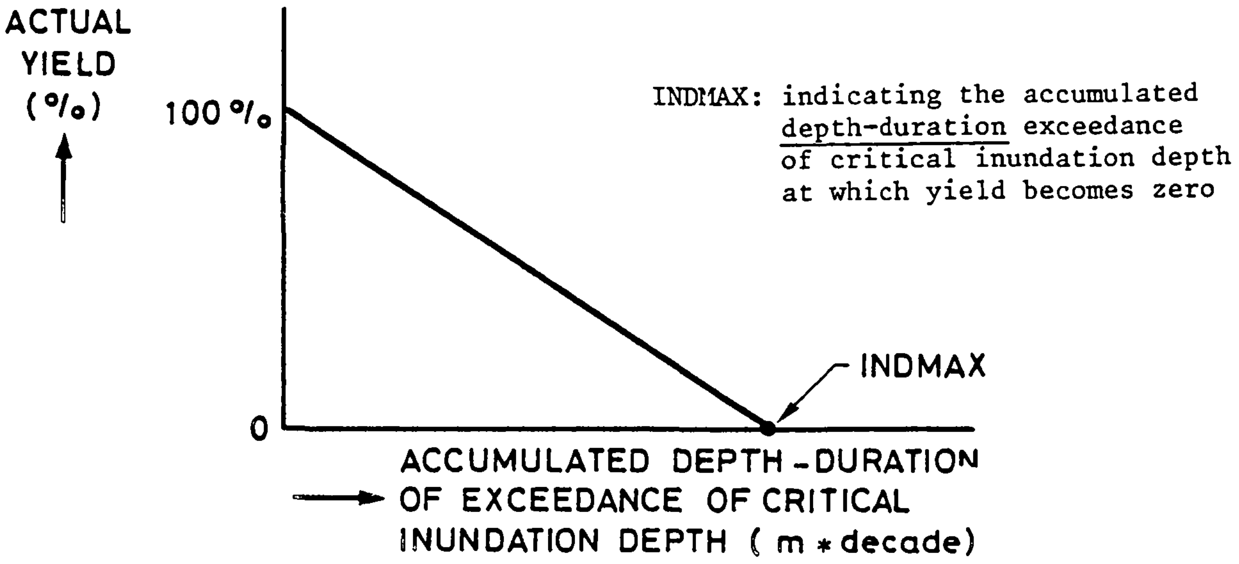
Table 9. Parameters of yield-reduction curve for drought damage
(by crop type)



EA/EP:
Actual evapotranspiration divided by potential evapotranspiration

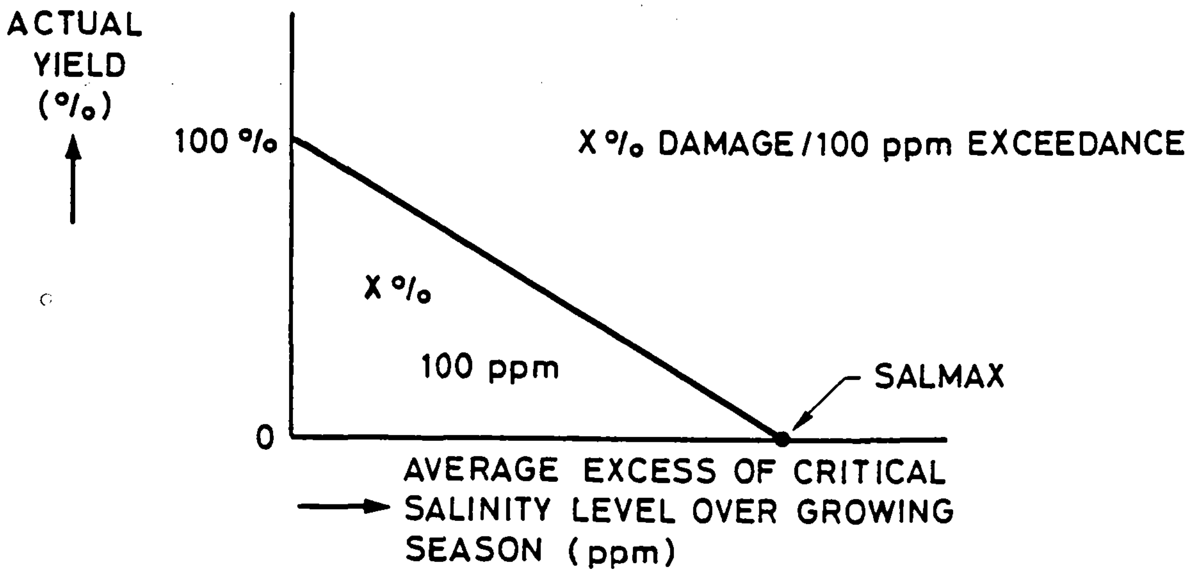
Crop type	Critical flood depth (in m)	INDMAX (m * decade) (see figure)
1. B. Aus	0.30	2.5
2. HYV. Aus	0.25	5.0
3. B. Aman	1.60	4.0
4. LT. Aman	0.45	5.0
5. HYV. Aman	0.45	6.0
6. L. Boro	0.40	3.0
7. HYV. Boro	0.25	1.9
8. HYV. Wheat	0.25	9.9
9. Jute	1.80	1.8
11. Sugarcane	1.50	4.2
13. Pulses	0.25	9.9
14. Oilseeds	0.25	9.9

Table 10. Parameters of yield-reduction curve for flood damage
(by crop type)



Crop type	Critical salt concentration (mg/l)	% damage for 100 ppm exceedance
1. B. Aus	1000	5.0
2. HYV. Aus	1000	5.0
3. B. Aman	1200	1.5
4. LT. Aman	1200	3.0
5. HYV. Aman	1200	3.0
6. L. Boro	1200	2.0
7. HYV. Boro	1200	3.0
8. HYV. Wheat	1500	2.0
9. Jute	1000	10.0
11. Sugarcane	1000	3.3
13. Pulses	750	10.0
14. Oilseeds	750	10.0

Table 11. Parameters of yield-reduction curve for salt damage
(by crop type)



d) Existing agricultural production system

Information on the agricultural production system for the present conditions is compiled in the so-called PLOT-file (see chapter III). This file indicated the area of a certain cropping pattern in a certain district; the landlevel on which the cropping pattern is located, the soiltype and whether or not it is irrigated, and by which source (surface water or groundwater). The PLOT-file contains a lot of information which is not easily accessible at first glance. That is why some of the characteristics of the present agricultural production has been condensed in a few figures and tables.

Figure 34 presents an overview of the existing agricultural land use. Indicated by district is the area which is non-cultivated and the areas on which one, two or three crops are grown. Also the crop intensity by district, as well as the overall value is presented in figure 34.

The irrigation situation by district in the present situation is shown in figure 35. The presented areas concern the non-irrigated area, the groundwater irrigated area and the surface water irrigated area.

Figure 36 provides an overview of the potential foodgrain production by district for the present situation. The numbers indicate annual foodgrain production in 1,000 tons.

Finally in table 12 an indication is presented of the relation between the existence of a certain cropping pattern and the irrigation situation. This information is important with respect to potential shifts in cropping pattern as a consequence of the execution of regional irrigation or flood control and drainage measures.

Fisheries

In the case study fisheries will only be dealt with to the extent fish production is influenced by water resources management strategies. For each district a potential fish production has been specified (in tons/year) in figure 37. It is assumed that actual fish production equals the potential production as long as the water depth exceeds 1.5 m. If the water depth falls below this critical level, actual production is reduced. A linear reduction in production is assumed.

Navigation

Based on an analysis of the present transportation system, the relative importance of the various navigation routes was determined. For each of the river branches this relative importance is expressed in the percentage of the total volume of transported goods passing the branch. As it turns out, two branches are by far the most important, carrying 36 per cent and 41 per cent of total transported goods, respectively (see figure 38). Within these two branches, the most critical location with respect to the water depth was determined (shown in figure 38). As the water level falls below the draft of the biggest vessels using the route, damage in terms of untransported goods starts to occur. If water depth is zero, no goods are transported. The relation between water depth and amount of untransported goods turns out to be almost linear. Damage in terms of untransported goods (expressed in tonmiles) are translated into money terms using a certain price per tonmile. In this way a direct relation is established between river water levels (to be influenced by water management strategies) and (financial) damage to navigation.

2.3 Socio-economic situation

Eldoran is a developing country facing a number of severe socio-economic problems that are more or less typical for developing countries in general. The country has a high and rapidly growing population. The biggest problem is that the current population cannot be sustained by the country's own food production. Capital means for food imports are lacking, making the country dependent on foreign aid. The balance of trade is always negative. The lack of financial means severely hampers the required investments to increase production capacity of food and industrial products.

The first objective should be to become (and remain) self-sufficient in food production. The target amounts of foodgrain to be produced can be derived from the number of people to be fed in the current and future situation. Figure 39 provides an overview of the (projected) number of people by district for the years 1985, 1990 and 2005 respectively.

Agricultural yields can be increased by using more non-water inputs (like fertilizer and pesticides). In the current situation, only 21 per cent of what would be optimal is used. An increased use of non-water inputs in future should be expected. This will raise both the cost of agricultural production and the potential yield. Other possibilities to increase agricultural production pertain to improvements to the water resources system. Such production increases can in principle be realized by:

— reducing damages (from drought, floods or salt); and

— improving growing conditions so that higher yielding crops can be grown.

An overview of possible measures is given in section 3. Given the country's socio-economic situation, a strong preference exists for low-cost, quick-yielding projects are typically high (between 10 and 20 per cent).

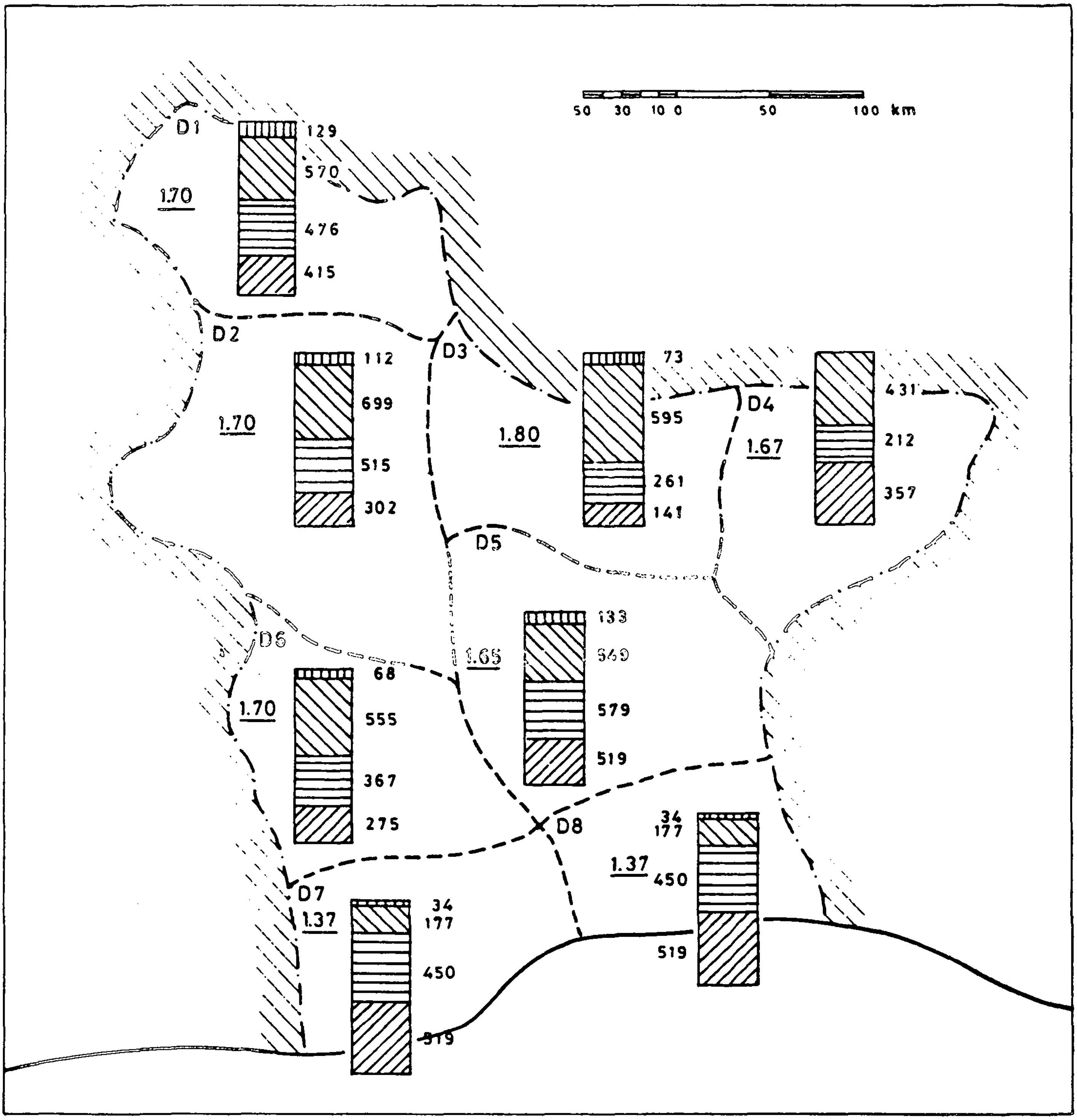
3. PROBLEMS AND MEASURES

3.1 Problems in present situation

The relevant problems in relation to the water sector

	Cropping pattern			No irrigation	Ground water	Surface water
1.	B. Aus	LT. Aman	Pulses	75	10	15
2.	B. Aus	HYV. Aman	HYV. Wheat	55	30	15
4.	B. Aus	LT. Aman	Local Boro	-	-	100
5.	HYV. Aus	HYV. Aman	HYV. Wheat	-	100	-
6.	HYV. Aus	HYV. Aman	Pulses	-	30	70
7.	HYV. Aus	HYV. Aman	HYV. Boro	-	-	100
9.	Jute	LT. Aman	Pulses	-	-	100
11.	B. Aus	Oilseeds		100	-	-
13.	B. Aus	HYV. Wheat		55	5	40
14.	B. Aus	HYV. Aman		75	15	10
16.	B. Aus	HYV. Boro		-	30	70
17.	B. Aus	Local Boro		60	-	40
18.	Jute	HYV. Wheat		30	70	-
19.	Jute	Pulses		100	-	-
20.	Jute	Oilseeds		100	-	-
21.	Jute	HYV. Boro		-	100	-
22.	Jute	Local Boro		-	35	65
24.	B. Aus	HYV. Aman	HYV. Boro	-	-	100
25.	HYV. Aus	HYV. Aman		-	30	70
26.	HYV. Aman	HYV. Boro		-	55	45
27.	LT. Aman	Local Boro		95	5	-
28.	HYV. Aman	HYV. Wheat		30	50	20
29.	B. Aman	HYV. Wheat		-	-	100
30.	Sugarcane			100	-	-
31.	B. Aman			100	-	-
32.	LT. Aman			65	10	25
33.	B. Aus			100	-	-
34.	Local Boro			80	-	20
35.	HYV. Boro			-	-	100
36.	B. Aus	Pulses		100	-	-
37.	-	-	-			

Table 12. Overview of irrigation intensity by cropping pattern and by source of irrigation water: present situation (in %)



LEGEND:

▥ 3 crops per year

▧ 2 crops per year

▤ 1 crop per year

▨ non-cultivated

1.70 : Average number of crops per year (crop intensity); Overall crop intensity is 1.65

Figure 34. Overview of agricultural land use (in 1,000 ha).

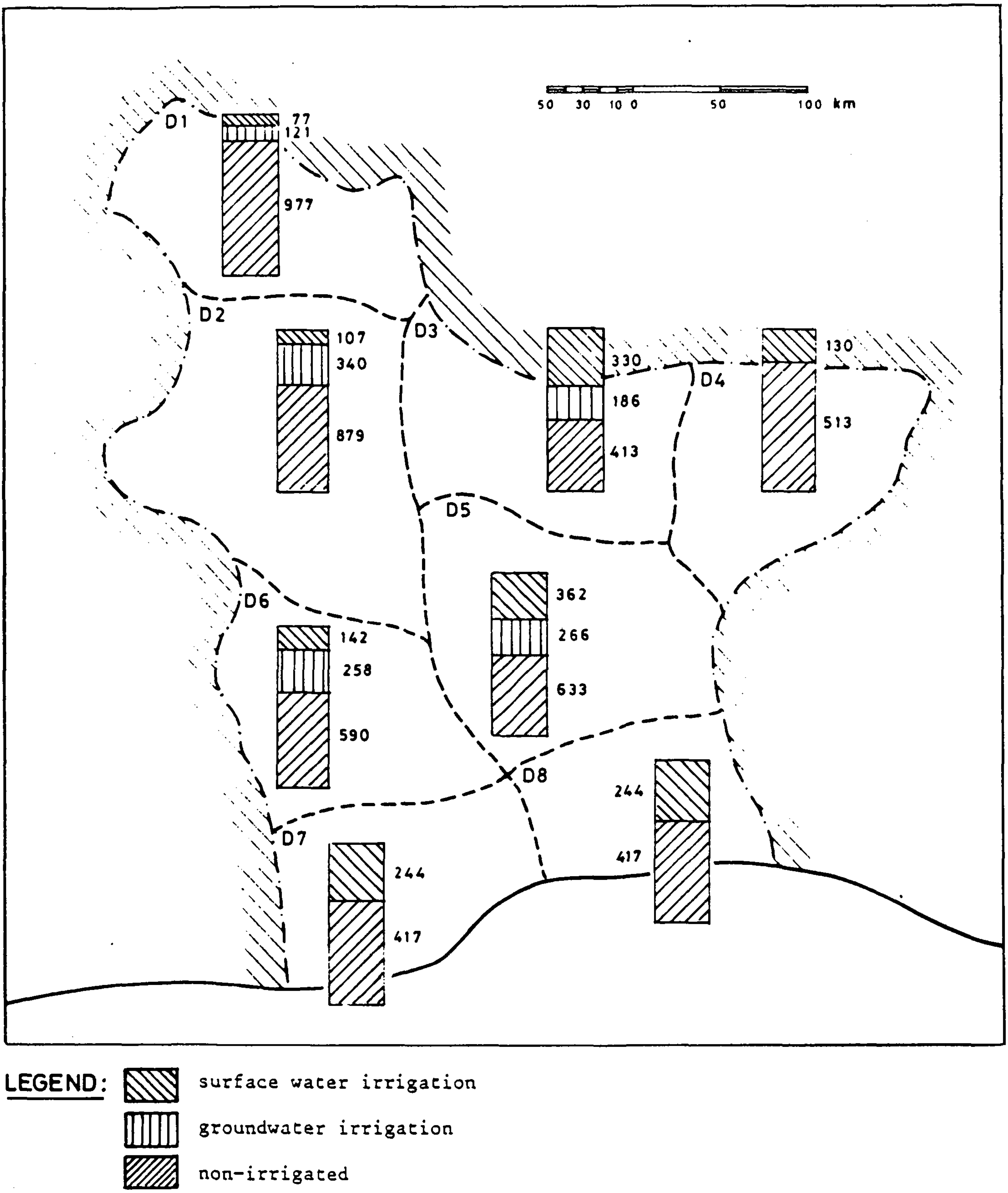


Figure 35. Overview of irrigated area by district and source of irrigation water (in 1,000 ha).

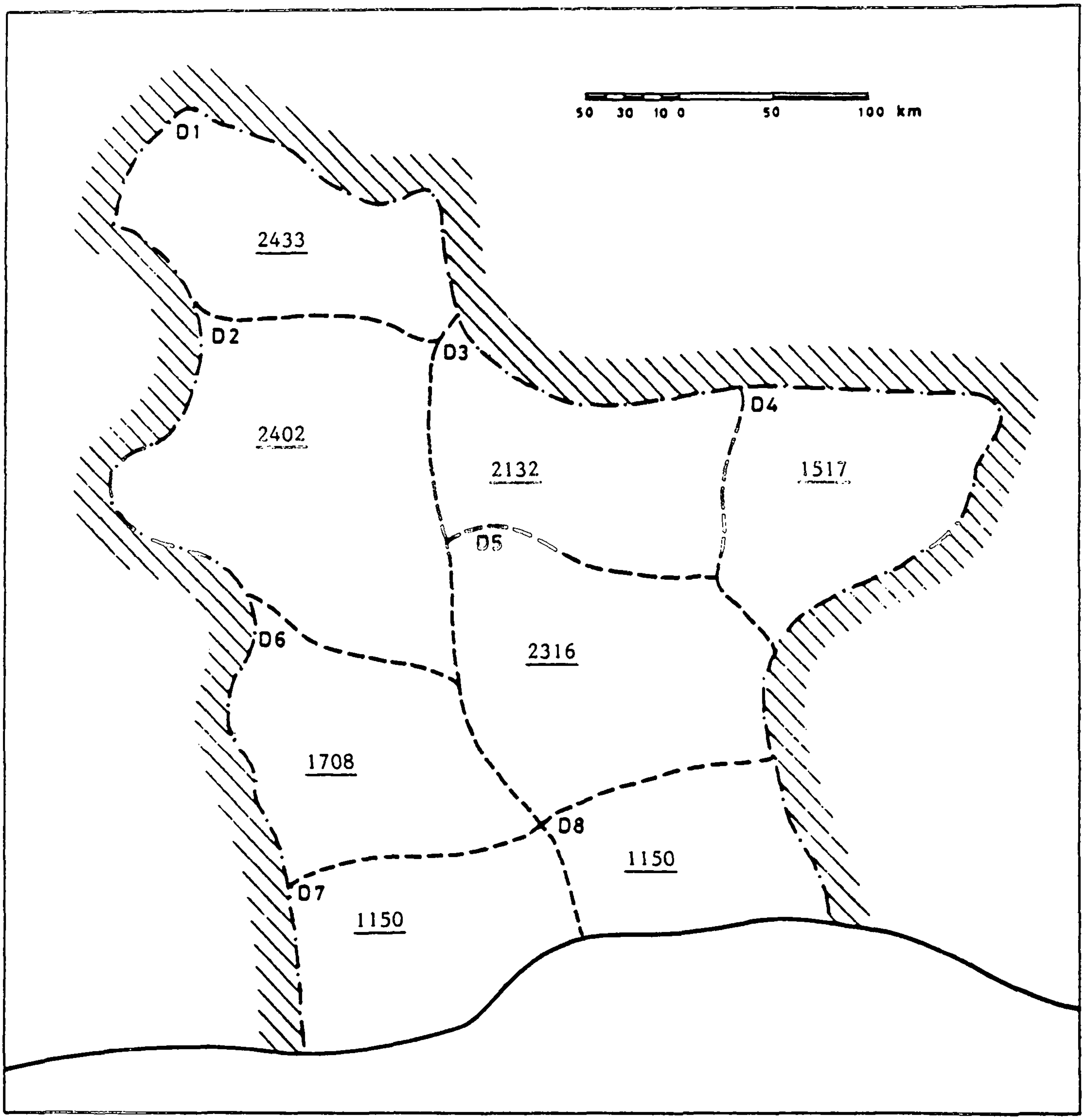


Figure 36. Overview of potential food grain production by district (1,000 tons per year)

