Integrated Planning and Management of Water Resources

(Guidance Material for Courses for Engineers, Planners and Decision-Makers)

Edited by S. Dyck

Technical Documents in Hydrology

International Hydrological Programme

United Nations Educational, Scientific and Cultural Organization

Unesco
Paris, 1990

isn 0348
free

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Edited by:

S. Dyck

Technische Universitaet Dresden
Dresden, German Democratic Republic

Unesco, Paris 1990 **IHP-III Project 14.3**

Preface

Although the total amount of water on Earth is generally assumed to have remained virtually constant during recorded history, periods of flood and drought have challenged the intellect of man to have the capacity to control the water resources available to him. Currently, the rapid growth of population, together with the extension of irrigated agriculture and industrial development, are stressing the quantity and quality aspects of the natural system. Because of the increasing problems, man has begun to realize that he can no longer follow a "use and discard" philosophy -- either with water resources or any other natural resource. As a result, the need for a consistent policy of rational management of water resources has become evident.

Rational water management, however, should be founded upon a thorough understanding of water availability and movement. Thus, as a contribution to the solution of the world's water problems, Unesco, in 1965, began the first worldwise programme of studies of the hydrological cycle -- the International Hydrological Decade (IHD). The research programme was complemented by a major effort in the field of hydrological education and training. The activities undertaken during the Decade proved to be of great interest and value to Member States. By the end of that period a majority of Unesco's Member States had formed IHD National Committees to carry out the relevant national activities and to participate in regional and international co-operation within the IHD programme. The knowledge of the world's water resources as an independent professional option and facilities for the training of hydrologists had been developed.

Conscious of the need to expand upon the efforts initiated during the International Hydrological Decade, and, following the recommendations of Member States, Unesco, in 1975, launched a new long-term intergovernmental programme, the **International Hydrological Programme (IHP)**, to follow the Decade.

Although the IHP is basically a scientific and educational programme, Unesco has been aware from the beginning of a need to direct its activities toward the practical solutions of the world's very real water resources problems. Accordingly, and in line with the recommendations of the 1977 United Nations Water Conference, the objectives of the International Hydrological Programme have been gradually expanded in order to cover not only hydrological processes considered in interrelationship with the environment and human activities, but also the scientific aspects of multi-purpose utilization and conservation of water resources to meet the needs of economic and social development. Thus, while maintaining IHP's scientific concept, the objectives have shifted perceptibly towards a multi-disciplinary approach to the assessment, planning, and rational management of water resources.

As part of Unesco's contribution to the objectives of the IHP, two publication series are issued: *Studies and Reports in Hydrology* and *Technical Papers in Hydrology*. In addition to these publications, and in order to expedite exchange of information, some works are issued in the form of *Technical Documents*.

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Foreword

This report on "Integrated Planning and Management of Water Resources (Guidance Material for Courses for Engineers, Planners and Decision-makers)," is the result of an IHP-III Project 14.3, established by the Intergovernmental Council of the IHP in 1984, at which time it also appointed the following members of the working group: Prof. Dr. Ing. habil S. Dyck (German Democratic Republic), Project Coordinator; Dr. Steven Bruk (Yugoslavia); Prof. Gunnar Lindh (Sweden); Dr. M.G. Khublaryan (USSR); and Dr. A.E. Leao Lanna (Brazil). Prof. U. Shamir (Israel) was the IAHS representative to the project.

The IHP Council also appointed the following individuals as National Correspondents to the Project: Dr. M. Abu-Zeid (Egypt), Mr. T.B.F. Acquah (Ghana), Dr. D.A. Mandadjiev (Bulgaria), Mr. J. Marien (Belgium), Ing. N. Marrero (Cuba), Prof. L.J. Mostertman (Netherlands), Dr. H.P. Rasheed (Iraq), Mr. A.H. Risiga (Argentina), Ing. J.M. Roa Pichardo (Dominican Republic), Mr. R.S. Seoane (Argentina), Dr. N.P. Smirnov (USSR), Mr. L. Ubertini (Italy), Dr. G.N. Yoganarasimhan (India), and Dr. Pavel Kovar (Czechoslovakia).

Professor Dyck and Dr. Bruk met with the Project Officer, Dr. John Gladwell, in Paris to initially set the procedures and assignments to the working group. Later, taking advantage of a Nordic IHP symposium "Decision support systems and related methods in water resources planning," in Oslo, Norway, 5-7 May 1986, the working group met and reviewed the project.

Following the meeting of the working group, the finalization of the project was assigned to Professor Dyck with the assistance of Dr. Bruk. In the meantime, a questionnaire was sent out to almost 200 universities around the world in order to ascertain the status of the education programs. The information content of the questionnaires was statistically evaluated by A.H. Schumann.

The editor would like to express his thanks to all who have contributed to the production of the report, in particular to Dr. N. Grigg (USA) who made many valuable suggestions on a late draft. Dr. J.S. Gladwell took an active part in all phases of the project, from initial conception to the finalization of the report.

1

CONTENTS AND METHODS OF EDUCATION IN WATER RESOURCES PLANNING AND MANAGEMENT.

1.1 Introduction

Water resources management (WRM) unites the totality of conditions and means for the assessment and planning of water resources and water demands, the rational use, comprehensive monitoring, effective protection, and conservation of water resources. It includes the long-term management modelling of existing and planned water resources projects and the efficient operation and rehabilitation of existing water resources systems, as well as the prevention of damages caused by water; in each case acting in the interest of society and its sustainable development and taking into account the role of water in the formation and regulation of local, regional, and global environmental and biophysical processes.

To ensure that water will be available in sufficient quantity and quality, at the right location and time, and to protect human lives and activities from the harmful effects of water, various water resources projects have to be planned and managed. A water resources project or system is a set of structural and/or nonstructural measures and activities for the purpose of developing or improving existing water resources for the benefit of human use.

The main tasks of WRM are:

- assessment and prediction of surface and groundwater, water quantity and water quality and the evaluation of its availability;
- assessment and planning of the water demand of society;
- compilation of water balances, the maintenance of their equilibrium and the development of a long-term strategy for the rational use of water resources;
- monitoring of water resources to protect them against depletion and pollution;
- planning of water resources systems;
- management modelling;
- prediction of the processes in water resources systems and real time operation of water resources systems;
- efficient use of technical means (e.g. reservoirs, treatment plants), administrative measures, economical rules (e.g. prices, fines) and legal measures (laws, standards) to enlarge the availability of water resources with regard to quantity and quality, to enable

the multiple use of water, to regulate the water demand, to promote the rational use of water, to maintain and to protect the waters with their natural potentials and to protect society against damages by water.

WRM integrates the relevant knowledge in the natural-, geo-, engineering and social sciences, and creates the theoretical and practical bases for its integrated, problem and object oriented transformation and application in water resources and in other branches of the national economy.

WRM accomplishes the conjunctive use and integrated management of surface and groundwater taking into account quantity and quality aspects, it coordinates legal, administrative and regulatory measures with economic instruments.

WRM uses all sources of information including fuzzy information for rational data sampling and management and develops techniques for the assessment and integration of various data bases.

WRM seeks to effect a change in the system, and in the water use and land use pattern through the use of structural and non-structural measures to obtain a specific goal, or to operate existing water resources systems in a most efficient way.

Integrated planning and management of water resources has to take into account various dimensions of the problem: space, aspect, time, objective, means, etc.

- *Space dimension:* The geographical scale of a project could be: locality, economic or political development, region, river basin, nation, international large river basin, continent. The space dimension determines the physical and institutional boundaries, and the appropriate scale and procedures of water resources planning.

In large scale models comprehensive hydrological models, derived from detailed observations in small catchments, cannot be directly applied. They must be aggregated developing the set of simplified models suitable for the simulation of large scale processes (e.g. use of grid-related variables).

- *Aspect dimension:* Once the scale of the project is given, the needs and goals must be properly defined. They can cover several aspects: political, economic (financial), legal, environmental control and protection, social welfare, health, recreation and others:

First of all, the planner must effectively consider the political aspects of the project, and he must be clear about needs, goals, objectives and expectations resulting from the socio-economic and cultural system and being influenced by the infrastructure.

A main aspect of water resources systems is economic efficiency. Important topics of economic analysis are benefit-cost evaluation, comparison of the benefit-cost ratio with other indexes of economic efficiency to guide project formulation and to rank alternatives, the special characteristics of the internal rate of return, sensitivity analysis and risk analysis, determination of prices for estimating benefits and costs for a range of project purpose, and economic incentives for improved management (OECD, 1989). Other important aspects are legal (water poses its own peculiar difficulties for law) (Department of Water Resources, 1986, Paterson, 1989), environmental control and protection (Unesco/UNEP, 1987), water quality management (Feenberg, 1980), social welfare and security (Unesco 1987a), emergency preparedness, health and safety, educational and cultural opportunities, and national infrastructures (Orloci, Szesztay, Varkonyi, 1985). Once a project is selected on an economic basis, financial analyses have to be made to determine the needs for financing the project construction and handling the flows of costs, revenues and subsidies after the project goes into operation. With regard to all these aspects the planner is confronted with a multiobjective, multijudgemental decision-making process, which requires conflicting management strategies to reach agreement on the objectives and to assure reasonable trade-off between the alternatives (Unesco, 1987d).

- *Time dimension:* Water resources management is an on-going process, performed in sequential iterative steps. The planning process is divided into a sequence of stages (see chapter 1.5). In general, dynamic problems of long-term planning and management are approached by time-discrete dynamic system models. The discretization depends on the variability in time of the processes to be considered. The planning horizon of about 30 or 50 years can be discretized into planning periods of small time steps of one year to long time steps of 5 or 10 years. The management models may use time steps of one month for management decisions within the year. Real-time operation uses smaller time steps according to the dynamics of the relevant processes. Water resources systems, water resources development projects, and decision problems can be highly complex (physical configuration), hydrogeographic endowments, general interaction of nature, society and technology, hydrological regime, impact of water and land uses on water and matter balances, water quality, environment and ecology, economy and society, political goals, legal constraints).

Once the project goals relative to each sub-system and stage structure have been defined, they must be explicitly translated into objectives for the stages in the decision flux. The basic phases of the decision process are shown in Fig. 1.

To achieve the goals of the project various tools and techniques, and an appropriate level of technology is needed. If the means are insufficient the planner or manager could take a decision within calculated risk or call on research.

Systems analysis can contribute to solve water resources management problems, it is an approach by which the components of a system and their interactions are described by means of mathematical or logical functions (Unesco, 1987d).

Since the decision-making process cannot be totally formalized and modelled, contrary to various technical and technological processes, mathematical programming techniques cannot provide a unique optimal solution for a water resources system. For long-term planning and management, methods are required which reflect the complex, interactive, and subjective character of the decision-making process, taking into account the experiences of the decision-makers (Orlovski, Kaden, van Walsum, 1986).

Computer aided decision support systems are needed which take into account the stochastic character of the system inputs, the uncertainties, and imprecisions of natural, man-made and socio-economic processes, the controversy among different interest groups, and the complex interactive and subjective character of the decision-making process, and which offer decision alternatives using multiobjectives programming (Kaden et. al. 1985). A scheme of the interactive computer aided decision process is given in Fig. 1.

Water resource planning and management includes the solution of three main groups of tasks by application of adequate methods (models) in the following hierarchy (Fig. 2):

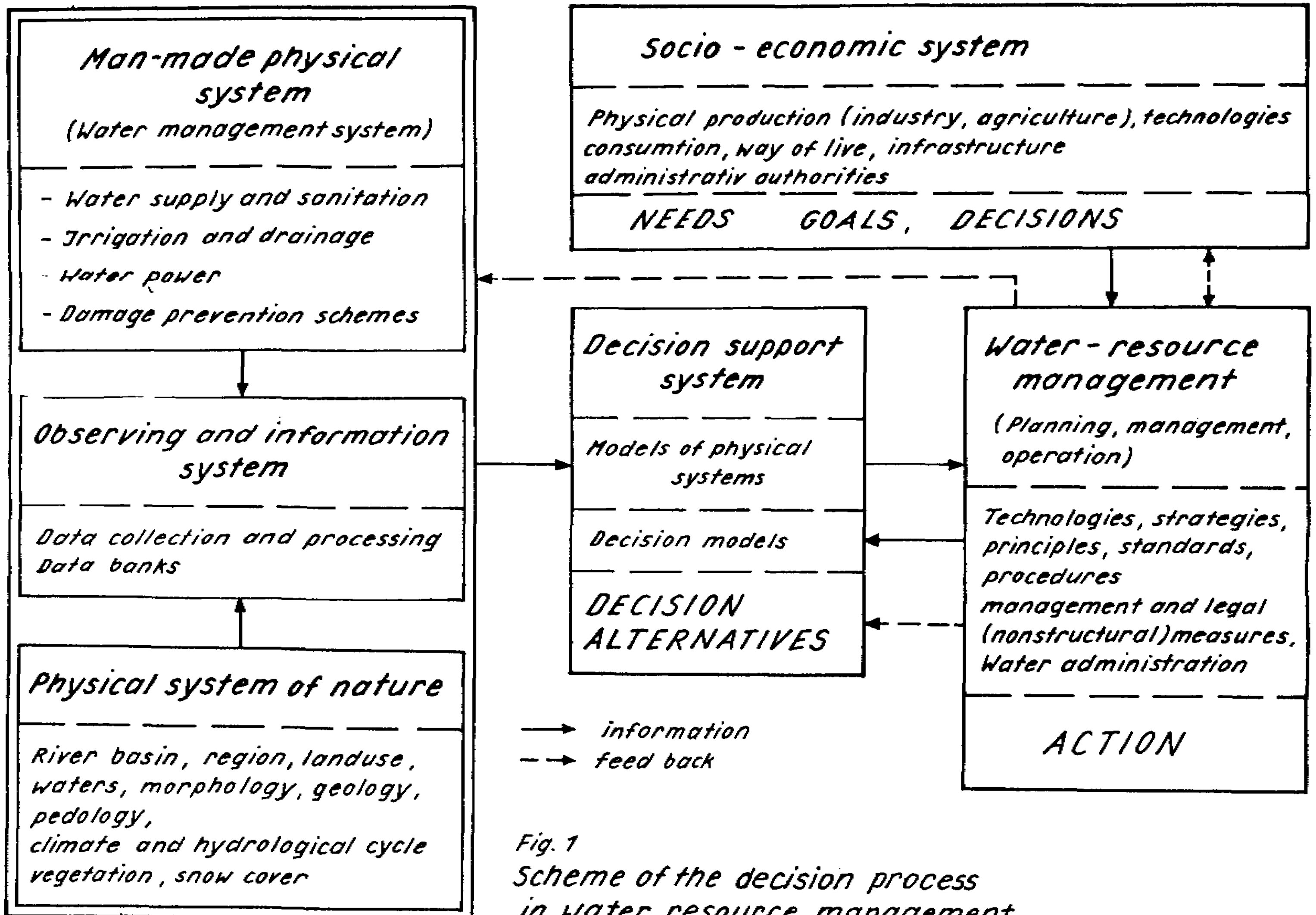


Fig. 1
Scheme of the decision process in water resource management

Figure 1: Scheme of the decision process in water resources management

1. *Planning models:* Long-term prediction of future states of hydrologic processes and water demands and local and large-scale planning to elaborate long-term development plans for the water resource system of a river basin or a region and to decide on location and capacity of large investments (hydraulic structures, technical means, technology) taking into account the requirements of the society upon water resources, depending on political, economical and social conditions, and objectives.

