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Guidelines for conducting water resources assessment

A contribution to the
International Hydrological Programme
within Project M.1-1(a) (IHP-IV)

Prepared by

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UNESCO Publishing

Published in 1998 by the United Nations
Educational, Scientific and Cultural Organization
7, Place de Fontenoy, 75700 Paris

Printed by:
Imprimerie Jouve, Mayenne

ISBN 92-3-103476-6

Printed in France

Preface

Although the total amount of water on earth is generally assumed to have remained virtually constant, the rapid growth of population, together with the extension of irrigated agriculture and industrial development, are putting stress on the quality and quantity aspects of natural systems. Because of the increasing problems, society has begun to realise that it 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 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 world-wide 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 relevant national activities and to participate in regional and international co-operation within the IHD programme. The knowledge of the world's water resources had substantially improved. Hydrology became widely recognised as an independent professional option and facilities for the training 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 launched a new long-term intergovernmental programme in 1975: the International Hydrological Programme (IHP).

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 utilisation 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 documents in hydrology. In addition to these publications, a special International Hydrological Series is issued in co-operation with Cambridge University Press.

The purpose of the continuing series 'Studies and reports in hydrology', to which this volume belongs, is to present data collected and the main results of hydrological studies, as well as to provide information on hydrological research techniques. The proceedings of symposia are also sometimes included. It is hoped that these volumes will furnish material of both practical and theoretical interest to water resources scientists and also to those involved in water resources assessment and planning for rational water resources management.

Acknowledgements

The authors would like to express their thanks to all who have contributed to the production of this report, in particular to Dr Stevan Bruk who made valuable suggestions on an earlier draft and to Vida Marjanovic for her help in ensuring that the English was up to standard.

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1. Introduction and problem definition

1.1 Introduction

Water plays a global role in an enormous variety of ways. In its liquid and solid forms, for example, water is a powerful agent of topographical change. Water is also a solvent in many of the chemical reactions that weather rocks, and it acts as a mechanical agent in weathering through freeze-thaw temperature cycles.

It is an essential element for life on earth, playing a major role in climate regulation and in biogeochemical cycles. The movement of such key elements as carbon, nitrogen, phosphorous and oxygen through the earth system are mediated by water in both liquid and gaseous forms producing a basic unity of the fluid and biological earth.

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Water is the most important and most abundant substance on earth and yet it is also the most lacking resource needed for the survival of the human society as we know it today. Man takes away from nature approximately 100x10^{9} tonnes of different raw materials annually, but uses almost 4000x10^{9} tonnes of fresh water per year.

Water is also a key element in socio-economic development. While the total amount of available water resources remains more or less constant, the demand for water tends to increase with the growth of population and the development of industry and agriculture. It is not surprising that water is becoming a scarce resource in many regions of the world where once it used to be plentiful. Social and economic development now require people to start making major efforts to protect water and control its use and pollution.

In order for water scarcity not to hamper socio-economic development, it is essential for many countries to improve their water resources planning and management. A water resources plan, consistent with the overall economic, social and environmental policies of a country, is an important element which ensures that water resources contribute to the sustainable development objectives of that country.

In 1977 the Mar del Plata Action Plan, adopted by the United Nations Water Conference in Argentina, recommended the formulation of Water Resources Master Plans (WRMP) for countries and river basins. The objective was to provide a long-term perspective for the planning and management of available water resources. The conference suggested that planning should be considered as a continuous activity, recommending that long-term plans be revised and completed periodically, preferably once every five years.

Since the successful management and the rational and sustainable use of water resources require an adequate assessment of the quantity and quality of available resources, UNESCO and other UN agencies have prepared a number of documents, forming the basis for water resources assessment as is necessary for the development of WRMP. According to this literature, Water Resources Assessment (WRA) is "the determination of the sources, extent, dependability and quality of water resources, upon which is based an evaluation of the possibilities for their utilisation and control and long-term development". Given below are the most important documents which were used extensively in the preparation of this guide.

1. Water Resources Assessment Activities, Handbook for National Evaluation, (UNESCO/WMO, 1988).
2. *Guidelines for the Evaluation of Water Resources Assessment Programmes* based on the handbook for National Evaluation, (UNESCO/WMO, 1988).
3. *Guidelines for Water Resources Assessments of River Basins,* (UNESCO/WMO, 1990).
4. *Report on Water Resources Assessment,* Progress in the Implementation of the Mar del Plata Action Plan and a Strategy for the 1990s, (UNESCO/WMO, 1991).
5. *Methodological Guidelines for the Integrated Environmental Evaluation of Water Resources Development,* (UNESCO/UNEP, 1987).
6. *Water Balance of Europe,* (UNESCO, 1978).
7. *Guidelines for the Preparation of National Master Water Plans,* (UN-ESCAP, 1989).

1.2 Problem definition

WRA is of critical importance for the wise and sustainable management of water resources because (see reference 4 above):

- the world's expanding population is placing increasing demands on drinking water, food production, sanitation and other basic social and economic needs (see Figure 1), but the world's water resources are finite. The rising demand has already reached this limit in some areas and will be reached in many others within the next two decades. Should the present trends continue, the world's water resources will be fully utilised before the end of the next century;
- human activities are becoming increasingly intensive and diverse with an ever growing and more evident impact on natural resources, through depletion and pollution. This is particularly true for water, whose quality is for many purposes severely degraded from pollution by a wide range of chemicals, micro-organisms, radio-active materials and sediments, and by physical changes;
- water-related natural hazards are among the most destructive to human life and property and, as such, have been responsible for the death and widespread misery of countless millions during the course of history;

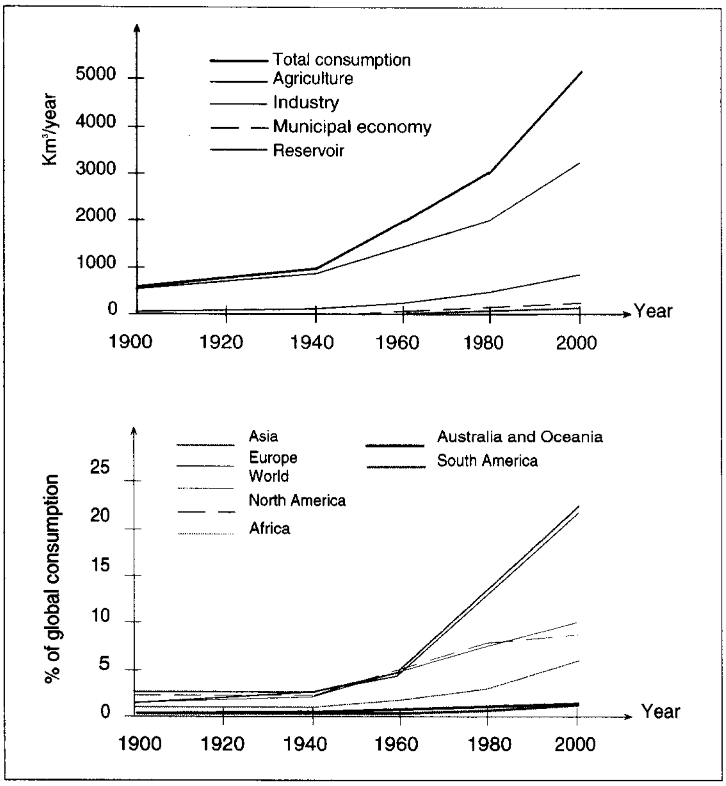


Figure 1. Increasing demand and consumption of water (after UNESCO/ WMO, 1991)

- there is growing awareness that the world's climate is not constant, and indeed may well be changing in response to human activity (see Figure 2). While the postulated rise in global temperature has been widely publicised, the more important effect is likely to be on the distribution of rainfall, runoff and ground water recharge. It cannot be assumed that the future patterns of these hydrological phenomena will continue to be as they have been in the past.

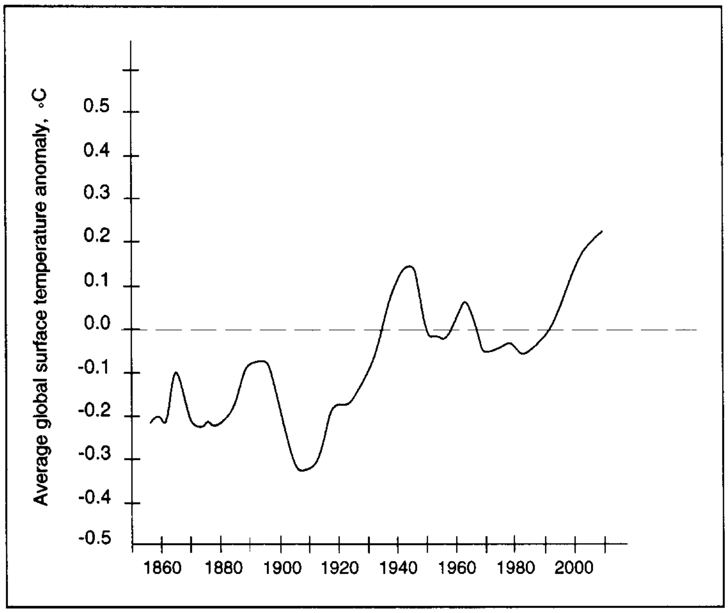


Figure 2. Global warming phenomena (1856-1989) (after UNESCO/ WMO, 1991)

It is obvious from all of the above that only with reliable and systematically-collected data concerning the status and trends of a water resource, including its quantity and quality, as well as statistics on major hydrological events and water use (for human activities), can there be sustainable and rational planning of water resources. Clearly WRA is a basic prerequisite for all aspects of water resources development, management and planning.

Figure 3 shows the components of the WRA programme as defined by the previously-mentioned publications and modified by the authors. The complex nature of the WRA programmes requires multidisciplinary work of many professionals. The methodology for conducting WRA programmes cannot be uniquely defined for every situation. However, because the water resources of any one country are not independent of those of another (with few exceptions), a degree of standardisation is necessary in WRA procedures for data collection, storage and retrieval.

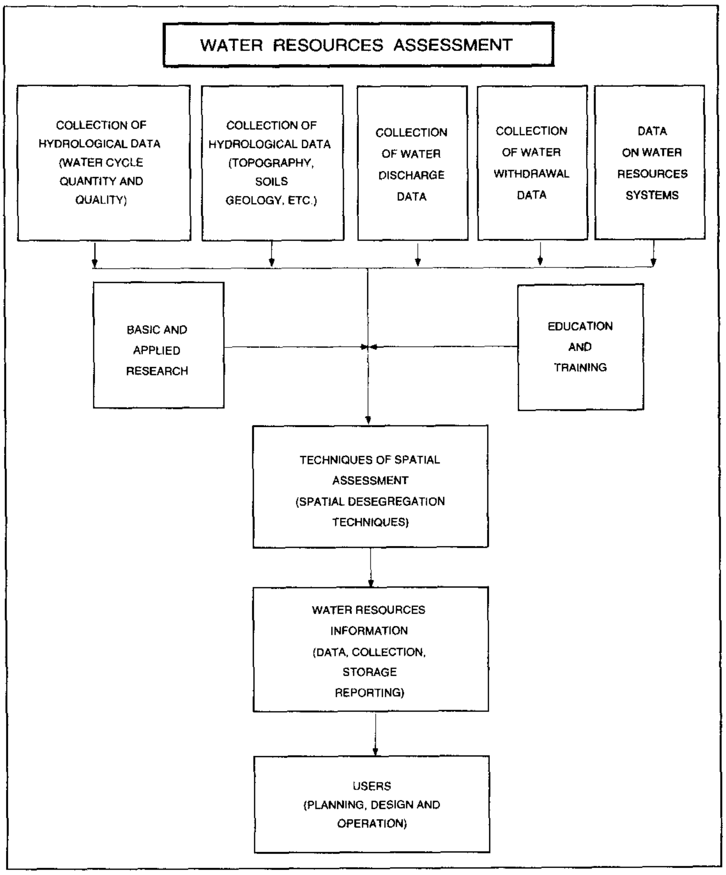


Figure 3. The process of water resources assessment

A great deal of work towards this end has already been completed by UNESCO and other UN agencies, and this guide has been produced as a further contribution to this goal. Readers should recognise that what follows is not a comprehensive evaluation of WRA procedures and methods, but rather a building block for such an evaluation. Most of the guide is devoted to a description of the methodology for the evaluation of water resources with respect to their quantity and quality, and their temporal and spatial variability, with substantial attention given to the evaluation of the comprehensive water resources management balance (a component of an integrated water resources assessment). In addition the guide outlines the procedures for collection, storage and retrieval of data required for assessing water resources. Together, these methods form the necessary conditions for the adequate preparation of WRMP and Environmental Evaluation System (EES) studies, and their periodic updating and revision.

A distinction should be made between the historical data used for planning and the current data used for day-to-day management of water resources. This guide covers both these aspects, but a discussion of data requirements necessary for day-to-day management is limited to data that can be and usually are used in water resources planning.

Readers are also asked to recognise that the background and expertise that went into producing this guide, cover only a part of the complex field of water resources and there may be some unintentional bias in the reported material. No doubt, most things can be done in more than one way. However, we believe that the material presented can serve as background material for the implementation of the methods for WRA studies in any place in the world. As do Godwin, Foxworthy and Vladimirov (1990), we suggest that after reading this guide, readers should use it on a "need to know" basis as shown in Figure 4. If further information on a specific subject is required, the reader should consult other literature and sources of relevant information and, in so doing, set the stage for better WRA and more-informed decision making.

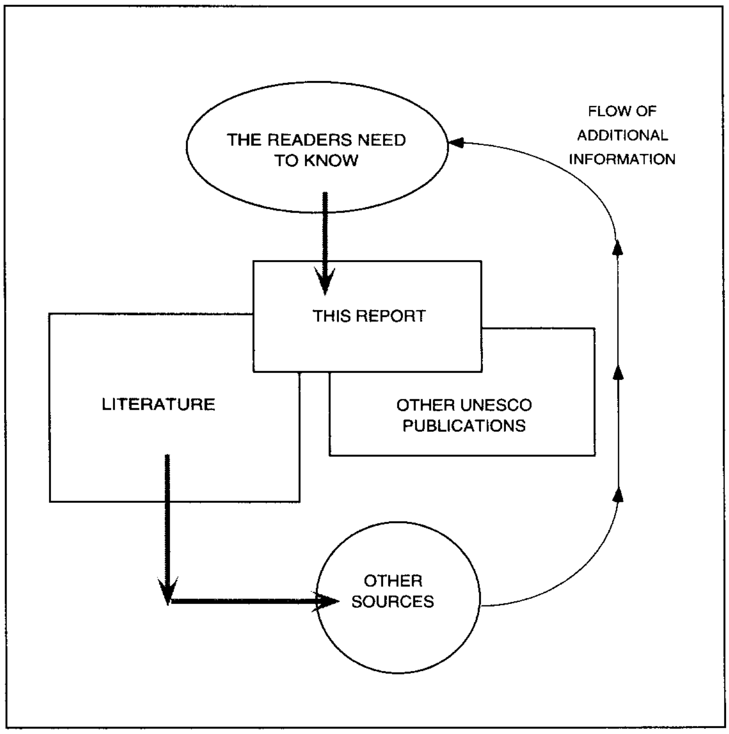


Figure 4. Getting information from different sources (after Godwin et al., 1989)

This guide first considers, in depth, the requirements for Water Resources Master Plans (WRMP) and Environmental Evaluation Studies (EES). After dealing with the general contents of WRMP and EES, both of which are based on the guidelines previously published by UNESCO, the guide then considers the spatial and temporal variability of the required data and the spatial and temporal scales of water resources planning and management. Based on this, the guide provides a definition for the territorial and temporal organisation of WRA data, its collection, storage and analysis. The second part is mostly technical and deals with the elements of water resources management balance and the collection, computation and evaluation of the required data. The final part of the report summarises the findings, touching on aspects of economic evaluation, and presents an integrated water resources management balance evaluation procedure which should be considered as the most important part of any WRA programme. The guidelines, methodologies and procedures presented in this report will be helpful in the development of effective water resources assessment for a wide range of hydrological conditions.

2. Water resources master plans, regulatory principles, data requirements and assessment needs

The primary goal of a national Water Resources Master Plan (WRMP) is to establish a basic framework for the orderly, sustainable and integrated planning, including management and implementation, of water resources programmes and projects. To meet this objective, a WRMP should (UN, 1989):

- Ensure the availability of water, adequate in quantity and quality, for all necessary uses.
- Develop a comprehensive and integrated approach to water resources and socio-economic development, particularly with respect to interrelated water, land management and environmental issues.
- Encourage the preparation and implementation of comprehensive long-term plans for the sustainable development and management of water resources.
- Formulate measures and/or water resources development projects which improve the efficiency of water supply and its use.
- Identify water resources problems and establish priorities for promising water resources development projects.
- Recommend the implementation of financial and economic policies which equitably distribute the costs of water supply and provide incentives for the most economic use of water resources, with due consideration for the social and environmental aspects of development.
- Contribute to the successful implementation of overall national socio-economic development plans which also include the water sector.
- Contribute to the formulation of long-term water policy for the country as a whole.

WRMP should also present the current status of development, make an assessment of water and related resources, look at the needs (both existing and future) for development and integrate these needs in accordance with the available potential resources. These are only some of the elements that the WRMP should contain. Readers are referred to the publications listed earlier for a more detailed discussion.

WRMP should generally cover a period of at least 20 years into the future. The UN recommended in 1979 that the 20-year period should be rolled over periodically, preferably every year, to account for changes such as advances in forecast technologies, in national development plans and their priorities and in database extensions coming on-line with time. Planning is a continuous process and WRMP should be reviewed and modified as its building blocks change and as the economy of a country develops. In view of all of this, WRMP and water resources planning and management today encompass the following:

- water regime regulation;
- qualitative and quantitative conservation of water;
- protection against the adverse impact of water; and
- the use of water in all forms of human activity.

A WRMP unites all the conditions for the assessment and planning of water resources and the demands placed on these resources. The procedure provides the means for rational use, comprehensive monitoring, effective protection, and conservation of water resources. It also anticipates long-term management and planning requirements for the efficient operation and rehabilitation of existing water resources systems and the prevention of damage caused by water. In each case, a WRMP acts in the interest of society and its sustainable development, taking into account the role of water in the development and regulation of local, regional and global environmental and biophysical processes. The main tasks of a Water Resources Master Plan (WRMP) are:

- the assessment and prediction of the quantity and quality of a surface and ground water resource and the evaluation of its availability;
- the planning of water resources development to protect them against depletion and pollution;
- the preparation, evaluation and selection of alternative solutions for water resources development and management;
- the assessment and planning of the demand by society on water resources; and
- the compilation of water balances, maintenance of their equilibria and development of a long-term strategy for the rational use of water resources.