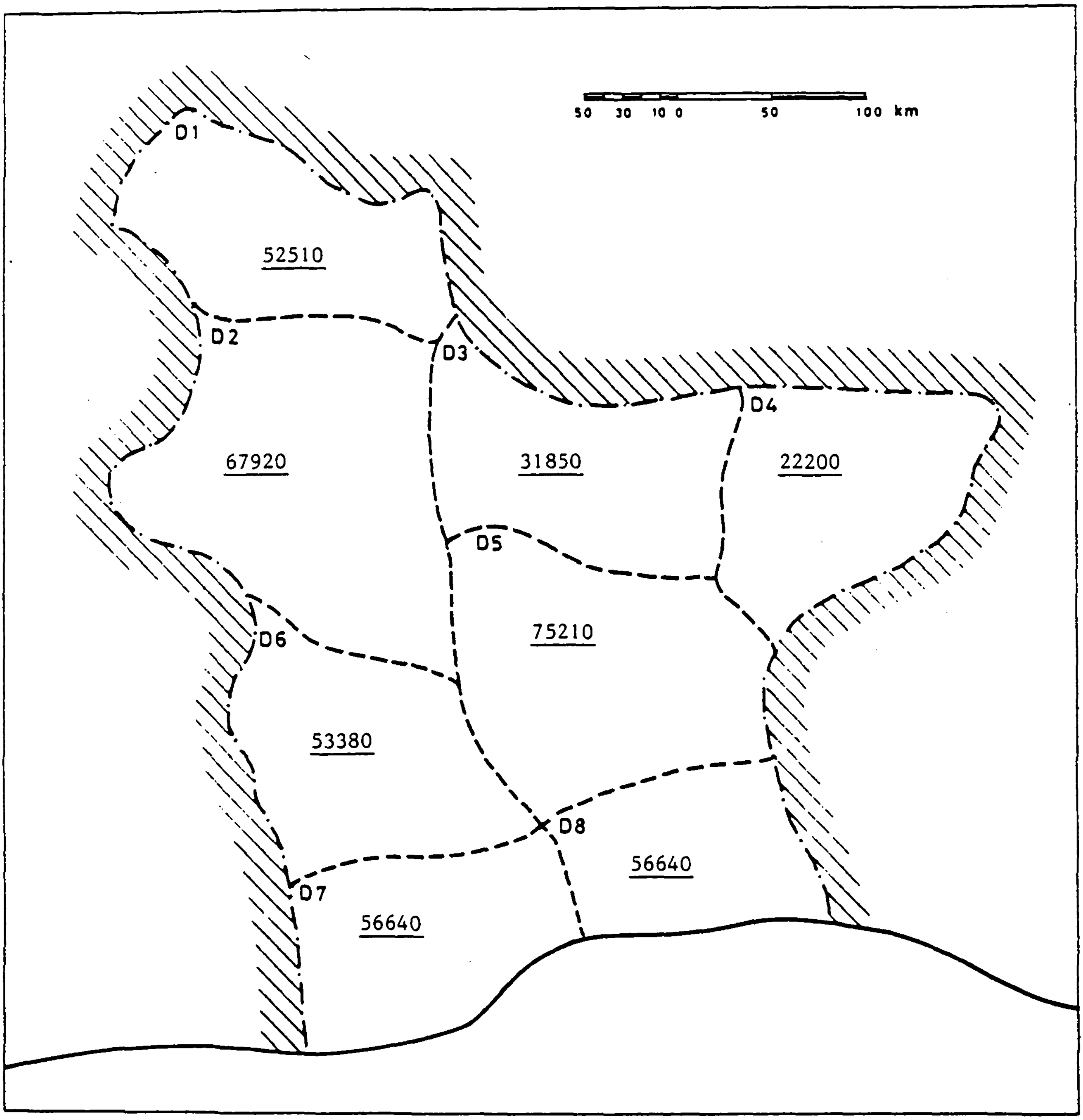


Figure 37. Overview of potential fish production by district (in tons per year)

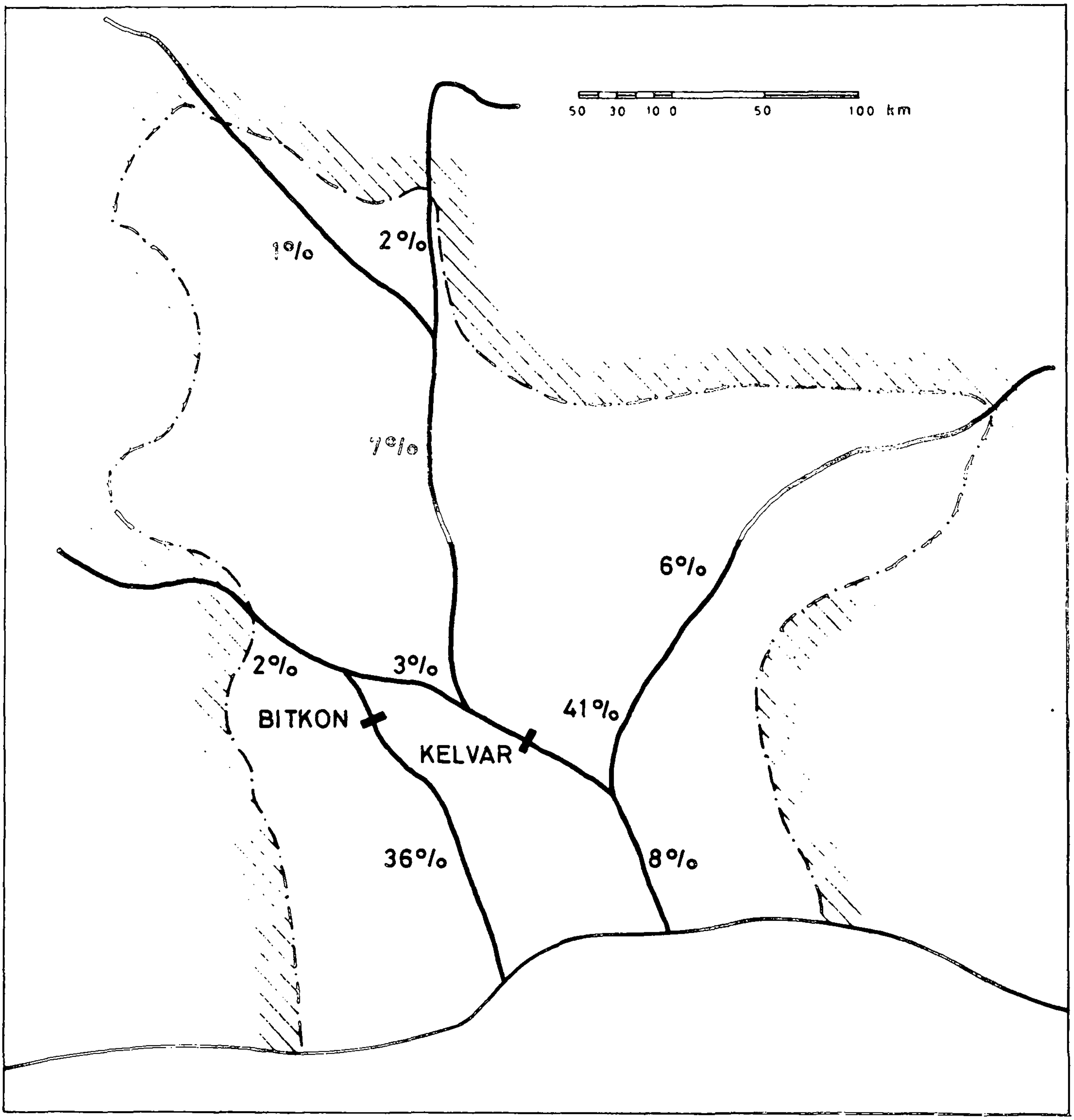
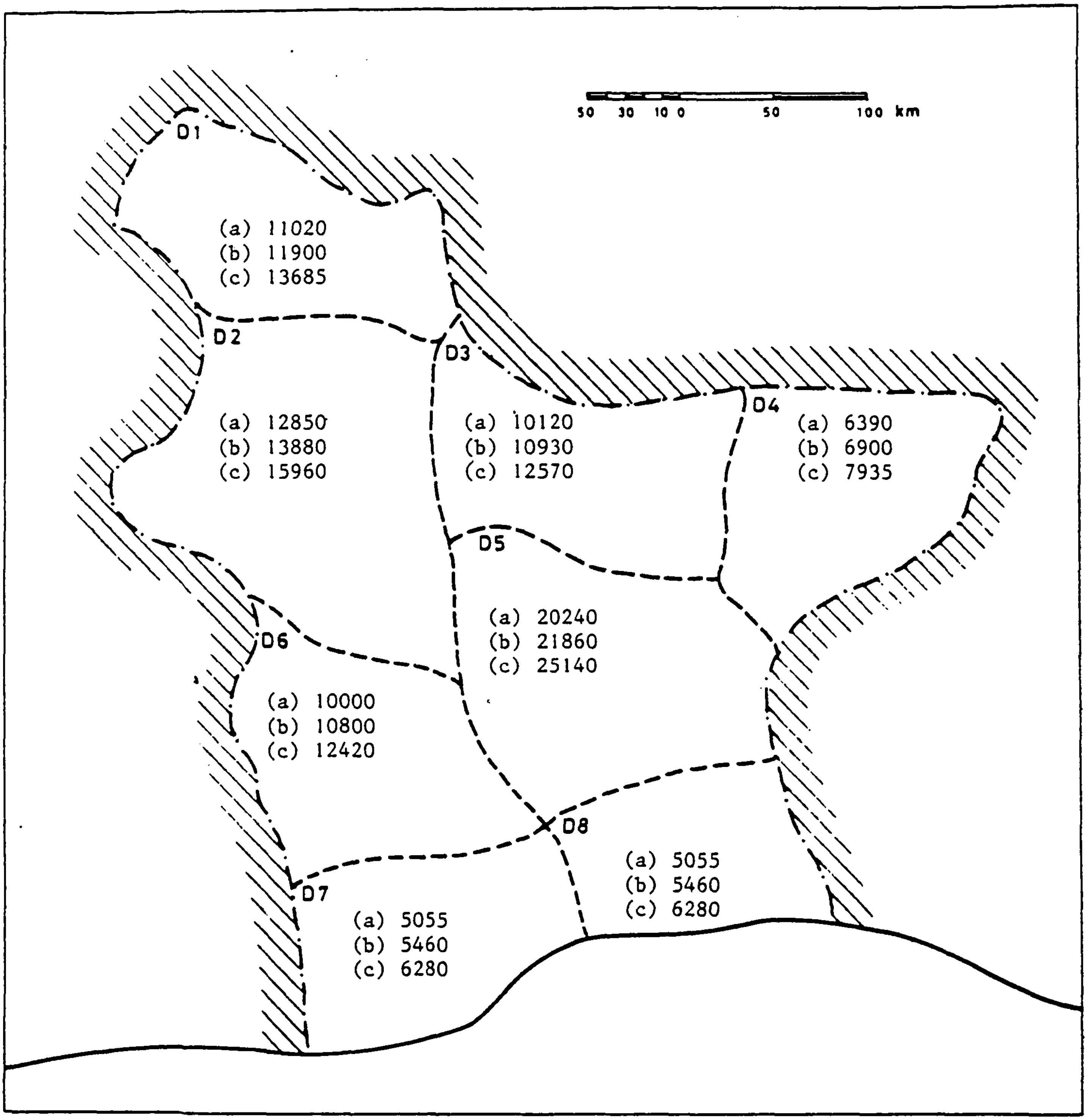


Figure 38. Overview of relative importance of major rivers for navigation and critical locations of two most important navigation routes



Legend

(a): 1985
(b): 1990
(c): 2005

Totals

1985: 80730
1990: 87190
2005: 100270

(numbers reflect thousands of people)

Figure 39. Projected number of people by district for 1985, 1990 and 2005

masterplan can be divided into three categories:

- water resources (natural system);
- water users (activity analysis); and
- socio-economic/political.

In the tables 13-15 an overview is presented of the type of problems that belong to these categories. Also the possible measures to solve or alleviate these problems are listed. Within the limited time of the workshop it is unfeasible to analyse all of these problems, even if it were done only superficially.

Instead, only a limited number of problems are considered. These belong mainly to the water resources category. The problems considered are related to the main objective of increasing the foodgrain production, and pertain to:

- flooding;
- drainage;
- water shortage;
- salt intrusion;
- insufficient waterdepth;
- land use;
- inadequate supply of modern inputs; and
- inefficient and inadequate irrigation facilities.

The extent to which problems exist in the present situation can be learnt from simulations with the computational framework. In fact the computational framework can be used to quantify the problem statement.

Problems are manifested in two ways: in undesirable values of the indicators of the water resources system (flood depth in metres, shortage in m^3/s, water depth in metres, etc.); and in impacts on water users (flood damage, reduction in fish production, transportation losses). Some examples are given below.

Figure 40 presents the simulation results with respect to the flooding of districts. The flooddepth-duration is shown by means of the number of time-steps that a specific flooddepth is exceeded. Figure 41 provides an overview of the flood damage to foodgrain production by district for average meteorologic and hydrologic conditions in the present situation. The impacts on food grain production by district of drought conditions are shown in figure 42.

3.2 Problems in future situation

In future, more severe problems with the water resources system are expected due to certain developments. These developments are related to:

- changes in demand;
- changes in supply.

Changes in demand pertain to foodgrain production, due to a growing population. Projections of future population were presented in paragraph 2.3.

Changes in supply have to do with an anticipated reduction of the cross boundary inflow of the river Salmar during low flow periods. This reduction is caused by the construction of the Rouros Barrage which is built in the neighbouring country of Lindon (see figure 29). The Rouros Barrage is meant to increase the discharge of the Mindeb River during low flow periods. As a consequence the inflow of the Salmar River will decrease. The extent of the reduction is not known yet, because no operation rules have been developed until now for the Rouros Barrage. The reduction of the inflow could however be considerable. Although no barrage is present yet in the Sirion River, similar developments could take place in this river on a somewhat longer term.

Due to the expected increase in demand and the decrease in supply, problems will become more severe in future. That is why a thorough analysis is required to examine the different trade-offs and development options in order to select an effective strategy to combat these problems.

3.3 Possible measures

Measures to improve the behaviour of the water resources system can be divided into:

(a) measures within a district;
(b) measures related to the interaction between district and network;
(c) measures related to the network; and
(d) measures within agricultural production system.

The following measures will be explicitly considered in the workshop.

(a) Measures within a district
  (i) Flood control and drainage measures
  (ii) Extension of surface water irrigated area
  (iii) Extension of groundwater irrigated area
  (iv) Water conservation within the district
(b) Measures related to district-network interaction
  (i) Increase of district inlet capacity
  (ii) Increase of district drainage capacity
(c) Measures related to the network
  (i) Raising embankments to protect districts from flooding
  (ii) Flood regulation and water conservation (DIMROST reservoir)
  (iii) Flow regulation to maintain water depths for navigation and to reduce salt intrusion (DAGOR barrage)
(d) Measures within agricultural production system
  (i) Changes in cropping pattern
  (ii) Increase of non-water inputs
  (iii) Improvement of irrigation efficiency.

In the following these measures will be briefly described. It will be indicated how these measures can be implemented in the computational framework which is described in section III. Also a specification of measurement costs will be provided. For the workshop, costs are expressed in an imaginary monetary unit, i.e., the "Escap". The procedure to compute costs and benefits of measures is further elaborated in paragraph 4.4.

PROBLEMS	MEASURES
Flooding	o Embankments major rivers minor rivers o Regulators o Channel improvement
Drainage	o Sluicing o Pumping o Channel improvement
Drought/Shortage	o Irrigation system o Waterconservation/storage o Change cropping pattern o Increase efficiency water use
Salt intrusion	o Close (small) estuaries o Increase upland discharge or decrease upland withdrawal o Poldering
Water quality	o Controlled use of pesticides/fertilizer o Regulations/legislation on effluent discharges
Erosion	o Channel improvement o Bank protection
Siltation	o Dredging, excavation o Afforestation of catchment area
Insufficient waterdepth	o Dredging o Control structures o Increase discharge

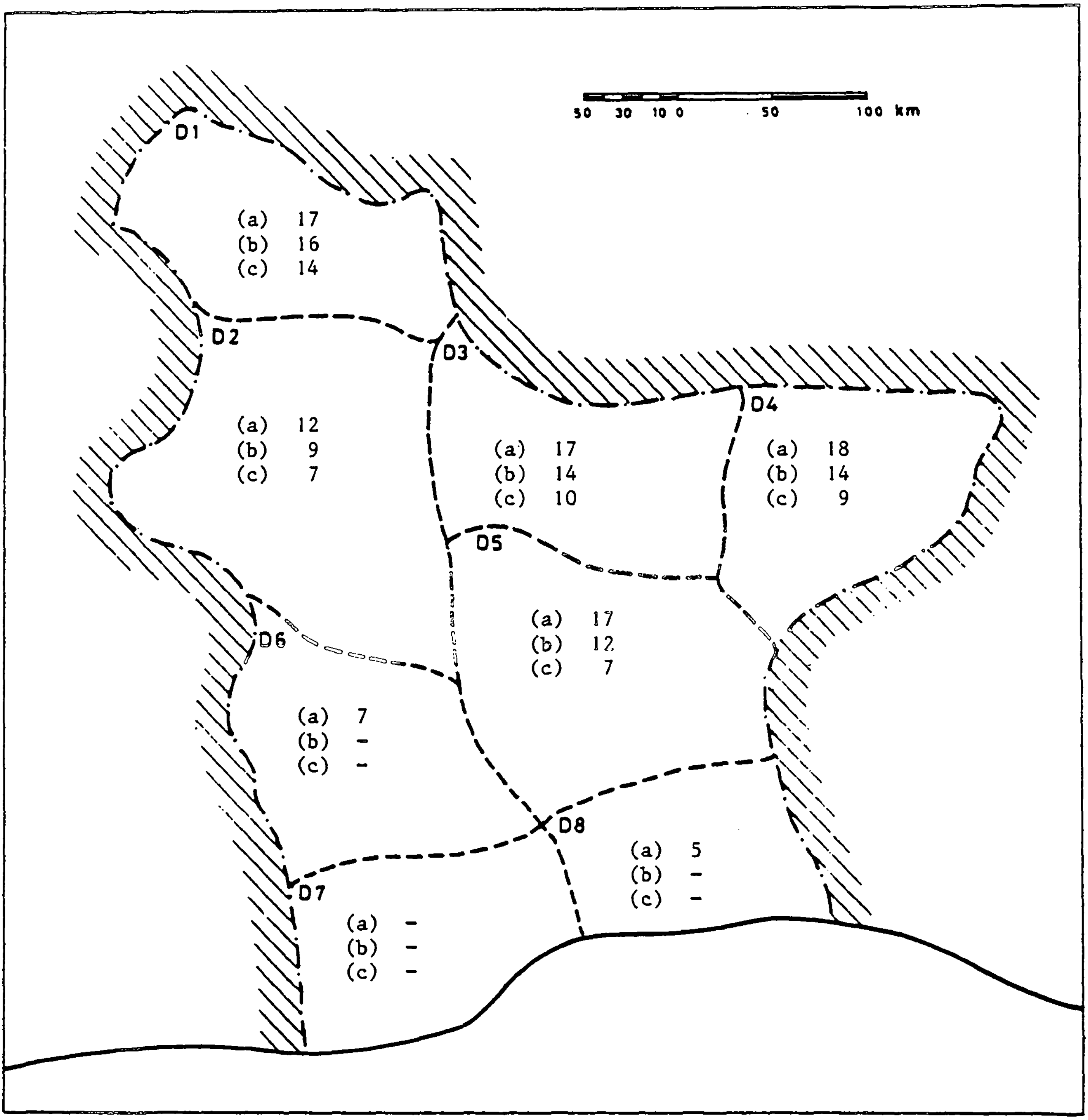
Table 13. Problems and measures related to water resources (natural system)

PROBLEMS	MEASURES
Technologic knowhow/ agricultural practices	o Provide education and training to farmers o Demonstration farming o Extension services
Inadequate supply of modern inputs (incl. fertilizer, pesticides, HYV)	o Ensure timely availability o Provide spare parts/repair facilities o Quality control
Inadequate or insufficient facilities for marketing, storage and processing	o Establish market and godown facilities o Increase storage facilities o Establish processing industry o Price regulation
Land use	o Increase cropping intensity o Proper management of soil o Diversification (pasture/fodder)
Insufficient land transportation	o Expand railway/road transportation system o Impose minimum dimensions for dykes
Insufficient power generation and distribution	o Increase power generation o Use natural gas instead of imported fuel
Inadequate irrigation facilities	o Expand/change irrigation system o Change cropping pattern
Inefficient irrigation practices	o Training of farmers o Impose water rates
Inadequate public water supply	o Water works/distribution o Fielding of tube wells o Creation of sanitary facilities
Inadequate industrial water supply	o Use groundwater or drinking water o Treatment of surface water
Inadequate fisheries production	o Extend fishing area o Rehabilitation of derelict tanks o Develop marketing and preservation system o Set up nurseries o Water pollution control
Insufficient navigation	o Dredging/excavation o Mechanisation of craft

Table 14. Problems and measures related to water users

PROBLEMS	MEASURES
Overpopulation	o Family planning
Low level education	o Improve basic eduction level
Capital	o Foreign aid o Raise taxes o Domestic savings
Credit	o Ensure timely credit facilities o Organizational improvement of credit agencies o Increase non-farm income
Taxes	o Betterment tax o Imposing of tax by executing agency
Land tenure system	o Land reform o Cooperative farming o Sharing of inputs by landowner and farmer
Inadequate institutional system/lack of efficiency	o Improve administrative set-up o Land acquisition procedure o Decision at lower level o Training of agency's employees o Training of farmers
Food habit	o Change in food habit through partial adoption of wheat, potatoes, vegetables o Publicity in mass media

Table 15. Problems and measures related to socio-economic/political situation



Legend:

Number of timesteps that lowest landlevel type is inundated

(a) inundation depth ≥ 0 m.
(b) inundation depth ≥ 1 m.
(c) inundation depth ≥ 2 m.