2. *Management models:* Rational long-term management strategies for the water resource system or for a region using hydrologic simulation to find optimal solution for the long-term water supply and management problem.

3. *Operational models:* Short-term forecasting of extreme hydrologic or water quality events and short-term (real-time) operation of water management systems.

1.2 Water resources and their characteristics.

With a total quantity of about $1.38 \cdot 10^{18}$ t water is the most abundant molecular substance of the earth crust. Water is the most used natural resources. Man takes away from nature nearly $100 \cdot 10^9$ t/y raw material, but uses almost $4000 \cdot 10^9$ t/y fresh water.

Water is a renewable natural resource. On a global scale it belongs to the inexhaustible natural resources, but regionally and locally it is exhaustible.

The fresh surface and subsurface waters with their natural supply form the water resources of an area. They have natural potentials such as the self-purification potential, the biological yield potential, the ecological potential, the transport potential, the energy potential, the recreation potential and others. The water supply of the surface and subsurface waters is the freshwater existing in a specific area for a specified time span as a component of the hydrological cycle of the earth.

Regarding the quantity of the water supply of an area we may distinguish:

- the potential water supply (difference between the long-term means of precipitation and evapotranspiration);

- the stable water supply (potential water supply minus the fast runoff components, e.g. the groundwater flow or base flow), and in addition,

- the regulated water supply (water provided by storage).

The net water supply for a specific use results from the gross supply after constraints due to hydrology, ecology, technology and economy are applied. It changes with development and must be quantified.

The existence of a source of water does not automatically define it as a usable water resources; it must be available, or capable of being made available, for use in sufficient quantity and quality at a location and over a period of time appropriate for an identifiable demand (Unesco/WMO 1988).

Figure 2: Hierarchy in water resources planning and management

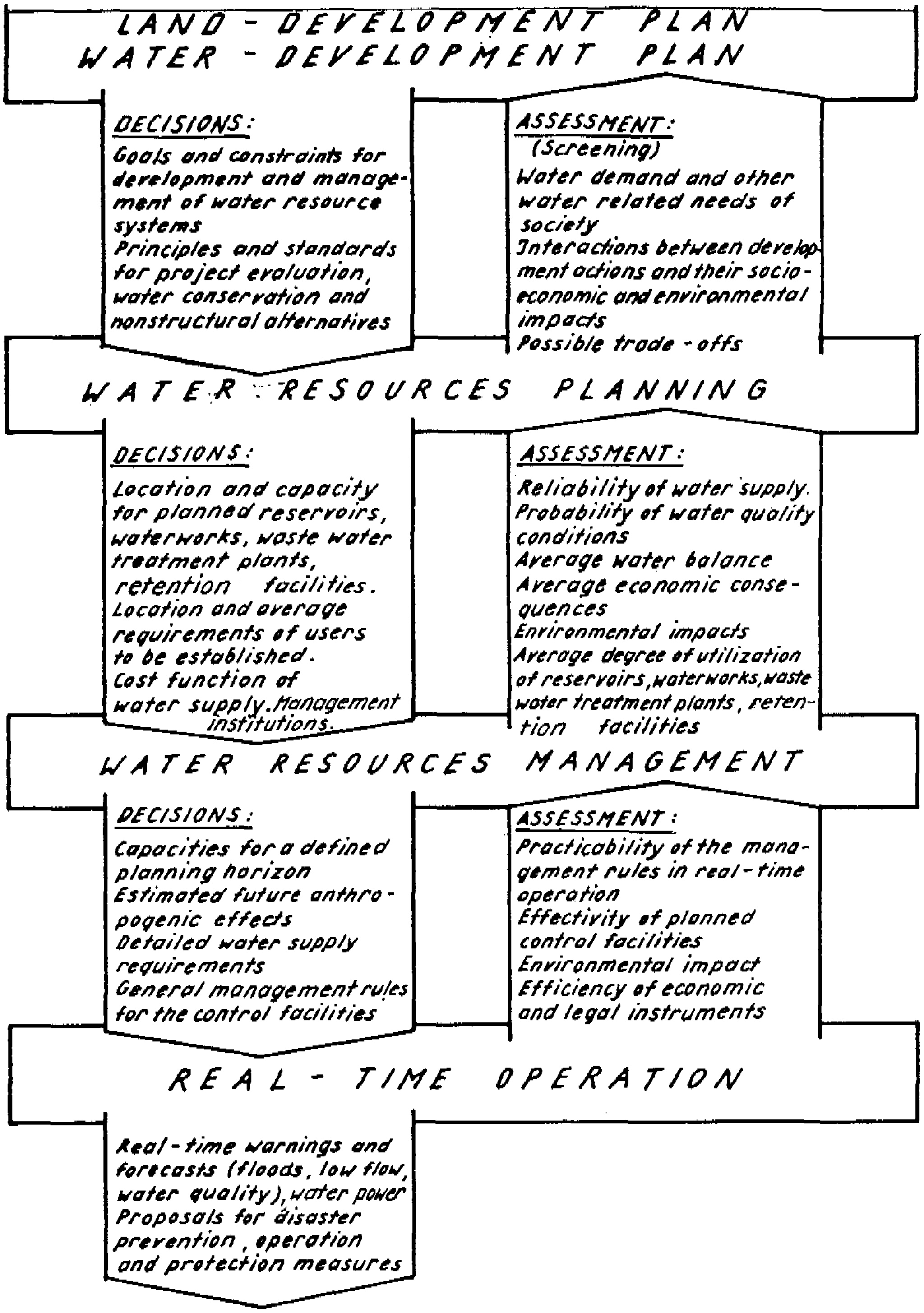


Fig. 2 Hierarchy in water resources planning and management

1.3 Importance of hydrology in water resources management.

As one of its main building blocks hydrology is an integral part of WRM. It enters into it through the use of empirical and causal hydrologic models in water resource planning, management and design, operation, and protection. The nature of hydrologic models and the relevance of their merits and drawbacks to water management decisions was examined by Klemes, 1982. He stressed the following points.

- Prediction of future states of hydrologic processes, of the future distribution of water resources in space and time, and of the state of the quality of water resources requires adequate modelling of the hydrologic cycle and water balance computations under man's intervention taking into account effects of land surface changes and of changes in climate variables.

- One of the main problems in the application of hydrologic models in a water resources management model is to guarantee their soundness and validity as a prerequisite to using them for any extrapolation. There is always the danger that under the pressure to solve urgent practical problems or to apply simple submodels in the framework of a large water management model that we may restrict ourselves to getting a fit or to produce a reasonable number based on a wrong concept. If not taken seriously into account this danger may increase with the growing ability of mathematics, the acquisition of new hardware, the broader application of systems analysis and of informatics.

- As extrapolation is the main application of hydrologic models in water management a wrong concept will lead to bad water management. The applied concepts of flood frequency extrapolation are an example of serious obstacles to progress in hydrology.

- Non-stationary conditions, lack of data, and of understanding the dynamics of the complex processes of climate variations, of runoff formation, and of runoff concentration under different natural conditions and the growing influence of man's activity on the hydrological cycle are main sources of the unsatisfactory situation.

The order of the main problems in WRM given in Fig. 2 is reverse to the order in which the difficulty of the problems and the need for a sound scientific basis of hydrologic models increase and our understanding of the relevant physical, chemical, and biological processes and the credibility of hydrologic and water quality models decreases.

For models in real time operation test data in most cases are available, model performance can be tested without difficulty, and forecasts can be compared with the actual occurrences. For flow models we can rely on the laws of hydraulics.

For management models high standards for verification of hydrologic models must be applied to guarantee their credibility. To narrow the gap between the validation standards applied to operation models and those applied to simulation models a systematic hierarchical scheme was proposed by Klemes (1982, 1985). For planning models for the prediction of long-term and large-scale hydrologic phenomena testing is impossible or at least very difficult, and there is no opportunity to correct a wrong extrapolation by comparison with an actual occurrence in an acceptable time span. Here we need scientifically sound hydrologic models incorporated in planning models, being based on an abstraction of reality of the water management system (Unesco, 1987c).

The climate and land surface systems are dynamically coupled through the physical processes of energy and water supply, transformation, and transport at the land-atmosphere interface. Large-scale patterns of climate are influenced by regional variability of the surface processes of the water cycle. In order to develop physically based water balance models which reflect the dynamic coupling of an atmospheric-soil-vegetation system, it is necessary to retain in the model both the underlying physical determinism and the uncertainty in the elements of the water balance (Eagleson, 1978).

With the exception of runoff, which is an intergrated measurement, for the elements of water balance the problem exists of areal representativity of point measurement. The high variations of site characteristics and of physical and physiological properties of plants lead to large differences in water balances of vegetated surface. The interaction of the site factors is of importance for the plant growth and, therefore, for the water balance of a site. As a result, new methods for water balance computations have been developed using findings of site science. For water balance computations using the concept of a digitized basin, the distributed parameter sets must be determined.

For generalizing and regionalizing site values of the water balance elements throughout the whole basin, the method of classifying hydrological unit areas can be applied. The parameter sets have to be determined for each unit area taking into account the close coincidence of geomorphological, soil, and vegetation distribution patterns.

For the subdivision of the basin into unit areas a basic matrix of site factor complexes must be established: main forms of land use, type of soil classes, depth of groundwater table, surface slope, slope position, aspect. Different time scales in the water cycle of a basin can be associated with different site units of the basin (Dyck, 1985).

1.4 Assessment and classification of the water resources

1.4.1 Assessment of water resources

Water resources can be neither developed nor managed rationally without an assessment of the quantity and quality of water available (Unesco/WMO, 1988).

To assist individual countries in developing and maintaining adequate programs for the assessment of their water resources, Unesco and WMO elaborated the following two documents:

- Water Resources Assessment Activities, Handbook for National Evaluation (Unesco/WMO, 1988).
- Guidelines for Evaluation of Water Resources Assessment Programmes based on the Handbook for National Evaluation.

In the "Handbook" the following definition is used for water resources assessment (WRA):

> *"Water resources assessment is the determination of the sources, extent, dependability and quality of water resources on which is based an evaluation of the possibilities of their utilization and control."*

The "Handbook" identifies the following three stages in the implementation of programs for the assessment of water resources:

1. Basin Water Resources Assessment:

   - Collection, processing and dissemination of:

     - hydrological data (water cycle);

     - data on water use by man and related projects;

     - auxiliary data which are used for interpolating network data to any point of the area under consideration. These are mainly physiographic data (topography, geology, pedology, land use and land cover).

   - Assessment of available water resources on which to found long-term plans of water resources development based on present and future water needs:

     - long-term mean values of groundwater recharge (humid, arid climatic regions);

     - surface water/groundwater interaction;

     - geological conditions (sedimentary, non-sedimentary);

     - groundwater quality;

     - conditions of water management (water use).

   - Classification of surface water and groundwater resources according to conditions of water management and degree of investigation, surface water and groundwater types.

2. *Regional (system oriented) Water Resources Assessment:*

   - Collection, processing and dissemination of hydrological, hydrogeological and auxiliary data for medium and long-term predictions for regional planning, water management and design projects.

   - Extension of networks, more detailed investigation.

   - Regional models (water flow, water quality, surface water/groundwater interaction).

   - Classification of water resources.

3. Local (project specific, operation) Water Resources Assessment. This highest level of investigation is characterized by:

   - Collection and processing of project-specific, operation data, pumping tests, etc.

   - Facility oriented GW models.

- Monitoring of water quantity and quality development.

- Measures for the control of groundwater abstractions and use to avoid over-exploitation and contamination.

- Precision of the regional classification of water resources.

The pilot project with which the "Handbook" is concerned deals only with the first stage, the basic water resources assessment. This inventory of water available for various uses, including characterization of time-space variation of water quantity and quality is considered to consist of three components:

1. Collection of hydrological data, i.e. the collection of historical data on water cycle components at a number of points distributed over the assessment area.

2. Obtaining physiographic characteristics of the territory that determine the space and time variation of the water cycle components, i.e. climate, topography, soils, surface and bedrock geology, land-use and land-cover inclusive man-made changes, phenological data of vegetation.

3. Techniques of relating the hydrological data to the physiographic data to obtain information on the water resources characteristics at any point of the assessment area.

Data collection, processing and retrieval includes:

- Data on the water cycle.

- Data on water resources projects and use.

- Physiographic data:

    - Data needs;

    - Data systems;

    - Adequacy of data;

- Data storage, primary processing, and dissemination:

    - Requirements;

    - Storage of water cycle and physiographic data;

    - Primary processing:
      Data cataloguing
      Conventional data banks
      Computerized data banks
      Preparation of consistent (user oriented) data banks.

- Publications (year books, etc.).

- Adequacy of data storage, primary processing and dissemination.

Areal assessment of water balance components by mapping and models is of high importance for water resources management.

1.4.2 Classification of water resources

The classification of water resources is becoming more and more important as pressures on water increase. To put the water resources in their proper place in national economy various regulations exist for flowing and stagnant surface waters and for groundwater. Proving, classification and certification of water resources should be regulated by law in each country.

Such regulations are mainly elaborated for groundwater reserves. Groundwater reserves are concentration of groundwater, which may be used with economical expenditure currently or in the future. They are characterized by water quantity and quality, conditions of tapping and treatment.