Water resources planning follows a logical course of actions leading to the selection of the best acceptable project in response to an identified need. Because of the wide regional distribution of surface water and ground water resources, planning is always very broad in scope. Such planning considers and evaluates many different uses of water, a process that often requires trade-offs between conflicting objectives. Planning decisions are made at many different levels, ranging from national or international plans to regional and local projects, and involve experts such as politicians, lawyers and social scientists. People from these disciplines have expertise that is necessary for sufficient planning, however, coming from different backgrounds, they are often not familiar with water-related problems.

This is why the process of water resources planning must be considered as an interactive process (as shown in Figure 5). The process begins with the development of a national plan for economic development, requiring a specific project related to the use and protection of water and to the protection against water. Two further plans pertaining to the development of water resources are then required: a national plan, directly connected with the national plan for economic development which actually may be its integral part; and a regional plan, usually prepared for river basins where a certain water resource may be created and for which it is possible to work out a plan for development, use and protection of the resource in the basin.

The national Water Resources Master Plan and the River Basin Master Plan differ in the space they cover and in their relation to the national plan for economic development. There is really no essential difference between the two with respect to the data required and the approach used in development planning. Hence, a general approach is provided here for the development of a Water Resources Master Plan which can be applied to both cases.

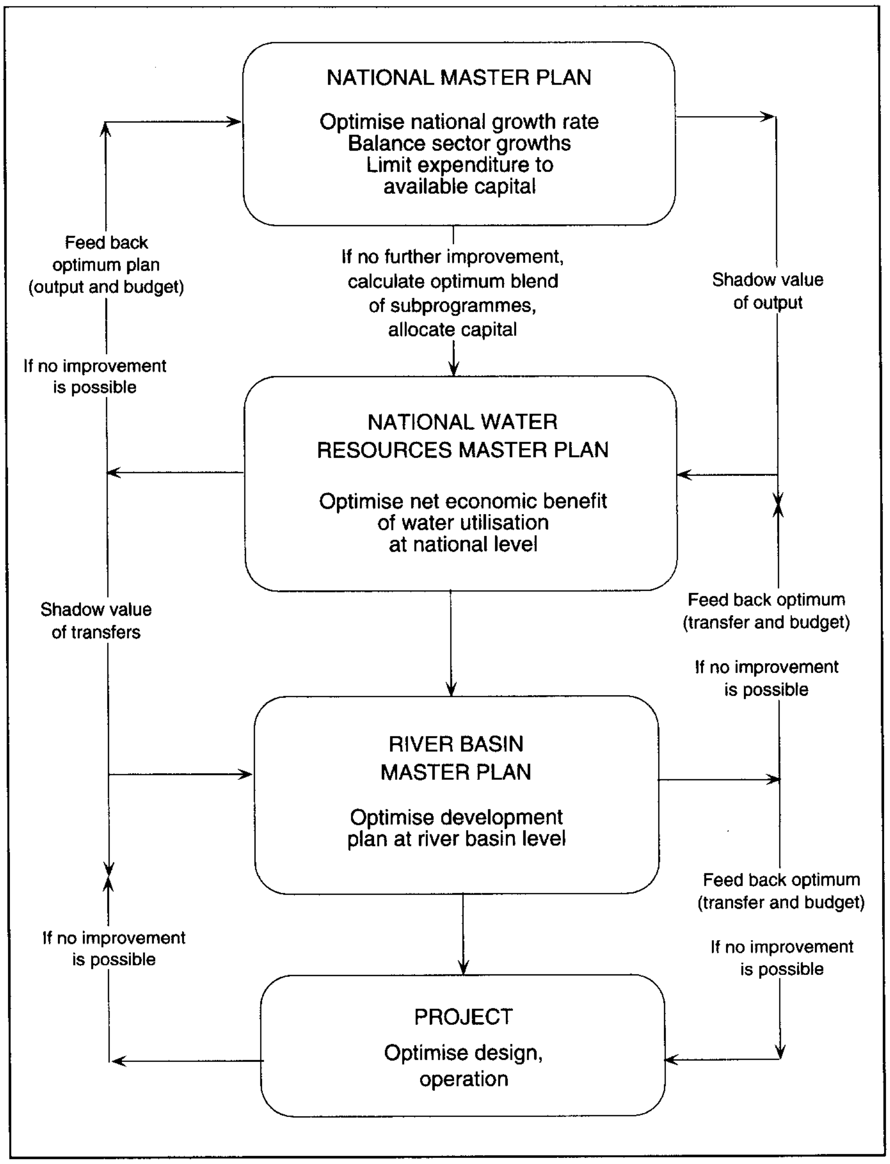


Figure 5. Water resources planning process

In preparing the plans it is most important to determine the most rational alternative enabling the transformation of available water resources, in terms of quantity and quality, into the required resource. Clearly it is essential to first identify tasks and objectives. Figure 6 represents the basic steps in the development of a plan, often involving very complex steps.

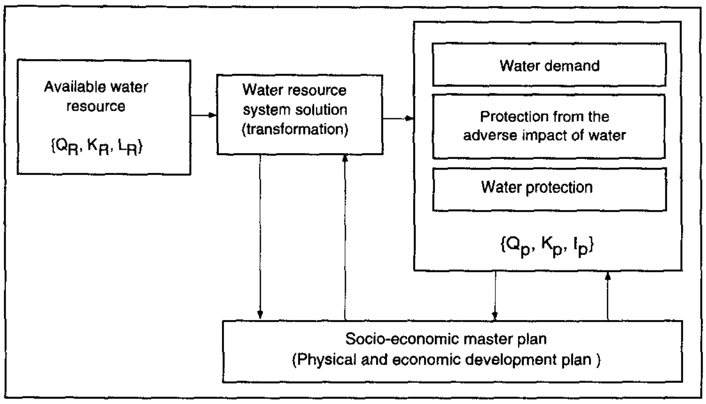


Figure 6. Objectives of water resources master plan

In developing the WRMP, a distinction should be made between the activity of planners and that of decision makers, while maintaining a close interaction between these two groups at all time. Figure 7 is a conceptual model of the planning process outlining the procedures that are operating during the development and use of water at a basin or at a national level. The two basic spheres of on-going activity are decision-making and drafting of the plan itself. It is the decision makers who determine the assignments and objectives of a plan, deciding on a definitive alternative. All other tasks belong to the planners. These two spheres of activity cannot develop separately or without mutual influence (although at first sight they may seem to be independent), because they are elements of a uniform process which involves the drafting and adopting of the Water Resources Plan.

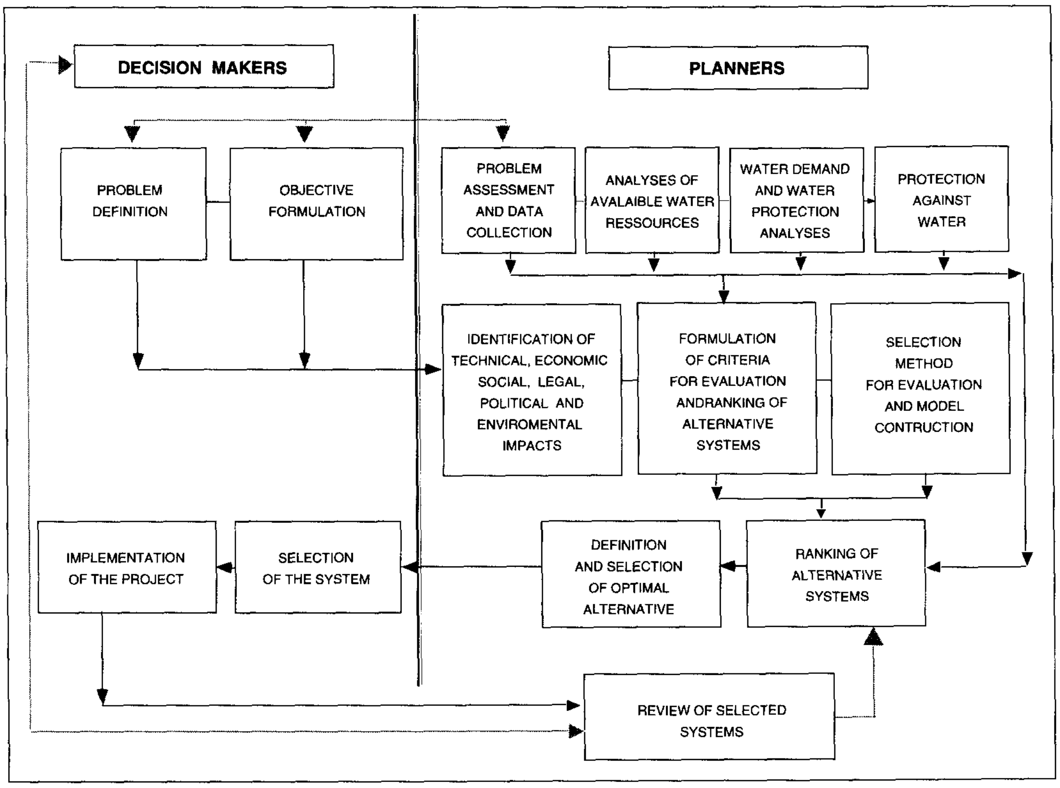


Figure 7. Outline of the planning and decision making process

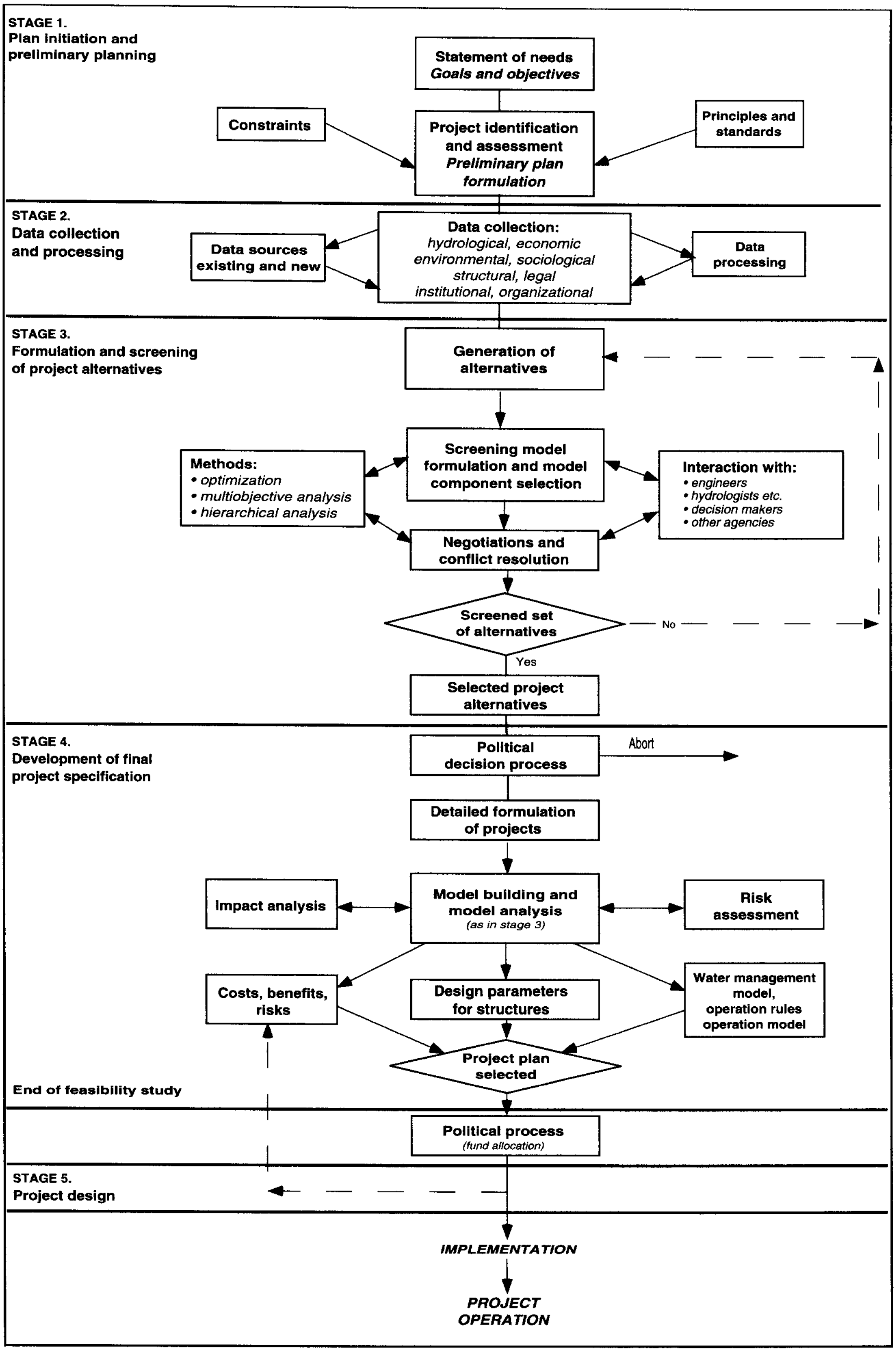


Figure 8. Stages in water resources planning (after Haimes et al., *1987)*

The stages in the process are shown as part of a sequential decision process, in which the tasks to be performed at each stage are represented by boxes and the decisions to be made by connecting lines. Arrows indicate the direction of the flow of information from one stage to the next. The connecting lines are only schematic and additional feedback loops may exist. The construction and operation stages are not part of the planning process. In fact, it must be clearly understood that the operation rule resulting from the planning process is a first approximation only. The planner must allow enough flexibility for later adjustments because most operational rules are developed on the basis of a forecast, and it is highly unlikely that the real world will behave exactly as predicted during planning.

Figure 7 can be applied to all levels of planning, perhaps with some of the stages being combined or omitted. In most countries or organisations, the planning regulations concerning water resources are spelled out in more detail. The planning process is often divided into four distinct stages (UNESCO-UNEP, 1987), with project implementation forming an additional fifth stage (Figure 8).

- *Stage 1. Plan initiation and preliminary planning.* This is the project initiation stage, which begins with a statement of needs and includes preliminary planning that ends with the decision on how to proceed.
- *Stage 2. Data collection and processing.* This is the data collection stage, during which data are gathered for system model development and for decision making.
- *Stage 3. Formulation and screening of project alternatives.* This step involves the determination of the final project configuration, in which all the available alternatives are investigated and a small number of representative and promising alternatives are selected for detailed analyses.
- *Stage 4. Selection of alternatives and funding decision making.* This is when the design parameters, operation rules, costs and benefits of the alternatives selected in Stage 3 are determined, leading to the selection of the final project configuration. This phase represents, in more spatial and temporal detail, the planning of stages 2 and 3, and is often performed by a different team of planners. The documents prepared during this stage often form the basis of funding decisions.

Following these four stages a project implementation stage begins and could be considered as Stage 5 of the water resources development process; a sort of design stage, in which the final configuration is translated into design documents and when the project is physically implemented. The above stages and levels are seen more from the logic of the system analyst. However, all these levels and stages form a network in the decision process, being strongly interdependent. Their interaction requires a structured administration with clear authorities (and responsibilities) and precise procedures for information exchange and for established legal actions. Furthermore, procedures for interaction with the users of a water resources project must also be developed and different countries have developed different administrative procedures for developing their Water Resources Master Plans.

In Germany, the planning process is described for the national and regional levels by public laws mostly intended to determine procedures for approving projects, while the stages of project planning for some types of projects are outlined in standards. For example, the reservoir planning process is spelled out in Standard #s DIN 19700-10, where a procedure which roughly corresponds to the stages presented in Figure 8 is described. The Principles and Standards of the Water Resources Council (WRC) of the USA are rather explicit in the priorities to be used in the planning process. Planners must recognise that objective functions may shift due to possible shifts in the value judgments for development objectives. The WRC uses the term, "strategic uncertainties", to describe such changing values that must be taken into consideration during planning (Kisiel & Duckstein, 1972).

However, data collection and its subsequent analysis do not fall within the domain of decision making. They form, instead, a technical basis for the decision making process. As such, the procedures for collecting and analysing all data relevant to the development of WRMP, are unique and applicable to any situation, regardless of the administrative organisation involved in the planning process (Figure 9). Being technical, these data represent the major part of the water resources assessment. Therefore, the activities outlined in Stage 2 should include the development of appropriate procedures and methodologies for data collection and subsequent analysis.

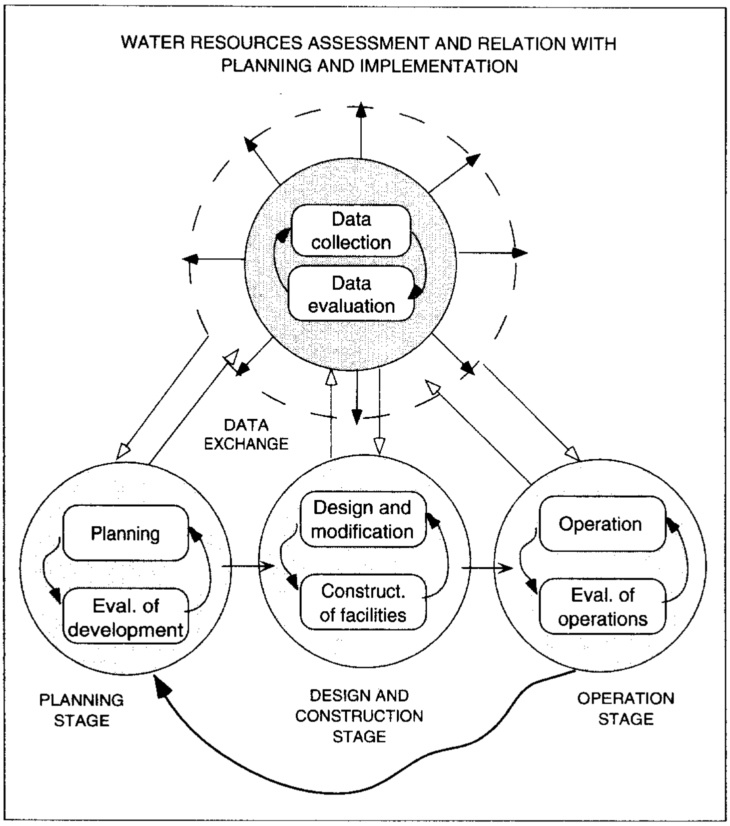


Figure 9. WRA planning and implementation

3. Basic concepts for the preparation of water resources assessment studies

3.1 Introduction

According to Godwin and his coworkers (1990), the questions that water resources assessment studies address can be summarised as follows:

1. Why should water resources of an area be assessed and how should the priorities between the sub-areas of a basin be determined?
2. How can priorities be determined when studying different components of a hydrological cycle and what is the desirable accuracy for each component?
3. What techniques and methods should be used to determine the values of different components of the hydrological cycle and their related data?
4. What precise data need to be collected ?
5. How should the assessment be organised; what are the manpower and equipment needs; what time-frame and administrative structure would be most practical?
6. How should the results be presented?