Figure 40. Overview of flood depth-duration by district

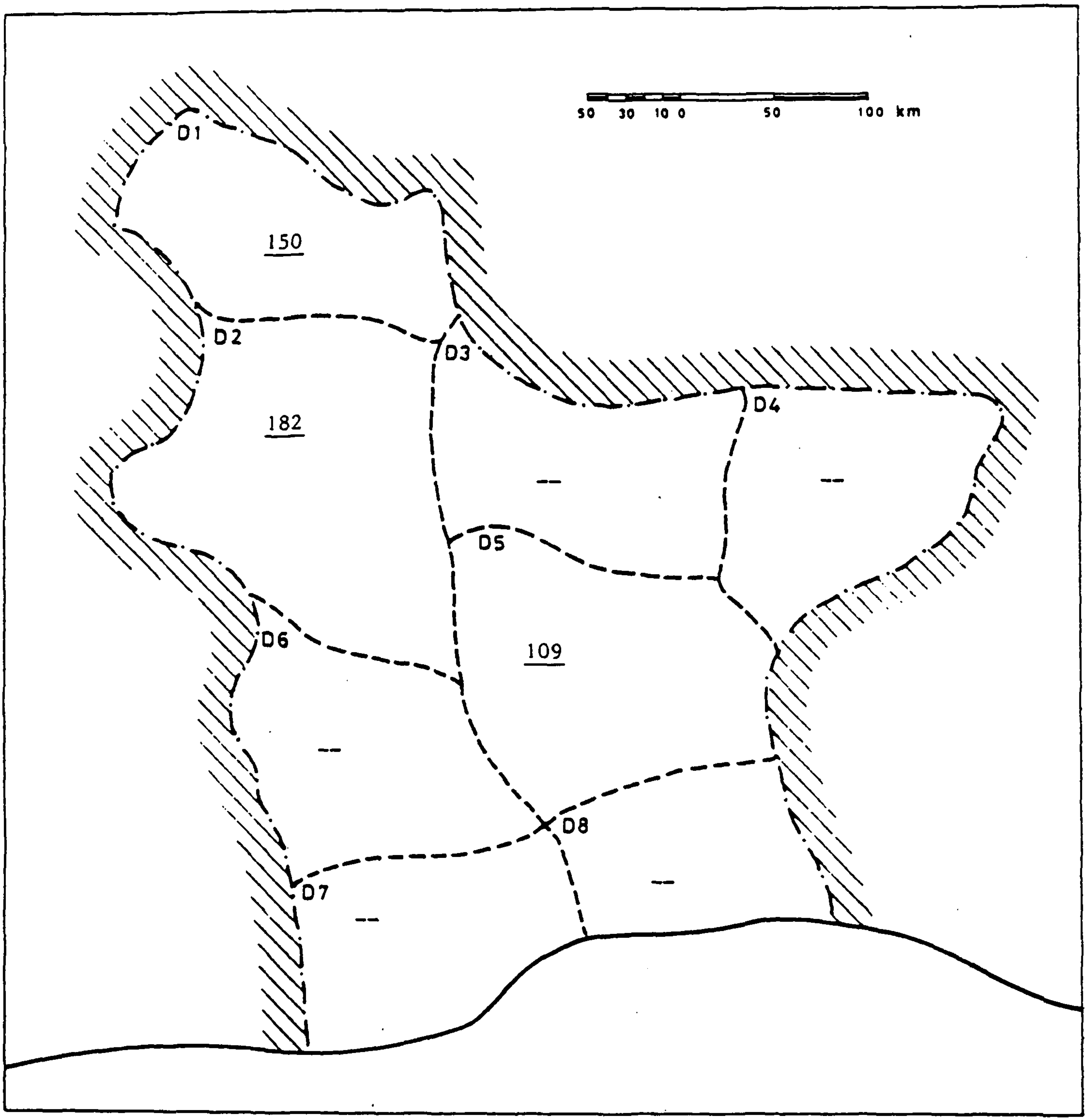


Figure 41. Overview of flood damage to foodgrain production by district (in 1,000 tons per year)

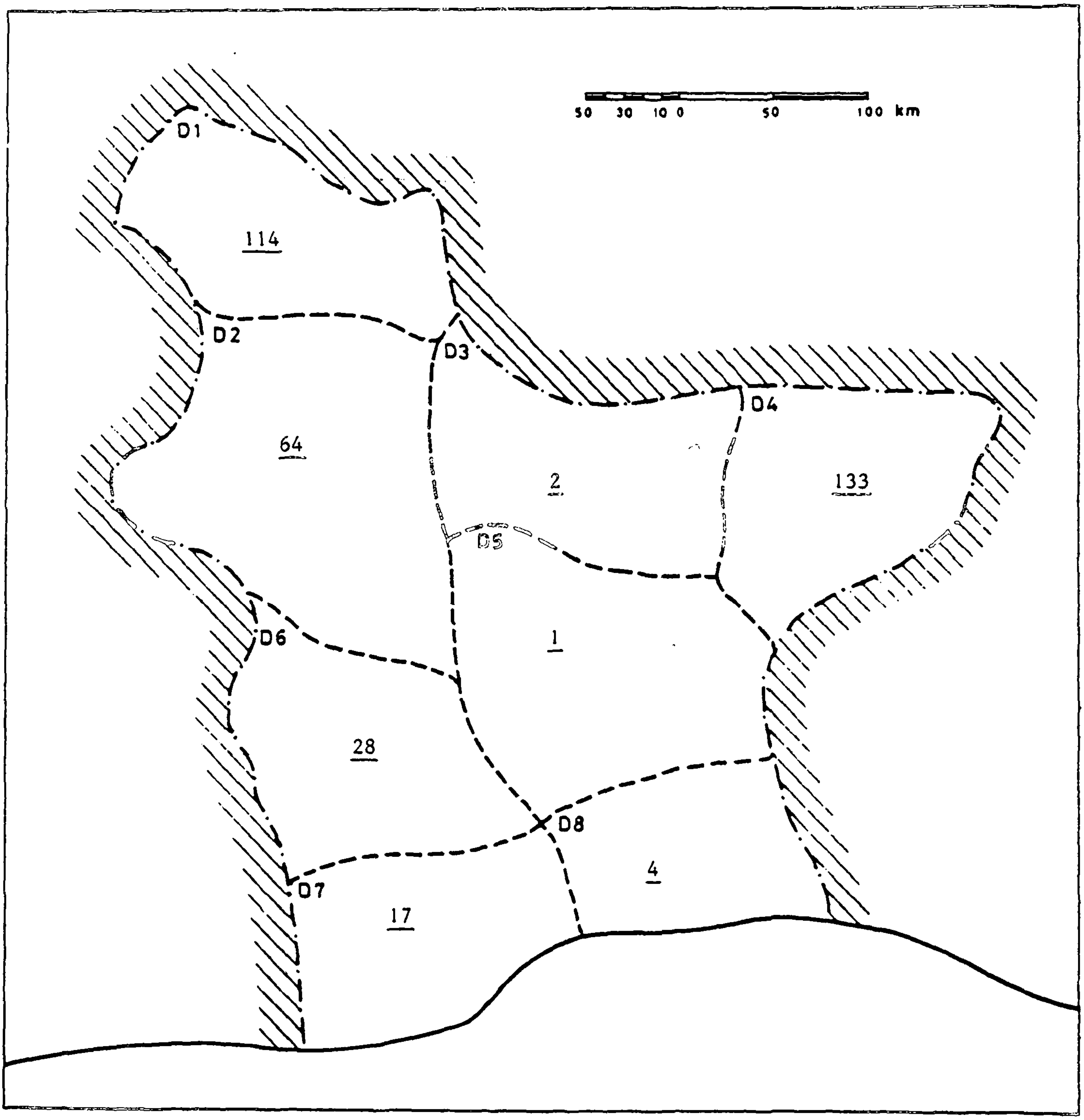


Figure 42. Overview of drought damage to food grain production by district (1,000 tons per year)

(a) Measures within a district

(i) Flood control and drainage measures (FCD measures)

In reality, these measures are implemented by making improvements to smaller rivers and drainage canals within the district, resulting in local reductions of flood depths. FCD measures are simulated in the model by shifting crop areas within the distinguished project areas to a landlevel type of higher elevation. In certain cases this will also lead to a change of the cropping pattern because of improved growing conditions. All changes are made to the PLOT file. The following rules are applied:

- cropping pattern 31 changes to cropping pattern 14;
- cropping pattern 32 changes to cropping pattern 27;
- other cropping patterns remain the same.

(For overview of cropping patterns see Table 12).

An overview of potential FCD project, related changes in cropping patterns and landlevels, and project costs is provided in Table 16. The first part of the code as is used in the table (D1, D2, etc.) refers to the district in which the measure is located.

(ii) Extension of surface water irrigation

In the real world, this measure involves certain improvements to the secondary and tertiary water supply system within the district to make surface water available to the farmers. Moreover, farmers have to purchase surface water irrigation equipment. The measure is implemented in the model by changing the irrigation code in the PLOT file from 0 (no irrigation) to 2 (surface water irrigation). In many cases this also means that the cropping pattern should be changed. The following rules are applied (see table 12):

- cropping pattern 11 changes to cropping pattern 13;
- cropping pattern 17 changes to cropping pattern 16;
- cropping pattern 27 changes to cropping pattern 26;
- cropping pattern 34 changes to cropping pattern 35;
- cropping pattern 32 changes to cropping pattern 28;
- cropping pattern 33 changes to cropping pattern 13;
- cropping pattern 14 changes to cropping pattern 2.

An overview of potential surface water irrigation projects, related changes in cropping patterns, and project costs is given in table 17. Total costs should also include the fixed and variable costs of irrigation and the costs of changes in cropping patterns (see paragraph 4.4).

(iii) Extension of groundwater irrigation

In reality, the measure implies the installation of groundwater wells and related equipment to carry the water to the fields. In the model, the measure is implemented by changing the irrigation code in the PLOT file from 0 (no irrigation) to 1 (groundwater irrigation). With respect to the changes in cropping patterns, the same rules apply as were given for surface water irrigation.

An overview of potential groundwater irrigation projects and changes in cropping pattern is given in table 18. Except for the fixed and variable costs of irrigation and the costs of cropping pattern changes, there are no project costs. Irrigation costs and costs of cropping pattern changes are dealt with in paragraph 4.4.

(iv) Water conservation within the district

The measure implies the increase of surface water storage by means of weirs or small dams in the local river system. The aim is to save water in wet periods, to be used for irrigation in dry periods. The measure is reflected in the model by increasing the surface water area (and volume) within the district. This means that the surface water area in the DISTRICT file should be adjusted together with the relation between surface water level and surface water volume. An overview of potential water conservation projects, *maximum* surface water area (after extension), and costs of extending is provided in table 19. Of course any extension up to the maximum area is possible.

(b) Measures related to district-network interaction

(i) Increase of district inlet capacity

If the natural inflow to the district is restricted, the inlet capacity can be increased by artificial means (inlet structures, pumping) to provide extra water to the district in dry periods. These measures can be simply implemented in the model by increasing the district inlet capacity in the DISTRICT file. An overview of potential projects to increase the inlet capacity of districts is given in table 20. The table presents the current and maximum inlet capacity, together with the unit cost for a capacity increase of 1 m^3/s.

(ii) Increase of district drainage capacity

The drainage capacity of districts can be increased by improving major drainage canals and/or providing pumping facilities. This can be implemented in the model by changing the drainage capacity coefficient in the DISTRICT file. Table 21 provides an overview of potential drainage capacity projects. Presented are: current and maximum value of the drainage capacity coefficient (expressed in m^2/s), and the cost for a unit increase of this coefficient.

For District 1 the maximum discharge capacity is currently 2000 m^3/s. This could be increased up to a maximum of 3000 m^3/s at a cost of 350,000 Escaps per unit increase of 1 m^3/s. For other districts there is no fixed capacity constraint.

Code	Area	Present		Future		Costs
	(1000 ha)	Crops	Landlevel	Crops	Landlevel	(10^6 Escaps)
D1FC1	28	14	3	14	4	920
	53	28	3	28	4	
D1FC2	42	28	3	28	4	750
	38	5	3	5	4	
D1FC3	118	32	3	27	4	1330
D2FC1	103	31	2	14	3	980
D2FC2	60	28	3	28	4	1540
	71	14	3	14	4	
D2FC3	35	26	3	26	4	880
	60	32	3	27	4	
D5FC1	132	31	2	14	3	1120
D5FC2	26	24	3	24	4	480
	37	1	3	1	4	
D5FC3	58	14	3	14	4	1030
	31	26	3	26	4	

Table 16. Overview of flood control and drainage projects

Code	Area (1000 ha)	Present crops	Future crops	Costs (10^6 Escaps)
D1S1	20	2	2	133
	40	28	28	
D1S2	40	13	13	188
	40	18	18	
D2S1	45	14	2	98
	15	13	13	
D2S2	25	14	2	125
	35	11	13	
D3S1	15	14	2	75
	25	32	28	
D3S2	87	14	2	165
D4S1	48	34	35	83
D4S2	20	14	2	97
	25	27	26	
D4S3	40	17	16	87
D6S1	33	14	2	123
	27	33	13	
D6S2	28	14	2	76
	26	11	13	
D7S1	55	14	2	212
	37	32	28	
D7S2	41	32	28	99
D8S1	21	14	2	78
	35	32	28	

Table 17. Overview of surface water irrigation projects

Code	Area (1000 ha)	Present crops	Future crops
D1G1	29	18	18
	21	11	13
D2G1	27	11	13
	34	13	13
D3G1	26	11	13
D3G2	38	32	28
D4G1	51	27	26
	25	17	16
D5G1	20	33	13
D6G1	22	11	13
	16	33	13

Table 18. Overview of groundwater irrigation projects

Code	Surface water area (1000 ha)		Costs of extending surface water area (10^3 Escaps/1000 ha)
	Present	Maximum	
D1WC1	25	65	900
D2WC1	190	390	750
D3WC1	250	310	1000
D4WC1	300	500	1200
D5WC1	250	610	800
D6WC1	150	275	1000
D7WC1	125	285	1200
D8WC1	125	285	1500

Table 19. Overview of water conservation projects

Code	Inlet capacity (m^3/s)		Costs of capacity increase (10^3 Escaps per m^3/s)
	Present	Maximum	
D1IC1	100	100	-
D2IC1	100	500	500
D3IC1	100	500	500
D4IC1	50	150	750
D5IC1	200	500	750
D6IC1	100	150	1000
D7IC1	50	150	750
D8IC1	50	150	1000

Table 20. Overview of district inlet capacity projects

Code	Drainage capacity coefficient (m^2/s)		Costs of increasing drainage capacity (10^3 Escaps per m^2/s)
	Present	Maximum	
D1DC1	500	1000	300
D2DC1	5000	7500	180
D3DC1	8000	10000	150
D4DC1	8000	10000	150
D8DC1	8000	10000	100
D6DC1	500	1000	50
D7DC1	600	1000	50
D8DC1	600	1000	50

Table 21. Overview of district drainage capacity projects

(c) Measures related to the network

(i) Raising embankments to protect districts from flooding

During floods water levels in major rivers increase and flooding of districts from the national system may occur. This can be prevented by raising the embankments along the major rivers. Such a measure can be reflected in the model by changing the critical water level at which flooding from the network starts. Each district is associated with a node of the national network from which flooding occurs, if the critical water level is exceeded. The critical water levels are included in the DISTRICT file.

An overview of potential embankment projects is given in table 22. Presented for each district are: the node from which flooding may occur in the present situation, the actual critical water level; and the costs of a unit increase of the embankment level of 1 m.

(ii) DIMROST reservoir

DIMROST reservoir is a potential measure located at DIMROST node in the Northeast (see figure 43). The purpose is to reduce the flood wave of the Upper Thalos river and save the water for use in the dry period. The measure can be implemented in the model by changing the cross boundary inflow of the Upper-Thalos river at node N6 of the network. The cost of the reservoir is estimated at 1250 x 10^6 Escaps. Expected benefits pertain to agriculture, fisheries and navigation.

(iii) DAGOR barrage

DAGOR barrage is a potential measure located in SALMAR river, just downstream of VALMAR node, where the river CELON branches off (see figure 43). Its purpose is to regulate the flow in CELON river, in order to maintain sufficient depth for navigation and sufficient discharge to reduce salt intrusion. In the model, a special option is provided to simulate this measure. The flow distribution between SALMAR and CELON river can be externally specified by changing some parameters in the NETWORK file. The cost of the barrage is estimated at 5000 x 10^6 Escaps. Potential benefits pertain to navigation and agriculture (reduction of salt intrusion, more water for irrigation and possible reduction of flooding).

(d) Measures within agricultural production system

(i) Changes in cropping pattern

A very promising way of increasing food production is to change cropping patterns from low yield to high yield varieties, and/or from single or double crop rotation to double or triple crop rotation patterns. This is especially useful for crops that are irrigated. With reference to table 12 the following changes are most relevant:

Old cropping pattern	**New cropping pattern**
1	24
6	7
14	5 or 7
13	5
16	7
25	5
32	26
34	7
35	7

The above changes pertain to irrigated crops only.

These measures are simulated in the model by modifying cropping pattern codes and areas in the PLOT file. Costs are incurred for the increased input requirements for the additional crops grown and the shift to high yield varieties. An example calculation of associated costs is given in paragraph 4.4.

(ii) Increase of non-water inputs

Agricultural yields can be improved by applying more non-water inputs like fertilizer and pesticides. Developments in this field are uncertain. Yield levels for the current situation and for a situation where the use of non-water inputs has been increased to 50 per cent of the optimal inputs have been presented in table 8. The increase of yield levels will be treated as a scenario variable.

(iii) Improvement of irrigation efficiency

Possibility and costs of this measure are uncertain. The effects of potential improvements of the irrigation efficiency can be taken into account in a sensitivity analysis.

4. Application of systems approach

4.1 Introduction

During the lecture, systems approach or systems analysis has been defined as: "a systematic process of generating, analysing and evaluating alternative strategies", where strategies are defined as courses of action to solve a given (planning) problem. Moreover a framework of analysis was introduced consisting of two phases: Setting Up The Analysis (SUTA) and Carrying Out The Analysis (COTA).

Most important elements of SUTA are:

- identification of planning objectives and evaluation criteria;
- specification of analysis conditions;
- preliminary analysis of problems and measures; and
- specification of analytical approach.

Most important elements of COTA are:

- estimation of temporal and spatial pattern of activities;
- analysis of water using and water related activities;
- analysis of natural systems;

Code	Flooding node	Present critical level (m)	Costs of raising embankments by 1 m (10^6 Escaps)
D1E1	2	20.0	1800
D2E2	5	7.5	2500
D3E3	7	6.5	1100
D4E4	7	6.5	900
D5E5	8	5.8	3000
D6E6	-	-	-
D7E7	10	3.5	750
D8E8	11	3.5	600

Table 22. Overview of embankment projects

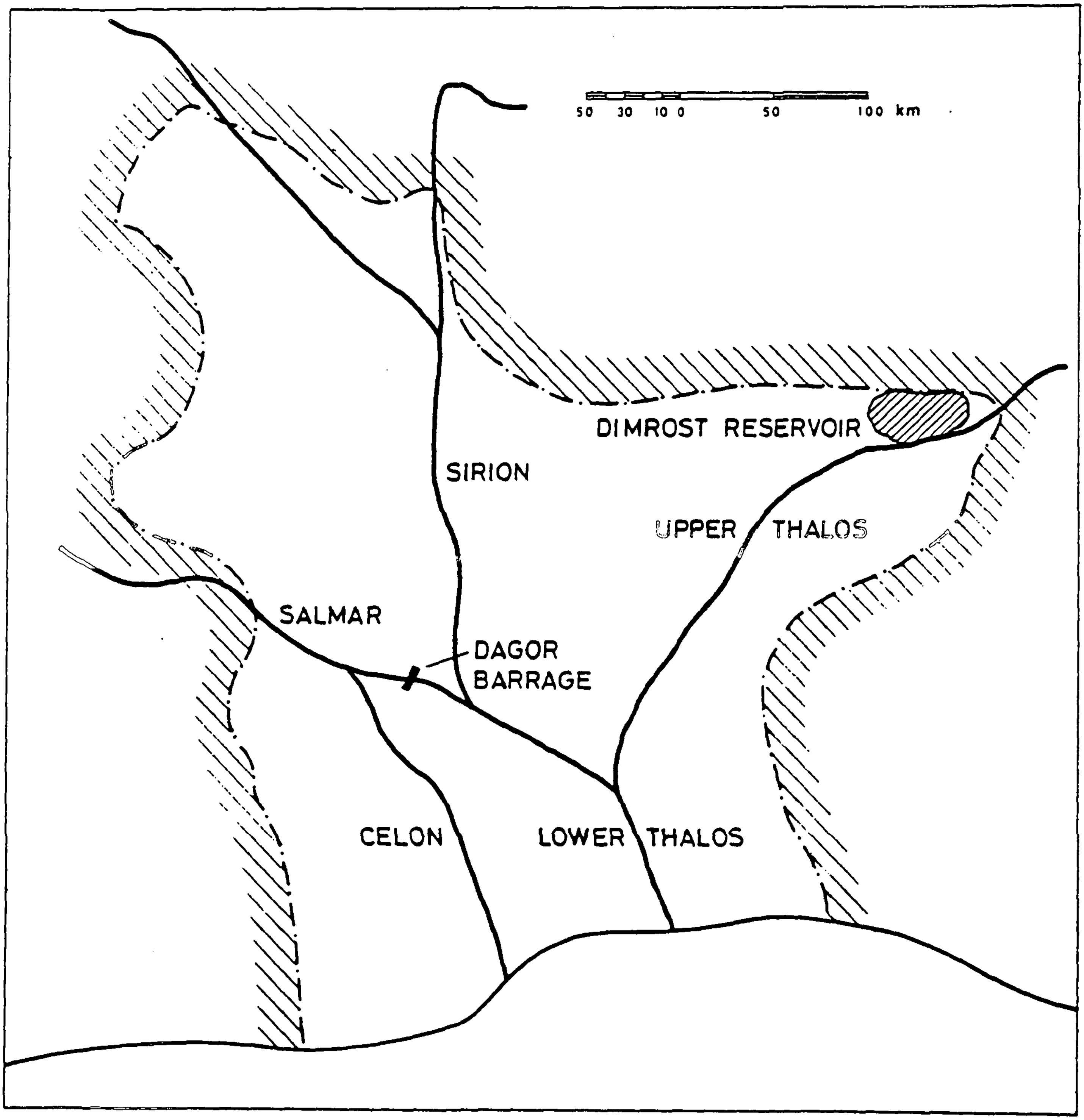


Figure 43. Location of DIMROST reservoir and DAGOR barrage

- formulation and analysis of WRM strategies;
- evaluation of WRM strategies; and
- presentation of results.

An overview of the elements in SUTA and COTA is given in figure 6. In the following two paragraphs it will be briefly described how the various elements of SUTA and COTA are dealt with in the workshop. In the last paragraph of this chapter, specific attention is given to the procedure and basic information for computing costs and benefits in the workshop.