According to their suitability for economical utilization, proved groundwater reserves should be grouped as groundwater balance reserves and groundwater-extrabalance reserves.

Each of the two groups can be divided into classes, differing in the degree of exploration and the water management conditions.

The following sorts of groundwater reserves can be distinguished:

- "Renewing groundwater reserves", forming in one or several aquifers in a period of time from:
  - natural groundwater recharge as percolating fraction of precipitation;
  - natural and rapid infiltration of surface water (e.g. in karst).

- "Supplemental groundwater reserves", originating from technical measures as bank filtration and artificial groundwater recharge.

- "Groundwater deposit reserves", available in one or several aquifers at a fixed time. These reserves are mobilized mainly by large scale groundwater depletions in open-pit mining areas, and are increasingly used for water supply.

Scientific-based predicted but not yet explored groundwater reserves are termed as "prognostic groundwater reserves". The proved groundwater balance reserves and groundwater extra-balance reserves and the "prognostic groundwater reserves" form the total groundwater resources of the basin.

The present and future stable groundwater utilization requires that the proved or certificated groundwater reserves are available as long-term mean values. Therefore, the withdrawal of only as much water from the groundwater resources of a drainage basin as is recharged is to be allowed. It should be guaranteed that seasonal and annual variations of groundwater recharge and thus of groundwater flow do not restrict groundwater utilization.

User-oriented classifications for flowing and standing surface waters and for groundwater are of growing importance. The regulations should allow the classification of water resources by hydrological, chemical, physical, biological and hydrogeological criteria.

Depending on the specific problem, groundwater is assigned to groundwater types or use classes. Groundwater types serve the area wide registering and assessment of the quality of natural groundwater, the determination of the genesis of groundwater, the regional delimitation of fresh and mineral waters and the hydrochemical mapping and regionalization (Bamberg, 1987).

Numerous methods for the classification of groundwater according to the mineralization and ion content of the main constituents have been published.

Groundwater use classes for the development of groundwater resources to be used for water supply should be characterized by quality and hazard classes.

Groundwater quality classes should be defined according to fixed limits for detrimental water consituents by the following groups of characteristics:

1. Toxic consituents such as noxious heavy metals, organic compounds and other companions, and trace substances.

2. Criteria of toxicity referring to physiologically critical substances.

3. Other criteria, notably main constituents, companions and properties which may cause a negative impact from the use of the water.

The use of groundwater for drinking water supply depends essentially on the degree of its protection against existing or potential anthropogenic contamination.

In the assessment of groundwater hazard classes a separate classification is performed (Bamberg, 1987):

- in classes of groundwater protection according to hydrogeological criteria (depth of groundwater table, thickness of confining overlying layers of loose rock);

- in classes of contamination hazards according to contamination criteria (flow time, quality class in the place of contamination).

1.5 Utilization of water resources and water demand

Water serves man in various distinct uses. Principal categories of water uses are listed in Fig. 3. In water resources management, the different effects on water resulting from its various uses, and their linkages to economic sectors and the hydrological cycle must be taken into account. Aquisition of water use data and forecasts of population and water needs is a very complex task. Past histories of water use indicate the principal influencing factors, and are valuable aids in making estimates of future water needs the principal influencing factors and possibilities of their manipulation to affect future water use and demand, water losses and water pollution or contamination must be considered; these include the impacts of water conservation and other nonstructural approaches on the various water use sectors, the effects of more economic (water sparing and recycling) technologies, the effects of metering and price on demand and water losses, and actions taken at the source by preventing or limiting pollution of the waters used or waste water reuse.

Most of the textbooks on water resources planning and management, on water supply and waste water treatment, on irrigation and on other water uses have chapters on water demand estimates. Mathematical models are discussed in Kindler et. al. (1984).

1.6 Long-term planning of water resources systems

Water resources systems are assemblies of natural and man-made physical systems (Fig. 2). The man-made physical system is a collection of various elements - for example water supply and sewage treatment plants, reservoirs, pipelines, irrigation and drainage structures, levees, dikes and other structures - which are built in response to various social needs and interact in a logical manner (Unesco, 1983c, Unesco, 1987d).

Since many water resources projects are very large and influence various sectors of society, the decision process which leads to the implementation of a water resources project is complex and takes a long time (Fig. 1). Decisions have to be made on a political, socio-economic, technical and environmental level and in most cases they have to take into account long time horizons. The more intensive the water use process the broader becomes the scope of the planning process. Most of the projects have to be seen from a basin wide, regional or even national or international context. It is therefore advisable to use a hierarchy of planning of water resources projects. Typical for such a hierarchy of planning is the division into three levels:

1. International agreements of water use of an international river.

2. National land development and national water resources development plans.

3. Regional water resources plans.

Another typical sequence of studies is the following:

1. Preliminary or reconnaissance study to identify major problems or prospective problems for large areas and temporal horizons of about 30 to 50 years based on a high abstraction of the water management system.

2. Feasibility study and report, generation of alternatives, screening and selection of project alternatives; comprehensive planning effort for a river basin or smaller region.

3. Implementation planning, where specific project designs are developed.

The applicability of systems analysis used in the various stages of the water resources planning process is documented and evaluated in Unesco, 1987d. That book contributes to the development of a common approach for project planning in water resources. It articulates problems that may defer application of systems analysis and plan acceptance; and provides the means of overcoming them. It can serve as a textbook for courses on integrated planning and management of water resources.

It identifies the following stages of the planning process (Fig. 4):

Stage 1: The plan initiation stage, which takes into account the political, economical, social and environmental conditions and the priorities for the long-term development of a country

Figure 3: Principal categories of water uses, United Nations (1976)

Infrastructure	F
Agriculture forestry and aquaculture	A
Industry	I

F	Drinking	W
F	Domestic uses	W
F	Public uses in settlements	W
A	Rain-fed agriculture	O
A	Livestock	W
A	Fish and Wildlife	N
A	Forestry	
A	Irrigation (a)	W
F	Navigation	N
I	Hydropower	N
I	Steam Power	W
I	Mining (b)	W
A	Swamp and wetland habitat	O
I	Cooling	W
I	Processing (b)	W
I	Hydraulic transport	W
I,A,F	Waste disposal	N
F	Recreation	N
F	Aesthetic enjoyment	N
A	Utilization of esturaries	N,O

W	Withdrawal
N	In-stream
O	On-site

(a) Highly consumptive uses

(b) Heavy impact on water quality

set by the national land development plan and national water resources development plan. It starts with the statement of needs, goals and objectives, and includes preliminary planning that ends with the decision on how to proceed (UNIDO, 1972).

Stage 2: The information and data collection stage, in which all the necessary information is gathered for system model development and decision-making.

Stage 3: General, investigation and screening of alternatives. The final project configuration is determined by selecting a small number of representative and promising alternatives for detailed analysis. It includes public involvement in water resources planning, interaction with representatives of various disciplines, concurrent consideration of water uses and land uses, application of methods of systems analysis for the formulation of alternatives, negotiations and conflict resolution considering the controversy among different water users and interest groups, including multiple criteria, taking into account the uncertainty and the stochastic character of the system inputs, and the inter-relation between the water management system and land development. From a screenbed set of decision alternatives project alternatives are selected, demonstrating the necessary trade-offs between different water users and interest groups to find "good" long-term strategies, seeking the "best" technical solution being politically feasible, environmentally sound, socio-economically acceptable, and legally permissible.

Stage 4: The process of planning in detail and of final project specification. In this stage the location and capacity for existing and planned structures (reservoirs, water works, waste water treatment plants, waste buffer facilities etc.), the location and average requirements of users to be established, costs, benefits, risks, impacts, etc., of the alternatives selected in Stage 3 are determined. In the plan evaluation using economic, environmental and social criteria the assessment of the water management model (see Fig. 2 and Section 1.7) plays an important role. This stage repeats, in more spatial and temporal detail, the model building and model analysis of Stage 3.

Stage 5: The project design stage, in which the final configuration is translated into design and contract documents, is not considered here. It is followed by the construction stage.

Other international organizations have also formulated recommendations for the integrated planning and management of water resources, and national agencies, e.g. the U.S.A., have formulated principles and standards for planning water and related land resources (Report to the National Water Commission, 1972; Report to the Water Resources Council by the Special Task Force, 1970).

1.7 Long-term management modelling

1.7.1 General task of the management model

Long-term management modelling must be based on an appropriate management policy (U.S. OTA U.S. Congress, Office of Technology Assessment, 1982. Lundquist, Lohm and Falkenmark, 1985). Basic patterns of water resources management policies can be based on static or dynamic yield concepts. A. Wiener (1972) describes the two opposing conceptions of management as follows:

"The static management concept operates with steady states: the initial steady state defining the resource system at the outset of the utilization, and the ultimate steady state describing the system in its planned "final" state when it supplies the desired "safe yield". Transients are recognized, but their utilization potential is not put to proper use. The safe yield is generally expressed as a percentage of the average recharge.

The dynamic management concept consists in devising alternative sequences of intervention and selecting the sequence that will optimize objective achievement."

The dynamic approach to water resources management is especially important

- *for systems featuring major groundwater resources*

- *if water quality aspects are included in the analysis*

- *for early phases of development, where availability of water might be a precondition to transformation of the socio economic system"*

And Wiener (1972) continues:

"The adoption of the dynamic management concept leads to three basic alternative long-term management policies:

1. *The equilibrium policy aimed at attaining, after transient stages, a target state that is in stable equilibrium, subject only to short-term fluctuations.*

2. *The quasi equilibrium policy aimed at attaining, after transients, a target state that requires continuous corrective intervention to keep the system in a quasi equilibrium and to avoid "run-away" conditions.*

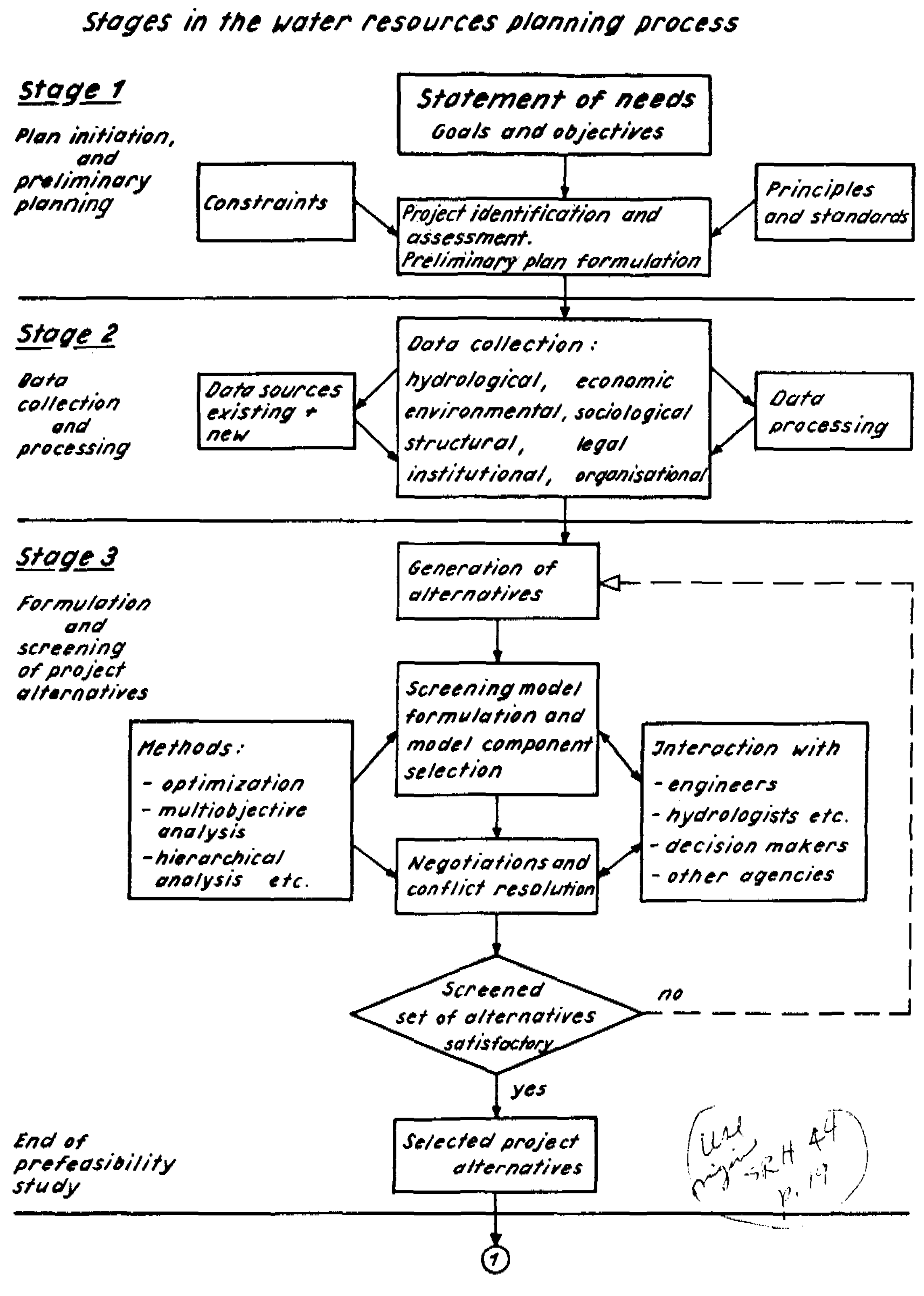
3. *The nonequilibrium policy reconciled to a nonequilibrium final state (i.e. relinquishing the aim of ending up with an equilibrium or quasi equilibrium), while ensuring for a specific period our ability to utilize the resource under such conditions."*

Typical applications of the three basic management policies are demonstrated by Wiener (1972).

The place and task of long-term management modelling in a hierarchical Decision Support System (DSS) for planning, management and real-time operation (which was already briefly discussed under Section 1.1, Fig. 2).

The results of the multi-criteria analysis using the planning model provide long-term oriented goal functions for the operational measures (operating rules) to be simulated in the management models (Kaden et al. 1985). The application of the management models allows detailed consideration of the optimum long-term water supply and other water related problems to derive rational long-term management policies for existing and/or planned water management systems. The necessary integration of submodels of all important subsystems and subprocesses in a DSS results in special requirements to the submodels. To be applicable in a DSS with its complex problems and solution concepts the submodels have to be as simple as possible.