The first two questions lie within the domain of the decision making process and are not within the scope of this report. Questions 3, 4 and 6 are technical and will be discussed in detail in later sections, while question 5, even though it is technical, is not discussed in detail because of the impact created by the local organisation and jurisdiction on water resources assessment in different countries.

Just like WRMP, water resources assessment (WRA) does not have to be repeated once it has been compiled and verified. However, it is crucial that a WRA is updated regularly. As a basis for planning and management which use historical data to evaluate the existing state and identify the trends to plan for the future (in both the short term and the long term), WRA has a time dimension which must be precisely defined. Data on existing use of water resources must be differentiated from the forecasts of future water demand and use. Most of the quantitative data are usually collected daily, while data on the water quality are usually collected weekly or even monthly. If the initial WRA is flexible enough to assimilate new information collected within this time-frame, it should be possible to conduct WRA on a scale from one week to as long as 10 or more years.

How frequently WRA are evaluated and on what scale depends primarily on the needs of the planning and management procedures used in practice. It is not unusual to report on WRA on a weekly or monthly time scale for individual Water Management Unit Areas (WMUA, for definition see next section). As the spatial scale of the WRA increases, so does the time scale, but a complete WRA of a water resources in a given country should be completed at least once a year and should encompass a complete hydrological year.

Experience has shown that the most enduring and reliable WRA are those using the qualitative and quantitative water budget approach involving all the definable elements of a hydrological cycle and all the elements of water use for the scope of different uses (e.g. withdrawals and discharges). The manner in which information is collected and stored should be compatible with foreseeable information needs, with data collection efforts in the future and with short-term objectives.

The effectiveness of a WRA also depends on the accuracy and reliability of the data used in the assessment. Procedures which can ensure the adequate accuracy and reliability of the basic data have been extensively considered by many authors and will not be discussed here. It is enough to mention that each data collection programme must include strict quality control and quality assurance protocols. Without these protocols data collection programmes will yield only a limited amount of information for use in water resources assessment programmes and this, of course, is insufficient.

Furthermore, the institutional arrangements and goals must be such that they allow the acquired information to influence the final planning and development decisions. The institutional arrangements should stimulate and aid the collection, evaluation and use of information that could apply to a broad range of decisions. If data quality cannot be guaranteed and institutional support cannot be provided, provided planning efforts may prove to be disastrous. The best way to avoid this from happening (Godwin *et al.*, 1990) is to ensure that resource assessment, planning and management are implemented within the following framework:

- Use the complete drainage basin as the basic areal unit for data collection, interpretation, planning and management whenever possible.
- Evaluate all components of the hydrological cycle, not just the surface water resources.
- Conduct quantitative water resources assessments and planning using a complete water budget approach.
- Include evaluations of water quantity and quality for surface and ground water, water withdrawals and discharges, and other relevant environmental considerations.
- Consider the long-term changes that would occur from management schemes, not just the existing situation and short-term results.

3.2 Spatial segregation for water resources assessment

In theory, major river basins are the most convenient unit for any planning, assessment or appraisal of water resources. Drainage divides of surface water systems are topographical features that are easily identified. In most places these drainage divides also separate ground water systems and areas of water use. However in practice, the situation is often not that simple. Watersheds are often divided into units that are under different planning and political jurisdictions. While this may seem to present a major problem, in practice it is not the case. All that is required is that an adequate spatial separation of water resources is implemented and that the principle of continuity of volume (mass) is maintained for adjacent spatial units. The first step in any water resources assessment study is to spatially divide the area that is studied into manageable unit areas for which water resources assessment data can be collected and for which, after aggregation on the river basin principle, WRA can be carried out. Different systems for spatial segregation exist in many countries but they all share some common characteristics. Typically, information that is gathered systematically is organised by geographical area. This information is usually divided into two basic types:

- water resources information, including data on natural, physical and geographical factors; and
- water management information, such as data on water use, administrative divisions involving political units, management aspects, and specific problems related to the management of resources, such as water quality and flood control.

Since watersheds generally cover large areas (frequently within different countries) with different natural and anthropogenic characteristics, it is clear that they need to be divided into smaller Water Management Unit Areas (WMUA). The division of territories into such units must be done systematically to define basin boundaries and hydrogeological, administrative, territorial, economic, and water management characteristics. When dividing a watershed or a given territory into WMUA, thereby establishing a system for data collection, it is important to:

- ensure that the division between surface and ground water coincides with the limits of the WMUA so that each region encompasses a smaller watershed and the Reference Data Collection Stations (RDCS) coincide with the existing flow observation stations at which the water quantity and water quality are monitored over longer periods of time;
- establish each WMUA and the positions of the RDCS within the existing administrative boundaries (country, state, provincial, municipal, regional and others);
- ensure that the boundaries of a WMUA do not cross the territory of an existing (or planned) regional hydro system which, from the point of view of its water resources structure, represents a whole; and
- bear in mind the changes in the water regime and the qualitative characteristics along the watercourse, such that RDCS are located in the zones of major tributaries, larger outlets and water intakes, avoiding waste water discharge locations.

It would be best if all the mentioned principles could be satisfied when deciding on the boundaries of the WMUA and the locations of the RDCS. In practice however, this is not always possible because, often enough, some of the principles oppose each other while some cannot be satisfied at all. Things are most difficult in transboundary, low-lying areas with a thick hydrographical network of natural and artificial stream flows, where it is often impossible to reliably define the boundaries between watersheds for surface water. In situations like this, it is necessary to analyse in detail the existing state and the future development of water resources, starting with the solutions and strategies (given in the planning documents) which may affect the water resources in the given (or some neighbouring) area. There is no doubt that the choice of boundaries for a WMUA and the locations of the RDCS should be given due attention, bearing in mind the reality of the water resources assessment in time and space, and the economic justification of establishing and monitoring the water quantity and quality. In this respect it may sometimes be necessary to allow for the phased development of a water resources assessment, including the establishment of new WMUA and the reclassification of already-existing units, along with gradual corrections to the network of RDCS. A standard methodology for the establishment of WMUA (Figure 10) is necessary for the development of WRA.

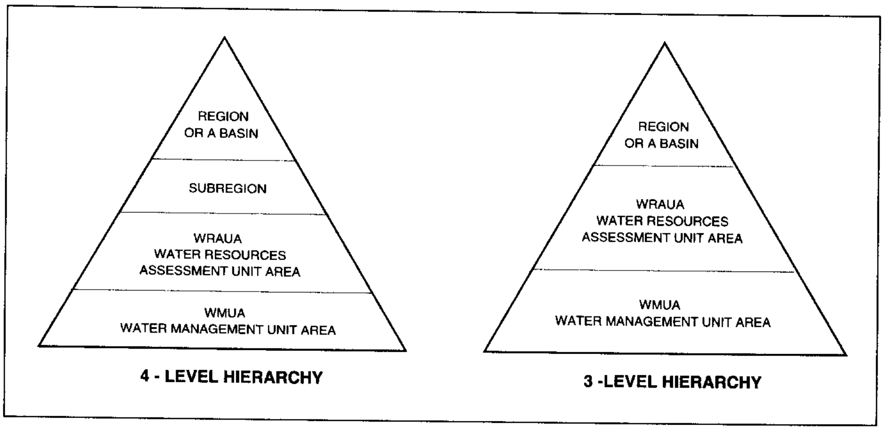


Figure 10. Hierarchy and spatial organisation

3.3 Standard spatial organisation for water resources assessment

The first level of territorial division is the Water Management Unit Area (WMUA) for which all the computations and analyses are carried out in accordance with the WRA equations presented later. As set out in the previous section, the WMUA is an area encompassing all or part of the watershed of a relatively small stream and representing a water resources unit suitable for planning. The size of the WMUA depends on the degree of hydrographical development, the topography of the terrain, and the size and administrative division of the country. In accordance with past experience such a balancing unit should have an area anywhere between 500 and 2,000 km^2.

In Yugoslavia for example, it was decided that a balancing unit should not be smaller than 500 km^2 while, at the time when State Hydrological Unit Maps where prepared in the USA (USGS, 1984), it was decided that the balancing units there should have an area of approximately 1,800 km^2.

All WMUA need not be of equal size, but care should be taken that each WMUA represents a logical unit for which it is possible to collect and analyse the required data for the purposes of WRA computations and for the development of Water Resources Master Plans. For each WMUA, at least two Reference Data Collection Stations (RDCS) should be established (an inflow station and an outflow station). There should also be at least one hydrometeorological station within the boundary of each WMUA.

The second level in the hierarchy includes parts of the watersheds of larger watercourses, or a group of the previously defined WMUA, representing the Water Resources Assessment Unit Area (WRAUA) or Water Resources Accounting Unit (WRAU), for which River Basin Water Resources Master Plans are usually developed.

Units in the third level of the hierarchy are termed sub-regions. A sub-region is an area which may best be described as a district similar to the famous Lake District in England, but which is delimited by political and administrative boundaries rather than by natural boundaries. If the basic principles for defining boundaries are adhered to, it is usually possible to organise areas so that no single WMUA falls within the territory of more than one sub-region. In situations when this does occur, it is necessary to establish RDCS along the sub-regional boundary within the divided WMUA.

The fourth level in the hierarchy is represented by major geographical areas dividing the state (country) into regions or basins. Each region, or basin, contains either the drainage area of a major river, such as the Rhine, or the combined drainage areas of a series of rivers draining into the sea. It therefore usually consists of a group of sub-regions. For smaller countries with a relatively simple hydrographical network, a three level hierarchy may be adequate and the sub-region level (level 3) may be dropped (see Figure 10).

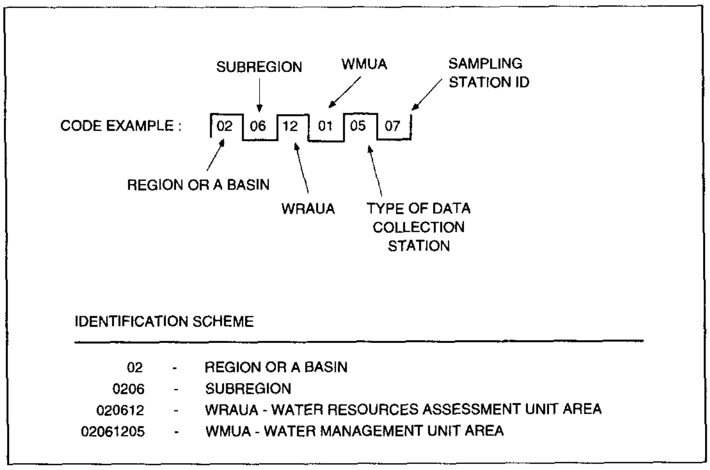
3.3.1 Spatial coding

To make communications easier, an adequate location coding system must be established. It must have a unique numerical identification number consisting of six or eight digits, based on the three or four level hierarchy of territorial division, and an additional three digits to identify the type and number of the RDCS.

This six or eight digit code uniquely identifies each level in the hierarchy by a two-digit field (i.e. the maximum number of units within the top level of the hierarchy is 99). The first two digits identify the region or a basin, the first four digits identify the sub-region, the first six digits identify the WRAUA while all eight digits identify the WMUA. In the three level hierarchy the procedure is analogous, with only six digits being required.

For the unique identification of each RDCS the areal code is extended by another three digits of which the first identifies the type of RDCS (quantitative station, qualitative station, control station etc.; see later sections) and the last two identify the station number (Figure 11).

The value 00 in the two-digit WRAUA field (instead of 12, as in Figure 11) indicates that the accounting unit and the sub-region are the same. Likewise, if the WMUA code is 00 (instead of the 05) then the WMUA and the WRAUA are the same. This means that a four-level coding scheme (territorial division) can easily be adapted for a three-level coding scheme by fixing two relevant digits in the code to 00.



IDENTIFICATION SCHEME

02	-	REGION OR A BASIN
0206	-	SUBREGION
020612	-	WRAUA - WATER RESOURCES ASSESSMENT UNIT AREA
02061205	-	WMUA - WATER MANAGEMENT UNIT AREA

Figure 11. *Coding of spatial units and stations*

3.3.2 Territorial segregation criteria

The basic criteria to be used for the territorial division and the corresponding mapping include the following:

- All smaller units nest within the next larger unit. All the boundaries of units within the continental part of a given country should match precisely.
- All boundaries internal to the country are hydrological (hydrographical) in nature (with a few exceptions when special procedures apply). Regional and sub-regional boundaries can coincide with international boundaries. However, because the boundaries of the WMUA and WRAUA are hydrological in nature, they should be extended into neighbouring countries through bilateral agreements, if possible. If not, additional RDCS along the border should be established. Every effort should be made to keep the topography of stream drainage basins as the sole preferred determinant for hydrological unit boundaries in any given country.

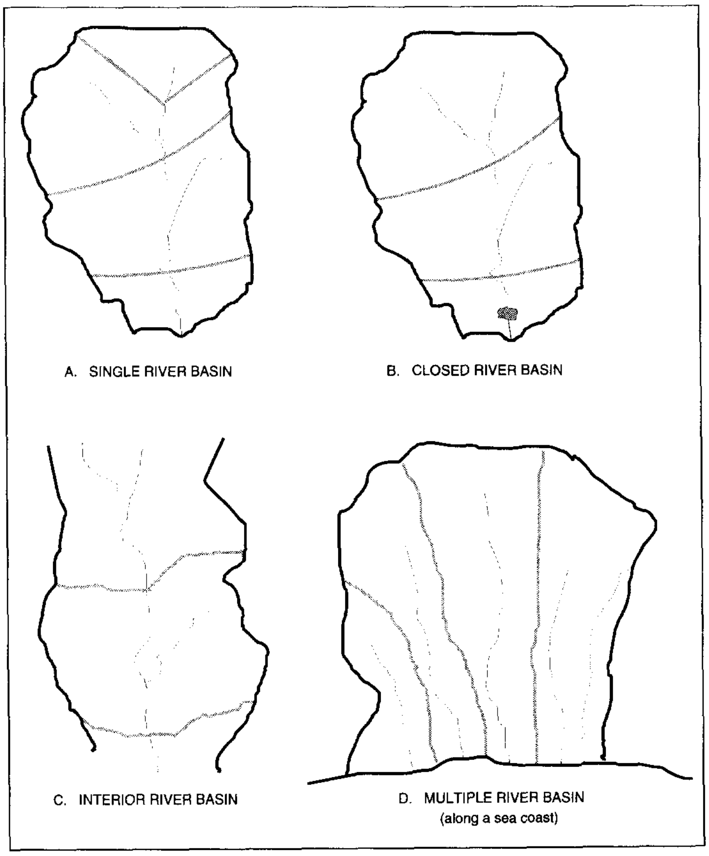


Figure 12. Examples of spatial segregation

The technical criteria to be used in defining the boundaries of an area are:

1. *Selection of major areas.* Figure 12 depicts the types of possible territorial segregation units and shows their mutual relationships. The limits of each sub-region are generally defined by the principal geographic units with the following exceptions:
    - At a major lake or reservoir, the boundary should be placed at the outlet of the impoundment rather than at its head, because the headwaters can vary

considerably over a period of time, whereas the outlet of an impoundment is usually a fixed point.

- The location of boundaries at RDCS, gauging stations, major cities, state lines, tidal or backwater effects, or other so called "strategic" hydrological, political or cultural points should be avoided.
- The boundaries of standard statistical areas should not be used as a criterion for defining hydrological unit boundaries. *The size of basins or unit areas.* No maximum size criterion should be specified. However, each river basin having a drainage area of more than 500 to 2,000 km^2 should be treated as a separate area at the lowest level of territorial division. The term "unique area" is used to designate an area that has been given a definitive name by the Board of Geographic Names and is shown and named on Base Geographic Maps.

2. Bays and estuaries. No special guidelines are developed. (WRA is developed only for fresh water.)
3. Small coastal islands. No firm guidelines are developed, but individual islands are usually treated as one WMUA (unless an island is of an area that justifies further territorial division).
4. Closed basins. Closed basins and large non-contributing areas should be delineated as separate WMUA if they are large enough (500 to 2,000 km^2).
5. Ground water areas. These areas are assumed to be the same as areas contributing to the surface water flow. They are therefore usually not given separate consideration when defining territorial divisions and establishing unit areas. The WMUA and WRAU are thus more hydrographical than true hydrological entities. However, if specific reasons exist, different WMUA could be determined for ground water as long as a record is kept of the water interchanges between all WMUA in an area.
6. Swamps and depressions. These are usually designated as separate areas, if they are large enough (500 to 2,000 km^2).
7. Inter-basin flow. An inter-basin flow should not be considered if it occurs only during flood conditions. At all other times it should be considered and an RDCS should be established to observe it.
8. Artificially-induced changes or diversions in natural drainage. If a flow is diverted continuously then the boundaries should be delineated correspondingly. However, if the flow is diverted only partially or intermittently, the boundaries should not be adjusted. Levees should be regarded as permanent structures.

3.4 Spatial and temporal scales in water resources assessment

In the previous section spatial scales were discussed from the point of view of the territorial organisation of WRA studies and nothing has been said about the spatial scales necessary for data collection. Furthermore, temporal scales were discussed in light of the planning and design procedures related to WRMP and WRA. This section deals with spatial and temporal scales to be used in the collection of data for these procedures. A number of basic principles must be adhered to when selecting suitable spatial and time scales for data collection. These basic principles are as follows:

- Spatial and temporal scales must allow the data to reflect spatial and temporal variability in the values of the parameters being measured. If, for example, a

WMUA encompasses complex topographical features and if weather patterns are known to be non-uniform (higher precipitation at higher altitudes, for example), then a single hydrometeorological station will not be sufficient to characterise precipitation and evaporation over a given WMUA and a number of stations should be installed.