4.2 Setting Up The Analysis (SUTA)

(a) Planning objectives and evaluation criteria

The following items are distinguished:

- national objectives;
- operational (specified) objectives;
- (operational) criteria.

National objectives

National objectives to be adopted as a basis for the workshop are:

(i) self-sufficiency in food;
(ii) enhancement of economic growth;
(iii) equitable distribution of benefits;
(iv) improvement of public health;
(v) improvement of employment opportunity; and
(vi) improvement of environmental quality.

Operational objectives

Operational objectives are specified objectives, derived from the national objectives, that serve as a basis for the analysis. The above national objectives could be translated into operational objectives in the following way.

(i) Self-sufficiency in food:
- produce an amount of food that will provide a minimum food requirement (500 g of food grain per person per day) to all people in the country, no later than 1990.

(ii) Enhancement of economic growth:
- increase per capita income by "a" per cent in 1990;
- increase the gross national product (GNP) by "b" per cent in 1990;
- increase the export volume by "c" per cent in 1990.

(iii) Equitable distribution of benefits:
- increase income of lowest ("d" per cent) income group by "e" per cent in 1990;
- allocate "f" per cent of total investment in new projects to underdeveloped regions;
- develop infrastructure and marketing facilities to ensure adequate physical distribution in 1990.

(iv) Improvement of public health:
- provide drinking water facilities to "g" per cent of the people in 1990;
- provide sanitation facilities to "h" per cent of the people in 1990.

(v) Improvement of employment opportunities:
- increase direct employment by "j" per cent in 1990.

(vi) Improvement of environmental quality:
- meet standards for industrial and urban waste discharges by 1990;
- meet standards for different types of water use by 1990; and
- limit extent of salt intrusion.

Remarks

- In general the above objectives should be interpreted as indicative **targets,** with the exception of the objective regarding the self-sufficiency in food.
- For the purpose of illustration, the indicative targets have been expressed as variables (a, b, c, etc.). In COTA, these variables should be made explicit. In the workshop this will be done to a limited extent.
- In view of the planning problem that is dealt with in the workshop only the contribution of WRM in reaching the objectives will be considered.

Evaluation criteria

The evaluation criteria to be considered could be organized in four categories, i.e.:

- related to the water resources system;
- related to water use categories;
- related to socio-economic impacts; and
- other.

In this division, the group "other" comprises the criteria that are based on experience and judgement rather than quantitative analysis. In the following, examples of criteria that might be used in the planning exercise will be given.

— Related to the water resources system:
  - extent of salt intrusion;
  - groundwater level;
  - flooded area, flooding depth and duration; and
  - water depths and water flows at locations of interest.

— Related to the water use categories:
  - direct benefits and costs;
  - amount of food produced (tons by product);
  - quantity of fish produced;
  - non-water inputs to agriculture;
  - irrigated area (ha);
  - area under HYV crop (ha);
  - tons transported by navigation; and
  - area provided with flood protection and drainage.

— Related to socio-economic impacts:
  - income distribution by region and target group;
  - employment (percentage);

- time before benefits are accrued;
- capital requirements over time;
- import requirements;
- export volume;
- per capita income;
- storage/marketing requirements;
- indirect costs and benefits;
- gross national product (GNP); and
- foreign aid required.

— Other:
- simplicity;
- flexibility;
- acceptability to the public;
- interdepartmental relations;
- required institutional changes/legal implications; and
- accuracy of estimates.

(b) Analysis conditions

In addition to the problem statement, objectives and criteria, the analysis conditions comprise the following specifications:

(i) system boundaries and water user categories to be taken into account;
(ii) time and cost aspects;
(iii) hydrologic and meteorologic conditions;
(iv) scenarios; and
(v) design criteria.

System boundaries and water use categories

The description of the (imaginary) country and the schematization of its natural system was given in paragraph 2.1. The water users to be taken into account were described in paragraph 2.2.

Time and cost aspects

These pertain to:
- time horizon;
- base year for monetary values; and
- discount rate.

A reasonable time horizon is e.g. 2005, with:
- short term: 1985-1990; and
- long term: 1990-2005.

The base year for monetary values will be 1985. The price and activity levels for the base year should be extrapolated from the most recent year for which data are available.

A reasonable estimate for the discount rate is between 10 per cent and 20 per cent. For the basic analysis a value of 15 per cent will be used.

Hydrologic and meteorologic conditions

To account for variations in the hydrologic and meteorologic conditions, different years (of different dryness) should be considered in the analysis. For example:
- a wet year;
- a medium year; and
- a dry year.

The dryness of the year pertains to both rainfall and river discharges.

Scenarios

Relevant scenario elements for the case-study are:
- cross-boundary inflow of Salmar River (in relation to operation of Rouros Barrage);
- population growth (in relation to food and other water related requirements);
- use of non-water inputs in agricultural production (autonomous increase in agricultural productivity); and
- hydrologic/meteorologic conditions (see above).

Design criteria

These relate to the (initial) design of technical measures, like e.g.:
- irrigation systems;
- drainage measures; and
- flood control measures, distinguishing between:
  - — major structures (barrages);
  - — embankments of major rivers; and
  - — embankments of minor rivers.

Design criteria are not absolutely fixed. If analysis shows that more or less strict criteria are more optimal, these can be adopted instead. In most cases however, effects may be involved that can hardly be expressed in monetary terms, so that design criteria cannot be simply based on a comparison of costs and benefits.

(c) Preliminary analysis of problems and measures

For the purpose of the workshop the problems and potential measures have already been identified in section 3.

(d) Specification of analytical approach

Again, for practical purposes, the analytical approach was defined and prepared in advance, to enable the actual use of mathematical tools during the workshop. A description of the analytical framework is given in Part II of the proceedings.

4.3 Carrying Out The Analysis (COTA)

(a) Estimation of temporal and spatial pattern of activities

Relevant estimates to be made in the context of the workshop are:

- projection of population;
- projection of activity levels, e.g. related to:
  - agriculture (cultivated area, cropping patterns, productivity);
  - navigation (cargo transported and type/number of vessels);
  - fisheries (fish production by type and district);
- projection of water management projects completed within time horizon.

(b) Analysis of water using activities and natural system

For practical purposes, the relevant information regarding the water using and water related activities and the natural system to be used in the workshop was provided in section 2.

(c) Formulation and analysis of WRM strategies

This step will form the core of the workshop activities. The emphasis in this step will be on the specification of "cases", consisting of WRM strategies and scenarios, the assessment of impacts using the available mathematical tools, and the interpretation of the generated results. Specific attention should be given to the interpretation of results in view of the fact that the performance of the water resources system depends on stochastic inputs like cross-boundary flows and meteorologic conditions. These phenomena are part of the scenario.

Given the limited available time, this step provides the best opportunities to get acquainted with the water resources planning process according to the principle of "learning by doing". For this reason, time consuming activities like data gathering and development of mathematical tools have all been prepared in advance by the course organization.

(d) Evaluation of WRM strategies and presentation of results

Given the costs of the various WRM strategies and the effects determined in the previous step, an evaluation of the various strategies can take place on the basis of the specified planning objectives and evaluation criteria. The final result of the analysis will consist of:

- a number of observations, conclusions and recommendations; and
- an overview of the relevant impacts of WRM strategies analysed in such a way that a selection of measures to be included in the masterplan can be made by the decision-makers.

4.4 Guidelines for computation of costs and benefits

This paragraph provides the basic information for calculating costs and benefits during various stages of the analysis. The information includes:

- basic assumptions;
- information on costs and benefits to water using activities:
  - agricultue;
  - navigation;
  - fisheries.

As an illustration it will be shown how the information is used to compute the benefit/cost (B/C) ratio for an example project.

Basic assumptions

The basic assumptions are:

- comparisons take place on the basis of annualized costs and benefits;
- in converting fixed investments to annualized costs, the capital recovery factor (CRF) is assumed to be 0.15; hence the annualized fixed costs are equal to 0.15 times the initial investment;
- annual operation, repair and maintenance (ORM) costs for infrastructural projects are assumed to be 5 per cent of the initial invesment.

Agriculture

Agriculture is by far the most important water user in the example problem. For this reason quite some attention was given to the agricultural activity analysis, leading to a more or less detailed modelling approach. In total, 12 different individual crops and 30 cropping patterns have been distinguished. The basic information for each individual crop is summarized in table 23. The table contains information on crop yields both in physical quantity and money terms, production costs and required labour inputs. In addition, the following assumptions are made.

- If non-water inputs are increased to 50 per cent of the optimal inputs (current level of inputs is about 25 per cent of optimal level), yields will increase by 10 per cent, required labour will increase by 10 per cent and total production costs will increase by 15 per cent.
- Costs of irrigation equipment are 2000 Escaps per ha for surface water irrigation and 3000 Escaps per ha for groundwater irrigation.
- Variable costs of irrigation (labour and energy) are 0.3 Escaps/m^3 for surface water irrigation and 0.4 Escaps/m^3 for groundwater irrigation (these costs are generated by the model).
- Required labour is 1 man-day for each 200 m^3 of irrigation water applied.

Crop	Yield data			Production costs	Labour requirements
	Tons/ha	Escaps/ton	Escaps/ha	Escaps/ha	Man - days/ha
B. Aus	0.74	6250	4625	2760	85
B. Aman	0.93	6250	5810	2320	80
LT. Aman	1.26	6250	7875	3140	110
L. Boro	1.34	6250	8375	3340	110
HYV. Aus	2.20	6250	13750	8800	140
HYV. Aman	2.20	6250	13750	8800	140
HYV. Boro	2.20	6250	13750	8800	140
HYV. wheat	1.75	3645	6380	2870	90
Jute	1.50	3240	4860	2920	105
Sugarcane	37.00	405	14985	6740	225
Pulses	0.80	5400	4320	2590	90
Oilseeds	1.20	5600	6720	4370	90

Table 23. Yield and cost data of crops

Navigation

Navigation losses in terms of ton-miles are computed in the model for two critical locations. Losses in ton-miles are converted into money losses by applying a cost of 10 Escaps per ton-mile. This is directly computed by the model.

Fisheries

The model determines losses to fisheries in tons. To convert these losses into money losses, a price of 25000 Escaps per ton will be used.

The money losses are *not* computed in the model.

Examples of benefit/cost calculation

Surface water irrigation project:

- area: 40,000 ha;
- project costs: 2,700 Escaps/ha;
- 25,000 ha cropping pattern 14 (B. Aus + HYV. Aman);
- 15,000 ha cropping pattern 32 (LT. Aman);
- cropping pattern 14 changes to cropping pattern 2 (B. Aus + HYV. Aman + HYV. wheat);
- cropping pattern 32 changes to cropping pattern 28 (HYV. Aman + HYV. wheat);

The model generates the following results:

- additional production of B. Aus: 6,000 tons;
- additional production of HYV. Aman: 87,000 tons;
- additional production of HYV. wheat: 68,000 tons;
- additional variable costs of surface water irrigation: 24 x 16^6 Escaps.

Total (annual) benefits are:
(6,000 + 87,000 – 48,000) x 6,250 + 68,000 x 3,645
= 529 x 19^6 Escaps (for prices per ton see table 23).

Total (annual) costs are:

— project costs: 40,000 x 2,700 x (CRF + ORM) = 40,000 x 2,700 x 0.2 = 21.6 x 10^6 Escaps
— SW irrigation fixed costs:
40,000 x 2,000 x 0.2 = 16 x 10^6 Escaps
— SW irrigation variable costs (from model):
= 24 x 10^6 Escaps
— costs of crop shifts:
HYV. Aman: 40,000 (8,800-3,140) = 226.4 x 106^6 Escaps
HYV. wheat: 40,000x2,870 = 114.8 x 10^6 Escaps
Total 402.8 x 10^6 Escaps

$$\text{Benefit/cost (B/C) ratio} = \frac{529 \times 10^6}{402.8 \times 10^6} = 1.31.$$

III. Description of the Computational Framework

1. INTRODUCTION

This section describes the main features of the computational framework for the workshop as prepared in advance by the course organizers. In general a computational framework ties together the different analytical techniques for carrying out the analysis of WRM strategies.

In section 2 a general outline of the framework is given, in which the water use categories are introduced in the context of the hydrologic cycle. Sections 3 through 5 deal with the various models and modelling concepts that constitute the computational framework, i.e. the Network Model (section 3), the District Model (section 4) and the modelling of water use categories (section 5). Finally, the inputs and outputs of the computational framework are described in section 6.

The computational framework described here has been developed in a rather short period of time for the specific purpose of being used in the workshop of the training course. In developing the computational framework the course organizers have put emphasis on the illustrative and educational value of the framework. The purpose was to show the connection between and the mutual relations of the various elements in a water resources system, and to illustrate the extent to which mathematical models may facilitate the analysis of such complex systems.

To be workable within the workshop context many simplifying assumptions have been made in developing the computational framework. Simplifications for example with respect to aspects considered, physical processes incorporated and data used.

The computational framework comprises elements of several other computer programs of the Delft Hydraulics Laboratory of which all rights are reserved. Hence the computational framework may only be used during the training course. For use of the framework outside the course, permission is required from the Delft Hydraulics Laboratory.

2. GENERAL OUTLINE OF THE COMPUTATIONAL FRAMEWORK

The purpose of the computational framework is to simulate the physical performance of the water use categories in their interaction with the natural system. The computational framework may be used to examine the impact of developments (scenarios) and measures on the natural system and the water use categories, to examine the trade-offs between regions and the trade-offs between water use categories.

The hydrologic cycle forms the base of the computational framework. In describing the hydrologic cycle a distinction is made between the major river system comprising the big rivers, and the various districts. The surface water within the districts (small(er) rivers, lakes, etc.) interacts with, and is influenced by, the major river system.

Waterflow within the major river system is schematized to waterflows in a simple network model consisting of branches and nodes. The interaction between the districts and the major river system is concentrated in specific locations (the nodes of the network). The hydrologic cycle within a district is assessed through a water balance approach. The groundwater and surface water storage within the district are simulated in their interaction with the atmosphere and the major river system. A description of the natural system and the district-network schematization was provided in paragraph 2.1 of Chapter II of Part Three.

Several water use categories may be connected to the hydrologic cycle: agriculture, fisheries, forestry, drinking water supply and navigation. Of these water use categories only the latter is directly linked to the results of the Network Model: water depths at critical locations. All other water users are linked to the regional hydrologic outcomes of the District Model, which are naturally influenced by the network. The model concepts for the network and districts, for the district-network interaction and for the modelling of the water use categories, are elaborated in the next sections.

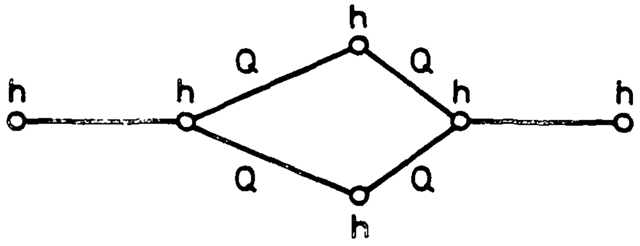
To be workable within the context of the workshop a high aggregation level has to be used. Within the district-network framework this implies that only the major rivers are taken into account and that the districts will cover a wide area.

3. THE NETWORK MODEL (modeling of river water levels and discharges)

3.1 Introduction

Purpose of the model

The Network Model computes water levels and discharges in time and space within a defined network of a river system. Water levels (h) are computed at nodes and discharges (Q) in branches, as shown in the example below.



The main *assumptions* are:

- Flow conditions are considered to be quasi steady state: computation is carried out timestep after timestep. For each timestep the flow condition in and into the network is considered to be constant. Changes are defined at the start of a 'new' timestep.
- The flow condition is defined by the formula of De Chezy:

$$Q = A \,.\, C\sqrt{RI}$$

where Q = discharge in branch (m^3/s)
C = coefficient of De Chezy ($m^{1/2}/s$)
R = hydraulic radius (m)
I = slope of water surface (m/m)
A = area of cross-section (m^2)

- The flow and related water levels are governed by boundary conditions:
  - (a) external in/outflow at boundary nodes; and
  - (b) fixed water levels at pre-defined nodes (mostly lake or sea level).

Related assumptions

- Storage effects during a timestep are not considered in the network.
- Resistance depends only upon the average water depth in a branch.

3.2 Computational background

a) Flow condition

From the equation of De Chezy:

$$Q = A \,.\, C\sqrt{RI} \tag{1}$$

and assuming a rectangular cross-section in each branch:

$$A = b\,.\,\bar{d}$$

where: b = average width of cross-section
$\bar{d}$ = average water depth of the branch

and assuming the width b to be large in relation to the depth $\bar{d}$,

$$R = \bar{d}$$

gives:

$$Q = b\,.\,\bar{d}\,.\,C\sqrt{\bar{d}}\,.\,\frac{\Delta h}{L} \tag{la}$$

where: h = difference in water level between connected nodes
L = length of the branch

Rewritten (la) gives:

$$\Delta h = \frac{L}{c^2b^2}\cdot\frac{1}{\bar{d}^3}\,Q^2 \tag{2}$$

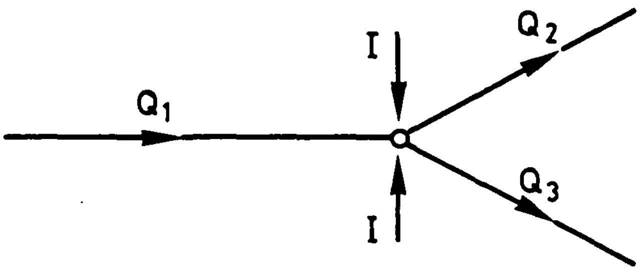
Assuming the term

$$\frac{L}{c^2b^2}$$

to be rather constant enables equation (2) to be rewritten as:

$$\Delta h = \frac{W'}{\bar{d}^3}\,Q^2 \tag{2a}$$

b) Nodal point condition



At any time level total sum of inflows to a particular node must equal zero.

$$\underset{\text{sum flow in branches}}{\sum_i Q_i} \quad = \quad \underset{\text{sum additional inflow at node}}{\Sigma\, I} \tag{3}$$

c) Solution

Combining equations (2a) and (3) gives a set of m+n equations (m = number of branches; n = number of nodes) with m+n variables (discharges Q_i, $i=1$ to m; water levels h, $j=1$ to n). This set of equations is however non-linear and cannot be solved directly. In most cases such a set of equations can be solved by using linearization and iteration. The actual solution method used in the Network Model is a Newton iteration.

d) Boundary conditions

Specification of a fixed water level at a particular node replaces one equation type (3) in the set of equations by the equation

$$h_i = h_i\,(\text{fixed}) \tag{4}$$

At least one fixed water level should always be specified.

4. THE DISTRICT MODEL (regional water balance)

4.1 Introduction

The base of the regional water balance model comprises the hydrologic cycle in a schematized way. Within a district (= area with assumed homogeneous characteristics with respect to the interaction with the major river system) a distinction is made between surface water and vegetation-covered area.

The vegetation-covered area is divided into smaller areas (subdistricts) reflecting different susceptibilities to flooding or ponding. These areas are characterized by a certain ground level and certain drainage conditions. A schematic representation of the division into subdistricts is shown in the figure below.

To account for different crops and irrigation situations these areas are further divided into plots (blocks). A plot is the smallest entity in a district that will be considered; it is homogeneous with respect to all relevant characteristics. It is characterized by a unique combination of ground level, drainage condition, cropping pattern and irrigation situation. A plot does not have a specific geographic location; it consists of all fields in a subdistrict that have the above described unique combination. An example of a plot is the plot that represents all fields in District 1 growing non-irrigated *Boro* rice on sandy/clay soils at two meters above reference level.

In the next sections a description will be given of the main features of the computations on plot, subdistrict and district level respectively and the assumptions being made. Figures 44 and 45 present an overview of the water-flows and water storages which are taken into account in the model.

4.2 Computations on plot level

Computations on plot level are essentially dedicated to the *rootzone storage* and the *field (surface water) storage* in their interaction with the atmosphere, the groundwater storage and the surface water storage. The various plots within a subdistrict reflect the different cropping patterns and irrigation situations.

Main *inputs* of the plot computation are:
- o rainfall and open water evaporation during the time step;
- o rootzone storage at the end of the preceding time step;
- o groundwater level and depth of inundation within the subdistrict at the end of the preceding time step; and
- o maximum infiltration rate.

The *outputs* comprise:
- o actual and potential evapotranspiration;
- o rootzone storage at the end of the time step;
- o irrigation demanded and applied (surface water or groundwater);
- o change in field storage; and
- o exchange between rootzone storage and groundwater storage.

Figures 46 and 47 show an overview of the modelled flows within a plot for the non-inundated and inundated situation respectively. The way these flows are calculated will be discussed below.

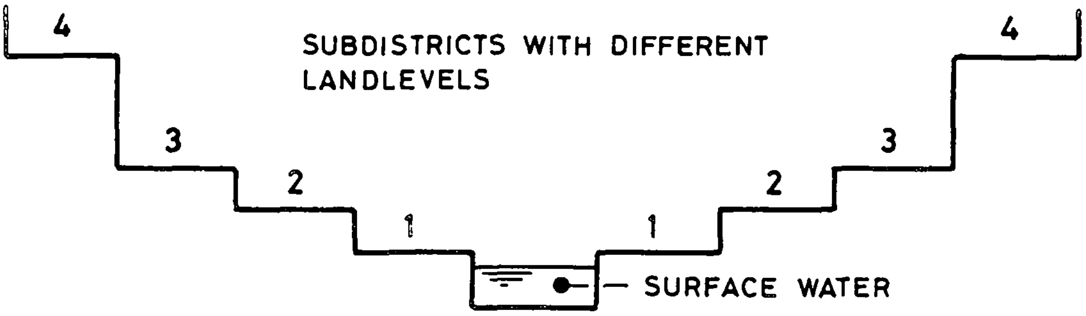
For the determination of the flows a distinction would be made between:
- o a non-inundated versus an inundated plot;
- o a situation of rainfall surplus versus evaporation surplus.

Non-inundated plot with evaporation surplus

In this situation the soil moisture in the rootzone storage has to make up the rainfall deficit. If the soil moisture in the rootzone is below field capacity, capillary rise from the groundwater storage may add water to the rootzone that becomes available for crop transpiration.

If rootzone storage gets deplenished, the actual evapotranspiration may fall below the potential evapotranspiration, unless irrigation is applied. In this situation it is relevant to distinguish between non-irrigated, surface water irrigated and groundwater irrigated plots. The distinction between surface water and groundwater irrigation is important, because the source for irrigation is different for these types and hence the mechanism to cut back the irrigation demand if supply is insufficient.