Figure 4: Stages in the water resources planning process



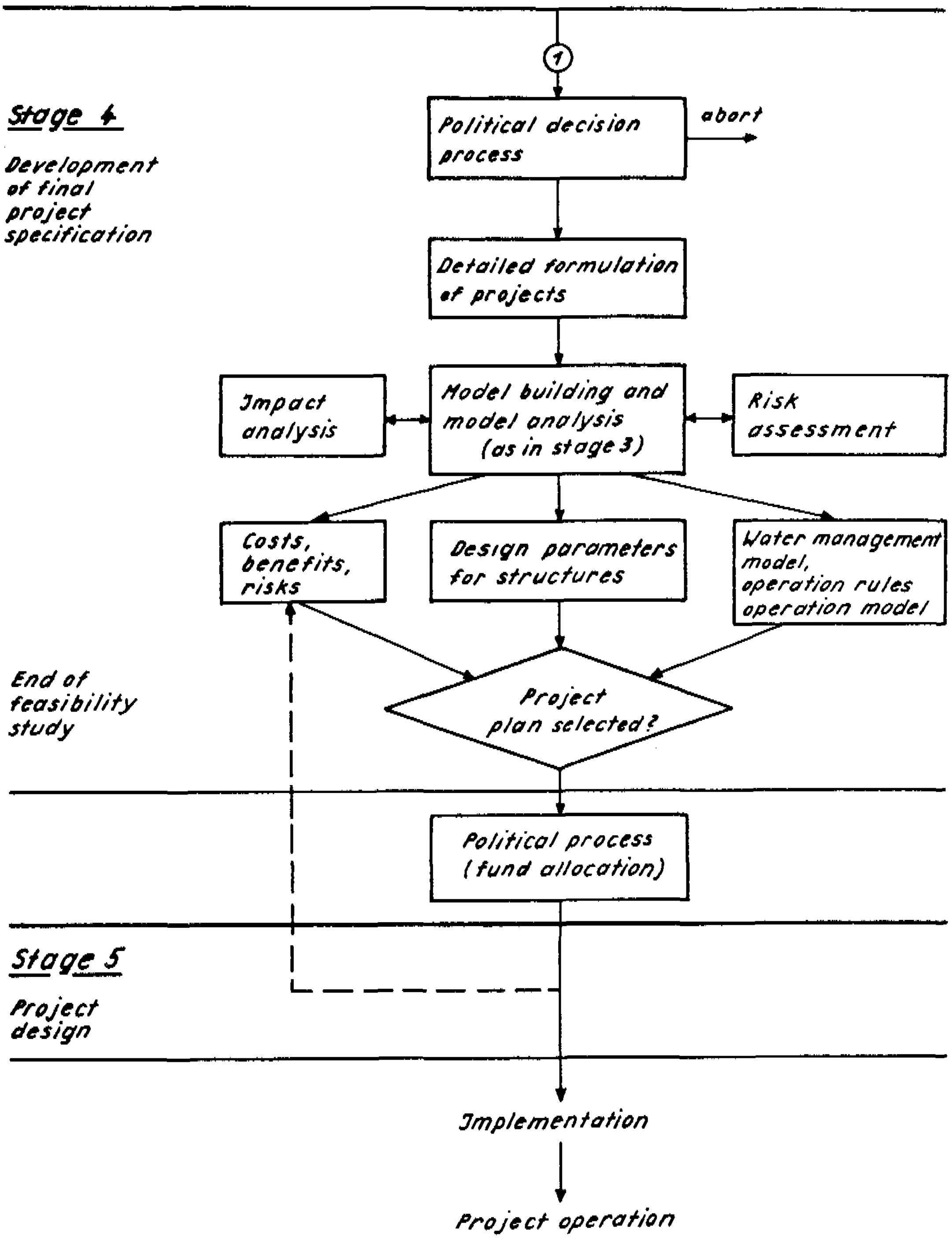


Fig. 4 Stages in the water resources planning process [24]

Various mathematical models are available for the simulation of the surface water and groundwater flow processes. Comprehensive hydrological models are based on the fundamental differential equations of fluid mechanics. These models have to be simplified for their application in the framework of water management models. The fundamental equations are used only in an integrated form. In most cases the continuity equation and a simplified relation as substitute for the dynamic flow equations is used. An analogous procedure is necessary for the reduction of comprehensive water quality models for surface water and groundwater.

The two main tasks of management modelling (Fig. 2):

- to derive an efficient long-term management policy and
- to assess the practicability of the water quantity and quality management rules for the control facilities and measures,

can only be solved if the management model adequately reflects:

- the real water management system in a river basin and its essential processes without systematic errors, and
- the stochastic character of the natural processes taken as input variables of the model.

If direct optimization is desired (linear, dynamic programming, etc.) one is confronted with serious problems in fulfilling these preconditions, mainly with regard to the adequate consideration of the stochastic character of the input variables, their time structure, magnitude, sequence of extremes, etc. The same is true with explicit stochastic optimization techniques in the case of complex water management systems.

In this stage of water resources management decision-makers are mainly interested in results of the efficiency of management and control policies, in information on trade-offs, in the reliability figures for all water users, in hydrological characteristics of the flood and low flow regimes, in water quality, etc.. A comprehensive analytical solution of those kinds of problems is at this time not available.

It is for these reasons that in the recent past the application of stochastic management models on the basis of the Monte Carlo method succeeded. Synthetic time series of the hydrologic or other input variables are used with a deterministic water management model to assess the efficiency of given management policy and its alternatives. This "experimental" approach to the problem allows for a computation of various decision alternatives.

If large scale river basins are to be investigated, a subdivision of the river basin area into simulation subareas and balance profiles is necessary. The partition is mainly determined by the location of main river gage stations, of tributary or water transfer junctions, of important water withdrawals and releases, of reservoirs, etc.

1.7.2 The basic model for stochastic water management simulation

The main steps of the long-term water management modelling by means of simulation technique (Monte Carlo method) are represented in a general form in Fig. 5.

Main steps or components are:

1. ***The stochastic simulation model***

The meteorological variables precipitation, gross radiation, air temperature, etc. and the hydrological input characteristics which define the available water resources are stochastic processes. The same is true of the water demand, depending on the actual meteorological situation, such as municipal water supply and irrigation. Efficient computer-based long-term simulation techniques using synthetic time series of the input variables have been developed. (Svanidze, 1964; Reznikovsky, 1969; Box and Jenkins, 1970; Fiering and Jackson, 1971; Kottegoda, 1980).

In most cases, a monthly time step is considered to be adequate. Thus, the runoff process in the river network can be described by simple continuity equations rather than by complex hydrodynamic models.

The application of the multidimensional synthetic generation technique ensures the generalization of the information involved in long observation series of the river basin. The probability distributions of the water related variables have to be based on sufficiently large data sets covering all ranges to be considered.

Beside stochastic simulation of the natural runoff process, water uses, and flow control facilities have to be modelled. Each use has to be specified with regard to the seasonal (monthly) water demand in concordance with the planning horizon and the runoff or other model variables, the amount of target return flow, and with a ranking which determines the priority of water supply among all uses (multistage supply scheme). For each flow control facility its location, capacity, seasonal varying storage volume and operation rule must be specified.

2. ***The deterministic water management model***

By using stochastically generated time series of hydrological processes and random demand factors the stochastic management model can be reduced to a deterministic balance scheme. This model simulates, based on the above-mentioned runoff simulation, according to given strategies, the processes of monthly water allocation, utilization and management in a river basin by means of typified algorithms for the various operations occuring in the system. In addition the model provides the registration of state variables, e.g. the runoff at selected balance profiles, water supply deficiences, water losses, flooding, resulting damages, extra costs, actual reservoir release and storage values, and other stated conditions of interest for the final statistical evaluation.

3. ***Statistical analysis***

Based on the registration mentioned above, a program is needed for statistical analysis, interpretation and representation of the model output data as a basis for evaluating the applied management policy and its alternatives. Examples of three different types of water supply reliability indexes are:

(a) Annual reliability, P_H

$$P_H = \frac{\text{number of nonfailure years}}{\text{total number of simulated years}}$$

Figure 5: Main components of the long-term water management modelling by means of simulation technique (Monte Carlo method)

Stochastic simulation model

Stochastic generation of time series of natural and random demand factors as input variables for the management model

Deterministic water management model

Deterministic simulation of water supply processes and detailed balancing of the available water resources with water demands and other requirements, and allocation of water yield according to a given water management or control policy, user priorities, flood protection levels, etc.

Registration in each computational time step

Statistical analysis

Analysis of the systems state and interpretation of selected state variables and occurence of critical events for probabilistic evaluation of the given management policy and its alternatives

Decision-making process

Analysis of the results of the computations with the decision-makers.

(b) Monthly reliability, P_D

$$P_D = \frac{\text{number of nonfailure years}}{\text{total number of months}}$$

(c) Volume Reliability, $P_{M,}$ for a fixed time period

$$P_M = \frac{\text{accumulated actual water supply}}{\text{accumulated water demand}}$$

The output program should be sufficiently flexible to provide various data tables which can be directly used for decision-making or for plotting to illustrate e.g. the trade-offs of conflicting objectives.

4. *Decision making process*

Discussion of the results with the decision-makers, to consider conflicts among different water uses and interest groups, to include the subjective and more qualitative experiences of the decision-makers and to set up new alternatives of water resources management and allocation if required.

1.7.3 Extensions of the basic management model

The basic stochastic management model assumes a fixed system configuration, stationary hydrological processes, and a defined management policy for each simulation run, that reflects either the present conditions or a future horizon. If there are trends in the runoff formation processes due to the activity of man or in the water demand processes a modelling procedure is needed covering balance periods with varying system configuations and strategies instead of fixed term horizons (Kaden et al. 1985). To take into account the actual runoff variations within a month, e.g. to integrate flood management directly into the model, a flood feature generation model can be used. The general principle of this method is, to describe the flood flow process by a certain number of main patterns of a flood hyrograph. If in the synthetic runoff time series a high value of mean monthly runoff is generated, stochastically generated flood hydrographs are used to replace the constant monthly mean value, and the management algorithm is switched over to a flood procedure. The decision on the appearance of a flood month is taken by a flood discriminator, using a reference level (threshold) of discharge. The advantage of this procedure is that a detailed generation of the runoff ordinates for each time interval is not necessary. Only during floods is a simulation with a suitable time step (e.g. one day) needed.

Since the hydrological system and processes are increasingly affected by human influences, information on the runoff process derived from existing historic observation series on the available water resources and on the hydrological regime cannot simply be extrapolated into the planning periods to be investigated. To take into account the effects of trends and changes in the hydrological and water management regime the available water resources should be computed by means of hydrological models of river basins from meteorological input fields (precipitation, evapotranspiration). The direct runoff simulation is replaced by the indirect runoff generation based on stochastic meteorological input data and a deterministic conceptual catchment model for long-term flow simulation with time increments of 10 days or 1 month. The basin can horizontally be classified into three hydrographic types: deep groundwater level, shallow groundwater level, open water tables. The first two may have a vertical subdivision into three layers, then three runoff components are simulated: overland flow (surface runoff), interflow (lateral soil water runoff), base flow (groundwater runoff).

If an intensive coupling between groundwater and surface water management must be taken into account reduced groundwater flow models have to be applied. These reduced submodels can be derived from comprehensive groundwater flow models, based on a methodology of model reduction (Unesco, 1986, 1987g).

Only a few water quality parameters (conservative chemical substances, e.g. salt) can be integrated into the basic stochastic management model up to now. To investigate water quality management problems, taking into account the complexity and internal interdependence of the water quality processes, comprehensive water quality models must be applied. Their inclusion in stochastic management models is not yet solved.

1.8 Real-time operation and monitoring of water resources systems

Even before a water resources system has been built and put into operation the planner or manager must search for the best methods of operation, monitoring and maintenance, with the most advanced operational rules and monitoring techniques, to maximize the outputs or effects, to minimize the cost of operation, and to protect water resources against depreciation.

Effective water resources planning and management includes a uniform concept for surface and groundwater monitoring, i.e. a unity of information acquiring, information processing and decision-making. Water resources monitoring is a fundamental prerequisite for the protection and rational use of surface and groundwater resources, it means a scientifically planned program with the following main targets:

1. Continuous inspection and observation of water quantities and qualities of flowing and standing surface waters and of groundwater, (sources of pollution and contamination, point source pollution, nonpoint source pollution, acid precipitation; effects of pollution, clean up efforts and results; main sources of groundwater contamination, e.g. intensive agriculture, injection wells, septic tanks, on-site waste water systems, land disposal of wastes, accidental spills and leaks, artificial discharge operations, salt water intrusion).

2. Protection of water resources against exhaustion and contamination. Regulations for groundwater use to prevent groundwater overdrafts and depletion; regulations for surface water withdrawals and specific flows to be maintained for instream flow use; water quality standards.

3. Analysis of occuring changes and the forecast of future changes regarding quantity and quality including the impact of planned and implemented protective and management measures, the protection areas and their management.

For basins or economic development areas with high intensity of water utilization a system of water resources monitoring is needed. Local monitoring concentrates on single projects such as water works and their protection zones, storage reservoirs, groundwater recharge plants, dumping sites for wastes, etc.

1.9 Expert systems as decision tools for water resources management

Decision making for water resources systems is characterized by a high extent of uncertainty caused by the non-stationarity and stochasticity of the natural processes and by the complexity and nonlinear dynamics of these systems. While the flexible simulation methods, discussed in the previous chapters, often allow the making of decisions under uncertainty by deterministic and probabilistic procedures, these methods depend critically on the validity of the underlying models (Rouhani and Kangari,1987). During the last decade the research in the field of Artificial Intelligence (AI) provided methods enabling a more intuitive handling of decisions or policies under uncertainty. The so-called expert systems are a result of knowledge engineering in a narrow domain. They render a new quality in computer based decision-making for water resources systems, using facts, empirical decision rules, expert judgements, heuristics and special knowledge of relevant disciplines. A brief overview on further developments towards expert systems is given in Rechnagel (1989), with this section based strongly on the conceptions of that overview. Expert systems are computer programs which mimic human reasoning based on special experience and qualitative knowledge. They are designed to simulate the problem-solving behaviour of an expert in a narrow domain (Denning, 1986) and to make his knowledge available to nonexperts.