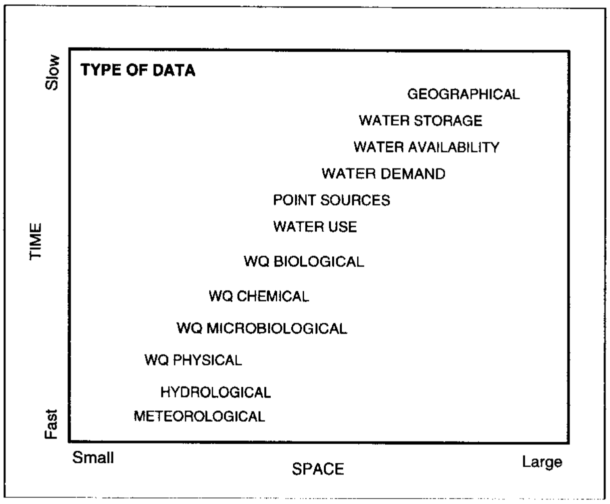


Figure 13. Spatial and temporal scales in relation to WRA data

- Spatial and temporal scales must allow for the detection of spatial and temporal variability in the values of major parameters, depending on the purpose for which the data will be used. If, for example, long-term planning is the main goal of the assessment, daily variations within space and time may not be important. However, if the goal is the operational assessment of water resources, then such variability must be considered.

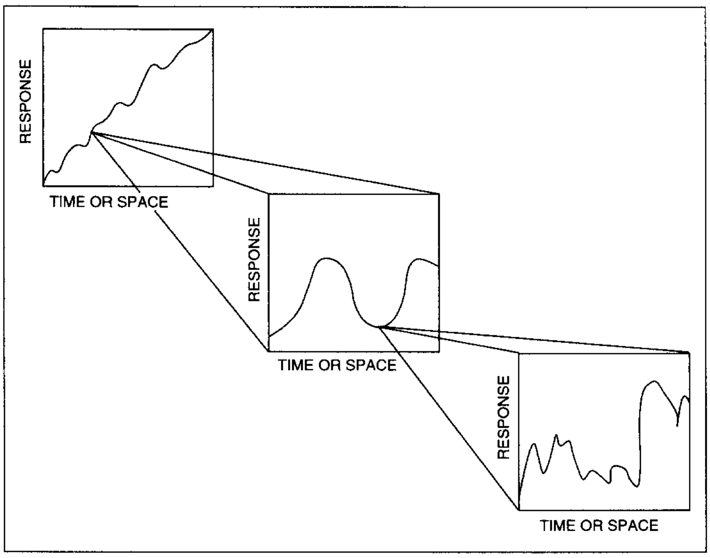


Figure 14. Spatial and temporal scales and behaviour detection limits

Figure 13 presents a general outline of spatial and temporal scales to be used in WRA depending on the type of data being collected. This outline should be used with care since for any given situation specific concerns may govern the choice of the corresponding scales, as is shown in Figure 14.

With respect to temporal scales, special care should be devoted to water quality parameters. A distinction should be made between the quality of the different components of water resources. For example, ground water quality may change relatively slowly while surface water quality changes much more rapidly. To complicate matters, the quality of the water discharges may change quickly, depending on process technology involved. In a similar way, water quality can change with time depending on the parameter being observed. For example, surface water temperature may not change as quickly as dissolved oxygen and so on (see Figures 15-17).

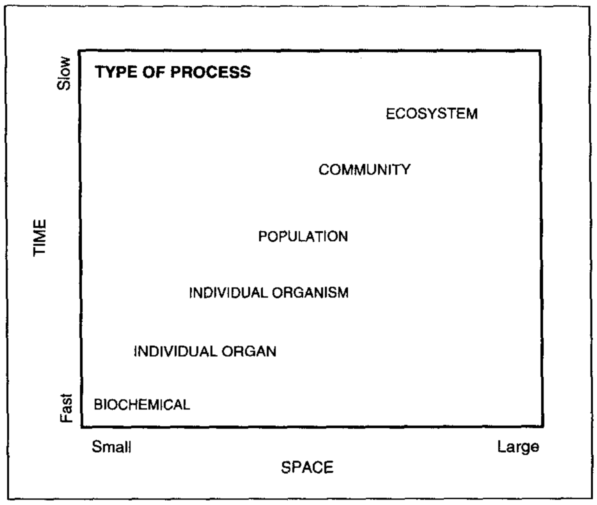


Figure 15. Spatial and temporal scales for biological processes

As mentioned earlier, WRA can be conducted on daily, weekly, monthly, or annual bases. For some of the above mentioned parameters, data will be available at temporal scales finer than these. For example, hourly flow data may be available and, in such cases, corresponding average values should be used (daily, weekly etc.). In other cases we may only have data on weekly and monthly bases and the values should be used (in corrected form - with respect to time scale) for finer resolution requirements.

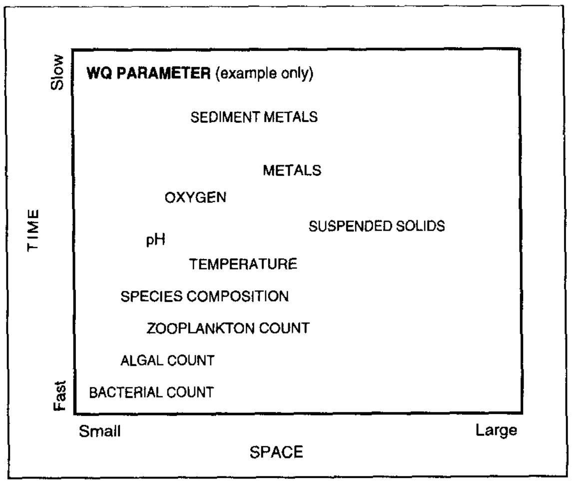


Figure 16. Spatial and temporal scales in relation to water quality parameters

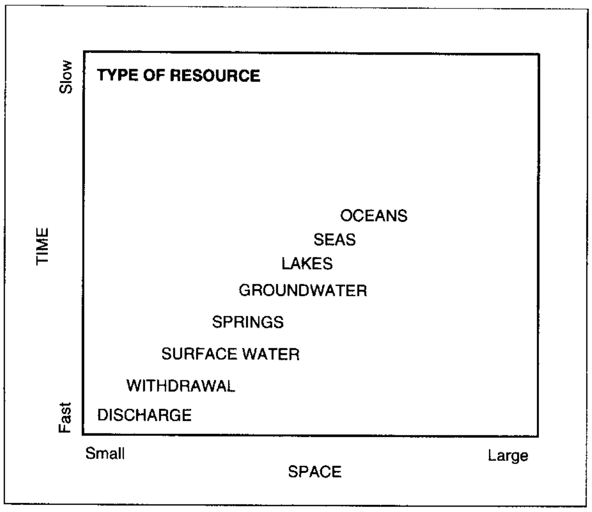


Figure 17. Spatial and temporal scales for resource change

It is beyond the scope of this guide to discuss in great detail all aspects of spatial and temporal scales, but readers should be aware to of the potential problems which may arise in conducting WRA if incorrect scales are selected. The most important principle is to collect representative data and, if necessary, data should be collected frequently from adense network of stations and then aggregated for the purposes of the WRA. For example, in areas with highly-polluted discharges it may be necessary to collect water quality data hourly, during a typical week, collating it to compute daily concentrations. Otherwise, if the parameter of interest does not change with space or time, one observation per month may be sufficient to characterise the quality of a particular discharge. The recommended frequency at which water quality data should be collected are given in Table 1.

Table 1. Sampling of surface and ground water

Type of resource	Frequency of water quality evaluation
Ground water	
shallow aquifers	weekly
deep aquifers	monthly
springs	monthly
Surface water	
Rivers*	
large rivers (Q > 250 m^3/sec.)	biweekly at a number of points across the river
medium rivers(Q < 250 m^3/sec.) **	biweekly from the centre of the river
small rivers(Q < 50 m^3/sec.)	weekly from the centre of the river
Lakes***	
Large (area > 10 km^2)	
shallow (average depth < 10 m)	weekly - at least 9 stations
deep (average depth > 10 m)	weekly - at least 12 stations
Small (area < 10 km^2)	
shallow (average depth < 10 m)	weekly - at least 6 stations
deep (average depth > 10 m)	weekly - at least 9 stations
Water withdrawals and discharges	
Q < 50 l/sec.	quarterly
Q < 100 l/sec.	bimonthly
Q < 500 l/sec.	monthly
Q < 10000 l/sec.	biweekly

* During rapid changes of the flow, daily sampling may be necessary.
** If local influences are known to exist, more than one point may be necessary.
*** Since vertical stratification may occur, depth sampling is also necessary and more frequent sampling may be needed at certain times of the year.

All water quantity data should be collected on a daily basis. This is only a general guide and for any given situation modifications may be necessary. Each situation should be analysed carefully before the data collection programme is implemented.

3.5 Locating data collection stations (RDCS, RWMS, RDMS)

As mentioned in the previous section, at least two RDCS and one hydrometeorological station should be established within each WMUA. However, this is not always possible because of the complexity of the WRA problems and the necessary analyses. It is not unusual to establish more than the recommended minimum number of stations. RDCS should also be established at each major river confluence and water withdrawal or discharge point. Similarly, if an area is characterised with major changes in topography, more than one hydrometeorological station should be established. Because WRA requires qualitative and quantitative balancing of water resources, the basic criteria for the selection of RDCS and their positioning are very important. The same holds for the extent of data collection at each RDCS, and is particulary so for water withdrawal and discharge points between two consecutive RDCS, within the same WMUA. Two other types of data collection stations should also be established:

- a Reference Withdrawal Monitoring Station (RWMS), which is used to monitor quantity and quality of water withdrawn from the surface and ground water; and
- a Reference Discharge Monitoring Station (RDMS), used to monitor quantity and quality of water discharged into the surface water from point sources of pollution.

The selection and location of all three types of stations primarily depends on the water regime and the quantity and quality of the water withdrawn and discharged within the WMUA. The criteria for selecting the locations of RDCS should be based on the following:

- an RDCS should be located at each confluence of a tributary, if the flow of the main river is increased by more than 5% immediately below the confluence;
- an RWMS should be located at each individual or group water withdrawal point if the amount of withdrawn water is greater than 50 l/sec. (or greater than 10% of the 95% probable low flow);
- an RDMS should also be located at each discharge point if the amount of water discharged is greater than 10 l/sec (or 10% of the 95% probable low flow); if a number of discharge points are located close to one another (in cities, for example) then each discharge point should be monitored separately or an RDCS should be established immediately downstream of the last discharge point (and water quality and quantity should be monitored accordingly); it is important to adjust the sampling programme to account for the mixing of the discharged effluents with the stream water (multiple sampling points, composite samples etc.);
- an RDCS should be located at the discharge point of all reservoirs and lakes (existing and planned); and
- an RDCS should be established wherever a stream crosses an international or regional border.

Depending upon the hydrographical network and the previously established criteria within a WMUA it is also possible to have not only two RDCS (inflow and outflow), but also a number of other "second order" RDCS, RWMS or RDMS. These second order RDCS and monitoring stations should be located at each point within the WMUA where there are significant changes in the water resources quantity and quality. Within a given WMUA, these stations should be considered as control stations to collect data for analysing water demand in the area and assessing the impact of waste water discharges on the water resources. The data collected at the control stations are not used for WRA at the higher levels of territorial division, since the data collected at the first order RDCS are sufficient for this purpose. Occasionally, when one analyses the impact of a discharge, within the lower levels of territorial division, on the overall water quality at a higher level of territorial division, the data from the second order RDCS can be used.

3.6 Other types of observation and monitoring

Since a complete WRA for a given area includes resources from ground water and springs, it is necessary to collect data about these resources too. Relevant data on the geology, hydrogeology, hydraulic conductivity and other parameters required for the evaluation of ground water aquifers and their yield should be collected regularly for each WMUA. To collect all the necessary data, the following should be carried out:

- monitoring of the sustainable yield of the ground water aquifers, the ground water elevation and the quality of ground water resources;
- monitoring of the quantity and quality of springs;
- geological, geophysical and hydro-geological studies of the potential ground water sources for water supply;
- monitoring of the quantity and quality of ground water withdrawn from the aquifers if these quantities are in excess of 10 l/sec.; and
- monitoring of meteorological parameters.

All the data acquired from the above observations, studies and monitoring programmes along with the data on the surface water resources and the hydrometeorological data for a given water resources balance unit represent the necessary database for WRA. The data collection and storage methodology for the above has been developed and published by UNESCO in the documents mentioned in the introduction to this guide and will therefore not be discussed here. It is assumed that the mentioned methodology is adequate and can be implemented easily at all levels of the hierarchical territorial division presented. However, the methodology for collecting and storing of data on water withdrawals and discharges, point and non-point sources of pollution, and drainage was not evaluated earlier and this will be done in the following chapters. This, together with the methodologies already available, represents a complete base for the collection of the data required for WRA.

4. Basic theoretical principles for processing a water resources balance

4.1 Introduction

The core component of any Water Resources Master Plan and Water Resources Assessment is the qualitative and quantitative water resources balance. A distinction must be made between a *water resources management balance* and a *water balance* (or water budget). A water resources management balance (WRMB) includes water withdrawals and discharges in the balance equations whereas a water balance does not. In other words, in the calculation of a WRMB for a given area, multiple use of a given volume of water is accounted for, while this is not the case with a simple water balance. By doing this, it is possible to satisfy the demand for water even when the natural water balance does not make that possible. This approach also forces planners and managers to look at a muchwider scope of alternatives to meet the demand than would otherwise be the case (e.g. reservoirs versus water recalculation and conservation). This process further reinforces the role of water quality in water resources assessment (Figure 18).

Quantitative WRMB can be defined relatively easily, in principle. However, in practice this is not the case. The first practical problem that experts faceis the estimation of ground water quantities. Since these quantities cannot be routinely monitored,estimates must be based on extensive use of mathematical models. Furthermore, in computing the quantitative WRMB, a distinction must be made between quantities of water that can be subjected to rational planning and those that are beyond any rational control measures.

The quantity of water that can be managed and controlled is not equivalent to the quantity available for use, since some water must always remain in place to support aquatic life. This instream use of water is, for all practical purposes, considered to be non-managable unless reservoir storage is available and flow augmentation can be implemented. Occasionally this becomes a controversial issue since different constituency groups may have different priorities regarding requirements for human use and maintenance of aquatic life.

With this guide we do not attempt to resolve decision-making issues and a huge body of literature on the topic can be consulted. However, it is clear that in calculating a WRMB, distinctions need to be made between surface and ground water resources, and between manageable and non-manageable quantities.

The qualitative WRMB is much more complex. It involves many issues which are technical as well as political and require the definition of water use and the development of water quality criteria for designated uses. Furthermore, for a given use a qualitative balance is not possible for every water quality parameter of importance. For these reasons it is necessary to define a list of general and specific water quality parameters prior to calculating the qualitative water balance. Temporal variations in water quality, even though they are important for specific purposes, cannot be evaluated in the same detail as the water quantities within the WRMB. Water quantity data collection can be automated easily which is not the case with data collection about the quality of water. This emphasises cost constraints on water quality monitoring programmes and limits the frequency of sampling.

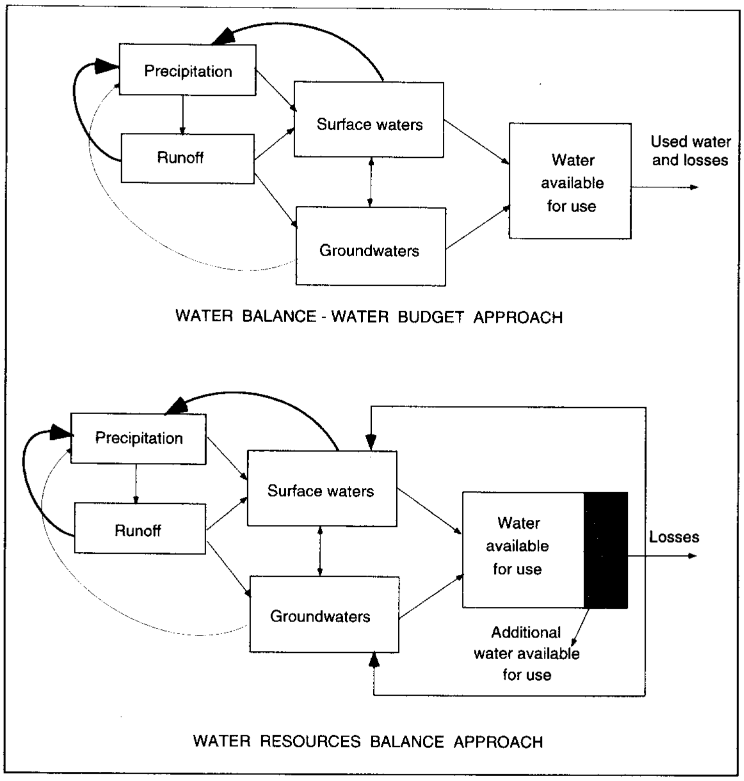
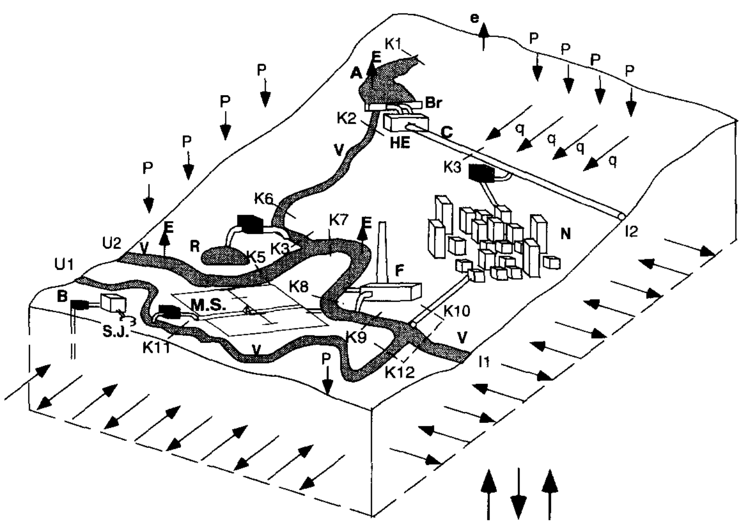


Figure 18. Differences between the water balance and water resources management balance approaches

The evaluation of a WRMB and the process of water resources assessment rely upon large amounts of data which must be collected, stored and analysed. This necessitates a modern, state of the art, water resources information system as one of the major tools for the preparation of an adequate water resources assessment. A whole chapter is devoted to this since without proper database design and without prompt and extensive data management systems, adequate WRMB and assessment will not be practical.