Surface water irrigation demand may be cut back if the demand exceeds the abstraction capacity or the available surface water in the district reaches a critical level. Groundwater irrigation may be (partly) cut back if the ground-water level gets too deep; the cutback depending on the type of abstraction device. The cutback for groundwater irrigation can easily be determined within the plot computation itself. For surface water irrigation the



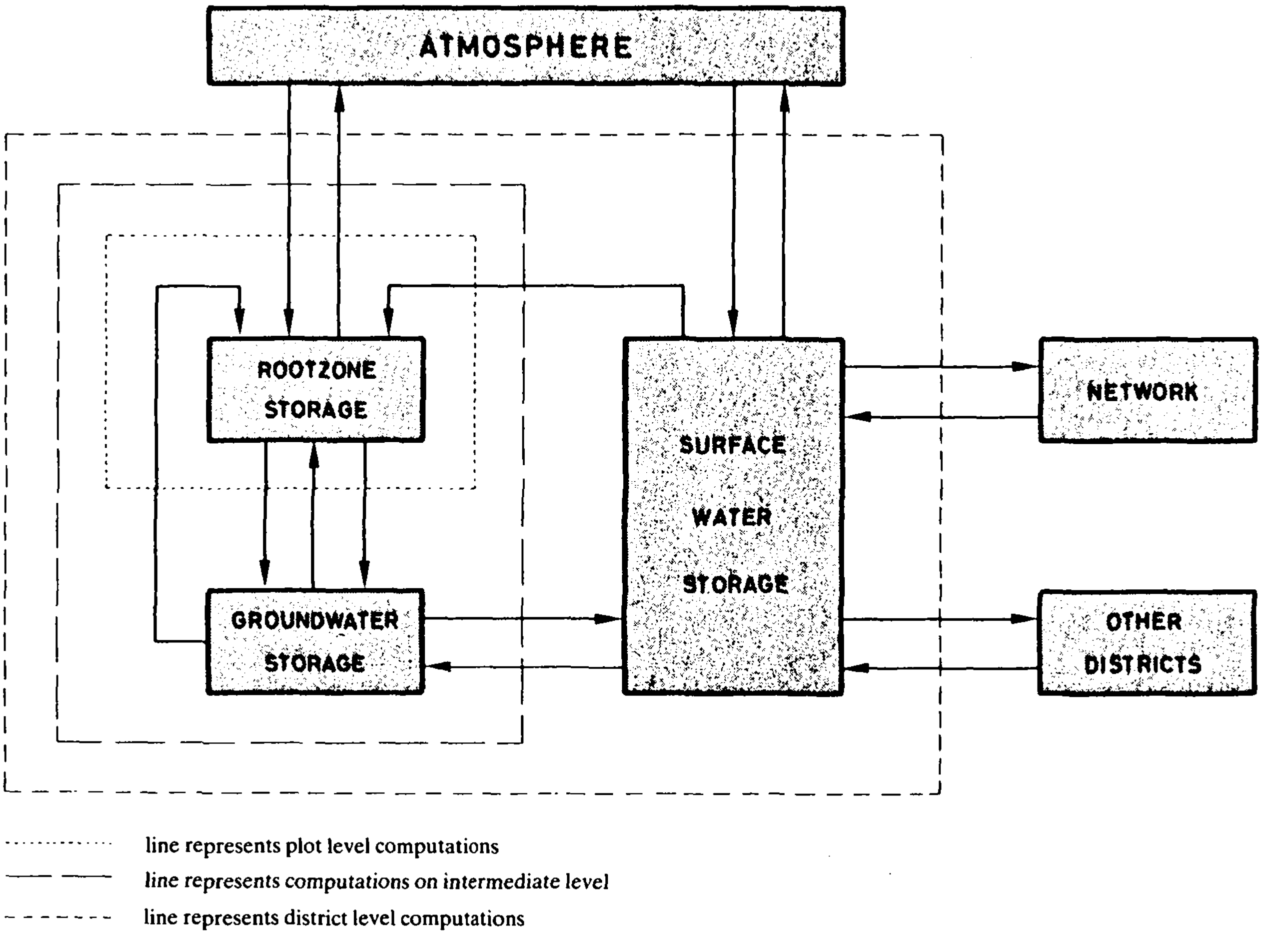


Figure 44. Schematic overview of water storages and water flows within a district; for a *non-inundated* situation.
(The flows are further described in the following figures)

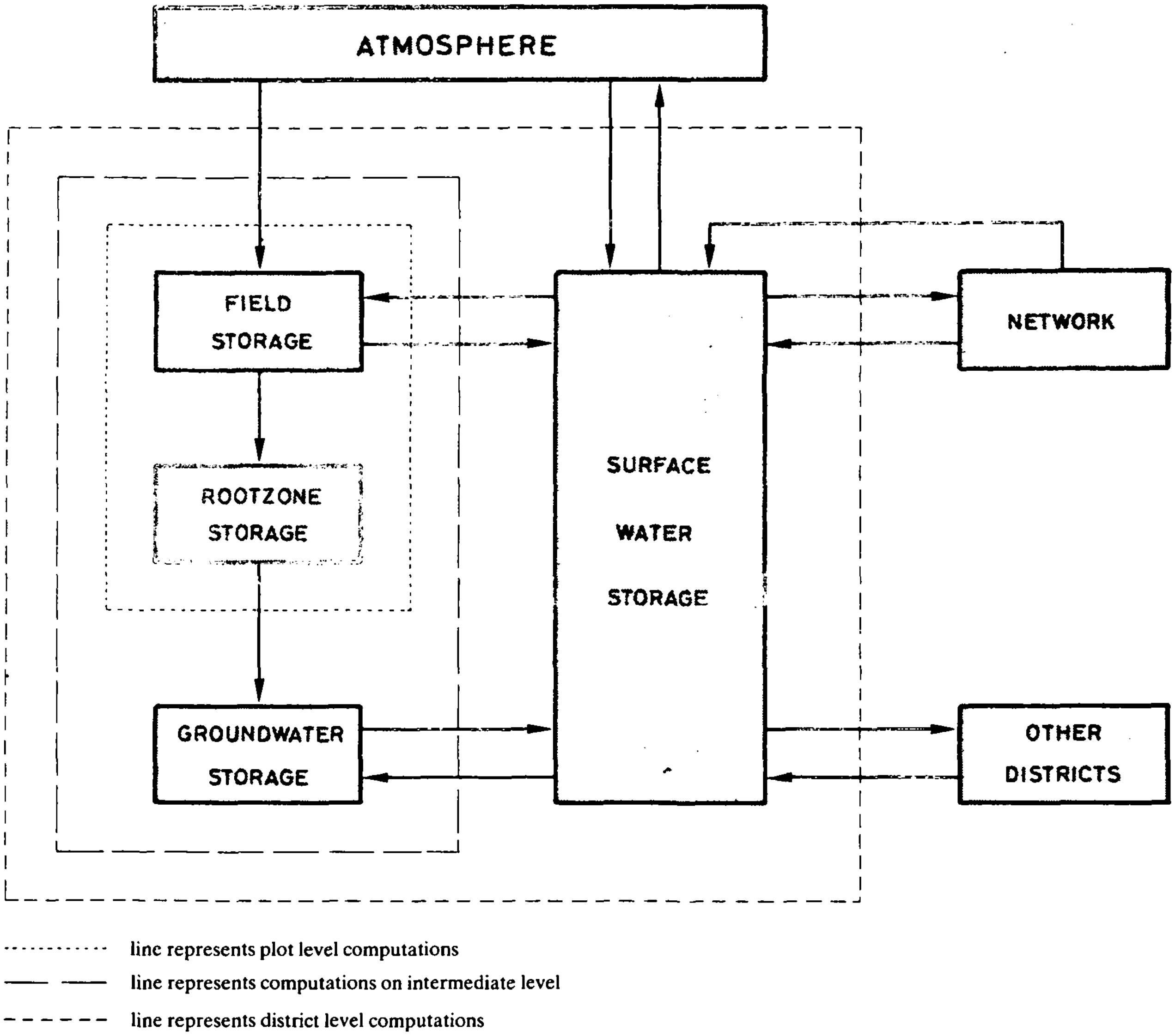


Figure 45. Schematic overview of water storages and water flows within a district; for an *inundated* situation
(The flows are further described in the following figures)

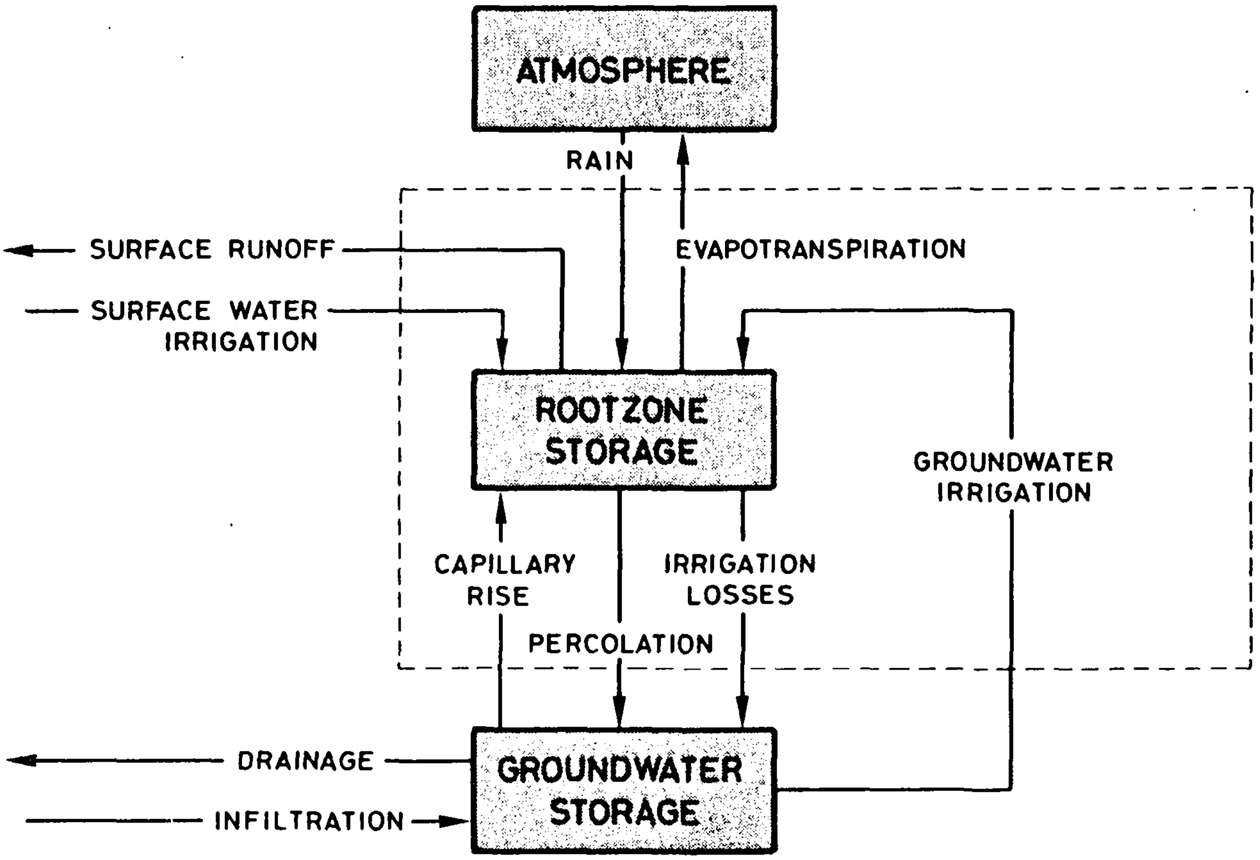


Figure 46. Schematic overview of storages and flows within a plot for the *non-inundated* situation.
(The relationship within the dashed block are solved for each time step.)

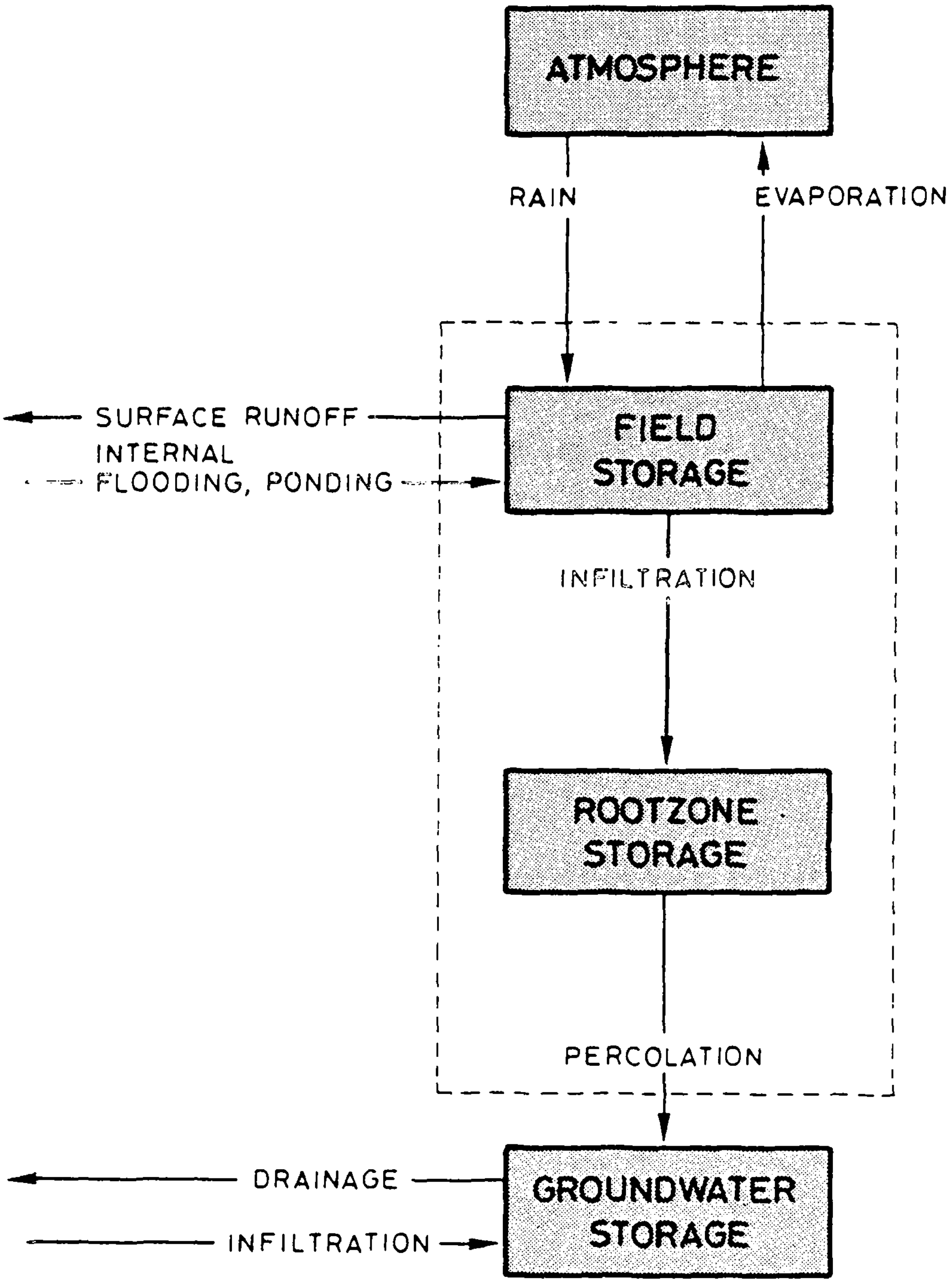


Figure 47. Schematic overview of storages and flows within a plot for the *inundated* situation. (The relationship within the dashed block are solved for each time step.)

cutback can only be determined after computation of the district water balance.

Non-inundated plot with rainfall surplus

When rainfall exceeds potential evapotranspiration, rootzone storage and groundwater storage gradually increase until their maximum is reached. The same procedure as described in the foregoing section is applied. The amount of rainfall entering the rootzone is restricted through the maximum infiltration rate. The rainfall which cannot enter the soil accumulates on the ground surface. In this situation actual evapotranspiration equals the potential evapotranspiration.

Inundated plot with rainfall surplus

Water from field storage infiltrates into the rootzone. Infiltration cannot exceed the maximum infiltration rate. At first soil moisture in the rootzone is brought to field capacity, if this has not been reached yet. After that, excess water percolates to groundwater storage until the groundwater level reaches the bottom of the rootzone. Next the rootzone storage is increased up to saturation. After rootzone storage is brought to saturation no more water can enter the soil and the remaining water ponds on the ground surface. This process of filling groundwater storage and rootzone storage up to saturation probably will only take a short period of time. Once saturation has been reached, field storage (inundation) will increase, until rainfall surplus disappears.

Actual evapotranspiration equals potential evapotranspiration in this situation. The change in field storage follows from the difference in rainfall and actual evapotranspiration minus the amount of water which has infiltrated into the soil.

Inundated plot with evaporation surplus

As long as the plot is inundated the procedure for the plot computations is the same as the one described in the foregoing section. Only the amount of field storage will decrease. Eventually a moment will be reached when field storage disappears because evaporation surplus exceeds field storage. From this moment on soil moisture in the rootzone storage is used to realize an actual evapotranspiration equal to the potential evapotranspiration.

Throughout the year each of the described conditions may occur in a sequence depending on the wet and dry season. At high-lying parts no inundation will take place and for these parts only the two first described conditions are relevant.

4.3 Computations on subdistrict level

Computations on the intermediate (subdistrict) level are dedicated to the changes in field storage and groundwater storage. The computations mainly comprise the aggregation of the waterflows calculated on a plot-basis. Moreover the interaction with the surface water system of the district is taken into account. The balances to be computed are shown in figure 48.

The determination of the water balances for all plots with the same land level is a rather straight-forward one. From the plot computations the change in field storage is known, as is the exchange between rootzone and groundwater storage, due to percolation, capillary rise, groundwater irrigation and irrigation losses. Aggregating these results for all plots with the same land level completes the water balance of the field storage and constitutes the main part of the water balance of the groundwater storage.

For the groundwater storage also the drainage into or the infiltration from the surface water should be taken into account. This interaction is assumed to be a linear function of the difference in head between the surface water level and the groundwater table of the plots. To avoid iterations, drainage and the corresponding infiltration are computed based on the head difference at the end of the preceding time step. Of course infiltration from the surface water system can only take place as long as groundwater storage has not reached its maximum.

4.4 Computations on district level

The computations on the district level are dedicated to the changes in surface water storage due to the interactions with the plots in the district, with other districts, with the atmosphere, and with the network representing the major river system.

The main *inputs* into the district computations are:

- surface water storage and level at the end of the preceding time step; storage and level are directly linked to each other by means of a storage-level relationship;
- the field storage within the plots;
- drainage from the plots and the corresponding infiltration;
- plot surface water irrigation demand;
- rainfall and evaporation; and
- incoming flow(s) from higher lying district(s).

The *outputs* comprise:

- discharge(s) to or withdrawal(s) from the nodes of the networks, including flooding from the major system;
- surface water storage and level at the end of the timestep;
- depth of inundation within the plots;
- discharge(s) of other district(s); and
- amount of applied surface water irrigation.

Figure 49 gives an overview of the water flows within the district computations. The interaction of the surface

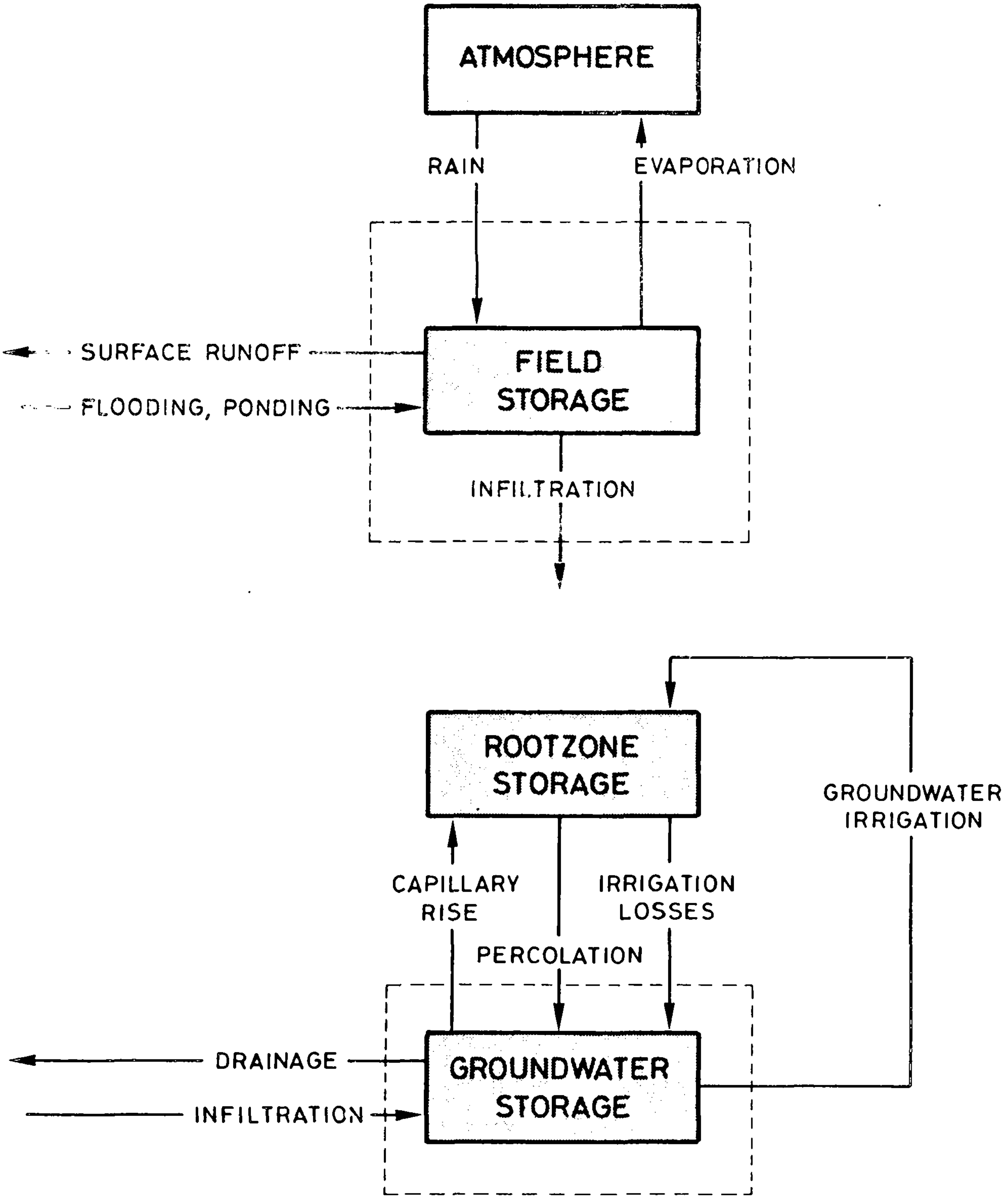


Figure 48. Schematic overview of water balance components of groundwater storage and field storage on subdistrict level.
(The relationships within the dashed blocks are solved for each time step.)