The general architecture of expert systems consists of four parts (Fig. 6) (Hayes-Roth, Waterman and Lenat, 1983).

- *an interactive user interface* that permits the user either to enter specific commands or to select menu options. The commands will then be transferred to the control and interference structure, which provides a mechanism for interpreting commands, defining the problem solving approach and access to the data and knowledge base;

- *a control and interference structure*, which is a set of rules or algorithms that governs the ability of the system to draw conclusions;

- *a data base*, including declarative knowledge in the form of data or facts about the particular problem domain; and

- *a knowledge base* containing procedural or relational knowledge in the form of procedures, rules and models for combining data.

Expert systems with empty data bases and knowledge bases are called shells. These program packages are in the general software market. Knowledge acqusition and representation prove to be bottle necks in elaborating expert systems (Feigenbaum, 1984).

According to Denning (1986) three types of systems for representing knowledge can be distinguished (Rechnagel, 1989):

1. Logic programming systems use the predicate calculus for representing declarative facts or procedural statements.

Figure 6: General architecture of expert systems

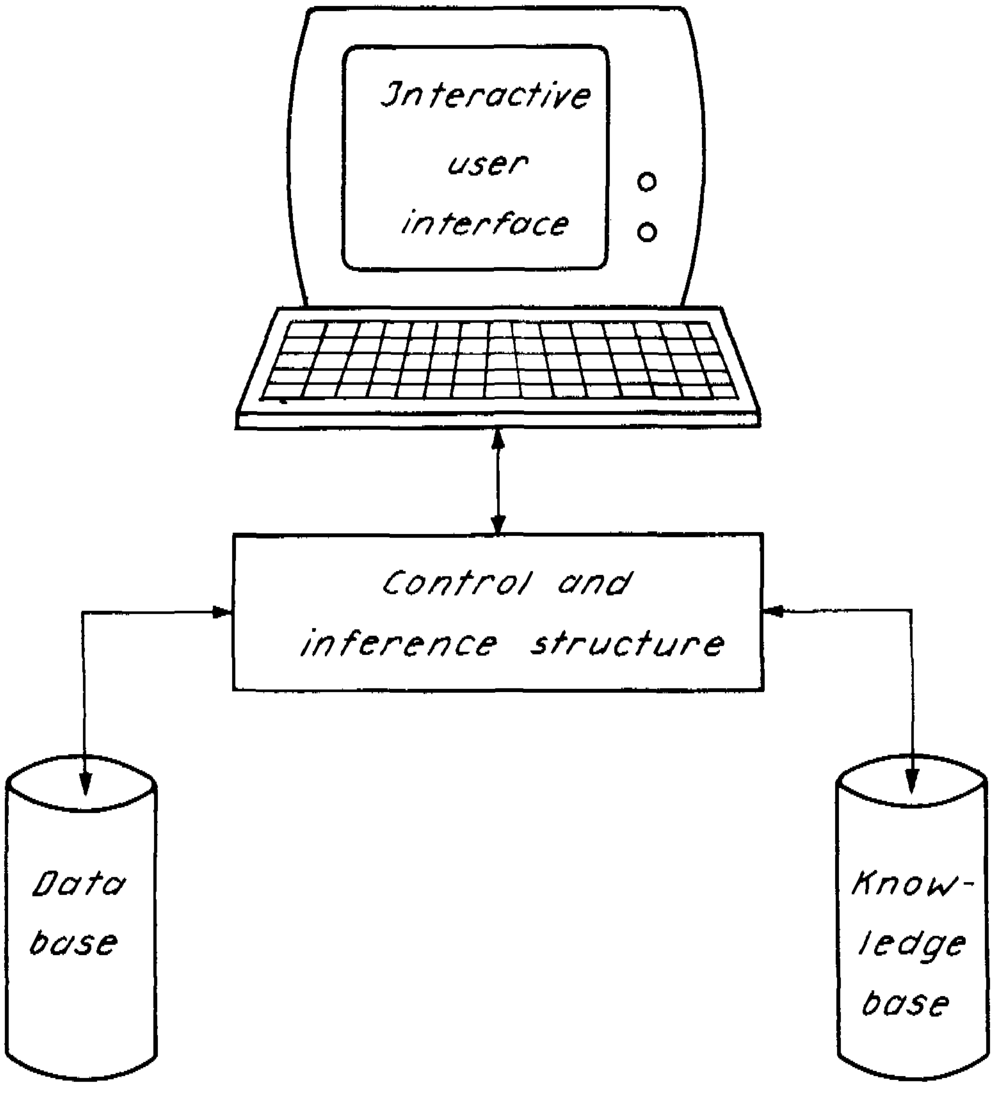


Fig. 6

General architecture of expert systems

2. Rule based systems are structured hierarchically by using rule sets, each rule set comprises a series of rules of inference according to the pattern "*if* conditions *then* consequences".

3. Frame based systems consist of a hierarchy of descriptions of objects referrred to in the rules, where a frame means the description of a class of objects or a single object by a collection of facts and data about the object.

For knowledge representing and processing in expert systems languages are needed which dispose of interpretive power. The languages mainly used are LISP (LISP Processing) (Winston and Horn, 1981) and PROLOG (PROgramming in LOGic) (Clocksin and Mellish, 1981).

Expert systems have wide applications in water resources management and in the water industry because problem resolution in these fields involves significant judgement and experience. Although the development of complex and deep expert systems with their special requirements for knowledge engineering can be very costly, their potential benefits are obvious.

2

OBJECTIVES OF EDUCATION FOR INTEGRATED PLANNING AND MANAGEMENT OF WATER RESOURCES FOR ENGINEERS, PLANNERS AND DECISIONS-MAKERS.

In this section a hierarchy of objectives of education programs for water resources engineers, planners and managers is presented. The term "education" is understood to contain the concepts of both general education and the more applied aspects sometimes referred to as "training".

Integrated planning and management of water resources must take account in the educational process of the following aspects of integration: management throughout the water cycle; integration of functions of water management through multiobjective approaches, including water quality/quantity; integration in time of planning, engineering and operation/management; and integration in space to overcome transboundary conflicts.

2.1 Classification of Objectives

The programs must be designed to satisfy demands for education/training that vary in detail and focus, by discipline and by level of worker in the organization.

Education requirements vary according to level of detail and focus on planning, engineering or management. Often planners, engineers and decisions-makers/managers are the same persons, but the separate needs for education of managers/decision-makers must be recognized to ensure that the attention of managers will be retained. Planners and engineers will be able to participate in management education, but often the reverse is not true. Education requirements vary according to discipline, and some interdisplinary topics are needed as well. The usual disciplines represented are: engineering (by subfield), economics/finance, biochemistry, law, social sciences, and mathematics/statistics.

Finally, education requirements related to level of the worker in organizations. Three management levels are normally distinguished: operator, manager and executive. These levels can also be used to classify the needs for planning and engineering education.

These classification parameters take care of the additional variables of stage of career and stage of the water resources management process. Stage of career is accounted for by the level in organization and the level of detail/focus. Stage of the water resources management process is accounted for by the separation of engineering, planning and management and by the design of topics for educational programs (Unesco 1987d).

2.2 Objectives of mangement education

The unique feature of management is its responsibility for decision-making. Management tasks are normally classified as planning, organizing, directing and controlling. Engineers share some of these tasks since the planning and organizing stages of water development correspond to planning, designing and constructing projects; the controlling stage corresponds to operation of the project. To shed further light on the distinctions between management, planning and engineering, the level of the decision-making must be introduced.

Education for water resources managers is unique in its focus on the higher levels of responsibility that deal with resources allocation and with policy questions. These higher levels of responsibility are experienced by managers in the broad fields of management of other infrastructure services are well, such as: electric power, transportation, public works and waste management.

Considerable thought has been given to the matter of public works or infrastructure management by Stone, 1974. Stone explained the need for management education programs dealing with public works in general with this statement:

> *"Engineering capability alone is insufficient for these multidimensional purposes. Engineers and other specialized skills must be complemented by public affairs and managerial competences. These include capacity to deal with the gamut of social, economic, environmental and political factors inherent in planning, policy resolution and program implementation. Practitioners are needed who can integrate public works systems and subsystems into urban and national development programs."*

While Stone's remarks deal with public works in general they apply also to water resources in particular. Note the emphasis on multidisciplinary competence in public affairs and managerial skills.

The general objective of management education for water resources professionals should therefore concentrate in building competence in the application of managerial and public affairs skills to the planning, development and operation of water resources systems.

2.3 Objectives of planning education

The term "planning" is normally considered to be part of the management responsibilities. However, in the case of water resources systems, the need for planning is so diffused throughout the management and technical responsibilities that the concept requires a broader understanding.

The different phases and objectives of planning can lead to confusing description unless clarified. Examples of planning terms are: strategies planning, master planning and policy planning. Planning applications for water resources require a four-dimensional matrix to describe. One dimension is the stages of management: planning, organizing, design and operation. Another is the subdivisions of the management units of the organization. A third dimension would be the levels within each of the subdivisions of the organization. The fourth dimension would be the different types of water management purposes. Everything has to be planned, and that includes the physical capital facilities as well as the operating systems. To grasp this view of planning, planning must be seen as a continuous responsibility of the entire organization.

The plan types can be shown on an individual diagram for each water management purpose, such as water supply, hydropower or flood control. This diagram would show the function, stage and level of the planning required. This allows each part of the organization to establish which plan is their responsibility. This establishment of responsibility is closely related to the establishment of information support requirements, and to the maintenance of data bases and routine studies to support decision-making.

Planning education, like planning itself, is inherently multidisciplinary. The final result of planning should be inter-disciplinary, reflecting one dimension of the integration needed in water management: the integration of disciplinary viewpoints.

The development of programs of planning education is evolving.

3

THE SPECTRUM OF EDUCATION IN WATER MANAGEMENT

3.1 Water management as a profession

The management of water resources (which includes planning, implementation and operation of water resources systems) is a multidisciplinary activity in which different groups of professionals and non-professionals take part. The composition of these groups and their relative importance depends upon the type of the water resources system, the institutional framework in the respective country, the socio-economic situation of the country, the mechanism of decision-making, the traditions and technical skills available, and on many other circumstances. The wide range of possible variations from project to project and country to country does not permit any generalization apart from the truism that all professions are equally important, in priniciple.

Water resources management has not been considered as the speciality of a definite profession and is therefore seldom the subject of a full academic curriculum, such as civil or hydraulic engineering, for instance.

In recent years, however, there is a tendency to replace the traditional profession of hydraulic engineering by a broader concept of "water engineering". According to Plate (1985):

> "*water engineering today is the planning, design, construction, operation and maintenance of water resources systems. This is of much broader scope than traditional hydraulic engineering because it interfaces, at the planning and operation level, with socio-economic issues involving the broad economic demand and supply structure for the water as commodity, in an environment of conflicting interests and multiobjective utilisation, under the requirement of providing safety of supply and protection during processes which are highly variable and subject to random uncertainty.*"

The very broadness of the scope for "water engineering" makes it difficult to cover it by a single profession. The various facets of water engineering call for different skills and academic education: it is obvious that the design of hydraulic engineering structures and their construction call for quite a different academic education than the planning and operation of the systems.

It is therefore more likely that the profession of water engineering (or water resources engineering) would rather complement than supersede the classical profession of hydraulic engineering, the latter being directed towards the increasingly sophisiticated task of designing and implementing of hydraulic structures and systems.

The various phases of water management - described above as planning, design, construction, operation and maintenance - follow each other in a logical sequence, but at the same time co-exist, simultaneously. Planning of water resources development is a permanent activity not only on a larger, national or regional scale, but also of any complex water resources system itself: such a system is never "completed" in the sense that no further development is possible or necessary. The planned system is implemented in stages, each stage lasting sometimes several years, and the changing technology, demand and socio-economic conditions require a permanent readjustment of the existing system and an adjustment of the next stages of the planned development. In consequence, it is possible to conceive water resources engineering and hydraulic engineering as separate professions which require distinct academic preparation.

Whether water resources engineering will develop as a separate profession or remain merely a speciality of hydraulic, civil or other professions, depends on many particular circumstances, which are characteristic of a country or region, such as, for example:

- The socio-economic structure of the country, the institutional framework of water resources management and the pattern of decision-making in planning and management;
- the relative size the respective country or economic region, its economic strength and prosperity;
- the relative importance of water resources development and the relationship between water demands and the resources available;
- the complexity of water resources systems and their economic impact on social and cultural characteristics;
- the general level of development of the country or region, its technological and educational infrastructure, manpower situation, self-reliance in development, foreign influence in financing, etc.;
- The regional and/or international constraints in water development, e.g. in the case of shared river basins and resources.

In view of the variety of these conditions and circumstances, no definitive recommendation can be given whether to consider water engineering as a new and separate profession or to take it as a speciality, the skill of which has to be acquired in different ways of continuing education. Both patterns may be followed in some regions of the world. However, the novelty of the concept and the present outlooks of the world economy would favour a cautious development towards the new profession. It seems to be more reasonable, at least for the time being and for the majority of countries, to branch off water engineering from the main stem of hydraulic, or even civil engineering - as a speciality, calling for postgraduate and/or continuing education.

Annex A is a suggested list of topics for education in Water Resources Management.

3.2 Categories of professional and non-professional participants in water management

A great many professionals and non-professionals participate in the management of water resources - in the planning, design, construction, operation and maintenance of water development projects. Some of them pursue water management as their career, while others get involved temporarily - as researchers, designcrs, constructors, etc., or take part from time to time in policy and decision-making - as planners, economists, politicians, representatives of the public, etc. Broadly, the following categories can be envisaged:

(a) Professionals of whom water management is a permanent, full-time employment.

(b) Professionals who occasionally take part in the various phases of water management.

(c) Planners and policy analysts whose area of work covers various aspects of water management.

(d) Managers whose responsibility includes water resources management in addition to other resources.

(e) Policy-makers and decision-makers.

(f) Non-professionals involved in the implementation and operation of water resources projects.

(g) Laymen occasionally taking part in the decisions and representing the users of the water resources projects or the communities affected by them.

Each of these categories presents a particular target group of education in water management, with different backgrounds and educational requirements. The spectrum of education in water management must cover all these requirements, with a wide variety of objectives, methods, contents and forms. Each target group requires a different approach. Annexes A and B may be referred to for sample course structures based on the background of the target audience. Annex C lists a number of textbooks on various aspects of planning and management of water resources.