By management in this context we mean the ability to store water during excess availability and to keep it for use during periods of deficiency. For practical reasons this is only possible with surface water through the construction of artificial reservoirs. This does not mean that ground water cannot be managed, only that their natural regime cannot be easily modified to serve the needs of society. Instead of modifying the ground water natural regime, management efforts are usually directed towards protecting ground water resources from depletion and qualitative degradation. Historically ground water has been preferred as a useful source not only because of the associated qualitative advantages, but also because of the stability of the supply and its buffered temporal variability. As a result, in many parts of the world ground water resources have been



LEGEND

N - COMMUNITY
R - FISH FARM
A - RESERVOIR
F - INDUSTRY
M.S. - DRAINAGE OR IRRIGATION SYSTEM
HE - HYDRO POWER
B - WELL
S.J. - SEPTIC TANK
C - SUPPLY MAIN
V - RIVER

Br - DAM
U1, U2 - RDCS (Reference data collection station)
K1,..., K12 - CRDCS (Control ref. data collection station)
I1, I2 - RDCS (Reference data collection station)
P - PRECIPITATION
E - EVAPORATION
q - SURFACE RUNOFF
e - EVAPOTRANSPIRATION

Figure 19. Schematic representation of a WMUA

developed to capacity (at certain locations even depleted) so that a shift has occurred towards more intensive use of surface water. This increasing use of surface water resources is also due to developments in hydro-power and dam construction for flood control.

4.2 General quantitative water resources balance

If we assume that a Water Management Unit Area (WMUA) encompasses an area on the Earth's surface (Figure 19) where there is a certain amount of water inflow, be it in the form of surface or ground water, or in some other form, and that there is a certain amount of runoff (surface, underground) or evaporation from the ground or water surfaces, or that some water is lost through the evapotranspiration of the plant cover, it is possible to define the ***general quantitative water resources management balance*** for a fixed time interval. The general WRMB equation is:

$$\sum_{g=1}^{G}(\Delta V)_g = \sum_{a=1}^{A}(V_{in})_a + \sum_{b=1}^{B}(V_{out})_b + \sum_{c=1}^{C}(V_{dis})_c - \sum_{d=1}^{D}(V_w)_d - \sum_{e=1}^{E}(V_E)_e - \sum_{f=1}^{F}(V_{ET})_f \tag{1}$$

where the following definitions apply:

$\sum_{g=1}^{G}(\Delta V)_g$	is the total change in the volume of water in a given WMUA over a given time interval. Subscript g refers to a total number of such water "reservoirs" in a given WMUA, each having a unique identification number.
$\sum_{a=1}^{A}(V_{in})_a$	the total surface or underground water inflow into a given WMUA over a given time interval, in the form of rain, snow, runoff or water flowing in from deep geological aquifers, as well as the water quantities flowing to the WMUA from the neighbouring WMUA. Subscript a refers to a total number of such inflows in a given WMUA, each having a unique identification number.
$\sum_{b=1}^{B}(V_{out})_b$	the total amount of water which in a given time interval flows out of a given WMUA either through surface water channels and artificial water conduits, ground water flow or which is lost through discharges into the deeper geological aquifers. This term includes both manageable and non-manageable quantities as has been mentioned earlier and it will be decomposed into two separate terms in the equation for surface water. Subscript b refers to the total number of such outflows in a given WMUA, each having a unique identification number.
$\sum_{c=1}^{C}(V_{dis})_c$	the total amount of water which in a given time interval flows into surface water bodies in a given WMUA due to discharges by different water users in the WMUA. This term refers to all point source discharges including drainage system discharges. It is assumed that no discharges into ground water aquifers exist. If they do exist an additional term must be added to the equation. Subscript c refers to the total number of such inflows into a given WMUA, each having a unique identification number.
$\sum_{d=1}^{D}(V_w)_d$	the total amount of water which is withdrawn in a given time interval from surface water bodies or ground water aquifers in a given WMUA by different water users in the WMUA. This term refers to all water withdrawals including those for water transfer to different WMUA. Subscript d refers to a total number of such withdrawal points in a given WMUA, each having a unique identification number.
$\sum_{e=1}^{E}(V_E)_e$	the total amount of water which is lost from a given WMUA in a given time interval from surface water bodies due to direct evaporation from water surfaces. Subscript e refers to the total number of evaporation accounting areas in a given WMUA, each having a unique identification number.

$\sum_{f=1}^{F}(V_{ET})_f$ the total amount of water which is lost from a given WMUA in a given time interval due to evapotranspiration by terrestrial and aquatic vegetation. It is assumed that all these losses occur from the ground water pool. Subscript *e* refers to the total number of evapotranspiration accounting areas in a given WMUA, each having a unique identification number.

As the above definitions imply, not all of the terms can be quantified by direct observation. Since water resources management balance should be based on as much observed data as is possible, it is necessary to decompose Equation 1 further. This equation includes all the changes of the water resources management balance terms for a given WMUA. However, even though it is necessary to approach the water resources balance integrally, it must be recognised that significant differences do exist in terms of the occurrence, movement, use and exploitation of water in the two major components of the water resources (surface and ground water). The quantity and the quality of surface water is much easier to monitor and evaluate due to the fact that measuring and observation stations are easily defined, easily accessible and visible which is not the case with ground water resources.

It therefore follows that the first step in this decomposition should be a division into surface water resources and ground water resources. Within each of these categories further division is then carried out to provide those terms which can be observed and quantified by direct measurement and to identify those terms which need to be estimated.

Applying Equation 1 to surface and ground water resources, paying careful attention todefinitions and to the associated assumptions, we can formulate Equations 2 and 3. The distinction between surface and ground water is also useful in WRA because, for a given WMUA, the use of ground water and surface water may differ (one being given a priority over the other in development) and a separate record should be kept of each resource.

4.2.1 Surface water

$$\sum_{n=1}^{N}(\Delta V_s)_n=\sum_{i=1}^{I}(V_{ins})_i-\sum_{j=1}^{J}(V_{outs})_j+\sum_{c=1}^{C}(V_{dis})_c$$
$$-\sum_{e=1}^{E}(V_E)_e-\sum_{k=1}^{K}(V_{ws})_k-\sum_{l=1}^{L}(V_{infs})_l+\sum_{m=1}^{M}(V_S)_m \qquad (2)$$

where new terms are as follows:

$\sum_{n=1}^{N}(\Delta V_s)_n$ is the total change in the volume of surface water in a given WMUA over a given time interval. Subscript *n* refers to the total number of such water "reservoirs" in a given WMUA, each having a unique identification number.

$\sum_{i=1}^{I}(V_{ins})_i$ the total surface water inflow into a given WMUA over a given time interval, in the form of rain, snow, runoff or water from precipitation over the area of a given WMUA, as well as the water quantities flowing to the surface water in a WMUA from the neighbouring WMUA. Subscript *i* refers to the total number of such inflows in a given WMUA, each having a unique identification number.

$\sum_{j=1}^{J}\left(V_{outs}\right)_j$	the total amount of water which in a given time interval flows out of a given WMUA through surface water channels and man made water conduits. Subscript *j* refers to the total number of such outflows in a given WMUA, each having a unique identification number.
$\sum_{k=1}^{K}\left(V_{ws}\right)_k$	the total amount of water which is withdrawn in a given time interval from surface water bodies a given WMUA by different water users in the WMUA. This term refers to all water withdrawals including those for water transfer to different WMUA. Subscript *k* refers to the total number of such surface water withdrawal points in a given WMUA, each having a unique identification number.
$\sum_{l=1}^{L}\left(V_{infs}\right)_l$	the total amount of water which is lost from a surface water pool in a given time interval in a given WMUA due to infiltration into ground water aquifers. This term refers to surface water infiltration from surface water bodies only and does not include direct precipitation infiltration. Subscript *l* refers to the total number of surface water infiltration accounting areas in a given WMUA, each having a unique identification number.
$\sum_{m=1}^{M}\left(V_S\right)_m$	the total amount of water which is discharged from the ground water pool in a given time interval in a given WMUA through both surface and submerged springs. This term includes deep aquifer springs and can be omitted from the equation in areas where springs are a rare occurrence or where quantities discharged by the springs are relatively small compared to other components of the equation. Subscript *m* refers to the total number of springs in a given WMUA, each having a unique identification number.

The V_{outs} term in Equation 2 consists of two components: one that can be managed and controlled artificially (construction of reservoirs, dams, storage tanks etc.) and one which cannot be controlled or managed, including those water quantities which are discharged from a given WMUA to support instream requirements and downstream users (see Equation 2a).

$$\sum_{j=1}^{J}\left(V_{outs}\right)_j=\sum_{j=1}^{J}\left(V_{outsm}\right)_j+\sum_{j=1}^{J}\left(V_{outsnm}\right)_j \qquad \textbf{(2a)}$$

where previously undefined terms are:

$\sum_{j=1}^{J}\left(V_{outsm}\right)_j$	the total amount of water which flows out of a given WMUA in a given time interval which **can** be controlled through a system of reservoirs and other systems of storage. This amount of water is not of a stochastic nature and is released from a given WMUA in accordance with management policies. Subscript *j* refers to the total number of outflows in a given WMUA, each having a unique identification number.
$\sum_{j=1}^{J}\left(V_{outsnm}\right)_j$	the total amount of water which flows out of a given WMUA in a given time interval which **cannot** be controlled. This amount of water is of a stochastic nature and is released from a given WMUA in accordance with the natural conditions for the requirements of instream water use such as aquatic life support and similar. Subscript *j* refers to the total number of outflows in a given WMUA, each having a unique identification number.

4.2.2 Ground water

$$\sum_{u=1}^{U}\left(\Delta V_{nmg}\right)_u = \sum_{p=1}^{P}\left(V_{ing}\right)_p - \sum_{q=1}^{Q}\left(V_{outg}\right)_q - \sum_{r=1}^{R}\left(V_{wg}\right)_r + \sum_{l=1}^{L}\left(V_{infs}\right)_l$$
$$-\sum_{m'=1}^{M}\left(V_{Ssa}\right)_{m'} - \sum_{s=1}^{S}\left(V_{dao}\right)_s + \sum_{t=1}^{T}\left(V_{dai}\right)_t - \sum_{f=1}^{F}\left(V_{ET}\right)_f \qquad (3)$$

where new terms are defined as follows:

$\sum_{u=1}^{U}\left(\Delta V_{nmg}\right)_u$	is the total change in the volume of water stored in ground water aquifers in a given WMUA over a given time interval. It is assumed that these volumes cannot be directly controlled or managed, i.e. no artificial ground water reservoirs exist. Subscript *u* refers to the total number of water aquifers in a given WMUA, each having a unique identification number.
$\sum_{p=1}^{P}\left(V_{ing}\right)_p$	the total ground water inflow into aquifers in a given WMUA over a given time interval. Subscript *p* refers to the total number of such inflows in a given WMUA, each having a unique identification number.
$\sum_{q=1}^{Q}\left(V_{outg}\right)_q$	the total amount of water which, over a given time interval, flows out of aquifers in one WMUA to aquifers in the neighbouring WMUA. Subscript *q* refers to the total number of such outflows in a given WMUA, each having a unique identification number.
$\sum_{r=1}^{R}\left(V_{wg}\right)_r$	the total amount of water which is withdrawn over a given time period from ground water aquifers in a given WMUA by different water users in the WMUA. This term refers to all ground water withdrawals including those for water transfer to different WMUA. Subscript *r* refers to the total number of such withdrawal points in a given WMUA, each having a unique identification number.
$\sum_{m'=1}^{M}\left(V_{Ssa}\right)_{m'}$	the total amount of water which is discharged from the shallow ground water pool in a given time interval in a given WMUA through both surface and submerged springs. This term does not include deep aquifer springs and can be omitted from the equation in areas where springs are a rare occurrence or where the quantity discharged by the springs is relatively small compared to other components of the equation. Subscript *m'* refers to the total number of shallow aquifer springs in a given WMUA, each having a unique identification number.
$\sum_{s=1}^{S}\left(V_{dao}\right)_s$	the total amount of water which is lost from a given aquifer in a given WMUA over a given time interval due to infiltration to deep aquifers. Subscript *s* refers to the total number of aquifers in a given WMUA, each having a unique identification number.
$\sum_{t=1}^{T}\left(V_{dai}\right)_t$	the total amount of water gained by a given aquifer in a given WMUA over a given time interval due to infiltration from deep aquifers. Subscript *t* refers to the total number of aquifers in a given WMUA, each having a unique identification number.

Some of the terms in Equations 1-3 are compound and need to be reduced to simpler terms that can, if possible, be measured by direct methods. This simplification of terms is also important because it defines the data collection, storage and retrieval requirements and the number and location of data collection stations. In Equation 2, the term V_{ins} can be simplified into components that can be quantified by direct measurement and those that cannot. This yields the following set of equations:

$$\sum_{i=1}^{I}(V_{ins})_i = \sum_{v=1}^{V}(V_{inp})_v + \sum_{w=1}^{W}(V_{inr})_w + \sum_{x=1}^{X}(V_{ina})_x + \sum_{y=1}^{Y}(V_{int})_y + \sum_{y'=1}^{Y'}(V_{in})_{y'} \tag{4}$$

and

$$\sum_{w=1}^{W}(V_{inr})_w = \sum_{w=1}^{W}(K_r)_w \times (P)_w \tag{5}$$

where new terms are defined as follows:

$\sum_{v=1}^{V}(V_{inp})_v$	the total amount of water entering surface water in a given WMUA due to direct precipitation (rain and snow) on the surface of the water bodies in a given WMUA. Subscript v refers to the total number of precipitation accounting units each having a unique identification number.
$\sum_{w=1}^{W}(V_{inr})_w$	the total amount of water entering surface water in a given WMUA and in a given time interval due to runoff from the territory of a given WMUA. Subscript w refers to the total number of runoff accounting units each having a unique identification number.
K_r	the runoff coefficient for a given runoff accounting unit w.
P	the average precipitation over a given runoff accounting unit w.
$\sum_{x=1}^{X}(V_{ina})_x$	the total amount of water entering surface water in a given WMUA and in a given time interval due to water transfers from the territory of another WMUA. Subscript x refers to the total number of water transfers each having a unique identification number.
$\sum_{y=1}^{Y}(V_{int})_y$	the total amount of water leaving surface water in a given WMUA and in a given time interval due to water transfers to the territory of another WMUA. Subscript y refers to the total number of water transfers each having a unique identification number.
$\sum_{y'=1}^{Y'}(V_{in})_{y'}$	the total amount of water entering surface water in a given WMUA and in a given time interval due to inflows at the boundary RDCS from the territory of another WMUA. Subscript y' refers to the total number of inflow RDCS on the boundaries of the WMUA.

In Equation 3 no further decomposition of the terms is justifiable since, apart from water withdrawals from aquifers, all other quantities have to be estimated rather than observed or directly measured. Estimation techniques are discussed elsewhere in the guide.

Because of the temporal variability of most of the terms in the above set of equations and because of the different time scales used in planning and management, it is necessary to study each component (surface water and ground water) of the quantitative WRMB over long periods of time. This is to ensure that sufficient data are collected for the computation of corresponding average and representative values. There are numerous studies, monographs and scientific papers about this procedure.

On a temporal scale, a WRMB can be designated on a daily basis or on the basis of data collected weekly, monthly, seasonally or annually (even covering periods of several years). This perspective enables us to distinguish between a *realised* and a *planned* WRMB. The *realised* WRMB is processed on the basis of recorded historical data, taking into account actual releases and withdrawals of water. The *planned* WRMB is processed for some future time, based on the forecasted demand for and release of water.

As is obvious, the *realised* balance processes observed data during the preceding period of time; data which can be processed and analysed for all the mentioned time intervals (depending on the periods of time for which there are data available). The *planned* balance is usually analysed when developing WRMP and other water resources solutions through the analysis of water demand in a given water area.

The assumption is that the input water quantities and the output water quantities of the water resources management balance for a given WMUA are computed using the daily values, when available, and are later processed for the weekly, monthly, seasonal and annual sums (and statistical values). Since there is a stochastic variability of the components of a water resources balance over a period of several years, they are analysed and defined over a period of several years using the mathematical and statistical methods. The same is done when analysing the quantities of water withdrawn,released and transferred. The difference being that these quantities usually do not represent stationary time series, as is most often the case with the other water resources balance components.

4.3 Qualitative water resources management balance

Equations 1 to 5 define the quantitative water resources management balance for a given WMUA and can be used for the qualitative WRMB with the understanding that the water quality is defined for each component of the balance. To do this, each term of the equations is multiplied by a value corresponding to the concentration of a given water quality parameter, hence determining a mass balance per unit time for each constituent of water quality. However, this does not include precipitation, evaporation and evapotranspiration, because precipitation is considered to be clean water (although we know today that it is not quite so, e.g. acid rain), while evaporation and evapotranspiration represent the loss of clean water. Furthermore, it is difficult to determine the quality for those components of a water resources balance which pertain to the quantities of released and withdrawn ground water, exchange with the deeper geological aquifers and surface water infiltration. This yields to the following set of equations for mass balance for each water quality parameter of interest.