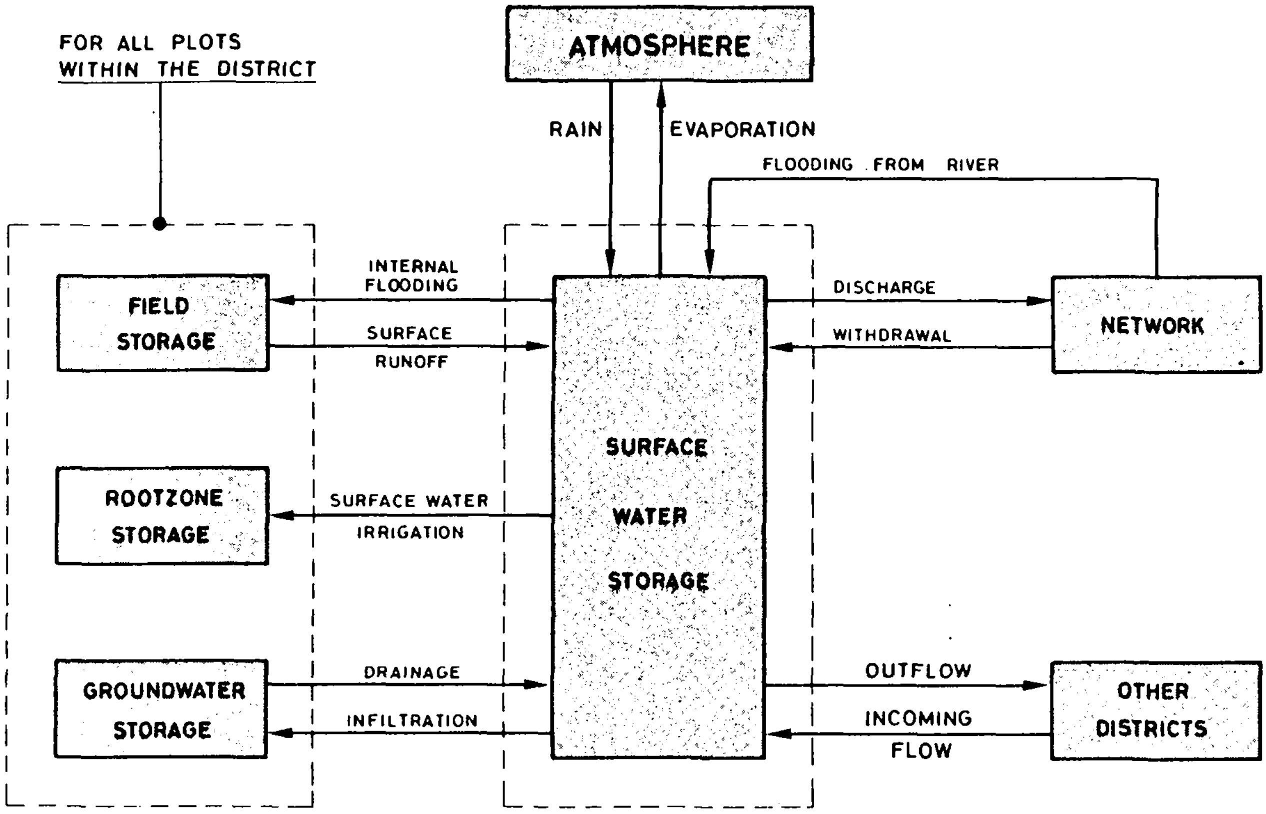


Figure 49. Schematic overview of the water balance components of the surface water within the district.

(The relationships within the dashed blocks are solved for each time step.)

water storage with the plots is an easy one. All components have already been determined on plot or subdistrict level; it is simply a matter of aggregation.

The interaction with the network, however, is a complicated one. The discharge to the nodes of the network or the withdrawal from these nodes depends on the head difference between district water level and the water level in the node of the network. Water levels in and discharges from districts as well as water levels and flows in the network, have to obey physical laws. To establish this relationship several iterations in the computing procedure may be necessary. This iteration procedure is discussed in paragraph 4.6. Moreover, flooding in a district may occur due to overtopping of embankments or levees.

In some cases the characteristics of the "minor" streams within a district are such that this district does not directly discharge into a node of the network. Instead such a district discharges to another lower lying district. The mechanism to determine how much water is discharged from one district to another is in principle the same as that for the discharge to a network node. However, application of this mechanism may lead to an increase in necessary iterations in the computing procedure. To avoid this, a more simple concept has been adopted. Discharge from one district to another takes place as soon as the surface water storage in the district exceeds a characteristic volume. The excess volume is discharged to the lower lying districts. This excess flow is constrained by a maximum discharge capacity.

4.5 Request and "delivery" stage

In the description of the plot computations it has been assumed that sufficient water for surface water irrigation is available and that no (additional) flooding of plots occurs due to high surface water levels within the district. These assumptions form an essential part of the so-called request stage. After solving the district water balance in its interaction with the network, it can be judged whether these assumptions were justified. If not, cutback of surface water irrigation demand or flooding of plots is taken into account. For this purpose the plot computations are repeated to update the relevant variables.

4.6 District-network interaction

Districts may discharge to or withdraw from the major river system. The exchange of water between district and river system is concentrated in specific locations: the nodes of the network. A district may be linked with more than one node of the network. The interaction of a district with a certain node being either one way (discharge *or* withdrawal) or two ways (discharge and withdrawal depending on river water level and the level of the district surface water).

The exchange between district and network may be natural or man-made. If the exchange is man-made, the maximum exchange is simply represented by the installed capacity. The change in volume of the district surface water volume is then easily computed. When however the exchange is determined by natural, physical laws, computation is much more complex. The exchange depends on the head difference between the district water level and the water level in the node of the network. Changes in water volume and water level within the district should be in accordance with the discharge to or withdrawal from the network. This is achieved by iteration.

In the first estimate of the discharge to or withdrawal from the network, the water level in the node of the preceeding timestep is used. Due to discharges/withdrawals and due to changing cross-boundary inflows, the water level in the node, as computed with the Network Model, will in nearly all cases differ from the water level in the previous timestep. Based on this "new river level" a new set of values for the district water volume, the district water level and the exchange between district and network is determined. This iteration procedure continues until sufficient accuracy is reached.

When the water levels in the major river system reach high values, flooding of districts may occur due to overtopping of embankments or levees. This phenomenon has been taken into account in a very schematized way. To each district a special connection with a node of the network may be assigned, a so-called overflow node. Flooding of a district from such a node takes place as soon as the water level in the node exceeds a certain "safety-level" *and* the water level in the district is lower than that in the node. The size of the inflow is restricted: as a result of the inflow the water level in the district will rise and that in the node will fall. "Equilibrium" is reached when district water level and water level in the node do not differ more than a prescribed distance or when the water level in the node has fallen below safety level.

5. MODELLING OF WATER USE CATEGORIES

5.1 Introduction

Several water use categories may be connected with the District and Network Model. From these water use categories agriculture is by far the most important one. Agricultural production as influenced by water shortage, water excess and water quality can be linked to the hydrologic part of the District Model.

Besides agriculture, fisheries, forestry and public water supply may also be dealt with on a regional basis (District Model). Impacts of measures on navigation may be studied using the Network Model of the main river system.

Of these water use categories agriculture has been modelled in advance by the course organizers in some detail and implemented in the computational framework.

Two other water use categories to be dealt with in this section have been modelled in less detail: fisheries and navigation. At the end of this section attention is given to the modelling of salt intrusion.

5.2 Agriculture

Cropping pattern and crop yield

The modelling of agriculture has been directed to the physical conditions influencing crop yield. Actual yield may differ from potential yield because of damages due to drought, flooding and salinity. Potential yield of a crop is not fixed, but depends amongst other things on the application of fertilizer and pesticides.

In general terms actual and potential yield are different for:

- o different cropping patterns; a cropping pattern may consist of 1-3 different crops;
- o different applications of fetilizer and pesticides; and
- o different water demand and supply situations.

To account for these differences a district is divided into smaller areas, called plots. As mentioned in paragraph 4.1 a plot is an area which is homogeneous, with respect to:

- o cropping pattern;
- o soil type:
  - — storage capacity of rootzone;
- o irrigation type:
  - — no irrigation;
  - — surface water irrigation;
  - — groundwater irrigation;
- o landlevel type:
  - — susceptibility to flooding/ponding;
- o drainage coefficient:
  - — drainage conditions.

For a description of crop types and cropping patterns to be used in the workshop, reference is made to paragraph 2.2 of Chapter II of Part Three.

Crop water requirements and irrigation

Crop water requirements are determined by multiplying the open water evaporation with a crop factor depending on crop type and period within the growing season. Available for evapotranspiration are the effective rainfall, the rootzone storage and possibly some capillary rise. If this sum of supply sources is less than the crop water requirements, actual evapotranspiration is less than potential, and drought damage occurs unless additional supply takes place by irrigation.

If the area can be supplied with irrigation water, irrigation demand is determined. The irrigation demand follows from the soil moisture deficit to make up potential evapotranspiration, taking into account irrigation efficiency*.

Source for irrigation water is either surface water or groundwater. The amount of surface water within the district may be too scarce to fully satisfy demand. Also groundwater depth may get so deep that (some of the) abstraction devices stop operating. This phenomenon has been taken into account: irrigation demand can be cut back, the cutback procedure being different for surface water and groundwater.

For surface water irrigation the possible cutback can only be determined after computation of the water balance for the district surface water. That is why in the hydrologic part of the District Model a distinction is made between a request stage in which sufficient supply is assumed and a delivery stage in which the results of the request stage are updated when irrigation demand has been cut back. Cutback takes place when the district surface water level or volume threatens to go below a critical level. This critical volume is an input variable. Besides for physical considerations the critical volume may be used as a "policy variable" to examine the trade-off between fisheries and agriculture.

Groundwater irrigation will be cut back when groundwater gets too deep. The size of the reduction depends on the groundwater depth and the composition of the abstraction devices. A general cutback function has been implemented within the model, for which the special characteristics can be specified as input data. The form of the cutback function is shown in figure 50. The cutback function may also be used to show the trade-off between agriculture and public and industrial water supply.

Crop damage

Crops may suffer damage from drought, flooding or salinity. To assess these damages simple relationships have been developed, using some outcomes of the hydrologic computations as indicators. For drought damage the ratio between actual and potential evapotranspiration is used. Flood damage is described through the depth of inundation, while for the salt damage the salt content of the surface water irrigation is used as an indicator. Flood damage and salt damage only occur if critical levels of their respective indicators are exceeded. All damages are determined as a certain percentage of potential yield. Values of the three indicators are determined for each timestep. The total damage (difference between potential and actual yield) is computed at the end of the growing season, using the values of the indicators for the timesteps within the growing season. For the drought damage the average value of the ratio between actual and potential evapotranspiration is used. This value is entered in a yield reduction-function to compute the resulting damage. The

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* Irrigation efficiency has been taken equal for both surface and groundwater irrigation. Irrigation efficiency has been assumed to be independent of the demand-supply-ratio.

general feature of the yield-reduction function is shown in figure 51.

For both flood and salt damage the extent of exceedance of the critical level for each timestep is accumulated over the growing season. This results in a combined effect of extent and duration of exceedance. For determining salt damage the next step is to calculate the average excess of the critical level during the growing season. This average excess of critical level is subsequently entered in a yield reduction function to determine the remaining yield. This function is shown in figure 52.

The accumulated exceedance of the critical inundation depth is directly entered into a yield-reduction function. This function is shown in figure 53.

Benefits and costs

Measures taken to improve water resources management (extension of irrigation, drainage improvements) will result in less crop damage. Improvements in WRM also may lead to a change in agricultural practices; e.g. cultivating of crops with a higher potential yield (using HYV and/or extended application of fertilizer and pesticides). The benefits of water resources management measures equal the increase in actual yield.

To implement these measures and to change agricultural practices certain costs are incurred. Costs for irrigation should distinguish between fixed annual costs (function of irrigated area) and variable annual costs (function of irrigated volume). Costs for changing agricultural practices comprise the (additional) costs for seeds, fertilizer and pesticides.

The actual computation of costs and benefits does not take place within the computational framework. Guidelines to carry out these computations, using the results of the computational framework, were provided in paragraph 4.4 of Chapter II.

5.3 Fisheries

To determine the impact of executing certain measures on fisheries, a very simple model concept has been used. Fish production and damage in a district is assumed to be related to the depth of the surface water within a district. As long as this water depth exceeds a critical depth the production is potential. When however the water depth falls below the critical depth, damage to fish production occurs. The size of this damage depends on the water depth. For the damage function a linear relationship has been assumed (see figure 54).

5.4 Navigation

Due to low water depths in the major river system the transportation of persons and goods may be reduced during certain timesteps. In the model the water depth is determined at two critical locations. The water depth in these locations is found by interpolating the water levels at the upstream and downstream node and subtracting the bottom level.

The water depth thus determined, is entered into a navigation-loss function. If the water depth is smaller than the depth of the biggest crafts some reduction in transported ton-miles takes place. If the water depth decreases further also other crafts cannot navigate and transportation losses increase. The relationship between water depth and loss in transported ton-miles has been found to be almost linear. In figure 55 an example of a navigation loss function has been presented.

5.5 Salt intrusion

Salt intrusion may affect several water use categories: agriculture, fisheries and forestry. Salt intrusion takes place along the lower reaches of the major river system, particularly during periods with low flows. The modelling of salt intrusion is kept very simple. To assess the salinity level in the nodes of the network, a simple relationship is used, depending on the discharge in the branch.

The actual interest in salt intrusion is on its effect on the salt concentration of the surface water within the districts. This salt concentration is of significance for the different water use categories. To avoid cumbersome modelling[*] of salt in a district it is simply assumed that the salt concentration within the district is the same as that of the nodes of the network from which the districts withdraw their water. Assumptions are made on which parts of the districts are influenced by the salt intrusion. Only the crops that are surface water irrigated in the influenced parts may be damaged by the salt. It is assumed that the rootzone salt concentration of the irrigated crops is 1.5 times the salt concentration of the surface water used for irrigation.

6. INPUTS AND OUTPUTS OF THE COMPUTATIONAL FRAMEWORK

6.1 Model inputs

Input data Network Model

Inputs to the Network Model comprise:

a. the layout of the network: the number of nodes and branches, which branches connect which nodes etc.;

b. physical characteristics of each node and branch:
  - a bottom-level for each node;
  - a resistance as a function of waterdepth for each branch; and

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[*] Actually a salt balance should be calculated taking into account the effects of precipitation, evaporation, drainage, withdrawals etc. This however is beyond the scope of the workshop.

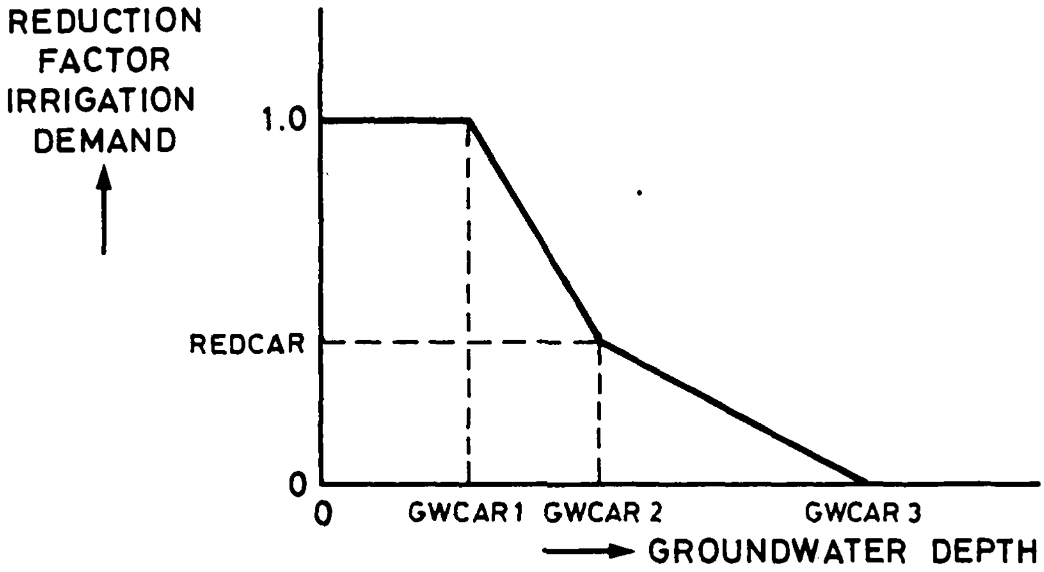

Figure 50. Reduction function for groundwater irrigation demand

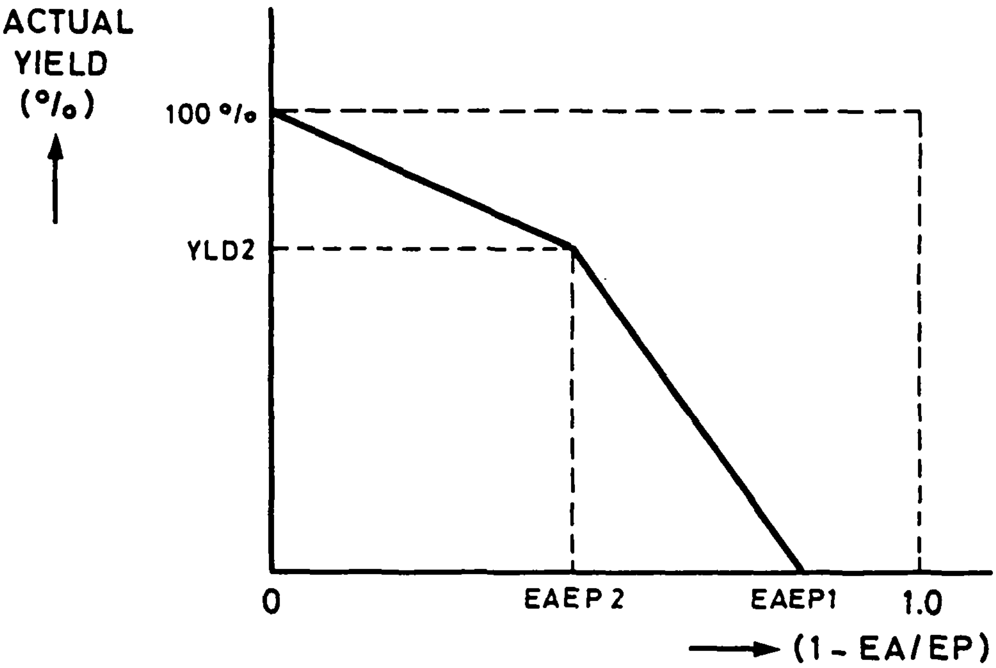

Figure 51. Yield-reduction curve for drought damage. Actual yield as a function of the ratio of actual and potential evapotranspiration (in % of potential yield)

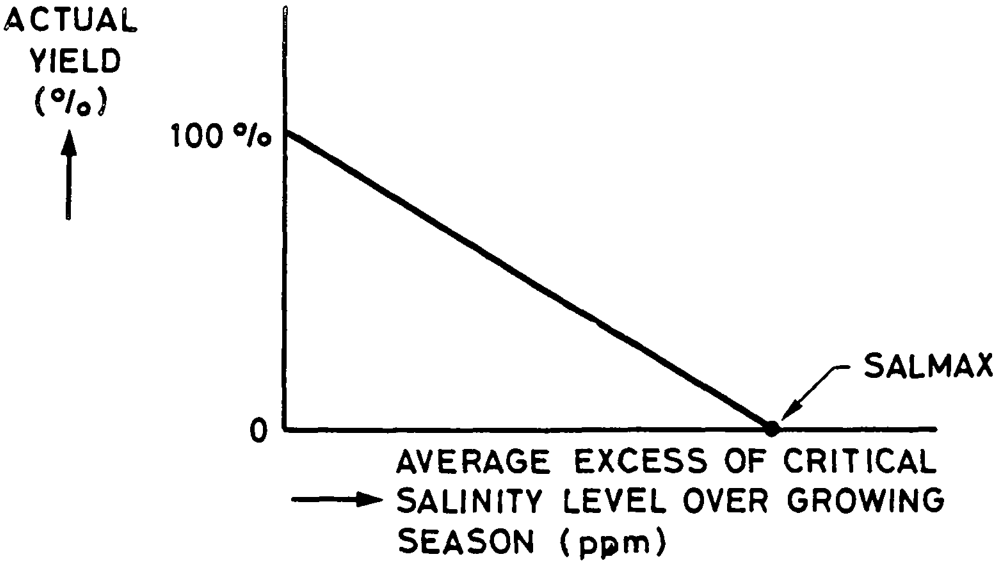

Figure 52. Yield-reduction curve for salt damage

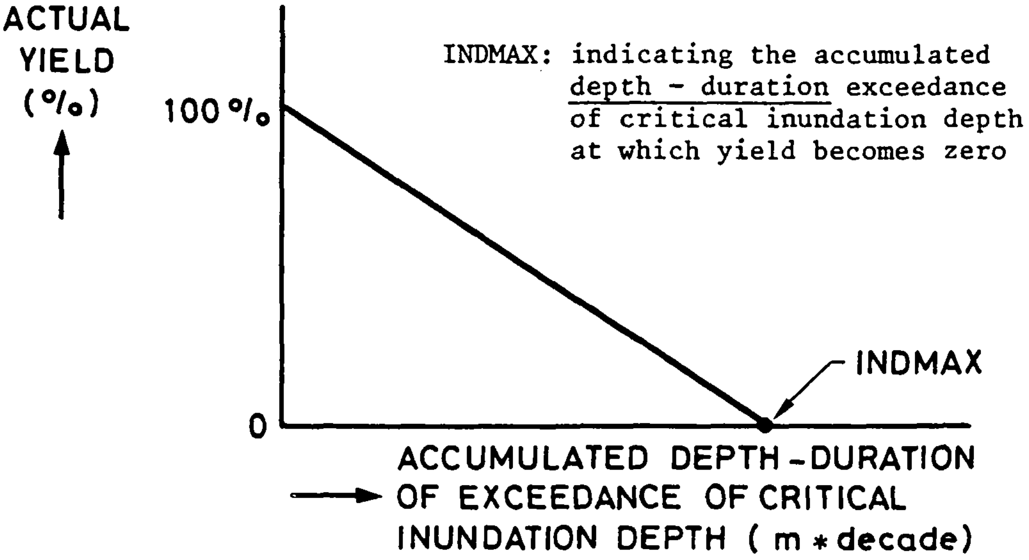

Figure 53. Yield-reduction curve for flood damage

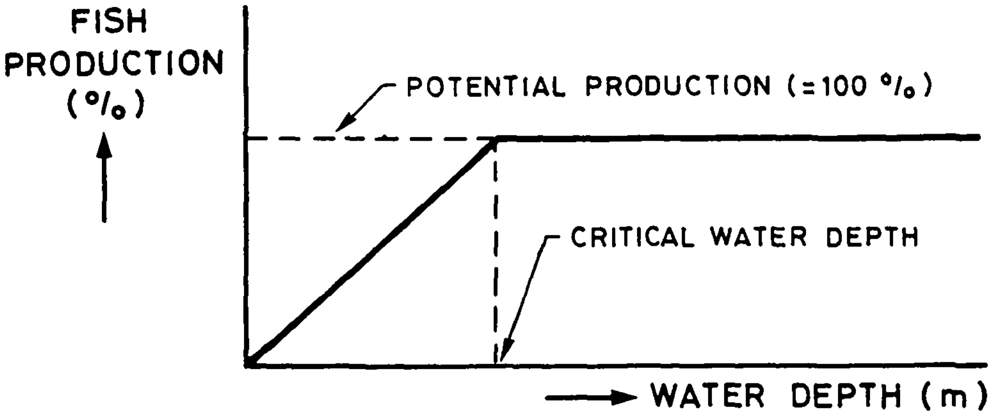

Figure 54. Damage function for fish production

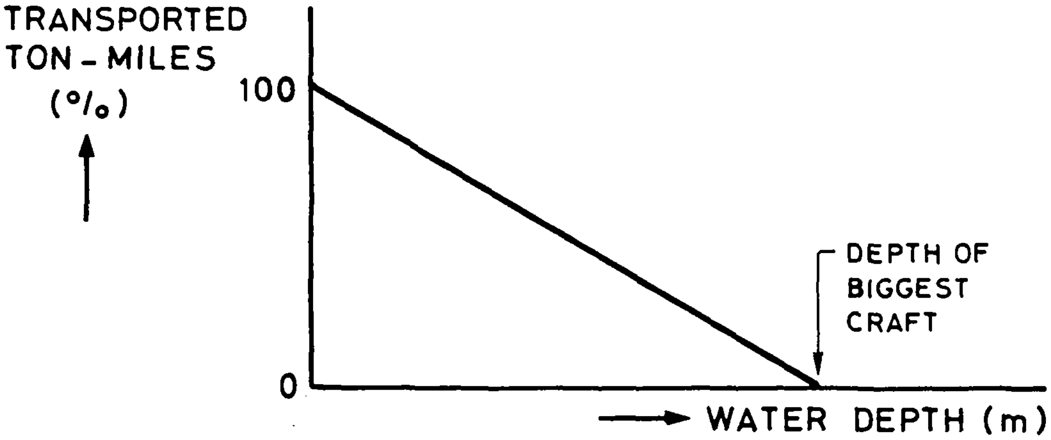

Figure 55. Navigation loss function

c. time-dependent input data to run the model for subsequent timesteps: water depths or flows at the inflow and outflow nodes of the network.