3.3 Approaches to the different target groups

Professionals employed in water management full time would need a complete academic training for their profession of water resources engineers. At present such programs do not exist and water resources engineering has not established itself as a separate profession (though there are attempts of introducing such program: Dresden University of Technology, GDR, is promoting a program for water management at the undergraduate level).

At some universities (in the U.S.A., Latin America, etc.) isolated course subjects are taught which lead the student to training in water resources management; more often, water management is offered as an option of postgraduate training.

However, according to the (incomplete) information gathered during the work on the present report, in most countries there is no degree program offered in water resources management. Certain courses like systems analysis, operational research, water economy, etc., are offered in undergraduate studies primarily for hydraulic engineers, though such courses may be included in the curricula of other engineering specialities as well (agriculture, forestry, etc.).

In consequence, full time professionals in water management are mainly recruited from professionals in hydraulic engineering, hydrology, agricultural engineering, chemical engineering, economy, social sciences, etc. This situation will most likely persist, at least in the majority of countries (and in particular, in developing countries) for many years.

It follows, therefore, that continuing education is the principal approach to the most important target group - the professionals in water management - in order to upgrade the knowledge of the various professionals involved in the practice of water management.

This statement does not mean that university education in water management has to be discouraged; it simply recognizes the fact that the promotion of such an education on a global scale, especially at an undergraduate level is not to be expected. In most countries, the number of available jobs in water management is limited and university education has to take this fact into account. Only in major centralized economic systems could a full time undergraduate program for water management be justified. In the other cases the speciality of water management can be built on the background of hydraulic engineering, by some kind of postgraduate or continuing education.

Postgraduate education has the advantage of offering a complete program, usually up to two years duration. Such a program can be repeated annually or from time to time, according to the needs of the economy of the respective country. The postgraduate degree courses cannot cover, however, all the needs in water management education: they are necessarily restricted to the academically best students only, while many others actually being employed in water management also need further education. Therefore, in addition to postgraduate degree courses, other forms of continuing education are also very important.

The advantage of continuing education (other than by postgraduate academic studies) is its adaptability to the wide range of needs which arise from the specific features of water resources projects and the various backgrounds of the professionals engaged in them. Success of this kind of education depends on both the programs of the courses and the motivation of the participants.

The options of continuing education aiming at the target group of professionals fully employed in water management are manifold:

- courses of longer or medium duration at educational institutions, attended full time by the participants;
- short courses or seminars at educational institutions;
- seminars at the water management projects;
- on-the-job training with specially prepared programs.

The choice would depend on the respective authorites, or water management project. International assistance might be organized through the IHP, for instance, if requested.

The category of professionals occasionally involved in water resources management is vital for any water resources project in all stages of its development, especially in a socio-political environment where no separate institutions for water management on governmental level exist. It represents an important, but difficult target group of water management education. It is not likely that professionals who are only occasionally involved in water resources management would be willing to participate in a full course on water management; it is, however, very important that they learn how to communicate with the water resources engineers.

These professionals can best be approached by good textbooks, guides and manuals, specially adapted to the backgrounds of the different professions, with a minimum of professional jargon. They must be capable of transmitting the complexity of water resources management.

Aspects of water resources management could be reflected also in the postgraduate or continuing educational courses of the various professions, in the form of specially introduced subjects or parts of subjects.

Finally, seminars and short courses could be designed for the same purpose, tailor-made to fit the very different requirements, and well advertised so that they will attract the interest of the relevant people.

The category of planners and policy analysts involved in water management can probably best be reached with well prepared information on case studies pointing out the various interactions between general planning and water management. This information can be imparted through a number of different ways, including papers published in periodicals or reported at conferences; by public lectures organized through professional societies, etc.

The education of policy and decision-makers in water management matters can hardly be the subject of any form of continuing education. It is, however, of utter importance to increase the awareness of this target group about the many facets of water management. This difficult task is relegated to the water resources engineers presenting their cases to the decision and policy making bodies. These presentations have to be well argued, devoid of professional jargon and should contain the right amount of information: enough to grasp the problem but without distracting the attention with too many details.

The skill of communicating with the decision-makers, which in addition to some general principles should be specific for each socio-economic and political environment, is an important but often neglected subject of the education of professionals in water resources management.

Of similar importance is the communication with the general public - the ultimate users of the water management projects. Instead of pretending to educate the laypeople in water problems, the specialists in water management need to educate themselves in how to approach the public, how to explain the principles and actual problems of water management, how to ensure that the projects are approved and accepted by those whose lives are affected by them (Unesco 1987b), and how to listen to the public.

3.4 Alternatives for gaining water management education

In view of the possible approaches to the different target groups of education in water management, several alternatives can be envisaged:

(a) Complete undergraduate training as a professional water resources engineer

As already discussed, this pattern can be followed primarily only in a socio-economical environment which could offer sufficient jobs for full employment of specialists in water resources management. In all other situations, postgraduate and/or continuing education for water resources professionals is preferable.

(b) Post graduate programs for the training of various categories of professionals engaged in water resources management. The objective of such programs is to train highly qualified professional personnel, fully employed in water resources management and eligible for postgraduate degree courses.

The most important aspect of such programs is their variability, respecting the needs in the specific circumstances, which in turn depend on the nature of the water resources projects, the socio-economic environment, the educational background of the target groups in question, etc.

(c) Continuing education for the training of professional personnel in water resources management.

Since postgraduate training cannot cover all the needs of supplementary education of fully employed water resources professional personnel, various patterns of continuing education are essential. These can take the form of longer (up to two years) academic courses organized at universities, research centers or governmental institutions; seminars and refresher courses on selected topics; on-the-job training organized by the project, for selected personnel.

Roving seminars, organized by competent experts and adapted to the specific needs of different regions are particularly well suited to water resources management projects in developing countries.

(d) Units of courses as parts of modular systems addressed to specific categories of professionals.

Since water resources management has many aspects of interest to engineering and non-engineering professionals, a very flexible way of academic education can be developed by combining units of courses into personally tailored programs, following some accepted pattern. This would enable students of various backgrounds to acquire the necessary knowledge and skills for professional activity in water resources management.

A similar pattern can be recommended for the postgraduate and continuing education of professionals who only occasionally take part in water resources management.

(e) Continuing education for senior personnel in water resources management.

Managers and other senior personnel in water resources management, who may have very different professional backgrounds, need specific approaches of well planned refresher courses and seminars, which must be different from those offered for the education of younger specialists. Such courses or seminars must be problem oriented and adjusted to the special needs of the projects in question, they can be run in a rather informal way - through round table or panel discussions and workshops on selected subjects, with an active involvement of the participants.

(f) Continuing education for professionals, partly or occasionally involved in water resources management.

Short courses, seminars and lectures on selected topics may be the principal forms of this activity, adjusted to the professional activities of the target groups. Opportunities like symposia and conferences of professional associations could be used for such purposes. Likewise, workshops and round table discussions organized by water management projects or institutions interested in the upgrading of the knowledge of the non-specialists involved in water resources management can be used.

(g) Practical training in a water-related enterprise, preferably after some kind of formal theoretical training.

Young professional personnel or senior personnel may wish to gain technological or managerial experience through a structured on-the-job training in an enterprise more advanced than their own. If there is no language barrier, such practical training could be organized in another country with supervision of an educational institute in the host country.

(h) Communication with the general public.

Contacts between water resources specialists and the general public have an important role in increasing the awareness and understanding of water management problems of the public at large, which is the ultimate beneficiary of water resources development and the victim of possible mismanagement. The professionals, likewise have an obligation to "hear" what the public is saying. Mass media - the press, TV, radio, educational films, popular lectures, books and brochures are the conventional means of communicating with the public (Unesco, 1986c, Unesco 1987b).

The success of this important activity calls for a cooperation between water resources specialists and professionals of mass media. A prompt reaction is often essential (e.g. pollution hazards, floods, water shortages, etc.), because whenever water related problems become acute in a region, an interested public will always be ready to listen.

4

PRESENT STATE OF EDUCATIONAL PROGRAMMES (ANALYSIS OF A QUESTIONNAIRE ABOUT PROGRAMMES AND COURSES RELATED TO THE INTEGRATED PLANNING AND MANAGEMENT OF WATER RESOURCES)

4.1 Introduction

The aim of the action was to get the state-of-the-art in the field of education in integrated planning and management of water resources. There was a special interest in the topics of education in this field. Unfortunately the contents of 40% of the questionnaires were not usable in this sense.

Some of the main reasons are

1. Some of the universities, which were asked to fill in the questionnaire have no programs or courses in this field of education.

2. At some universities the contents of water-related courses are very much specialized for the main targets of education. For example in the syllabi for civil engineering, mining, agriculture, geology or construction one will often find courses in hydrology. In most of these cases it is not justified to speak of education in integrated planning and management of water resources.

Other problems resulted from misinterpretation of the questionnaire. Sometimes only a few details were mentioned for programs with a duration of 4 or 5 years. In other cases complete information was given about courses of 4 or 6 weeks duration.

As a result the relative information about education in planning and management of water resources shows special emphasis on the selection of subjects. The numerical analysis of the questionnaire has only a relative validity as a result of the heterogeneous information which have been used because the input was not representative.

4.2 Analysis of the questionnaire

Total number of questionnaires : 126
Quota of usable questionnaires : 76 (60.3%)

4.2.1 Number and duration of programs for specialization in water resources planning and management

Total number: 43 (The program of the Technical University of Dresden, GDR, was worked into the analysis by the authors.)

(a) first degree : 20

duration (information by 17 institutions) : from 1 semester only until 5 years, in average 3.3 years, in 11 cases 4 years or more

(b) post-graduate : 35

(in some cases these are special programs to earn Master of Science or Doctor of Philosophy degrees.)

duration (information of 30 institutions) : from 6-8 weeks (training program of the University of Lund, Sweden) to 4 years; in most cases 1.5 years (M.Sc.) and 3 or 4 years (Ph.D.).

4.2.2 Number and duration of individual courses in water resources planning and management within other programs (only institutions which are not mentioned under 4.2.1)

Total number : 34

(a) first degree : 32

duration (information of 13 institutions) : from 24 hours until 5 years, in most cases 1 or 2 semesters

(b) post-graduate : 15

duration (information of 28 institutions) : from 3 days until 3 years, in most cases 1 semester

4.2.3 Analysis of Contents

The topics mentioned were classified under 43 keywords to facilitate the analysis. In this way the lists of topics, which were given in very different quality became comparable.

The five main groups of topics are:

basic knowledge
water supply and use
analysis and modelling
water resources planning
water management.

There are some frequency analyses in the following. But as mentioned in the preface, they are only relatively reliable since the input is quite heterogeneous. It should also be mentioned that the numbers of declared topics differ very much between developing and developed countries. This is a result of lack in brochures and copies of syllabi from developing countries. The numbers of topics mentioned in general are shown in Tables 1 and 2.

4.2.3.1 Analysis of Programmes

As Table 1 shows there are differences in the numbers of mentioned topics of programs from developing and developed countries. The reader should have in mind these differences in judging the conclusions.

The numerical analysis is displayed in Table 3.

In part of the syllabi dedicated to the imparting of BASIC KNOWLEDGE, the most favourable topics are:

hydrology (a part in 95% of all syllabi) and

hydraulics (a part in 65% of all syllabi)

In only one third of all programs are mentioned : hydogeology (or geology), law (including water law), economics, water quality (including water analysis) and statistics. Surprising is the small part of educational programs which contain meteorology (including climatology). In developing countries a bit more emphasis is given on imparting of knowledge in statistics than in developed countries but much less in water quality. The education in economics and law is stressed much more in developed countries than in developing countries. The imparting knowledge in informatics is only in few cases part of the syllabi.

The problem of WATER SUPPLY AND USE are only partially topics of the programs. Important are especially irrigation, drainage and water supply. Water treatment and waste water treatment are only mentioned in developed countries as parts of syllabi. The maintenance of equipments was not mentioned in any syllabus.

In the field of ANALYSIS AND MODELLING a special emphasis is given on stochastic or simulation models (in one third of all programs). In developing countries the utilization and developing of models for groundwater, surface water and water quality is not commonly a part of an educational program as it is in the developed countries. In both groups the problems of erosion and sedimentation are relatively emphasized. Not mentioned in syllabi were the problems of remote sensing.

The problems of WATER RESOURCE PLANNING are contained in 45% of the syllabi of developing countries, but only in 36% of the developed countries. Much more highly stressed in developed countries are the questions of water policy in education especially in the USA. The problems of administration in the field of water resources planning and management are of secondary interest.

The imparting of knowledge in WATER MANAGEMENT is the concern in 30% of all syllabi. But in developed countries most emphasis is given on water quality management. In developing countries there is no special emphasis in this field.

Table 1: Number of Topics, mentioned in PROGRAMMES (Average of topics per syllabus

Developed Countries (19 institutions)

Basic knowledge	:	7	Water Supply and Use	:	3
Analysis and Modelling	:	3	Water Resources Planning	:	2
Water Management and Engineering	:	3			
Total	:	18			

Developing countries (24 Institutions)

Basic knowledge	:	5	Water Supply and Use	:	2
Analysis and Modelling	:	2	Water Resources Planning	:	1
Water Management and Engineering	:	2			
Total	:	12			

All countries (43 Institutions)

Basic knowledge	:	6	Water Supply and Use	:	2
Analysis and Modelling	:	3	Water Resources Planning	:	2
Water Management and Engineering	:	3			
Total	:	16			

CONCLUSION : The most obvious differences between the syllabi of developed and developing countries are imparting of knowledge in the fields of water quality and social sciences. Especially there seems to be a lack in such topics as law, economics and water policy in developing countries.