Surface water

$$\begin{aligned}\sum_{n=1}^{N}\left(\left(\Delta V_{s}\right)_{n}\times C_{n}^{x}\right)=&\sum_{i=1}^{I}\left(V_{ins}\right)_{i}\times C_{i}^{x}-\sum_{j=1}^{J}\left(V_{outs}\right)_{j}\times C_{j}^{x}\\&+\sum_{c=1}^{C}\left(V_{dis}\right)_{c}\times C_{c}^{x}-\sum_{e=1}^{E}\left(V_{E}\right)_{e}\times C_{e}^{x}\\&-\sum_{k=1}^{K}\left(V_{ws}\right)_{k}\times C_{k}^{x}-\sum_{l=1}^{L}\left(V_{infs}\right)_{l}\times C_{l}^{x}\\&+\sum_{m=1}^{M}\left(V_{S}\right)_{m}\times C_{m}^{x}\end{aligned}\tag{6}$$

Ground water

$$\begin{aligned}\sum_{u=1}^{U}\left(\left(\Delta V_{nmg}\right)_{u}\times C_{u}^{x}\right)=&\sum_{p=1}^{P}\left(V_{ing}\right)_{p}\times C_{p}^{x}-\sum_{q=1}^{Q}\left(V_{outg}\right)_{q}\times C_{q}^{x}\\&-\sum_{r=1}^{R}\left(V_{wg}\right)_{r}\times C_{r}^{x}+\sum_{l=1}^{L}\left(V_{infs}\right)_{l}\times C_{l}^{x}\\&-\sum_{m'=1}^{M}\left(V_{Ssa}\right)_{m'}\times C_{m'}^{x}-\sum_{s=1}^{S}\left(V_{dao}\right)_{s}\times C_{s}^{x}\\&+\sum_{t=1}^{T}\left(V_{dai}\right)_{t}\times C_{t}^{x}-\sum_{f=1}^{F}\left(V_{ET}\right)_{f}\times C_{f}^{x}\end{aligned}\tag{7}$$

All the concentrations for a substance identified in these equations by the superscript x are expressed in the same units, while the subscripts refer to the components of the quantitative WRMB. Equations 6 and 7 are applied, in succession, for each quality parameter of interest.

For all other terms it is necessary to determine the qualitative parameters according to a uniform methodology. This raises the issue of which parameters are relevant for defining the quality of certain components of the balance, especially of those pertaining to the surface and ground water resources. After looking into the existing practice in considerable detail and analysing the quality of the water resources in many countries, we recommend the WHO guidelines (Barabas, 1986). These guidelines are observed by 113 countries which have signed an agreement concerning the monitoring of surface and ground water quality in an attempt to overcome the current water quality and environmental pollution problems.

Water quality parameters are designated as either basic or specific. The basic parameters are important regardless of the proposed use of water (Table 2). Specific parameters are those parameters which are important when water is used for a specific purpose (Table 3). For example, the concentration of boron is important when water is used for irrigation purposes, while it is not important when water is used for certain industrial purposes. Of course, besides boron there are other parameters which are important when referring to irrigation (sodium, potassium, chlorides etc.); they are not listed in the group of specific parameters since their analysis is planned within the scope of the basic water quality parameters. In contrast, the basic water quality parameters are important for all water uses, particularly for conserving aquatic life.

Table 2. Basic water quality parameters

PARAMETER	FOR AVAILABLE AND WITHDRAWN WATERS		
	rivers	lakes and reservoirs	ground water
alkalinity	+	+	+
bicarbonates	+	+	+
biological O_2 demand (BOD)	+	+	
calcium	+	+	+
chlorides	+	+	+
chlorophyll		+	
colour	+	+	+
dissolved oxygen	+	+	+
electroconductivity	+	+	+
flow	+		
free ammonia	+	+	+
free CO_2	+	+	+
magnesium	+	+	+
nitrates	+	+	+
nitrites			+
odour	+	+	+
orthophosphates	+	+	
pH value	+	+	+
transparency		+	
potassium	+	+	+
sodium	+	+	+
sulphates	+	+	+
temperature	+	+	+
total phosphorus	+	+	
total suspended matter	+		

The division into specific parameters, or parameters which are a function of the use of water, can be done in a different way, however, care must be taken to include those parameters which are of importance in a given situation.

Table 3. Specific water quality parameters

PARAMETER	FOR AVAILABLE AND WITHDRAWN WATERS		
	rivers	lakes and reservoirs	ground water
water supply of settlements			
total coliform bacteria	+	+	+
faecal coliform bacteria	+	+	+
arsenic	+	+	+
cadmium	+	+	+
chromium	+	+	+
lead	+	+	+
mercury	+	+	+
selenium	+	+	+
cyanide	+	+	+
fluorides	+	+	+
total OC compounds	+	+	+
dieldrin	+	+	+
aldrin	+	+	+
DDT	+	+	+
copper	+	+	+
iron	+	+	+
manganese	+	+	+
zinc	+	+	+
phenols	+	+	+
oil and grease	+	+	+
detergents	+	+	+
humid substances	+	+	+
radio-activity	+	+	+
irrigation			
boron	+	+	+

5. Evaluating the surface water resources management balance

5.1 Water quantity

This section refers to the basic procedure for evaluating each term in the quantitative water resources management balance equations given in Chapter 4. These equations contain all the parameters which effect the quantity of surface water within a Water Management Unit Area, including all the water withdrawals and discharges, and the exchanges between surface water and ground water pools within the WMUA. The terms on the right hand side can either be measured directly or estimated using standard techniques. These equations imply that water quantities need to be evaluated at each data collection station (see Section 3.5).

$$\sum_{n=1}^{N}(\Delta V_s)_n = \sum_{i=1}^{I}(V_{ins})_i - \sum_{j=1}^{J}(V_{outs})_j + \sum_{c=1}^{C}(V_{dis})_c - \sum_{e=1}^{E}(V_E)_e - \sum_{k=1}^{K}(V_{ws})_k - \sum_{l=1}^{L}(V_{infs})_l + \sum_{m=1}^{M}(V_S)_m \tag{2}$$

$$\sum_{i=1}^{I}(V_{ins})_i = \sum_{v=1}^{V}(V_{inp})_v + \sum_{w=1}^{W}(V_{inr})_w + \sum_{x=1}^{X}(V_{ina})_x + \sum_{y=1}^{Y}(V_{int})_y + \sum_{y'=1}^{Y'}(V_{in})_{y'} \tag{4}$$

$$\sum_{w=1}^{W}(V_{inr})_w = \sum_{w=1}^{W}(K_r)_w \times (P)_w \tag{5}$$

As a part of the analyses carried out after raw data have been collected, some basic statistical processing must be done to compensate for the stochastic nature of the natural hydrological processes. This requires some elementary data synthesis prior to the computation and subsequent assessment of the WRMB.

In a WMUA which as a rule does not represent a uniform watershed in the hydrological sense of the word, the available surface water in terms of quantity and quality is defined in space "j" and time "t" based on:

- the measured values of mass flow (quantity and quality) at the inflow and outflow of the RDCS located on natural and artificial watercourses;

- the quantity of water which appears in the form of runoff formed from precipitation, sources on the surface of the "j" area itself and from areas which gravitate towards region "j";
- the quantity of water that is lost through evaporation from all aquatic media (watercourses, lakes, ponds etc.) within the "j" area;
- the quantity and quality of the water accumulated in, or discharged from, river channels, reservoirs and other aquatic media;
- the quantity and quality of the water artificially transferred from area "j" to a neighbouring or distant area, or vice versa (water transfers), which were not measured at the RDCS; and
- the quantity and quality of water infiltrating the ground water in a given area "j" which cannot be measured and must be estimated using modelling techniques.

V_{ins} and V_{outs} and V_{outsm} and V_{outsnm}

The quantity and quality of water at the RDCS of natural and artificial watercourses (V_{ins} and V_{outs} and V_{outsm} and V_{outsnm}) is usually determined based on measurements and observations performed, processed and made available by the hydrometeorological service. The state hydrometeorological service should follow standard procedures for flow and quality measurements. It is usually necessary to use the "typical discharge curves" (the up-to-date curves are established by doing periodic hydrometric measurements of the water level changes as a function of the discharge for the whole range of expected flow conditions at the studied station) and the daily water levels. If a profile (station) is located in a zone with a varying flow regime (backwater or depression), the discharges for such profiles are determined by parameter or module discharge curves, using data about the water levels at the upstream and downstream stations. For smaller watercourses, such as various types of spillways, it is possible to determine the water quantity using other methods (such as the volumetric method).

The water quantities at the RDCS along the boundaries of the WMUA are usually obtained by measuring the individual flows and discharges. This is done by hydrometeorological institutions responsible for a given territory. If data on water flows and discharges cannot be obtained for a given station, then the data have to be collected (observed, measured or estimated adequately) by those responsible for the preparation of the WRMB using standard methods (stage discharge curves, hydrometric measurements, comparative analyses with data from nearby stations etc.). At those stations where the flow regime varies considerably, continuous-flow measurement devices should be installed and data should be collected continuously.

For each station, the average daily discharge (flow) is determined and the database should allow for the computation and reporting of average weekly, monthly and annual flows, as well as the corresponding minimum and maximum values. Even though the water level data is not strictly a component of the WRMB, it should be collected since it can be used for different control computations and boundary conditions for the computations carried out as a part of the WRMB. The data sheets for each RDCS should also contain the total quantities of annual, seasonal, monthly, weekly and daily discharge and the corresponding average, minimum and maximum values (see Appendix B). If an RDCS does not coincide with the location of the existing hydrometric profile, then the water flow at the hydrometric profile is transferred to the inflow profile by hydrological-hydraulic methods.

V_{inp} and $(K_r)_w$ and P_w

The runoff which flows directly into watercourse and other aquatic media V_{inp} is the product of the amount of precipitation for a given area and the corresponding runoff coefficient for that area, $(K_r)_w \times P_w$. The amount of precipitation is determined by data obtained from precipitation and hydrometeorological stations, as well as those from isohyet maps for daily, weekly, monthly and annual sums of precipitation. The runoff co-efficients are determined from the measured precipitation and runoff data for the previous period. The quantity of precipitation which falls directly on a water surface, V_{inp}, is determined for a given WMUA, as the product of the precipitation data (obtained from at hydrometeorological stations and isohyet maps for daily, weekly, monthly and annual periods) and the area of a given water surface.

V_s

The quantity of water from a given spring, V_s, is determined by measuring of the individual spring yield. Such measurements should be carried out at least 6 times a year. For major springs it is necessary to establish gauging stations so that good quality data on spring yields can be obtained continuously.

V_E

The loss of water due to surface evaporation, V_E, is determined using data from representative station evaporation pans situated at characteristic locations within a given WMUA. However, if no such data are available, evaporation is then determined using empirical formulas based on meteorological data (temperature and air humidity, wind characteristics, partial water vapor pressure and so on).

V_{ina} and V_{int}

The transfer of water from V_{ina} or to V_{int}, refers to the amount of water which is transported to a distant area (or areas) by gravitation or by pumping through artificial water conduits (pipelines or canals) which can stretch over several WMUAs. The quantity of transferred water is determined using measuring devices with continuous recordings at the water intakes of all the water conduits.

ΔV_{nms} and ΔV_{ms}

The amount of water which is temporarily stored in, or released into, river channels, lakes, reservoirs and other aquatic media is calculated from direct measurements at the inflow and outflow points. It can also be determined separately on the basis of volume curves of the aquatic media and corresponding water level changes in the aquatic media.

V_{ws}

The amount of water withdrawn from surface water in a given WMUA, V_{ws}, is determined by direct measurement at each water withdrawal point. These measurements should be automated using standard instruments to provide continuous collection of data. The many different purposes for which water is used in all forms of human activity reflect the large number of required parameters for analysing this component of the WRMB. However, considering the quantity and the required physico-chemical characteristics of water for different uses, this component of the WRMB can be studied by investigating the major uses of water. These include water captured for use in:

- settlements;
- industry;

- agricultural (irrigation, cattle breeding etc.);
- fisheries; and
- energy production (thermal, nuclear, hydro).

In principle, this captured surface or ground water should be recorded at the point where it is captured. These measurements and the collection of data should be systematically organised.

V_{dis}

Similarly, the amount of water which is discharged into surface water, V_{dis} , is determined by direct and continuous measurement at each water withdrawal point. The term ‘discharged water’ refers to all water which, after having been captured and used, is returned to surface water, in part or fully. This term includes water which is collected from drainage systems, settlements and other surfaces prior to being released either by gravitational means or by pumping through stations into surface flows and other aquatic media. It is clear that part of this water might originate from underground (drainage) waters. The discharged water should be registered as belonging to one of the following categories:

- municipal waste water;
- industrial waste water;
- waste water from cattle farms;
- water from drainage systems;
- water from fisheries;
- water from power plants (thermal, nuclear); or
- other discharged water.

For these seven types of discharged water, the quantity and quality is measured directly at the outlet from the plant, that is immediately downstream of the waste water treatment plant (if there is such a system and if it works).

V_{infs}

The amount of water lost from surface water due to infiltration, V_{infs}, cannot be measured directly. This value is also used in the balance equation for ground water resources and must be estimated. There are a number of estimation techniques in the literature, most of which are based on mathematical models whose calibration and verification is required for each particular application. The same estimation technique should be used for all WMUAs, so as to reduce the amount of error due to estimation.

5.2 Water quality

Water quality evaluation needs to be carried out for all terms of the general balance equation except for the evaporation term. Samples of water should be collected using standard sampling procedures while analyses should be performed using standard analytical methods (WHO or AWWA Standard Methods). The general water quality parameters specified in Chapter 3 should be analysed for all the samples. For water discharged into surface water, additional analyses should be performed for specific water quality parameters which depend on the type of the water discharge (municipal, industrial, agricultural and so on).

Sampling frequencies should correspond to the temporal variation of the water quality for a given term in the balance equation and the quantity discharged at a given station, but it should never fall below one sample per month. Table 4 is a general guide to the number of samples necessary for evaluating the quality of discharged water. Sampling frequency for surface water has been given in Section 3 (Table 1). The quality of precipitation should be monitored on an event basis; each precipitation event being sampled and analysed. The quality of the water lost due to infiltration is the same as the water quality in the corresponding surface water body and does not need to be evaluated.

Table 4. Frequency of effluent sampling

Amount of waste waters at the outlet (in litres/sec.)		Waste waters with hazardous material		Other waste waters	
from	*to*	*N*	*frequency*	*N*	*frequency*
1	50	3	in 3 months	3	in 4 months
50	100	6	in 2 months	4	in 3 months
100	500	12	a month	6	in 2 months
over	500	24	a month	12	a month

N=number of samples per year

Quality of waste water should be tested at every outlet and before the waste water is mixed with the water of the recipient. Samples are taken at more or less equal time intervals, but at different waste water discharge regimes. A sample is considered to be the two hour composite sample obtained by mixing the content of the captured water every 15 minutes over a period of two hours.

The specific water quality parameters are determined for each pollutant separately because they depend on the type of pollutant. As for the analysis of some characteristic parameters for certain pollutants, it must be said that there is no uniform practice for the time being. The convention is to use the list of parameters compiled by an authorised institution which does the analysis and by representatives of the companies producing the pollutants, in co-operation with the governmental inspection. To introduce more order into this field, it will be necessary to determine the characteristic parameters that need to be analysed for each polluting substance.

Once water quality analyses have been performed, a set of statistical values should be computed. By using average values in conjunction with the corresponding data for flows, the mass flows for each pollutant can be calculated in accordance with the qualitative balance equations given in Chapter 4.

In order to close the water balance of an area and check the data obtained, the water quantity and quality values measured at the inflow and "control" profiles of natural and artificial watercourses should be compared and analysed for discrepancies. All disagreements must be accounted for prior to final storage of the data and WRMB reporting.

All the standard forms for collecting and reporting are appended to the guide. These forms have been designed for use in Yugoslavia and are given here as an example of what typical forms should look like. These forms include information which may seem excessive, and modifications can be made if necessary. However, practice has shown that all the mentioned data are necessary at some time during the planning and management of water resources.

6. Evaluating the ground water resources management balance

6.1 Introduction

An analysis of terms in the general WRMB equation for ground water resources (defined in Chapter 4) shows that as far as these resources are concerned, the only measurable quantities are those for water discharged by freshwater springs V_{Ssa} and pumped for some kind of use V_{wg} All other terms in the general balance equation need to be estimated using one of the many available techniques. Most of the available methods are based on mathematical models of ground water flow for a given water resources balance unit. V_{Ssa} and V_{wg} should be measured in a manner similar to the way in which analogous terms for surface water are measured. Readers are referred to the previous section for a description of the methods for measuring surface water.

6.2 Water quantity evaluation

Analyses of the ground water regime and the ground water balance need to be evaluated differently for various aquifer structures which depend on the local hydrogeological and hydrological conditions. The following procedures are generally used:

- For unconfined ground water aquifers in alluvial planes and on river or lake terraces, the hydrodynamic method is used, with mathematical modelling of the ground water flow in a two layer media.
- For confined and unconfined aquifers in the region of neogen basins, the hydrodynamic method is also used, but this time the ground water flow is modelled for multi-layer media.
- For dispersed, fractured and karst aquifers in hilly regions, the hydrological method is used; involving statistical and stochastic methods of analysis for spring yields in a given territory, particularly if the aquifer is formed from carbonaceous rocks (i.e. chalk and marble).
- For small fractured aquifers in hilly regions, the hydrological method is used at the time that surface water balance is evaluated.

Since this is a general methodological guide the models of ground water flow in porous media are not evaluated. Instead, the basic principles of the hydrodynamic and the hydrological methods of ground water flow analyses are presented. In doing this, special attention is devoted to boundary conditions for parameter estimation, model calibration, and data modelling requirements, as well as the systematisation of data collection and analysis.

In order to analyse and develop a ground water balance, it is essential to have field data on the characteristics of the aquifers, especially data about the lithological and chronostratigraphical structure of the profile obtained from field investigations. It is also important to do geomechanical, sediment and palaeontological investigations of soil samples; geo-electrical probing and electro-sounding of drilling holes; seismic investigations; and investigations of well yields by test pumping. Complete analysis include data on the observed ground water levels, on the infiltration of surface water, on the evapotranspiration and evaporation from water surfaces and soil, on the amount of captured ground water for all types of water use, and other meteorological data from the observed area.

6.2.1 Hydrological and hydrodynamic schematization of an area

The basic principles for the schematisation of a given area are:

- The geometry of an aquifer, its filtration characteristics, its semi-permeable deposits and the representative parameters of a ground water flow are estimated using specific studies designed for this purpose. The best possible description of the hydrogeological and hydrological characteristics of a given area are also prepared.
- All the available data should be used for hydrodynamic and hydrological schematisation of a given area. The data are usually collected by geophysical studies (geo-electric testing, drilling etc.), research drilling, petrographical and palaeontological research and other methods of core analyses, as well as by the chemical and laboratory analyses of ground water. All these methods should be used in the schematisation of a given area.