Input data hydrologic part of District Model

For running the hydrologic part of the District Model various types of input data are necessary. The following information is required for each district.

a. The topography of the district: which area is occupied by surface water or covered by vegetation. To account for different susceptibility to flooding the vegetation covered area has to be divided into subdistricts with different ground level.
b. The relationship between the surface water volume within the district and the water level; taking into account flooding of the lower lying parts of the district.
c. The area which is occupied by polders, a polder being an area with a water control independent of the surrounding area.
d. The discharge situation: whether a district discharges to the network or to another district. In the latter case the volume of district surface water should be specified at which discharge starts and also the maximum discharge capacity. The discharge to nodes of the network is discussed in the next section.
e. Discharge and infiltration coefficients which describe the size of the exchange between surface water and groundwater within the district.
f. Soil type: connected to the soil type are various soil characteristics — infiltration rate, rootzone storage at field capacity and at saturation, specific yield and parameters describing capillary rise.
g. Cropping pattern determining evapotranspiration.
h. Initial conditions with respect to district surface water level, groundwater level, rootzone storage and depth of inundation.
i. Parameters describing the reduction of irrigation demand: for groundwater irrigation, a reduction function depending on groundwater depth; for surface water irrigation, a critical volume at which surface water demand is cut back.
j. Time series of precipitation and open water evaporation.

Input data for district-network exchange

The required information for the district-network exchange includes the following.

a. The lay-out: to which node(s) a district is linked.
b. A specification of the district-node link. For a natural exchange a resistance has to be specified, which, together with the head difference in water level between district and node, results in a discharge or withdrawal. For a man-made exchange a maximum capacity has to be specified.
c. A specification of the network-district bank-overtopping situation: the node from which a district can be overflown and the critical embankment level at which overtopping starts.

In case a district-node link is only used for discharge or withdrawal this may be indicated by a discharge capacity equal to zero.

Input data for water use categories

Of the water use categories only agriculture, shipping and fisheries have been modelled. The following information is required.

a. The area occupied by a certain cropping pattern and with a certain irrigation situation. A unique combination of these two factors constitutes a plot.
b. Several characteristics depending on cropping pattern:
   - root depth (also depending on soil type);
   - crop factors describing potential evapotranspiration;
   - start and end of growing season;
   - potential yield (also depending on application of fertilizer);
   - parameters describing the yield reduction due to drought, flooding or salt.
c. Potential fish production by district and a critical water level below which damage to production may occur.

Miscellaneous input data

Some input data are independent of both district and crop type. These data comprise:

- irrigation efficiency;
- unit cost for application of irrigation, both for surface water and groundwater;
- constants to describe the relationship between salt concentration and river discharge;
- the price per transported ton-mile; and
- accuracy specification of computations.

Data files

The above input data have been organized into 16 different data files. An overview of these data files is presented in Appendix 1.

The computational framework is used for simulating the effects of water management measures under various conditions regarding the meteorologic situation and cross boundary inflows, which are reflected in the files RAIN and INOUT, respectively. Years of different dryness are simulated by using alternative RAIN and/or INOUT files, which have been prepared in advance.

The implementation of measures is generally simulated by changing the characteristics of the network, the districts, or the plots, which are collected in the files NETWORK, DISTRICT and PLOT, respectively. All other data files usually do not change when applying the computational framework. Hence, the files NETWORK, DISTRICT and PLOT are very important tools in executing the impact assessment analysis. Appendices 2, 3 and 4 describe the contents and format of the files NETWORK, DISTRICT and PLOT, respectively. Moreover, an example is provided of each of these files.

6.2 Model outputs

The output of the computational framework is divided into:

- a hydrologic overview; and
- a user oriented overview

Hydrologic overview

The hydrologic overview comprises the following tables.

(i) Discharges in network branches per timestep (m^3/s).
(ii) Water levels in network nodes per timestep (m above M.S.L.).
(iii) District-network exchange per timestep (m^3/s).
(iv) District-district exchange per timestep (m^3/s).
(v) Applied irrigation per district per timestep (both for surface water and groundwater) (m^3).
(vi) Flooded area and depth per district per timestep (in ha, respectively in m above ground level).
(vii) Depth to groundwater per district per timestep (in m below ground level).

User oriented overview

The user oriented overview comprises the following water use categories:

- agriculture;
- fishereis; and
- navigation.

Agriculture

- Actual and potential yield by district in 1,000 tons for each of the crop types, as well as a total value accumulated over the districts.
- Damages due to flooding, drought and salt by district and crop type (in tons), as well as a total value accumulated over the districts.
- Total amount of surface water and groundwater irrigation applied (by district and accumulated over all the districts).

Outputs for the other water use categories take the following form.

- **Fisheries**
  Actual fish production and damage by district (in tons).

- **Navigation**
  Overview of waterdepths at the two critical locations. Navigation losses caused by depth limitations (in monetary terms).

IV. Results of the Workshop

1. INTRODUCTION

The workshop consisted of two major phases:

- Inception-phase: Setting Up The Analysis (SUTA); and
- Carrying Out the Analysis (COTA).

Main elements of SUTA are:

- identification of planning objectives and criteria;
- preliminary analysis of problems and measures; and
- specification of analysis conditions and analytical approach.

Main elements of COTA are:

- preparation; and
- integration.

Preparation involves the estimation of temporal and spatial pattern of activities, the analysis of water using and water related activities, and the analysis of the natural system. The integration phase includes the formulation and analysis of water resources management strategies, the evaluation of such strategies and the presentation of the final results.

In the workshop, the emphasis has been on the integration phase of COTA (3½ days) and only limited time was spent on SUTA and COTA-preparation (approximately 2 days in total). Therefore, the greater part of SUTA and the first part of COTA had to be prepared in advance by the course organization. The following briefly describes the results of SUTA, COTA-preparation and COTA-integration, respectively.

This last section of the workshop part of the seminar proceedings gives an overview of the outcome of the workshop. Its purpose is only illustrative. Emphasis during the workshop has been on applying the framework of analysis and the use of analytical techniques, and not on correctness and completeness of the actual numbers used and calculated. Moreover, due to time limitations, insufficient attention was paid to completeness of the analysis, e.g. aspects taken into account, the number of strategies investigated, scenarios and sensitivity analysis. Hence, the following "results" should be interpreted as illustrative examples of the outcome of a systems analysis study and not as *the* solution of the problem of the case-study.

2. SETTING UP THE ANALYSIS (SUTA)

The most important part to be dealt with in this part of the workshop was the identification of planning objectives and criteria. The following national objectives served as a starting point of the analysis.

(i) Selfsufficiency in food production.
(ii) Enhancement of economic growth.
(iii) Equitable distribution of benefits.
(iv) Improvement of public health.
(v) Improvement of employment opportunities.
(vi) Improvement of environmental quality.

Most time of the SUTA-phase in the workshop was spent on the translation of these general planning objectives into *operational* objectives and to associate these operational objectives with relevant criteria, to be actually used in the analysis. An overview of the adopted operational objectives and the related criteria is given in table 24.

The preliminary analysis of problems and measures had been prepared in advance. In Section II a description was given of an imaginary country, its water resources system, its main water users and socio-economic system, its main water resources management problems and the potential measures to solve or alleviate these problems. This imaginary country served as a basis for the planning exercise.

The following analysis conditions were adopted:

- System boundaries: the imaginary country, its natural system and water users as described in Chapter II.
- Time horizon: 2005;
  - o short term: 1985-1990;
  - o long term: 1990-2005.
- Base year: 1985.
- Discount rate: 15 per cent.
- Hydrologic/meteorologic conditions: base analysis on medium year; wet and dry year to be used for sensitivity analysis.
- Scenario elements to be included:
  - o cross-boundary inflows of Salmar and Sirion River;
  - o agricultural production in relation to non-water inputs (fertilizer, pesticides)

The analytical approach had been defined and prepared in advance. The analytical framework, as described in Chapter III was explained during the course.

3. COTA-PREPARATION

This involves:

- estimating temporal and spatial pattern of activities (ETSPA);
- activity analysis of water users and water-related activities; and
- analysis of natural system.

ETSPA mainly dealt with the translation of available population projections into food production targets for 1990 and 2005, both by region (North-East, South-East etc.) and for the country as a whole. For agriculture, navigation and fisheries it was assumed that the 1985 situation would not autonomously change in future, except for the possible increase in agricultural production due to non-water inputs (to be included in the scenario).

Operational objectives	Criteria
1. Selfsufficiency in food production	Amount of foodgrain produced (tons)
2. Enhancement of economic growth	
(a) Increase GNP with 14% by 1990	(a) Change of GNP contribution by agriculture, navigation and fisheries (Escaps)
(b) Increase export value with 10%	(b) Change of production value of jute and pulses (Escaps)
3. Equitable distribution of benefits	
(a) Selfsufficiency in food production by region in 1990	(a) Sufficiency rate for regions NW, NE, SW and SE
(b) Damages/benefits for various users	(b) Fish production in tons and navigation production in ton-miles
4. Improvement in public health	o Exceedence frequency of -6 m gw level o Flooded area, depth and duration
5. Improvement of employment opportunities: increase employment by 10% in 1990	Change in agriculture labour requirements (manyears)
6. Improvement of environmental quality	Change in mean river discharges during dry period of branches 9 and 10
7. General	o Capital requirements over time o Time before benefits accrue o Simplicity of strategy o Flexibility of strategy

Table 24. Operational objectives in relation to criteria

With respect to the activity analysis the key items are:

- current and future water demands and determining factors; and
- damages (loss functions) related to insufficient water supply.

The analysis of natural systems involves the analysis of river inflows and river characteristics, precipitation and evaporation, land and soil system and salt intrusion. Both the activity analysis and the analysis of the natural system had been prepared in advance. During the course, explicit attention was given to the kind of data required for the analysis and the way these data had been processed and organized into the most important data files to be used in the analysis, i.e. the NETWORK file, the DISTRICT file, and the PLOT-file.

4. COTA-integration

The integration phase involves:

- formulation and analysis of WRM-strategies;
- evaluation of strategies; and
- presentation of results.

The formulation and analysis of strategies includes the following steps:

- screening of potential measures;
- formulation of WRM strategies; and
- impact assessment of WRM strategies.

The following types of potential measures had been identified:

- (regional) flood control and drainage projects (within the districts);
- surface water irrigation projects;
- groundwater irrigation projects;
- water conservation projects (within the districts);
- district inlet capacity projects;
- district drainage capacity projects; and
- embankment projects for national rivers.

All identified measures in the above categories were separately considered in the screening process. For measures that were potentially effective, benefits and costs were determined using the computational framework. For details about the actual measures and the benefit/cost calculation, reference is made to paragraphs 3.3 and 4.4 of Chapter II. An example of such a calculation is provided in table 25. An overview of the complete screening results by district is presented in tables 26 through 33.

Strategies have been formulated based on the screening results (B/C-ratios) and the operational objectives to be fulfilled. Promising strategies have all been investigated using the computational framework. While the screening was based on the present situation (1985 and medium hydrologic/meteorologic conditions), the analysis of strategies was done in three groups using three different scenarios, i.e.:

(i) continuation of present situation;
(ii) reduced future inflows of Salmar and Sirion River; and
(iii) reduced future inflows of Salmar and Sirion River in combination with a 10 per cent increase of agricultural production due to additional non-water inputs (fertilizer, pesticides, etc.)

In order to facilitate the evaluation of potential WRM strategies, an overview of the most relevant effects of these strategies has been presented for the three different scenarios in tables 34 through 36. These tables constitute the final results of the workshop.

Project code: D3S1

(SW-irrigation project in District 3)

Changes in crop areas and crop costs								
Old crops			New crops			Changes		
Code	Crop	Area (ha)	Code	Crop	Area (ha)	Crop	Area (ha)	Costs (10^6 Escaps)
14	B. Aus	15000	2	B. Aus	15000	LT. Aman	-40000	-126
	LT. Aman	15000		HYV. Aman	15000	HYV. Aman	+40000	+352
				HYV. Wheat	15000	HYV. Wheat	+40000	+115
32	LT. Aman	25000	28	HYV. Aman	25000			
				HYV. Wheat	25000			
							Total:	+341

Annual benefits		
Crop	Tons	10^6 Escaps
LT. Aman	-50400	-315
B. Aus	+ 70	+ 0.5
HYV. Aman	+88000	+550
HYV. Wheat	+70000	+255
	Total	491

Annual costs (10^6 Escaps)	
Crop costs:	341
Project costs: 0.2 x 75 =	15
Irrigation costs:	
- Fixed: 0.2 x 45 x 2 =	18
- Variable:	23
Total	397

B/C ratio = 397/341 = 1.24

Table 25. Example of calculation of B/C-ratio for screening

TYPE OF PROJECT	CODE	Δ FOODGRAIN (10^3 tons)	BENEFIT (10^6 Escaps)	COSTS (10^6 Escaps)	B/C RATIO	REMARKS
Flood control/drainage	D_1FC_1	- 3	173	216	0.80	Drought damage
	D_1FC_2	+ 17	156	182	0.86	
	D_1FC_3	+136	852	660	1.29	
SW-irrigation	D_1S_1	+ 30	113	85	1.33	
	D_1S_2	+ 33	120	101	1.19	
GW-irrigation	D_1G_1	+ 50	64	40	1.58	
Water conservation	D_1WC_1	-	-	-	-	No effect yet
Inlet capacity	-	-	-	-	-	
Drainage capacity	D_1DC_1	-	-	-	<1	
Embankment	D_1E_1	+ 89	601	367	1.63	Δ H = 1 M

Table 26. Screening results District 1

TYPE OF PROJECTS	CODE	Δ FOODGRAIN (10^3 tons)	BENEFITS (10^6 Escaps)	COSTS (10^6 Escaps)	B/C RATIO	REMARKS
Flood control/drainage	D_2FC_1	+ 185	1156	626	1.85	
	D_2FC_2	+ 74	484	321	1.51	
	D_2FC_3	+ 144	901	376	2.39	
SW-irrigation	D_2S_1	+ 132	603	467	1.29	
	D_2S_2	+ 97	307	252	1.22	
GW-irrigation	D_2G_1	+ 37	87	59	1.48	
Water conservation	D_2WC_1	-	-	-	-	No effect yet
Inlet capacity	D_2IC_1	-	-	-	-	No effect yet
Drainage capacity	D_2DC_1	+ 37	228	102	2.23	ΔW = 2500 m^2/s
Embankment	D_2E_1	+ 172	1060	500	2.12	ΔH = 1 m

Table 27. Screening results District 2

TYPE OF PROJECTS	CODE	Δ FOODGRAIN (10^3 tons)	BENEFITS (10^6 Escaps)	COSTS (10^6 Escaps)	B/C RATIO	REMARKS
Flood control/drainage	-					
SW-irrigation	D_3S_1	+ 108	491	397	1.24	
	D_3S_2	+ 223	1060	846	1.25	
GW-irrigation	D_3G_1	+ 45	60	3	20.5	
	D_3G_2	+ 103	449	375	1.20	
Water conservation	D_3WC_1	-	-	-	-	No effect yet
Inlet capacity	D_3IC_1	-	-	-	-	No effect yet
Drainage capacity	D_3DC_1	-	-	-	-	No effect yet
Embankment	D_3E_1	-	-	-	-	No effect yet

Table 28. Screening results District 3

TYPE OF PROJECTS	CODE	Δ FOODGRAIN (10^3 tons)	BENEFITS (10^6 Escaps)	COSTS (10^6 Escaps)	B/C RATIO	REMARKS
Flood control/drainage	-	-	-	-	-	
SW-irrigation	D_4S_1	+ 161	313	311	1.01	
	D_4S_2	+ 112	603	457	1.32	
	D_4S_3	+ 54	335	282	1.19	
GW-irrigation	D_4G_1	+ 152	944	824	1.15	
Water conservation	D_4WC_1	-	-	-	-	No effect yet
Inlet capacity	D_4IC_1	-	-	-	-	No effect yet
Drainage capacity	D_4DC_1	-	-	-	-	No effect yet
Embankment	D_4E_1	-	-	-	-	No effect yet

Table 29. Screening results District 4

TYPE OF PROJECTS	CODE	Δ FOODGRAIN (10^3 tons)	BENEFITS (10^6 Escaps)	COSTS (10^6 Escaps)	B/C RATIO	REMARKS
Flood control/drainage	D_5FC_1	+ 303	1877	749	2.50	
	D_5FC_2	+ 3	144	131	1.10	
	D_5FC_3	+ 40	251	206	1.22	
SW-irrigation	-	-	-	-	-	
GW-irrigation	D_5G_1	+ 50	128	83	1.54	
Water conservation	D_5WC_1	-	-	-	-	No effect yet
Inlet capacity	D_5IC_1	-	-	-	-	No effect yet
Drainage capacity	D_5DC_1	+ 1	4.4	2.0	2.20	$\Delta W = 100\ m^2/s$
Embankment	D_5E_1	+ 112	700	330	2.12	$\Delta H = 0.55\ m$

Table 30. Screening results District 5

TYPE OF PROJECTS	CODE	Δ FOODGRAIN (10^3 tons)	BENEFITS (10^6 Escaps)	COSTS (10^6 Escaps)	B/C RATIO	REMARKS
Flood control/drainage	-					
SW-irrigation	D_6S_1	+ 137	593	455	1.30	
	D_6S_2	+ 79	324	255	1.27	
GW-irrigation	D_6G_1	+ 49	146	93	1.57	
Water conservation	D_6WC_1	+ 1	8.9	2.0	4.45	+ 10000 ha
Inlet capacity	D_6IC_1	+ 1	11.6	10.0	1.16	+ 50 m^3/s
Drainage capacity	D_6DC_1	-	-	-	-	No effect yet
Embankment	D_6E_1	-	-	-	-	No effect yet

Table 31. Screening results District 6

TYPE OF PROJECTS	CODE	Δ FOODGRAIN (10^3 tons)	BENEFITS (10^6 Escaps)	COSTS (10^6 Escaps)	B/C RATIO	REMARKS
Flood control/drainage	-	-	-	-	-	
SW-irrigation	D_7S_1	+ 221	1012	953	1.06	
	D_7S_2	+ 204	1229	399	3.08	
GW-irrigation	-	-	-	-	-	
Water conservation	D_7WC_1	+ 13	78	24	3.25	+ 100,000 ha
Inlet capacity	D_7IC_1				< 1	Salt damage
Drainage capacity	D_7DC_1	-	-	-	-	No effect yet
Embankment	D_7E_1	-	-	-	-	No effect yet

Table 32. Screening results District 7

TYPE OF PROJECTS	CODE	Δ FOODGRAIN (10^3 tons)	BENEFITS (10^6 Escaps)	COSTS (10^6 Escaps)	B/C RATIO	REMARKS
Flood control/drainage	-					
SW-irrigation	D_8S_1	+ 252	674	558	1.21	
GW-irrigation	-					
Water conservation	D_8WC_1	0.23	1.27	0.25	4.60	+ 400 ha
Inlet capacity	D_8IC_1	0.5	2.4	2.0	1.20	Δ IC = 10 m^3/s
Drainage capacity	D_8DC_1	-	-	-	-	No effect yet
Embankment	D_8E_1	-	-	-	-	No effect yet

Table 33. Screening results District 8

Scenario 1: Continuation of present situation

Criteria	Units	Base case	Comparison case	Strategy 1990	Strategy 2005
o Food grain production:					
target	M tons	14.700		15.900	18.300
actual	M tons	13.900		16.100	19.600
o Gross national product (GNP)					
Agriculture and fisheries and navigation	M Escaps	108 200		118 900	139 200
% change (target 14% in 1990)	%	-		9.0	29.0
o Export value (jute and pulses)	M Escaps	4 600		4 500	7 700
% change (target 10% in 1990)	%	-		-4.0	+67.0
o Self sufficiency rate					
NW	%	93		105	107
NE	%	109		128	123
SW	%	90		98	83
SE	%	66		88	130
Total	%	87		101	106
o Fish production	M tons	0.390		0.392	0.391
o Navigation production	M tonm.	722		722	722
o Exceedence frequency - 6 m gw level	-	-		10	10
o Employment agriculture	M my	4.515		5.095	5.175
% change (target 10% in 1990)	%			12.8	14.6
o Mean discharge Jan-Apr					
Q B9	m^3/s	473		540	523
Q B10	m^3/s	7 280		7 577	7 529
o Annual benefits	M Escaps	-		10 700	31 200
o Annual costs	M Escaps	-		10 594	27 990
o B/C - ratio	-			1.01	1.11
o Simplicity				+	—
o Flexibility				++	++