Table 2: Number of Topics, mentioned in COURSES (average of topics per syllabus)

Developed Countries (7 institutions)

Basic knowledge	:	3	Water Supply and Use	:	2
Analysis and Modelling	:	2	Water Resources Planning	:	1
Water Management and Engineering	:	2			
Total	:	10			

Developing countries (27 Institutions)

Basic knowledge	:	3	Water Supply and Use	:	2
Analysis and Modelling	:	1	Water Resources Planning	:	1
Water Management and Engineering	:	1			
Total	:	8			

All countries (34 Institutions)

Basic knowledge	:	3	Water Supply and Use	:	2
Analysis and Modelling	:	2	Water Resources Planning	:	1
Water Management and Engineering	:	1			
Total	:	8			

Table 3: Analysis of PROGRAMMES

Topics	(1)	(2)	(3)	(4)	(5)	(6)
Basic knowledge						
hydraulics	28	65 %	14	58 %	14	73 %
hydrology	41	95 %	23	95 %	18	94 %
meteorology	11	25 %	3	12 %	8	42 %
soil physics	7	16 %	2	8 %	5	26 %
hydrogeology	16	37 %	6	25 %	10	52 %
law	13	30 %	4	16 %	9	47 %
economics	16	37 %	5	20 %	11	57 %
water quality	16	37 %	3	12 %	13	68 %
mathematics	3	6 %	1	4 %	2	10 %
statistics	13	30 %	9	37 %	4	21 %
optimization	10	23 %	6	25 %	4	21 %
informatics	8	18 %	4	16 %	4	21 %
Water Supply and Use						
water use	7	16 %	3	12 %	4	21 %
industrial use	2	4 %	0	0 %	2	10 %
municipal use	3	6 %	1	4 %	2	10 %
irrigation and drainage	17	39 %	10	41 %	7	36 %
water power	4	9 %	3	12 %	1	5 %
navigation	0	0 %	0	0 %	0	0 %
water supply	10	23 %	5	20 %	5	26 %
water treatment	8	18 %	1	4 %	7	36 %
waste water (incl.treatment)	7	16 %	2	8 %	5	26 %
water & waste water networks	7	16 %	3	12 %	4	21 %
Analysis and Modelling						
stochastic hydrology	12	27 %	7	29 %	5	26 %
simulation models	13	30 %	6	25 %	7	36 %
hydrological models	7	16 %	3	12 %	4	21 %
groundwater models	7	16 %	2	8 %	5	26 %
water quality models	5	11 %	0	0 %	5	26 %
erosion and sedimentation	12	27 %	6	25 %	6	31 %
Water Resources Planning						
water resources planning	18	41 %	11	45 %	7	36 %
decision-making	3	6 %	1	4 %	2	10 %
risk and uncertainty	3	6 %	2	8 %	1	5 %
planning models	2	4 %	0	0 %	2	10 %

	(1)	(2)	(3)	(4)	(5)	(6)
water resources system design and project planning	9	20 %	4	16 %	5	26 %
water policy	6	13 %	1	4 %	5	26 %
administration	5	11 %	2	8 %	3	15 %
infrastructure	1	2 %	0	0 %	1	5 %
regional planning	2	4 %	0	0 %	2	10 %
Water Management						
water management	13	30 %	7	29 %	6	31 %
watershed management	3	6 %	3	12 %	0	0 %
groundwater management	4	9 %	3	12 %	1	5 %
water quality management	10	23 %	3	12 %	7	36 %

Explanation of the columns :
(1) numbers of syllabi, where this topic is noted
(2) as in (1), but in percentage of all syllabi
(3) as in (1), but for developing countries only
(4) as in (2), but for developing countries only
(5) as in (1), but for developed countries only
(6) as in (2), but for developed countries only.

4.2.3.2 Analysis of Courses

The analysis of courses (Table 4) shows essentially the same results as the analysis of programs.

The imparting BASIC KNOWLEDGE in developing countries includes more statistics but less economics than in developed countries. The problems of WATER SUPPLY AND USE are very much oriented on irrigation and drainage. The industrial and municipal utilization of water has no great emphasis in the syllabi of the courses.

The ANALYSIS AND MODELLING of elements of the water cycle is in developing countries not an integral part of courses in water management. In developed countries special emphasis is given on groundwater models.

The problems of WATER RESOURCES PLANNING are very seldom part of the syllabi. Also topics which are relevant to WATER MANAGEMENT are not included in the analysed courses.

CONCLUSION : Courses in water management have the main objective of giving a survey of the basic knowledge, especially in the fields of hydrology and hydraulics. In developed countries the utilization and development of models is also in many cases an item of the syllabi. Less common topics in developing countries are water resources planning and water management. In developed countries such topics are sometimes included, but not in great detail.

Table 4: Analysis of COURSES

Topics	(1)	(2)	(3)	(4)	(5)	(6)
Basic knowledge						
hydraulics	18	52 %	16	59 %	2	28 %
hydrology	26	76 %	20	74 %	6	85 %
meteorology	2	5 %	1	3 %	1	14 %
soil physics	1	2 %	0	0 %	1	14 %
hydrogeology	3	8 %	3	11 %	0	0 %
law	3	8 %	2	7 %	1	14 %
economics	7	20 %	4	14 %	3	42 %
water quality	7	20 %	4	14 %	3	42 %
mathematics	2	5 %	2	7 %	0	0 %
statistics	5	14 %	5	18 %	0	0 %
optimization	4	11 %	3	11 %	1	14 %
informatics	1	2 %	1	3 %	0	0 %
Water Supply and Use						
water use	4	11 %	3	11 %	1	14 %
industrial use	0	0 %	0	0 %	0	0 %
municipal use	0	0 %	0	0 %	0	0 %
irrigation and drainage	15	44 %	12	44 %	3	42 %
water power	3	8 %	3	11 %	0	0 %
navigation	0	0 %	0	0 %	0	0 %
water supply	6	17 %	5	18 %	1	14 %
water treatment	2	5 %	2	7 %	0	0 %
waste water (incl.treatment)	2	5 %	2	7 %	0	0 %
water & waste water networks	2	5 %	2	7 %	0	0 %
Analysis and Modelling						
stochastic hydrology	5	14 %	2	7 %	3	42 %
simulation models	4	11 %	3	11 %	1	14 %
hydrological models	5	14 %	2	7 %	3	42 %
groundwater models	5	14 %	3	11 %	2	28 %
water quality models	1	2 %	1	3 %	0	0 %
erosion and sedimentation	3	8 %	1	3 %	2	28 %
Water Resources Planning						
water resources planning	6	17 %	4	14 %	2	28 %
decision-making	0	0 %	0	0 %	0	0 %
risk and uncertainty	2	5 %	2	7.%	0	0 %
planning models	0	0 %	0	0 %	0	0 %

	(1)	(2)	(3)	(4)	(5)	(6)
water resources system design and project planning	3	8 %	2	7 %	1	14 %
water policy	1	2 %	0	0 %	1	14 %
administration	1	2 %	0	0 %	1	14 %
infrastructure	0	0 %	0	0 %	0	0 %
regional planning	2	5 %	2	7 %	0	0 %
Water Management						
water management	4	11 %	4	14 %	0	0 %
watershed management	1	2 %	0	0 %	1	14%
groundwater management	0	0 %	0	0 %	0	0 %
water quality management	1	2 %	1	3 %	0	0 %

explanation of the columns :
(1) numbers of syllabi, where this topic is noted
(2) as in (1), but in percentage of all syllabi
(3) as in (1), but for developing countries only
(4) as in (2), but for developing countries only
(5) as in (1), but for developed countries only
(6) as in (2), but for developed countries only.

4.3 Comparison of Syllabi of Selected Programmes

In Annex D are displayed syllabi of programs of a few selected developed and developing countries. Typical for these programs are the range of topics in the field of basic knowledge, which is wider than in developed countries. Especially such topics as statistics, optimization and informatics are integrated. These topics seem to be selected in respect of an educational background of the participants, which is not as comprehensive as that in developed countries. On the other hand such topics as law or economics are not so common in the syllabi of the developing countries (an exception is the syllabus of the Karnataka Regional Engineering College, India).

The problems of water supply and use are not given great emphasis in the developing country syllabi as they are in developed countries (an exception is the syllabi of the University of Nairobi, Kenya). Surprising is the lack of topics which are relevant to water quality problems in educational programs from developing countries. With regards to the problems in the supply of the third world with drinking water in sufficient quality there seems to be a backlog of demand in these countries. On the other hand the technical problems of water supply are part of syllabi from both groups of countries. In the imparting of knowledge in the field of industrial water use, waste water and water treatment are contained in programs of developed countries only. Water power utilization and irrigation or drainage are parts of most syllabi.

5

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Annex A

TOPICS FOR EDUCATION IN WATER RESOURCES MANAGEMENT

A.1 Economics

1. Financial analysis, financing water projects
2. Production function and costs
3. Benefit/cost analysis
4. Evaluation of natural resources
5. Welfare economics, equity issues, economic incentives for improved management
6. Fees, charges, penalty system
7. Social rate of discount
8. Dealing with uncertainty and risk, trade-offs between benefit, cost, technology and risk/uncertainty
9. Methodologies for evaluation of water resources plans and projects

A.2 Social/Cultural Sciences

1. Policy sciences
2. Labour sciences (organizational and personal sciences)
3. Psychology
4. Administration and management, communication
5. Social and cultural considerations of water resources management

A.3 Law

1. Common Law (legal systems, land use law)
2. Basic concepts of water law (riparian, first-in-time, upstream-downstream, permits and licenses)
3. Water law of the country and its affect on policies and strategies
4. International aspects (fundamentals of roman, chinese, hindi, buddhist, moslem, socialist water laws)

A.4 Mathematical methods

1. Analytical and numerical analysis
2. Numerical differentiation and integration
3. Analytical geometry
4. Solution of simultaneous linear equations
5. Finding roots of non-linear equations
6. Solution of simultaneous non-linear equations
7. Numerical solution of differential equations
8. Numerical solution of partial-differential equations
9. State- spade modelling

A.5 Statistics

1. Probability theory
2. Probability distributions
3. Likelihood, hypothesis testing
4. Regression and correlation
5. Data collection and analysis
6. Time series analysis
7. Synthetic data generation
8. Use of computer package

A.6 Optimization

1. Definitions, basic concepts, components of an optimization problem
2. Classification by application and by method
3. Linear programming
4. Non-linear programming
5. Dynamic programming, deterministic and stochastic
6. Use of ready-made programs and packages
7. Stochastic programming

A.7 Simulation

1. General description
2. Deterministic
3. Stochastic
4. Design and implemention of simulation experiments

A.8 Decision support

1. Multiobjective decision-making: the discrete and continuous cases
2. Game theory and negotiations
3. Decision support systems
4. Expert systems

A.9 Natural sciences

1. Physics
2. Chemistry
3. Biology

A.10 Geosciences

1. Meteorology, Climatology
2. Hydrometeorology (Precipitation, Evaporation, Transpiration)
3. Geology
4. Hydrogeology
5. Soil science
6. Geomorphology, including erosion and sedimentation
7. Site science

A.11 Ecology and ecotechnology

1. Ecosystem analysis (stability, equilibrium, feed-back mechanism, self-regulation, ecological models)
2. Aquatic ecosystems (structures and main processes)
3. Ecotoxicology
4. Effects of water resources projects on flora, fauna, fish
5. Ecotechnology

A.12 Hydrology

1. General hydrology (water cycle, hydrological systems, processes and models)
2. Hydrometry (networks, measurements and data handling)
3. Surface waters (rivers, lakes reservoirs)
4. Groundwater
5. Geohydrology (infiltration, geofiltration, migration, soil-plant-atmosphere interaction)
6. Hydrological regimes - means flows, extreme events (floods, droughts)
7. Water balance computations in different scales
8. Operation hydrology (information systems, hydrological forecasting)
9. Urban hydrology
10. Agricultural hydrology

11. Forest hydrology
12. Regional (comparative) hydrology
13. Hydrological services

A.13 Informatics

1. General introduction to informatics (hardware, software)
2. A scientific programming language
3. Data management, data base programs
4. Graphic
5. Use of micro computers
6. Documentation and information retrieval
7. Use of data bases (GIS, hydrologic data bases)

A.14 Hydraulics

1. Hydraulics of structures
2. Flow in pipes
3. Open-channel flow, river hydraulics
4. Flood routing
5. Groundwater hydraulics
6. Sediment transport
7. Coastal hydraulics
8. Principles of similitude and theory of models

A.15 Hydraulic engineering

1. Hydraulic structures (dams, weirs, intake and outlet structures...)
2. Pumps and turbines
3. Hydropower generation
4. Abstraction techniques for surface water and groundwater
5. Water distribution networks
6. Irrigation and drainage
7. Urban drainage
8. River engineering
9. Coastal engineering

A.16 Surveying and photo-interpretation

1. Surveying
2. Aerial survey and remote sensing
3. Image processing and photo-interpretation

A.17 Water Demand and uses

1. Strategy of rational water use
2. Domestic water demand and use
3. Industrial water demand and use (process water, cooling water)
4. Agricultural water demand and use (irrigation technologies, planning and scheduling)
5. In-stream water demand and use (recreation, hydropower, navigation, self-purification)
6. Demand management: legislative and economic influences on the demand, technological changes, education, public appeal
7. Swimming, recreation, tourism
8. Nature preservation

A.18 Water quality

1. Composition of natural waters
2. Standards and criteria for various types of water uses
3. Natural processes effecting water quality
4. Man-made processes effecting water quality: point and non-point sources
5. Mechanisms of water pollution caused by water utilization (chemical, physical, biological)
6. Consequences of water pollution: saprobisation, eutrophication, contamination, infection, acidification
7. Principles of water quality control: legislative and economic measures, low waste and wasteless technologies, limitation of harmful matter input, monitoring, protection, sanitation measures, damage combat
8. Water quality modlling

A.19 Water treatment

1. Unit processes
2. Treatment plant design
3. Treatment plant operation and maintenance
4. Waste materials and disposal

A.20 Sewage treatment

1. Classification of sewage for treatment
2. Unit processes
3. Treatment plant design
4. Treatment plant operation and maintenance
5. Effluent discharge into: rivers, lakes, sea, groundwater
6. Waste materials and disposal
7. Sewerage systems

A.21 Water resources planning and management

1. Policies and strategies for water resources development, conservation, control and protection
2. Methodologies for water resources assessment and predicition in different scales
3. Monitoring, protection and sanitation of water resources under different geographic and socio-economic conditions
4. Protection against floods and excess waters
5. Water resources information systems for different national infrastructures
6. Water resources systems analysis (socio-economic, natural, and water management systems, conceptual framework for the management of a project (space-, time-, aspect-, objective dimension and means)). Strategy of policy oriented interactive decision support model systems
7. Long-term planning of multi-structure, multi-purpose and multi-source water resources systems
8. Water resources management (long-term management modelling)
9. Real-time operation, control and maintenance of water management systems
10. Social and environmental impact studies (climatic vagaries, interaction of water systems with environment, effects of humans on environment)
11. Regional water projects (industrial, agricultural, mining areas)
12. Capacity expansion (e.g. of treatment facilities, reservoir systems)
13. Reservoir capacity planning
14. Design and operation of water distribution systems
15. Groundwater management models (quantity and quality)
16. Conjunctive use of surface and groundwater and abstraction techniques
17. Project selection process taking into account political, economic, social, cultural aspects
18. Institutional frameworks and public participation
19. Integration of water planning into land-use planning and total national plans

Annex B

SAMPLE COURSE STRUCTURES BASED ON BACKGROUND OF THE TARGET AUDIENCE

A model curriculum for courses in hydrology and water resources has been proposed in Unesco 1988a taking into account about twenty years of experience with Unesco-sponsored post-graduate hydrology courses.