The geometric and hydrodynamic schematisation of an area thus requires a three-dimensional definition of the water-bearing strata, as well as a clear definition of the spatial distribution of parameters which the model uses to describe the filtration characteristics of a porous media, be it an aquifer or the semi-permeable layers above or below it. The basic filtration parameters are: (a) the coefficient of filtration, K, (measured in m/sec.); and (b) the effective porosity, as a non-dimensional characteristic, of the media (symbolised by μ).

The vertical schematisation (with respect to depth) should extend only as far as the usable ground water resources. The separation of the different water-bearing layers from the semi-permeable or non-permeable layers in between is carried out using the boundary anisotropy principle. The integration of more than one aquifer into aquifer complexes can be done only if the long-term exploitation of ground water resources leads to a hydraulic connection between the relevant aquifers. If this is not the case, then each aquifer should be treated separately.

The horizontal schematisation of an area depends on the type of mathematical model that is used and the numerical integration method implemented for the solution of the ground water flow equations. The density of the schematisation must also be adjusted to the available data on the geometry and filtration characteristics of the aquifers as well as to the dynamics of the ground water flow and available boundary conditions. The density usually increases with time as more and more data become available.

6.2.2 Determination of the boundary and initial conditions

To solve a system of differential equations which describe an unsteady state ground water flow, it is necessary to know the set of boundary and initial conditions. Initial conditions depend on the type of aquifer under consideration and are determined in accordance with the following:

- the distribution of piezometer levels at time $t=t_0$, which represents the beginning of hydrodynamic computations in the x-y-z coordinate system, for each aquifer, where

$$H_{i,1;t=t_0} = h_{i,1}^{k-1} \quad \text{for each field or network node} \qquad \textbf{(8)}$$

- the distribution of free water levels in the semi-permeable confining layer over the aquifer at time $t=t_0$ in the x-y-z coordinate system, where

$$H_{i,1;t=t_0} = h_{i,1}^{k-1} \text{ for each field or network node} \qquad \textbf{(9)}$$

The boundary conditions for ground water flow problems may be either external, when they define the flow conditions at the boundaries of the studied area or internal, when they define the flow conditions at characteristic points within the water resources balance unit. External conditions can be further defined as one of the following:

- hydrological (e.g. river stage for rivers whose bottom cuts into the aquifer) of the following type, where

$$H_{i(t)} = H_i^g(\mathrm{t}), \ \mathrm{i} = 1,2,3... \qquad \textbf{(10)}$$

- geological (e.g. aquifer boundary for which the water inflows into the aquifer are known), where

$$T_i \frac{\partial H}{\partial n} = q_i^G \quad \mathrm{i} = 1,2,3.... \qquad \textbf{(11)}$$

with G representing the boundary of the relevant area $\frac{\partial}{\partial n}$ the first derivative along and the line perpendicular to the boundary plane.

A special case of this boundary condition arises if the boundary is a non-permeable layer and in such a case,

$$T_i \frac{\partial H}{\partial n} = 0 \qquad \textbf{(12)}$$

Internal boundary conditions are also subject to further specification where different factors concerning the ground water system are in play (e.g. irrigation and drainage canals, ground water extraction fields and similar). For example, when considering the water level in a canal, the bottom of which cuts into the aquifer's semi-permeable confining layer, the equation, $h_{i(t)} = h_{i\,(t)}^{k}$ is used. In the case of ground water extraction, where water is held within confining layers, the formula applied is $Q = g(t)$, where $g(t)$ represents the time distribution of a well's capacity or the inflow of water from the confining layers of the well to the aquifer.

6.2.3 Determination and preparation of the hydrodynamic and hydrological parameters for ground water flow models

The basic hydrological and hydrodynamic parameters which should be determined for each WMUA on the basis of the data collected in the field are:

- elevation data for aquifer boundaries and semi-permeable layers, and the surface elevation data for shallow aquifers recharged by surface infiltration and subject to loss from evapotranspiration;
- filtration co-efficients for each aquifer;
- piezometric water levels and free water levels in the semi-permeable layer immediately above the aquifers;
- hydrological and climatological data, such as stream, river and canal water levels, evaporation from a free water surface, and evapotranspiration data; and
- biological data (vegetation cover data).

6.2.4 Calibration of the mathematical models

Model calibration and parameter estimation are two essential processes which must precede the quantitative model analysis of the ground WRMB computations. The mathematical model calibration must also precede any ground water regime simulation for any given year. This process is implemented by reverse computations, using the method of diminishing differences between the model predictions and the observed piezometric water levels at a redefined set of observation stations. During this process, the hydrodynamic and hydrological parameters are adjusted within realistic limits for those unit areas and nodes for which accurate estimates and measurements are not available.

A mathematical model can be considered calibrated if the computed results do not differ from the observed values by more than ±10% of the maximum annual amplitude of the water level oscillations in the piezometric water levels.

6.2.5 Output data and feedback from modelling efforts

Mathematical model outputs must provide the data required for computing the WRMB in accordance with the basic relevant general balance equation. The water balance elements (in & out) should be reported for each WMUA and should include:

- initial piezometric water levels and free water levels within the aquifer boundary layers;
- piezometric water levels and free water levels at the end of each computation period;
- free water levels at the start and end of each vegetation period (seasonal) or at the end of each month or computation period;
- precipitation infiltration and evapotranspiration data;
- horizontal water balance for each aquifer (inflow and outflow);
- vertical water exchange rates between different aquifers and for semi-permeable confining layers below and above the aquifer; and
- ground water withdrawal rates for each category of ground water use.

6.2.6 Data requirements for the analysis of the ground water regime and ground water resources management balance

Basic data requirements

The basic data required for the analysis of the ground water regime and the ground water resources balance consist of information provided by suitable hydrogeological maps, showing the geometric and filtration characteristics of a WMUA, as well as information obtained from the set of historical data available for all ground WRMB elements. Other data can be obtained from field work and includes research drilling, exploitation wells, geophysical investigations and laboratory analyses.

Research drilling

The following data should be provided for each drilling:

- drilling identification (location, purpose, internal id, year of drilling etc.);
- co-ordinates and surface elevation at the drilling point (if the piezometric structure has been installed);
- depth of drilling;
- lithological and stratigraphical profile of the drilling hole;
- diameter and depth of installation of the piezommetric structure, (the depth at which the filter is installed should be recorded separately);
- depth of the first occurrence of ground water at the time of drilling, the static water level and the date the record is taken; and
- data about the samples collected for laboratory analyses, as well as the relevant piezometer testing data.

Research and exploitation wells

Besides the data required for research drilling, the following additional data is also required:

- diameter of the drilling and the diameter of the well structure;
- depth at which the filter is installed and the interval of the gravel layer installation; and
- other relevant data on well testing.

Geophysical research

The data required from geophysical research includes:

- type of research carried out (geoelectric tests, geoelectric mapping, electro-sounding of the drilling experiments, seismic tests etc.);
- time span during which the research was carried out;
- geoelectric, seismic and other relevant profiles and maps; and
- geophysical electro-sounding of the drilling halls especially to depths of approximately 250 m.

Laboratory analyses

- granulometric analyses / particle size distribution;
- water permeability data; and
- chemical analyses of ground water.

6.2.7 Data on systematic observation and monitoring

- precipitation (daily data from existing stations);
- air temperature and humidity (daily data from existing stations);
- evaporation from free water surface (data from existing stations);
- daily data on infiltration and evapotranspiration obtained from lysimeter stations;
- stream and river water level (water levels at the existing stations);
- data on ground water exploitation for all kinds of purposes including the data on artesian well discharges (for all withdrawals exceeding 50 l/sec., the daily data on the water withdrawals is also necessary; for smaller withdrawal rates, monthly data is sufficient and for artesian wells, annual data can be used);
- data on the existing drainage systems that are being used (drainage area, drained quantities of water, water volumes collected with timely - daily data);
- data on the piezometric water levels for those aquifers where the general WRMB is being computed (weekly data is required for free and subterranean aquifers in alluvial planes up to 500 m from the stream, while bi-weekly data on water levels are sufficient for distances in excess of 500 m; for aquifers in the neogen basins, bi-weekly water level data are also sufficient; all these data should cover a period of at least one hydrological year); and
- data on the spring yields (daily data, or springs with yields in excess of 50 l/sec.; for springs with yields from 10 to 50 l/sec., weekly data is sufficient, while monthly data are regarded as sufficient for those springs with yields lower than 10 l/sec.).

6.3 Water quality

The water quality evaluations must be done for all the aquifers included in the balance equation. The samples of water should be collected using standard ground water sample collection procedures and the analyses should be performed using standard analytical methods (WHO, AWWA). The general water quality parameters, specified in Chapter 3, must be analysed for each samples. The frequency of sampling for water quality analyses should correspond to the temporal variation of the water quality in a given aquifer and it usually amounts to one sample per month.

Once water quality analyses have been conducted, the set of statistical values generated should be used in conjunction with corresponding data on flows to compute the mass flows for each pollutant, in accordance with the qualitative balance equations given in Chapter 4. As for the analysis of water quantity, all the standard record forms for water quality data are provided in the appendices.

7. Integrated water resources management balance

When developing an integrated WRMB, spatial and temporal scales and the general balance equations are the starting point of the analyses. For the spatial scale, the hierarchical structure of spatial segregation given in Chapter 3 must be used and care must be taken to adequately consider the physical characteristics of runoff processes and the topography of the area analysed. The smallest territorial unit for evaluating water resources is the Water Resources Assessment Unit Area (WRAUA) which is formed by a group of Water Management Unit Areas (WMUA) defined as:

A geographic area which encompasses the watershed of a relatively small stream or part of the watershed which represents a water resources unit suitable for water resources planning. The size of the WMUA depends on the degree of hydrographical development, the topography of the terrain and the size of the country and its administrative division. In accordance with past experience such a balancing unit should have an area anywhere between 500 and 2000 km^2.

When the WMUA is a part of a larger watershed, the interdependencies between neighbouring WMUAs are accounted for in the corresponding balance equations through the corresponding V_{in} and V_{out} terms and through the application of the principle of continuity (Figure 19a). All the analyses are carried out from the uppermost region and along the water flow. The outflow from the upstream WMUA is, at the same time, the inflow to the downstream WMUA, and these quantities must be equal. This means that the boundary Reference Data Collection Station (RDCS) is same for both WMUA.

In principle, when developing an integrated surface WRA for one or more WRAUA, a clear record must be kept of all the "internal" components of the balance equations (water withdrawals, water discharges, losses, and so on). While for inflows and outflows, only data from the boundary RDCS need be considered in the balance equations (inflow and outflow) as is shown on the water balance record sheets in Appendix A. A similar approach can be used in dealing with WRA at the 3rd and 4th levels of territorial hierarchy if the territory analysed is within the same hydrological system (major watershed).

When conducting WRA for ground water the procedure is practically identical with the added constraint that hydrogeological continuity must be satisfied. The only limitation which may occur is related to the application of mathematical models for the analyses and their limit on the complexity of the system analysed. The usual practice is to do the analyses for area units which are of a similar hydrogeological characteristic.

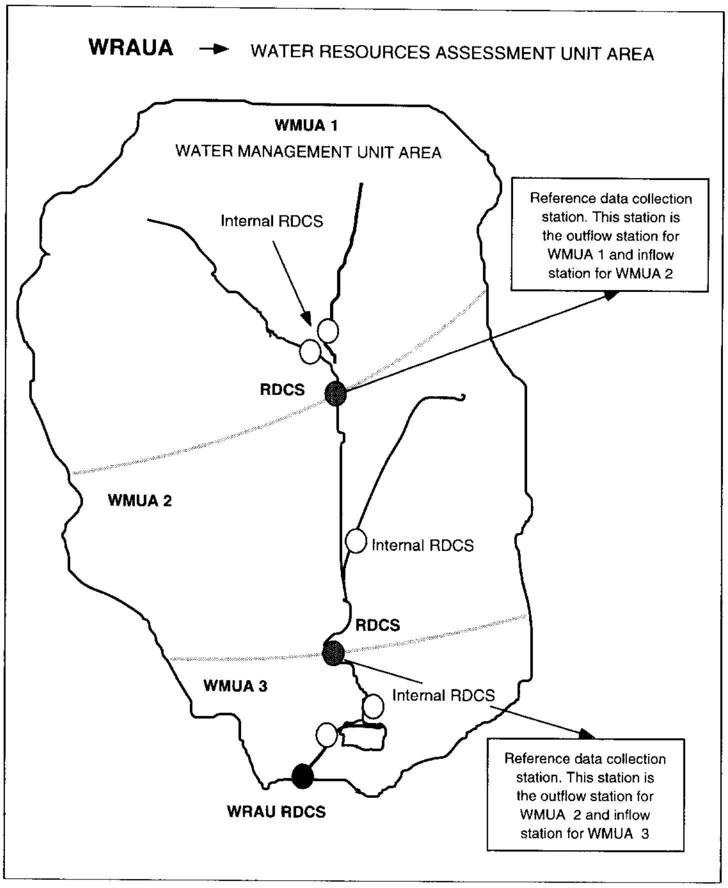


Figure 19a. Integrated WRA - WMUA - principle of continuity

From the territorial point of view it would be best if the integrated water balance was given for one watershed (in the hydrological sense). This enables the definition of available water in time and space, in terms of both quantity and quality, and with sufficient reliability. This would make it possible to view the real capacity of a given watershed, to meet the existing demand in the given watershed and to meet the demand outside of the considered watershed.

When a WRMB is required for relatively small regions which do not represent watersheds from the hydrological and hydrogeological points of view, the precision with which the water resources are evaluated is brought into question, thereby compromising the entire water resources balance.

Although the basic time unit for calculating an integrated WRMB (see Chapter 2) is one day, the variability of discharges and water consumption, and the fact that a water resources balance is developed for relatively wide areas, make it essential to analyse the components of a water balance for longer time intervals. Depending on whether the realised or planned WRMB is being calculated, and because of the occurrence of water resources is of a stochastic nature (i.e the realised water intake or planned demand is different for various spheres of use), a WRMB must be made for long time intervals (week, month, season, year, decade). Using the daily values processed for a WMUA as the starting point and given the data provided by long-term analyses of WRMB parameters, it is possible to get good information about the present and future likelihood of meeting the demands put on water resources.

Within the scope of these analyses it is essential to emphasise that the likelihood of meeting demands must be considered by analysing a number of parameters such as the possibility of satisfying needs, in terms of both quantity and quality; demands with respect to the duration of an interruption, generally caused by meeting a demand; and demands from the point of view of the frequency of interruptions in meeting the demands.

These parameters are especially important when considering the management of the water regime in conditions of an insufficient reliability of meeting the water requirements. Not all water users can tolerate supply deficiencies of a different probability equally. For the sake of giving an example, in conditions when there is a shortage of water, there can be short interruptions in the water supply to settlements, but not long ones. Contrary to this, some industrial consumers (such as the steel industry) cannot survive short and frequent interruptions, but can support a complete interruption for longer periods of time, if this is planned in advance. Some consumers can reduce the amount of water they use but cannot tolerate any interruptions and so on. This suggests that all data concerning the parameters of a water resources management balance must be made available. The complete data set, when it is readily available, enables proper operational management, sufficient planning and timely implementation of all the investment and operational measures designed to protect our water resources and our environment.

8. Non-point sources of pollution and water resources management balance

8.1 Introduction

In conducting the water resources assessment, non-point sources of pollution need to be considered with the same attention as point sources. In previous chapters, a detailed discussion has emphasised the role of quantity and quality as essential elements of the WRMB, however, the impact of non-point sources of pollution on the WRMB has not been discussed so far. In this section we discuss those aspects of non-point source pollution which are of importance for WRMB computations and for water resources assessment.

The general equations presented in previous sections provide for the impact of non-point sources of pollution in the equation terms for precipitation and runoff. Measurement and estimation techniques for these have already been discussed. In this section we address those aspects which relate to the necessity of separating the impact of non-point sources of pollution from that of natural water resources loading. This is necessary in order to provide adequate data for planning and management of water resources for the benefit of the end users.

8.2 Evaluation of non-point source pollution of water resources

In contrast to the assessment of point sources of pollution for which it is possible to determine the location, the time of occurrence and the quantity and quality of discharged waters, in the case of non-point sources of pollution this is not usually possible. Non-point sources of pollution include all those sources which are spatially dispersed, such as:

- precipitation polluted by constituents in the atmosphere (air pollution impact);
- fluvial erosion of soil;
- runoff from non-seaward urban communities;
- runoff from unprotected solid waste landfills;
- runoff from agricultural lands polluted by fertilisers and other agricultural chemicals;
- discharge from seepage septic tanks; and
- discharge from construction sites, open pit mines and similar areas.

Even though some of these sources of pollution could be classified as point sources (septic tanks, for example), it is not convenient to do so because of their relative magnitude, their large number and their spatial distribution. Furthermore, differences exist between the two types of pollution source (Table 5) and these differences require that "apparent point sources" be classified as non-point sources of pollution.

The relative magnitude of non-point sources of pollution is permanently increasing and is becoming more significant for water quality assessment. According the Water Encyclopedia (1990), 15% of water resources in the USA falls below the quality standard because of pollution from non-point sources.

To evaluate the magnitude of this type of pollution, a number of different methods can be used. These methods range from relatively simple empirical estimation techniques to highly complex systems approaches which rely heavily upon mathematical modelling. In preparing a water resources balance, pollution from non-point sources should be evaluated for each WMUA, thus requiring a significant amount of specific data. Which data will be collected is a function of topography and other characteristics of the WMUA. In principle the data which needs to be collected do not differ from the data for point sources of pollution. The following categories of data should be included:

- hydrological data (collected in accordance with the discussion in previous sections);
- water quality data (collected in a manner similar to point sources, event based intensive sampling and analysis); and
- data on possible sources of pollutants (location of landfills and septic tanks, use of pesticides and fertilisers).

Most of these data are usually collected for planning and assessment purposes anyway. However, these data need to be analysed in a specific way in order to determine the loading due to non-point sources of pollution. From the WRA point of view, non-point sources of pollution are of special importance because their relative magnitude may have a significant impact on water resources planning and management decisions.