Table 34. Impacts of WRM strategies — Scenario 1

Scenario 2: Reduced inflows of Salmar and Sirion River

Criteria	Units	Base case	Comparison case	Strategy 1990	Strategy 2005
o Food grain production:					
target	M tons	14.700		15.912	18.299
actual	M tons	13.900	13.897	15.913	18.298
o Gross national product (GNP)					
Agriculture and fisheries and navigation	M Escaps	108 200	103 271	113 021	134 281
% change (target 14% in 1990)	%			9.5	30.0
o Export value (jute and pulses)	M Escaps	4 600	4 570	4 516	4 560
% change (target 10% in 1990	%			- 1.1	-
o Self sufficiency rate					
NW	%	93	93	111	102
NE	%	109	109	119	107
SW	%	90	90	104	99
SE	%	66	66	75	94
Total	%	87	87	100	100
o Fish production	M tons	0.390	0.393	0.391	0.390
o Navigation production	M tonm.	722	689	689	729
o Exceedence frequency-6m gw level	-	-	1	1	1
o Employment agriculture	M my	4.515	4.515	4.836	5.486
% change (target 10% in 1990)	%			7.1	18.9
o Mean discharge Jan-Apr					
Q B9	m^3/s	473	414	415	686
Q B10	m^3/s	7 280	3 939	3 718	3 243
o Annual benefits	M Escaps	-	-	9 750	31 010
o Annual costs	M Escaps	-	-	7 774	19 507
o B/C - ratio	-			1.25	1.59
o Simplicity				++	--
o Flexibility				++	+

Table 35. Impacts of WRM strategies — Scenario 2

Scenario 3: Reduced inflows, increased non-water inputs to agriculture

Criteria	Units	Base case	Comparison case	Strategy 1990	Strategy 2005 *)	Strategy 2005
o Food grain production:						
target	M tons	14.700	-	15.912	18.299	18.299
actual	M tons	13.900	15.768	18.607	18.607	18.635
o Gross national product (GNP)						
Agriculture and fisheries and navigation	M Escaps	108 200	116 900	119 500	132 400	132 900
% change (target 14% in 1990)	%			2.2	13.3	13.7
o Export value (jute and pulses)	M Escaps	4 600	5 030	4 990	4 930	4 950
% change (target 10% in 1990	%			- 0.7	- 2.0	- 1.6
o Self sufficiency rate						
NW	%	93	102	103	111	111
NE	%	109	119	119	130	129
SW	%	90	100	100	107	109
SE	%	66	74	83	71	71
Total	%	87	96	99	102	102
o Fish production	M tons	.390	.393	.391	.391	.391
o Navigation production	M tonm.	722	690	688	688	723
o Exceedence frequency-6m gw level	-	-	1	1	3	3
o Employment agriculture	M my	4.515	4.956	5.048	5.399	5.399
% change (target 10% in 1990)	%			1.8	8.9	8.9
o Mean discharge Jan-Apr						
Q B9	m^3/s	473	414	419	410	554
Q B10	m^3/s	7 280	3 939	3 664	3 374	3 398
o Annual benefits	M Escaps			2 600	15 500	16 000
o Annual costs	M Escaps			2 013	11 526	12 526
o B/C - ratio	-			1.29	1.34	1.28
o Simplicity				++	--	---
o Flexibility				++	+++	++

2005 *) = 2005 + barrage

Table 36. Impacts of WRM strategies — Scenario 3

Appendix 1. Overview of input files for the computational framework

NETWORK : network characteristics
INOUT : cross boundary inflows by decade
DISTRICT : district characteristics by district
PLOT : plot characteristics by plot
SOIL : soil characteristics by soil type
DRODAM : parameters describing drought damage by cropping pattern
SALFLODA : parameters describing salt/flood damage by croping pattern
GROWYLD : growing seasons and potential yield by cropping pattern
ACRCUM : composition of cropping patterns
RAIN : rainfall by decade by district
EVAPOW : evaporation by decade by district
MISCEL : miscellaneous data
CROPFAC : crop factors by decade by cropping pattern
ROOTDEPT : root depth by decade by cropping pattern
CRITDEPTH : critical inundation depth by decade by cropping pattern
SALTCRIT : critical salt concentration by decade by cropping pattern

Appendix 2. Description of NETWORK file

Record 1

Field	Position	Format	Description	Name
1	1-80	A80	run identification	RID

Record 2

Field	Position	Format	Description	Name
1	1-5	I5	number of branches	NTAK
2	6-10	I5	number of nodal points	NKNOOP
3	11-15	I5	number of districts	NDIST
4	16-20	I5	number of intake points	NINL
5	21-25	I5	number of outtake points	NOUTL
6	26-30	I5	number of timesteps	NTMST
7	31-35	I5	switch for debugging purposes	IDEBUG
8	36-40	I5	switch for additional output of district computation results	IOPTD
9	41-45	I5	switch for additional output of plot computation results per landleveltype	IOPTS
10	46-50	I5	switch for additional output of plot computation results	IOPTP

Remarks:

1. IDEBUG, IOPTD, IOPTS, IOPTP :

   0 indicates no additional output required
   1 indicates additional output required

2. For use of the postprocessing program BANNA2
   IOPTD must be equal to 1.

NETWORK (Continued)

Record 3

For each branch in the network a record containing:

Field	Position	Format	Description	Name
1	1-2	I2	branch index	II
2	3-6	I4	nodal point index upper stream reach	KNTAK(1)
3	7-10	I4	nodal point index lower stream reach	KNTAK(2)
4	11-18	F8.0	initial flow in branch (m3/s)	QB
5	19-30	D12.0	resistance value W' of branch	WAKS
6	31-36	F6.1	(average) bottom level of branch (to refer. level) (m)	HBODEM

Remark : If WAKS for branch 6 is equal to 0 than a barrier is assumed in this branch.

Record 4

For each nodal point a record containing:

Field	Position	Format	Description	Name
1	1-2	I2	nodal point index	II
2	3-10	F8.2	initial waterlevel (to refer. level) (m)	HN

Record 5

For each intake point (max. 12 points) a field in this record containing:

Format	Description	Name
I5	nodal point index of intake point	IWORK

NETWORK (Continued)

Record 6

For each outtake point (max. 12 points) a field in this record containing:

Format	Description	Name
I5	nodal point index of outtake point	IWORK

Record 7

Field	Position	Format	Description	Name
1	1-5	I5	index of first nodal point with fixed water level	IVKN1
2	6-15	F10.0	waterlevel (to refer. level) of IVKN1 (m)	VSTWS1
3	16-20	I5	index of second nodal point with fixed water level	IVKN2
4	21-25	F10.0	waterlevel (to refer. level) of IVKN2 (m)	VSTWS2

Record 8

Field	Position	Format	Description	Name
1	1-2	I2	max. number of iteration to compute the waterlevels at the nodal points and the flows in the branches	ITRELA
2	3-10	F8.4	accuracy criterium for the computation of the flows in the branches	DELTAD

NETWORK (Continued)

Record 9

Field	Position	Format	Description	Name
1	1-8	F8.0	) Parameters	BARQ0
2	9-14	F6.0	) describing	BARA0
3	15-22	F8.0	) flow in branch 6	BARQ1
4	23-28	F6.0	) with barrier	BARA1

Remarks:

1. Record 9 is only relevant if WAKS of branch 6 in record 3 is equal to 0. In this case a barrier is assumed in this branch.
2. The parameters of the flow in the barrier branch 6 are also shown in figure 56.

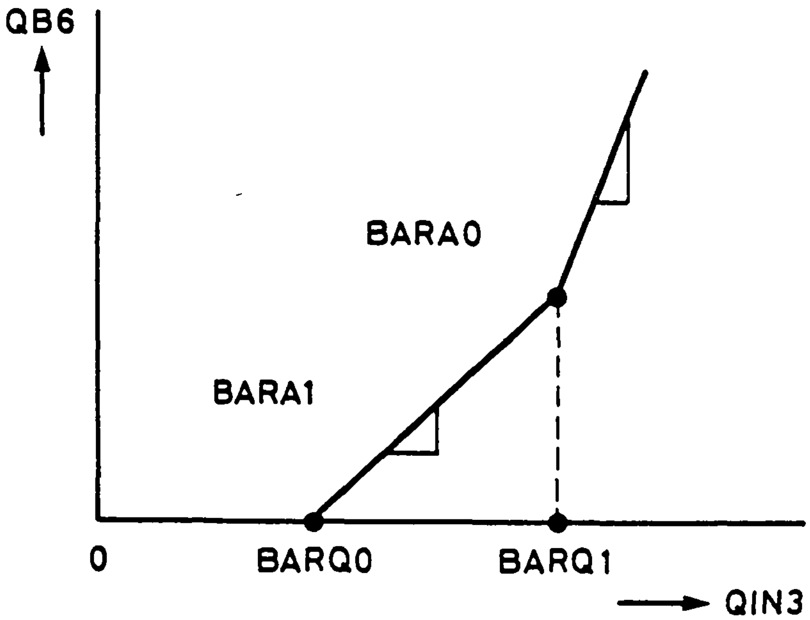

Figure 56. Function between the inflow at node 3 (QIN3) and the flow in branch 6 with the barrier (QB6)

Example NETWORK file

```
THIS RECORD IS FOR RUN IDENTIFICATION
   10   11     8    4    2   36     0    1    0    0
 1   1   2     50.  300.000D-6  20.0
 2   2   5   3200.    3.260D-6   6.5
 3   6   7     50.  202.210D-6   2.0
 4   7   8    950.    0.300D-6   0.4
 5   3   4   1900.    2.250D-6   3.0
 6   4   5   1400.    1.000D-6   2.5
 7   5   8   4400.    0.120D-6  -0.8
 8   4   9    100.  139.000D-6   1.6
 9   9  10    120.    2.040D-6  -0.3
10   8  11   5520.    0.055D-6  -0.8
 1   26.00
 2   14.50
 3    5.50
 4    4.00
 5    1.20
 6    3.50
 7    1.80
 8    1.00
 9     .50
10     .00
11     .00
    1    2    3    6
   10   11
   10        0.   11         0.
20     .01
    100.    .5   1000.    1.
```

Appendix 3. Description of DISTRICT file

Record 1

Field 1	Position	Format	Description	Name
1	1-2	I2	district index	IDIST
2	3-14	A12	district name	-
3	15-22	F8.0	district area (1000 ha)	DISTAR
4	23-30	F8.0	district surface water (s.w.) area (1000 ha)	DISWAR
5	31-32	I2	discharge type	DISTYP
6	33-38	F6.2	bottom of dist. s.w. (m)	HDREF
7	39-44	F6.2	initial dist s.w. level (m)	HDISWL
8	45-55	F11.0	critical water volume (s.w. irrigation) (mill.m3)	VDCRMI
9	56-58	I3	index of district where inflow comes from	NRDQIN
10	59-61	I3	index of nodal point from which overflow may occur	KQOVFL
11	62-67	F6.2	critical waterlevel (overflow) (m)	HDCROV
12	68-77	F10.0	resistance per district/ node overflow interaction	WQOVFL

DISTYP: 0 indicates discharge to other district
1 indicates discharge to network node

VDCRMI: indicates surface water volume at which cutback of surface water irrigation starts

HDCROV: indicates the waterlevel at the nodal point KQOVFL at which overflow from KQOVFL to the district starts

DISTRICT (Continued)

Record 2

Field 1	Position	Format	Description	Name
1	1-6	F6.2)	parameters (m)	GWCAR1
2	7-12	F6.2)	describing (m)	GWCAR2
3	13-18	F6.2)	groundwater (g.w.) irrigation (m)	GWCAR3
4	19-23	F5.2)	demand reduction	REDCAR
5	24-31	F8.0	capacity of discharge (m3/s)	DISCAP
6	32-42	F11.0	characteristic storage volume (mill.m3)	STORCA
7	43-53	F11.0	critical watervolume for discharge (mill.m3)	VDCRLO

DISCAP: indicates the maximum discharge from one district to another

STORCA: indicates the volume at which districts that discharge to other districts start discharging

VDCRLO: indicates the volume at which districts that discharge to the network start discharging

The parameters of the groundwater irrigation demand reduction are also shown in figure 57.

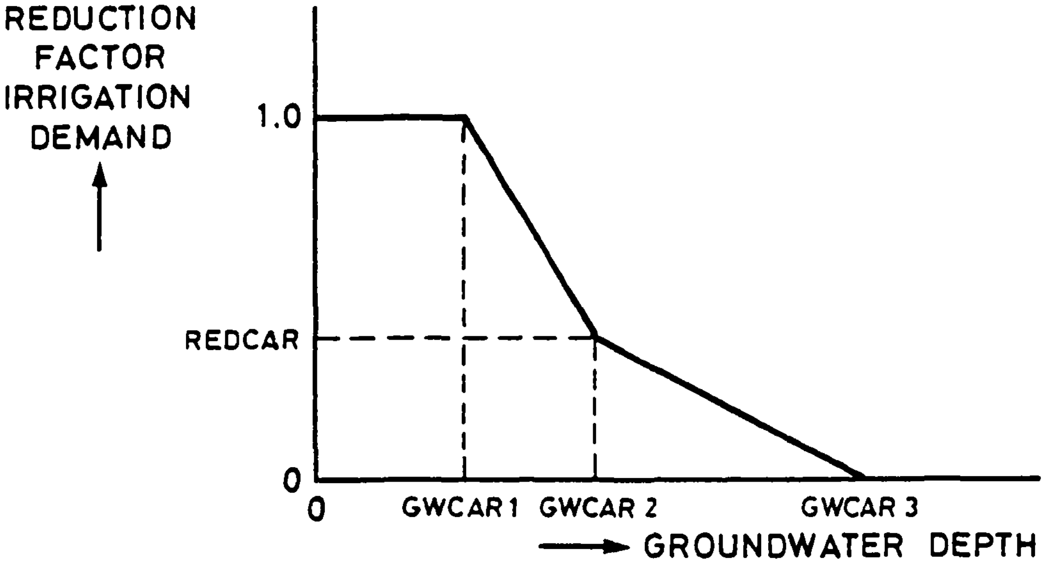

Figure 57. Reduction function for groundwater irrigation demand

DISTRICT (continued)

Record 3

Field	Position	Format	Description	Name
1-7	1-70	7I10	indices of nodes with which the district is connected	IHULP
Record 4				
1-7	1-70	7F10.0	resistance per district/ node interaction	WODK
Record 5				
1-7	1-70	7F10.0	capacity of withdrawals (m3/s)	CAPONT
Record 6				
1-7	1-70	7F10.0	capacity of discharges (m3/s)	CAPLOZ
Record 7				
1-6	1-66	6F11.0	surface water level district (m)	HDCURV
Record 8				
1-6	1-66	6F11.0	district surface water volume (mill. m3)	VDCURV

The relation between the district watervolume and the district waterlevel is determined by the 6 values of HDCURV and VDCURV.

Example DISTRICT file (base file DISTRICT.DAT)

```
1 ANDOR           1615     25 1 14.50 16.50       600  0  2     20. 10000.
 6.00  9.00 20.00 0.50      0           0       500
      1         2         0          0          0         0          0
    450      3500         0          0          0         0          0
    100         0         0          0          0         0          0
      0      9999         0          0          0         0          0
   14.50     18.50      19.50      20.50      23.50     28.50
      0      1000      1650       3800      43250     124000
2 CARDOLAN        1820     190 1  1.00  3.00      3800  0  5    7.5 10000.
 6.00  9.00 20.00 0.75      0           0       3800
      5         4         3          0          0         0          0
   8000      5000      1000          0          0         0          0
    100       150       150          0          0         0          0
   9999      9999         0          0          0         0          0
    1.00      5.00      6.00       7.00      10.00     15.00
      0      7600     11500      19400      61100     152100
3 GONDOR          1320     250 1 -0.50  1.00      5000  0  7    6.5 10000.
 6.00  9.00 20.00 0.5       0           0       5000
      2         7         0          0          0         0          0
    200      8000         0          0          0         0          0
    100         0         0          0          0         0          0
      0      9999         0          0          0         0          0
   -0.50      3.50      4.50       5.50       8.50     13.50
      0     10000     13100      17200      55000     148000
4 VALINOR         1300     300 1 -0.50  1.00      6000  0  7    6.5 10000.
 6.00  9.00 20.00 0.20      0           0       6000
      6         7         0          0          0         0          0
    150      8000         0          0          0         0          0
     50         0         0          0          0         0          0
      0      9999         0          0          0         0          0
   -0.50      3.50      4.50       5.50       8.50     13.50
      0     12000     17500      25500      63000     128000
5 HIMLAD          2030     250 1  -.50  1.00      2500  0  8    5.8 10000.
 6.00  9.00 20.00 0.25      0           0       5000
      5         8         0          0          0         0          0
    400      8000         0          0          0         0          0
    200         0         0          0          0         0          0
      0      9999         0          0          0         0          0
    -.50      3.50      4.50       5.50       8.50     13.50
      0     10000     16800      29100      82500     184000
6 DIMBAR          1415     150 1  0.00  1.50      4000  0  0   100. 10000.
 6.00  9.00 15.00 0.20      0           0       3000
      4         9         0          0          0         0          0
    330       500         0          0          0         0          0
    100         0         0          0          0         0          0
      0      9999         0          0          0         0          0
    0.00      4.00      5.00       6.00       9.00     14.00
      0      6000      8750      14800      45250     116000
7 FALAS           1305     125 1 -2.00 -0.50      3000  0 10    3.5 10000.
 6.00  9.00 20.00 0.00      0           0       2500
      9        10         0          0          0         0          0
    200       600         0          0          0         0          0
     50         0         0          0          0         0          0
      0      9999         0          0          0         0          0
   -2.00      2.00      3.00       4.00       7.00     12.00
      0      5000      6250       9800      45050     110300
8 LADIOS          1305     125 1 -2.00 -0.50      3000  0 11    3.5 10000.
 6.00  9.00 20.00 0.00      0           0       2500
      8        11         0          0          0         0          0
    200       600         0          0          0         0          0
     50         0         0          0          0         0          0
      0      9999         0          0          0         0          0
   -2.00      2.00      3.00       4.00       7.00     12.00
      0      5000      6250       9800      45050     110300
```

Appendix 4. Description of PLOT file

1 record per plot containing:

FIELD	NAME	DESCRIPTION	POSITION	FORMAT
1	IDIST	district-index	1-2	I2
2	LALTYP	landlevel type	3-4	I2
3	HGRNDL	level of surface (m)	5-10	F6.2
4	PLOTAR	area of plot (ha)	11-18	F8.0
5	SOLTYP	soiltype	19-21	I3
6	DRCOEF	drainage coefficient (mm/dec)	22-27	F6.5
7	INCOEF	infiltration coefficient (mm/dec)	28-33	F6.5
8	PLDTYP	polder type	34-35	I2
9	CRPTYP	cropping pattern	36-38	I3
10	IRRTYP	irrigation type	39-40	I2
11	RZSTOR	initial rootzone storage (mm)	41-46	F6.0
12	HGRWTL	initial groundwater level (m)	47-52	F6.2
13	DEPIND	initial inundation depth (m)	53-58	F6.2

With respect to the "types" in this file, the rule is such that the first record to appear is the one with the lowest number for that type: all other parameters being equal. The same counts for the district-index. The file starts with district 1 and goes down to the last district.

LALTYP : 1 indicates lowest lying plots
4 indicates highest lying plots

PLDTYP : 0 indicates "no polder"
1 indicates "polder"

IRRTYP : 0 indicates "no irrigation"
1 indicates "groundwater irrigation"
2 indicates "surface water irrigation"

Example PLOT file (simplified version: 1 plot per landlevel type)

```
1 1 18.50   40000  2 0.020  0.02 0 37 0   10 16.00   0.0
1 2 19.50  150000  1 0.020  0.02 0 31 0   10 16.50   0.0
1 3 20.50 1100000  3 0.015  0.02 0  6 1   15 17.00   0.0
1 4 23.50  300000  3 0.005  0.02 0  8 1   30 19.50   0.0
2 1  5.00  200000  1 0.020  0.02 0 34 2   10  2.50   0.0
2 2  6.00  400000  1 0.020  0.02 0 31 0   10  3.00   0.0
2 3  7.00  598000  3 0.020  0.02 0  3 1   15  3.50   0.0
2 4 10.00  430000  3 0.020  0.02 0 15 0   15  6.00   0.0
3 1  3.50   60000  2 0.030  0.02 0 37 0   10  1.00   0.0
3 2  4.50  100000  1 0.030  0.02 0 31 0   10  1.50   0.0
3 3  5.50  850000  3 0.025  0.02 0  1 0   15  2.00   0.0
3 4  8.50   60000  3 0.015  0.02 0 15 0   15  4.50   0.0
4 1  3.50  250000  1 0.025  0.02 0 34 0   10  1.00   0.0
4 2  4.50  200000  1 0.025  0.02 0 31 0   10  1.50   0.0
4 3  5.50  500000  2 0.018  0.02 0  2 0   10  2.00   0.0
4 4  8.50   50000  3 0.010  0.02 0 11 0   15  4.50   0.0
5 1  3.50  430000  1 0.025  0.02 0 35 2   10  1.00   0.0
5 2  4.50  550000  1 0.018  0.02 0 29 2   10  1.50   0.0
5 3  5.50  550000  2 0.015  0.02 0 24 2   10  2.00   0.0
5 4  8.50  250000  3 0.007  0.02 0 18 1   30  4.50   0.0
6 1  4.00  125000  2 0.020  0.02 0 37 0   10  1.50   0.0
6 2  5.00  330000  1 0.020  0.02 0 31 0   10  2.00   0.0
6 3  6.00  410000  3 0.015  0.02 0  1 0   15  2.50   0.0
6 4  9.00  400000  2 0.007  0.02 0 13 2   10  5.00   0.0
7 2  3.00  230000  1 0.020  0.02 0 31 0   10  0.00   0.0
7 3  4.00  820000  3 0.020  0.02 0  1 2   15  0.50   0.0
7 4  7.00  130000  2 0.007  0.02 0 13 1   10  3.00   0.0
8 2  3.00  230000  1 0.020  0.02 0 31 0   10  0.00   0.0
8 3  4.00  820000  3 0.020  0.02 0  1 2   15  0.50   0.0
8 4  7.00  130000  2 0.007  0.02 0 13 1   10  3.00   0.0
```

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