The following sample course structures, more or less based on the background of the target audience, are guidelines. In a specific environment, it will be necessary to detail the prerequisites or corequisites for each topic. The introduction of credit-units for each topic would allow for a flexibility with respect to the student's background. Course contents could also be characterized by the following labels:

INTRODUCTORY (ID):	i.e. a course content for students who never had such a course of the given topic;
INTERMEDIATE (IM):	i.e. a course content for students who have had an ID-course of the given topic;
ADVANCED (AD):	i.e. a course content for students who have had an IM-course of the given topic

For more details on credit-units and labels see: Van der Beken, 1988.

B-1. A 7-week course for university graduates in fields of engineering other than water resources, and in other fields who want to switch to water resources management.

(a) *Prerequisites*

A university degree in fields such as mechanical engineering, electrical engineering technology, economy, geodesy.

(b) *Duration*

7 weeks x 30 hours/week = 210 hours.

(c) *Format*

Classroom work only, lectures and exercises

(d) *Course content*

Topic (Annex A)	Hours
1-1, 1-2, 1-3, 1-5	20
2-5	10
3-3	20
6-1, 6-2	10
7-1, 7-3	10
8-1, 8-2	30
11-1, 11-4	20
12-1, 12-4, 12-5	30
13-1	10
17-1, 17-2, 17-3, 17-6, 17-7, 17-8	30
18-2, 18-5, 18-6	20
	210

B-2. A 7-week course for university graduates in various fields, who are in charge of water resources analysis work and water resources management.

(a) *Prerequisites*

A university degree in civil engineering, technology, hydrology, chemistry, biology, geography, agriculture, economy.

(b) *Duration*

7 weeks x 30 hours/week = 210 hours.

(c) *Format*

Classroom work, lectures and exercises

(d) *Course content*

Topic	Hours
1-4, 1-7, 1-8, 1-9	20
2-4, 2-5	8
4-8, 4-9	10
5-6, 5-7, 5-8	12
6-5, 6-6, 6-7	20
7-4	6
8-3, 8-4	14
12-7	10
13-3, 13-4, 13-7	20
17-1, 17-6, 17-8	20
18-7	20
21-1, 21-6, 21-7, 21-8, 21-10	30
21-11, 21-19	20
	210

B-3. A 7-week course for university graduates in fields such as geography, regional planning, political sciences, economics, social sciences.

(a) *Prerequisites*

A university degree in fields such as geography, regional planning politcal sciences, economics, social sciences.

(b) *Duration*

7 weeks x 30 hours/week = 210 hours.

(c) *Format*

Classroom work, lectures and exercises

(d) *Course content*

Topic	Hours	
1-1, 1-2, 1-3, 1-6	20	
2-5	10	
3-3	20	
4-1, 4-2, 4-3, 4-4	20	
5-1, 5-2, 5-4, 5-5	20	
6-1, 6-2, 6-3	15	8-1,
8-2	10	
9-1, 9-2, 9-3	30	
12-1	10	
13-1	10	
17-1, 17-2, 17-3, 17-4	20	
18-1, 18-2	10	
21-1, 21-6	15	
	210	

B-4. An 18-month course leading to an MSc degree in water resources management

(a) *Prerequisites*

A university degree in engineering: civil, agriculture, mechanical

(b) *Duration*

3 semesters, each 13-14 weeks long, each week 25-30 class hours

(c) *Format*

Lectures, exercises, final project/paper

(d) *Programme*

1st Semester:	5 courses
	Topic 13 Topic 1 Topic 4 Topic 5 Topic 10
2nd Semester:	4 courses
	Topic 12 Topic 6 + 7 Topic 11 Topic 21
3rd Semester:	3 courses + Final Project/paper
	Topic 17 Topic 18 Topic 19 + 20 Final Project/paper

Annex C

TEXTBOOKS ON PLANNING AND MANAGEMENT OF WATER RESOURCES

Buras, N. 1972. *The Scientific Allocation of Water Resources.* Elsevier, New York/Amsterdam.

Burke III, R,; J.P. Heaney, 1975. *Collective Decision Making in Water Resources Planning.* Lexington Books, D.C. Heath and Comp., Lexington.

Cohon, J.L. 1978. *Multiobjective Programming and Planning.* Academic Press, New York.

Cunha, L.V.; V.A. Figueiredo; M.O. Correira; A.S. Goncalves. 1977. *Management and Law for Water Resources.* Water Resources Publ. Fort Collins, Colorado, USA.

Gittinger, J.P. 1982. *Economic Analysis of Agricultural Projects , Second Ed.,* The Johns Hopkins University Press Baltimore and London.

Goicoechea, A.; D. Hansen and L. Duckstein. 1982. *Introduction to Multiobjective Analysis with Engineering and Business Application.* Wiley, New York.

Goodman, A.S. 1984. *Principles of Water Resources Planning.* Prentice-Hall inc. Engelwood Cliffs, New Jersey.

Grigg, N.S. 1985. *Water Resources Planning.* McGraw-Hill Book Comp. New York.

Haimes, Y.Y.; D.J. Allee (eds). 1984 *Multiobjective Analysis in Water Resources.* American Society of Civil Engineers, New York.

Haimes, Y.Y. 1977. *Hierarchical Analysis of Water Resources Systems: Modelling and Optimization of Large-scale Systems.* McGraw-Hill, New York.

Haimes, Y.Y. (ed). 1981. *Risk-Benefit Analysis in Water Resources Planning and Management.* Plenum, New York and London.

Haimes, Y.Y.; W.A. Hall; H. Freedman. 1975. *Multiobjective Optimization in Water Resources Systems: The Surrogate Worth Trade-off Method.* Elsevier, Amsterdam.

Hall, W.A.; J. Dracup. 1969. *Water Resources Systems Engineering.* McGraw-Hill, New York.

Helweg, O.J. 1985. *Water Resources Planning and Management.* John Wiley & Sons, New York.

Howe, C.W. 1971. *Benefit-Cost Analysis for Water System Planning. Water Resources Monograph 2.* Americ. Geophys. Union, Washington D.C.

Hufmschmidt, M.M.; M.B. Fiering. 1966. *Simulation Techniques for Design of Water Resources Systems.* Havard Univ. Press, Cambridge, Massachusetts.

James, L.C.; R.R. Lee. 1971. *Economics of Water Resources Planning.* McGraw-Hill Book Co. New York.

Kindler, J.; C.S. Russell, in collaboration with B.T. Bower, I. Gouevsky, B.R.Maidment and R.W.T. Sewell (eds). 1984. *Modelling Water Demands.* Academic Press, London.

Kuiper, E. 1971. *Water Resources Project Economics,* Butterworths, London.

Loucks, D.P.; J.R. Stedinger; D.A. Haith. 1981. *Water Resources Systems Planning and Analysis.* Prentice Hall, Englewood Cliffs. NJ.

Loucks. D.P.; J.R. Stedinger; U. Shamir. 1984. *Research in Water Resources and Environmental Policy Modelling: Some historical perspectives, current issues, and future directions.* Natural Resources Forum. Vol. 8, No. 3.

Maass, A. et. al. 1962. *Design of Water Resource Systems.* Havard Univ. Press, Cambridge, Mass.

Major, D.C. 1977. *Multiobjective Water Resources Planning, Water Resources Monograph No. 4.* American Geophysical Union, Washington, D.C.

Thorn, R.B. (ed) et. al. 1966. *River Engineering and Water Conservations Works.* Butterwork, London.

Thrall, R.M. et. al. (eds). 1976. *Economic Modelling for Water Policy Evaluation.* North-Holland/American Elsevier.

Viessman, Jr. W.; C. Welty. 1985. *Water Management,* McGraw-Hill, New York.

Wiener, A. 1972. *The Role of Water in Development.* McGraw-Hill, New York.

Yaron, D.; C. Tapiero, (eds). 1980. *Operations Research in Agriculture and Water Resources.* North-Holland Publ. Co.

Annex D

EXAMPLE OF UNDERGRADUATE AND GRADUATE COURSES IN WATER RESOURCES MANAGEMENT

D.1 Country: INDIA

Institution: KARNATAKA REGIONAL ENGINEERING COLLEGE

Kind of Programme:

post-graduate duration: 18 months

BASIC KNOWLEDGE

fluid mechanics
open channel hydraulics
hydrology
groundwater hydrology
meteorology
hydrogeology
water laws
economics
statistics
optimization
informatics

WATER SUPPLY AND USE

water supply

ANALYSIS AND MODELLING

hydrometrics
water balance elements
stochastic hydrology
hydrological models
groundwater models
erosion and sedimentation
water resource systems analysis

WATER RESOURCES PLANNING

water resources planning
decision-making
risk and uncertainty
water resource project planning

WATER MANAGEMENT AND ENGINEERING

groundwater engineering
irrigation engineering
water power engineering
systems engineering
groundwater management
flood control

D.2 Country: KENYA

Institution: UNIVERSITY OF NAIROBI

Kind of Programme:

first degree	duration: 1 course
post-graduate	duration: 2 years

BASIC KNOWLEDGE

hydraulics
fluid mechanics
hydrology
water balance
economics
statistics
optimization

WATER SUPPLY AND USE

water use
irrigation and drainage
recreation
fishery
water power
multiple use
water supply

ANALYSIS AND MODELLING

hydrometrics
time series analysis
simulation models
modelling
rt - forecasting

WATER RESOURCES PLANNING

water resources planning
water policy
administration in planning and management

WATER MANAGEMENT AND ENGINEERING

water resources engineering
flood control

D.3 Country: TANZANIA

Institution: UNIVERSITY OF DAR-ES-SALAAM

Kind of Programme:

post-graduate duration: 18 months

BASIC KNOWLEDGE

hydraulics
fluid mechanics
open channel hydraulics
hydrology
groundwater hydrology
statistics
optimization
informatics
economic considerations

WATER SUPPLY AND USE

ANALYSIS AND MODELLING

water balance elements
stochastic hydrology
simulation models

WATER RESOURCES PLANNING

water resources planning
risk and uncertainty
environmental impact assessment

WATER MANAGEMENT AND ENGINEERING

water resources management
drought control
flood control

D.4 Country: UNITED STATES

Institution: COLORADO STATE UNIVERSITY

Kind of Programme:

post-graduate duration: ?

BASIC KNOWLEDGE

river mechanics
hydrology
groundwater hydrology
meteorology
water laws
economics
optimization

WATER SUPPLY AND USE

water use
irrigation and drainage
water power
water supply
waste water
design of urban drainage systems

ANALYSIS AND MODELLING

simulation models
groundwater models
rt - forecasting
erosion and sedimentation

WATER RESOURCES PLANNING

planning models
administration in planning and management
infrastructure
optimal sizing of multi-reservoir systems

WATER MANAGEMENT AND ENGINEERING

water resources engineering
irrigation engineering
flood control
systems engineering
water quality management

D.5 Country: UNITED STATES

Institution: UNIVERSITY OF TENNESSEE

Kind of Programme:

post-graduate duration: 2 years

BASIC KNOWLEDGE

open channel hydraulics
optimization
informatics

WATER SUPPLY AND USE

industrial use
municipal use
water treatment
sewage treatment
water and wastewater networks

ANALYSIS AND MODELLING

water balance elements
water analysis
stochastic hydrology
time series analysis
simulation models
modelling
hydrological models
groundwater models
water quality models
rt - forecasting
erosion and sedimentation

WATER RESOURCES PLANNING

water resources planning
water resource system design
decision-making
regional planning

WATER MANAGEMENT AND ENGINEERING

water resources engineering
water quality management
urban water management
flood control

D.6 Country: UNITED STATES

Institution: UNIVERSITY OF ILLINOIS

Kind of Programme:

first degree	duration: 4 years
post-graduate	duration: 2-5 years

BASIC KNOWLEDGE

hydraulics
hydrology
groundwater hydrology
meteorology
soil physics
hydrogeology
law
water quality
hydrobiology
optimization
ecology

WATER SUPPLY AND USE

water use
water treatment

ANALYSIS AND MODELLING

water quality models
erosion and sedimention
water resource systems analysis

WATER RESOURCES PLANNING

water resource systems design
decision-making
risk and uncertainty
water policy

WATER MANAGEMENT AND ENGINEERING

water resources engineering
irrigation engineering
flood control
systems engineering
water management
water quality management

D.7 Country: GERMAN DEMOCRATIC REPUBLIC

Institution: DRESDEN UNIVERSITY OF TECHNOLOGY

Kind of Programme:

first degree duration: 4 1/2 years

SOCIAL/CULTURAL SCIENCES

policy sciences
labour sciences
economics

LAW

GENERAL BASIC KNOWLEDGE

mathematics
informatics (computer sciences)
physics
chemistry
biology
geology

SPECIFIC BASIC KNOWLEDGE

meteorology
hydrology, hydrometry
hydraulics
soil sciences
water quality
hydrobiology
hydrochemistry
engineering and hydraulic constructions
soil mechanics and foundation engineering
surveying

WATER SUPPLY, USE AND TREATMENT

water demand and rational water use
water supply and water treatment
sewerage systems and sewage treatment

ANALYSIS AND MODELLING

water resource systems analysis
assessment of water resources
dynamics of subsurface water
hydrogeology
hydrological models, groundwater models

water quality models
stochastic methods, time series analysis
rt - forecasting

WATER RESOURCES PLANNING

water resources planning
water resources system design, including CAD
decision-making, risk and uncertainty

WATER MANAGEMENT AND ENGINEERING

water resources management, including CAM
monitoring and protection of water resources
real-time operation of water resources systems
irrigation and drainage
geohydrotechnology
flood control
water quality management