Table 5. Differences between point and non-point sources of pollution

Characteristic	Point sources	Non-point sources
water discharge, flow	relatively stable; variability rarely exceeds one order of magnitude	- highly unstable, of stochastic nature; variability a few orders of magnitude
degree of dependence on hydrometeorological and climatic factors	almost independent of hydrometeorological and climatic factors	- highly dependent on hydro-meteorological and climatic factors, especially the amount of precipitation
source of pollutants	originates from spatially concentrated human activities; highly predictable production activities, urban activities etc.	- originates from unconfined areas due to unpredictable events; - consequence of natural phenomena; due to a limited extent to human activities (landfills, septic tanks)
major water quality parameters	BOD, oxygen, suspended solids, nutrients, metals, toxic substances etc.	- sediment load (erosion), nutrients, heavy metals (urban runoff), humid substances and other organic matter, pH, pesticides

In the general water resources management balance equation for a given WMUA, non-point sources of pollution are included in the terms for calculating quantitative and qualitative data concerning runoff and precipitation (V_{inp}, V_{inr}, K_r, P, and the corresponding water quality parameter concentrations). Data record sheets for information concerning non-point sources of pollution are provided in Appendix B. In some cases, this information may not be sufficient and mathematical modelling, or empirical estimation techniques relating the use of agricultural chemicals and their subsequent loss to water resources, may be necessary. These methods are beyond the scope of this guide, but the literature abounds with the description of methods and techniques for estimation of non-point source pollution.

9. Assessment of the present and future water demand

9.1 Introduction

This chapter deals with the calculation of the present and future water demand of different users. The demand should be computed and analysed for the same territorial units described for the analysis of water resources. If there is to be any planning and management of water resources in an area in the future, it is essential to have data on the characteristics of the available water resources and on the water demand because all the planned solutions should meet the present and future water demand. There are two ways the water demand can be analysed: one approach uses data on water uses in the past and then forecasts the future demand based on the obtained results; and the other uses computations of empirical relationships and experience from other areas.

The first approach requires long-term data on the use of water in the observed territory since this would make it possible to analyse the increased consumption trends and then the forecasted demand. Unfortunately, in most cases there is no such data (this very methodology is a result of such a situation) and, as such, the first method can rarely be implemented. Consequently, the methods for the analysis of trends and the implementation of these methods will not be discussed. Given instead are some possible empirical procedures that can be used for computing the present and future water demand. These include the assessment of population and settlements, industry, agriculture (especially irrigation, livestock breeding, and fisheries), and power production plants.

9.2 Water demand in settlements

The water demand in settlements depends on a number of elements such as:

- economic development (standard of living);
- how developed the water supply and sewage system are;
- the public services;
- the number of major and minor industries connected to the water supply system;
- the price of water;

- the climate in the area where the settlement is located; and
- the regime and conditions for exploitation.

To analyse all these factors in all the settlements found in a water area, it would be necessary to have data on the standard of living and the habits of each population, as well as data concerning the exploitation regime in each settlement, the manner in which water consumption is measured and charged for each settlement, the development of public services, and so on. Even when such data are available, the question remains open as to how much the analyses would help to precisely determine the true water demand since it ranges between very wide limits (Table 6).

Table 6. Average water consumption for various cities around the world

City	Population	Average consumption per capita per day
Amsterdam	870.0	177
Athens	1800.0	128
Barcelona	1660.0	262
Belgrade	740.0	248
Bern	170.0	400
Birmingham	1287.0	655
Bratislava	258.5	348
Brno	322.8	259
Bordeaux	254.0	310
Brussels	1187.4	132
Copenhagen	710.9	215
Dublin	726.0	227
Edinburgh	468.0	275
Essen	731.0	188
former East Berlin	1065.0	293
former West Berlin	2177.0	186
Glasgow	1050.0	369
Hamburg	1853.0	191
Helsinki	517.0	404
Istanbul	1600.0	156
Leipzig	585.4	194
Lisbon	900.0	160
London	6249.5	263
Madrid	2426.3	305
Milan	1671.4	530
Moscow	6300.0	600
Munich	1165.8	337
Oslo	485.6	593
Paris	2811.0	500
Plsen	141.0	320
Stockholm	805.0	375
Torino	1100.0	360
Vienna	1550.0	300
Warsaw	1222.0	235
Zagreb	518.0	175
Zurich	444.0	443

This is why the following empirical relationship is most often used in practice to determine the water demand in settlements:

$$Q = K_p K_m \left(k_d q N + Q_i\right) \tag{13}$$

where:

K_p is the coefficient denoting consumption for the treatment of water etc.;

K_m the coefficient denoting the water loss in the water supply network ;

k_d the coefficient denoting the changes in the mean daily consumption during 1 year;

N the number of inhabitants in a settlement at the present time or in the future;

Q_i the required reserve amount of water for extinguishing potential fires in the settlements; and

q the specific daily water consumption per capita which depends on most of the factors mentioned in the introduction to this chapter. It is determined based on the analysis of the water consumption in the past and on a comparison of the water consumption in other inhabited areas in the world.

Table 7. Water required for different non-industrial activities

Activity	Unit of measure	Requirements
Apartment cleaning	l/cap/day	3-10
Bakery	l/worker/day	150-250
Bathing	l/cap/day	20-40
Beaches	l/visitor/day	150-200
Car washing/bucket	l/car	20-40
Car washing/hose	l/car	100-200
Clothes washing	l/cap/day	20-40
Dish washing	l/cap/day	4-6
Drinking and cooking	l/cap/day	3-6
Drinking-large animals (small)	l/animal/day	50-200 (10-40)
Hospitals	l/patient/day	250-600
Household grass irrigation	l/m2/day	5-10
Personal hygiene	l/cap/day	10-15
Schools	l/pupil/day	10
Shopping centre with restaurants	l/user/day	500-1000
without restaurants	l/user/day	100-400
Spas	l/patient/day	150-180
Storage	l/user/day	250-400
WC	l/cap/day	20-40

The future number of inhabitants can be calculated using the following formula:

$$N = N_a(1+0.01p)^n \qquad (14)$$

where:

N_a is the present number of inhabitants;

p the parameter denoting the birth rate; and .

n the number of years for which the number of inhabitants needs to be calculated

To understand the value of this specific consumption, we shall give an analysis of the water consumption standards for different types of water uses in inhabited areas and an evaluation of the total water demand based on experience and analyses carried out in the former Soviet Union, the USA and Germany (Tables 7-9).

Table 8. Water use for different types of apartment

Type of water use	Needs (l/cap/day)		Coefficient of hourly variation
	average annual	max daily	
Apartments with water, sewerage and:			
no other installations	125-150	140-170	1.5-1.4
gas	130-160	150-180	1.4-1.35
service buildings, with hot water using solid fuel	150-180	170-200	1.3-1.25
service buildings, with hot water gas heated	180-230	200-250	1.3-1.25
service buildings, with hot water centrally supplied	275-400	300-420	1.25-1.2
Apartments without public water supply and sewerage	30-50	40-60	2-1.8

Table 9. Water use for different activities

Water use category	l/cap/day	
	range	average
Personal population needs	57-265	190
Industry and trade	38-380	247
Municipal use	19-380	38
Service sector	38-76	95
Total	152-797	570

9.3 Various industries and their water requirements

An assessment of the present and future water demand by various industries largely depends on available data concerning present and future production in all fields of industry and on the assessment of the present and future water consumption per production unit in all branches of industry. All these parameters can change considerably depending on the investment and economic development dynamics in an area and the implemented technology in the production process, since it too can greatly influence the water consumption per unit product.

Table 10 gives some data on the water consumption per unit product in different parts of the world. The differences are obvious and can have a considerable effect on the total water consumption (i.e. total water demand in the coming period).

Table 10. Water consumption by manufacturing product

Product	Unit measure tonnes	Quantity of water m^3	Product	Unit measure tonnes	Quantity of water m^3
Bread	1	1-4	Fine paper	1	900-1000
Fruit juices	1	2-20	Paper for print	1	500
Packed meat	1	10-30	Wrapping paper	1	125-200
Butter	1	cca 20	Ammonium sulphate	1	800
Cheese	1	10-30	Calcium carbonate	1	125
Sugar (beet)	1	10-20	Magnesium carbonate	1	160
Beer	1000 litres	10-30	Soap, detergents	1	70-200
Distilled alcohol	1000 litres	30	Textile	1	30-250
Steel smelter	1	50-100	Automobile	1	38

The total water demand of various industries can be computed based on what has been said so far, using the following empirical relationship:

$$Q_i = \sum_{i=1}^{n} q_i P_i \tag{15}$$

where:

q_i is the specific water consumption per unit product "i" of the branch of industry expressed in m^3/unit product;

P_i the total daily production "i" of a branch of industry in a given area; and

i the type of industrial production in a considered area.

9.4 Agriculture and water demand

The most common uses of water in agriculture are related to irrigation for plant production, and consumption for livestock breeding.

9.4.1 Water demand for irrigation purposes

The water demand for irrigation purposes mainly depends on the size and characteristics of the soil suitable for irrigation, on the climate in the area and on the type of plants that are grown or will be grown in the area. The general empirical equation used for computing the required amount of water for irrigation is:

$$Q_{ir} = q_{ir} \frac{S}{K_s + K_a} \tag{16}$$

where:

S is the area suitable for irrigation, i.e. area that is irrigated or will be irrigated expressed in ha;

K_a the coefficient of water loss in the irrigation network;

K_s the applied irrigation system's coefficient of effectiveness; and

q_{ir} the specific water demand expressed in m^3/(month/ha).

The specific water demand depends on the climatic conditions, plant evapotranspiration, water reserves of the soil, ground water level, and the empirical methods used for computing reference evapotranspiration values. The general equation for determining this quantity of water is as follows:

$$q_{ir} = (ET_c - P_e) \times 10 - (R_i - R_f) - H \tag{17}$$

where:

$$ET_c = ET_0 \times K_c \tag{18}$$

and where:

ET_c is the evapotranspiration of the plants that are grown in mm/month;

ET_0 the reference evapotranspiration in mm/month;

K_c the plant factor;

P_e the effective precipitation in mm/month which depends on the total precipitation, runoff conditions and the infiltration, and it is determined experimentally;

R_i the water reserves in the ground which can be used in the beginning of the computation procedure , expressed in m^3/ha;

R_f the water reserves in the ground at the end of the computation period in m^3/ha; and

H the possible ground water input in the water supply in m^3/ha.

The effective precipitation can also be calculated using empirical relationships or tables recommended by FAO.

9.4.2 Water demand for livestock husbandry

The water requirements for livestock raising depend on the type of livestock that is involved, the feeding technology and the maintenance of the livestock farms. The following equation can be used for determining the required quantities of water in this field:

$$Q_s = k_d(q_k N_k + q_s N_s) \tag{19}$$

where:

k_d is the fluctuation coefficient of the mean daily water consumption during the year;

q_k the average daily water consumption per head of meat cattle l/day;

q_s the average daily consumption of water per sheep and goats l/day;

N_k the total number of meat cattle that is raised; and

N_s the total number of sheep and goats.

9.5 Water demand for tourism

The water demand in tourism and sports depends on the type of facilities on offer, on the climatic conditions, on the time of the year and on the number of individuals using the facilities. The general equation for calculating the water demand in this field is :

$$Q_t = k_d q_t N_t \tag{20}$$

where:

k_d is the fluctuation coefficient of the mean daily consumption during the year;

q_t the average daily consumption per individual; and

N_t the average number of tourists who use the facilities.

9.6 Other water demands

Besides the water demands mentioned so far there are of course others, the most important probably being the demand for cooling thermal and nuclear power plants. The water required for these structures is determined for each individual case separately since it entirely depends on the capacity, climatic conditions in the area location, technical solutions pertaining to the cooling system, and the exploitation regimens of these structures. This is why empirical formulae for computing the water demand are not given for these types of structures.

10. Geographical information systems for water resources assessment

10.1 Introduction

The care of water resources and environmental protection are without doubt important subjects and are worthy of any efforts of management and preservation. For water resources assessment (WRA) and for planning, including management and administrative activities, the use of information and communication capabilities is of paramount importance. The experts know that the communication problems caused by insufficient tools and equipment must be improved in order to bring environmentally-sound development and sustainable management of water resources into reality.

Geographical information systems (GIS) provide a major tool which can improve the efficiency and quality of WRA. Furthermore, GIS can benefit greatly by taking advantage of new developments in distributed computing provided by new network architecture models now being provided by the hardware manufacturers. Particular attention should be devoted to operating systems, hardware CPUs and communication networking software.

In the previous sections we discussed the procedures for WRA and the data needs related to these procedures. It was pointed out that large amounts of data need to be collected, stored and analysed for the purposes of the WRA. What is even more important is that raw data which are collected must be turned into information, since it is the information content of data which is important for WRA and water resources planning and development.

Planning, management and administration of water resources is not possible without information and it is information technology which turns data into information. However, thosesame data may not provide the same information to different individuals. The outcome very much depends on the way the data are handled. This section deals with information technology and the ways in which it can be used to aid WRA. Most recent developments in information technology which are suitable for use in WRA are those developments related to GIS.

GIS is a broad, complex and rapidly-evolving technology highly suitable for spatial and temporal data analyses and information extraction. Dueker (1990) defines a

GIS as a special type of information system in which a database consists of: (1) observations on spatially distributed features, activities or events; and (2) procedures to collect, store, retrieve, analyse, and display such geographical data.

Berry (1987) and Tomlin (1990) specify that a GIS serves both as a tool box for data analyses and as a database. As a tool box it allows planners and managers to perform spatial analyses using its geoprocessing and cartographical modelling functions such as data retrieval, map overlay, conductivity and buffer. As a database, a GIS provides the possibility of linking spatial, textual and numeric data to a georelational model for data query and retrieval.

Other authors (Burrough, 1987; Yapa, 1991; Starr & Estes, 1990) have also given definitions of a GIS. All these definitions are similar and point out the connection between spatially-distributed data and the ability to analyse this data while retaining its geographical features. This is a basic prerogative of the WRA information system. Thus, a GIS is the most suitable tool box for analysing water resources data and evaluating WRA. A major advantage of GIS technology is that it has the potential for improving our understanding of water resources development.

Successful GIS implementation requires system design, prototyping, pilot studies, and organisational leadership. It should be mentioned that geoprocessing has finally become a reality with the advent of database oriented GIS in the early 1980s. The trend today is towards distributed computing environments allowing networks of servers, workstations and peripheral devices to be linked together and shared by many users. The backbone of the whole system is a series of application tools and protocols that allow these heterogeneous devices to be connected together and communicate with each other.

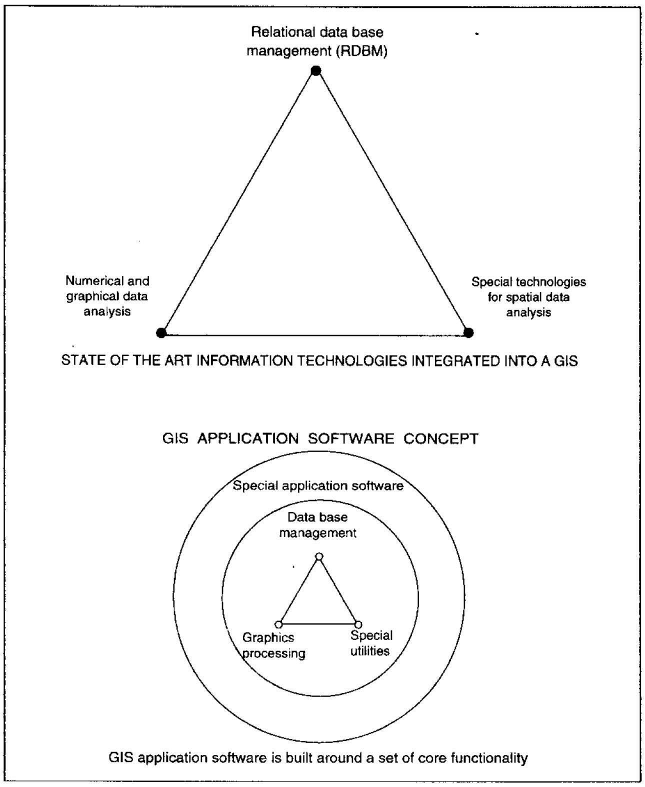
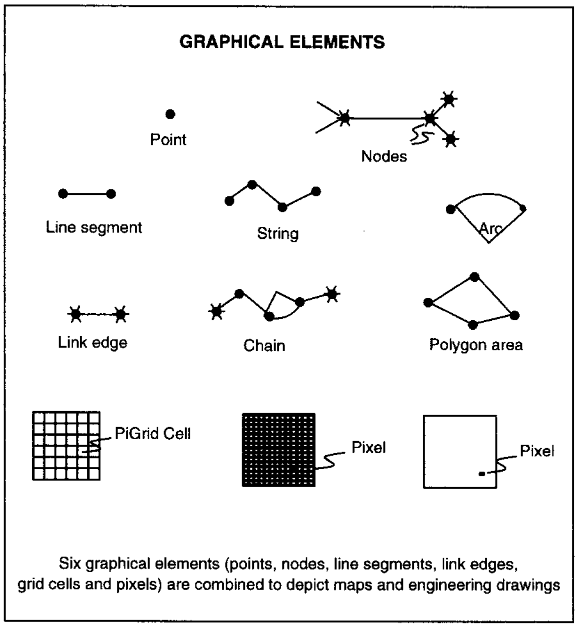


Figure 20. State of the art information technologies integrated into GIS

10.2 Overview of GIS for WRA

Since water resources engineers and managers are not always familiar with the terminology from information technology it is first necessary to present the general terms often used in the GIS. Terminology most often used in GIS is outlined in this section.

Each GIS system consists of software and hardware elements making possible the collection, storage, retrieval, segregation, manipulation and management of diverse data categories. GIS technology is characterised by the three components of modern information technology (Figure 20): (1) database management technology; (2) numerical and graphical data analysis and presentation technology; and (3) technology for spatial data analysis.


GRAPHICAL ELEMENTS

Six graphical elements (points, nodes, line segments, link edges, grid cells and pixels) are combined to depict maps and engineering drawings

Figure 21. Graphical elements used in GIS

GIS technology develops procedures for complex analyses of spatial attributes and generation of graphical and/or statistical data about the resources over a given territory. For these reasons, the basis of any GIS system is a database about geographical features or about the attributes of these geographical features (usually resource data). Spatial or geographical data include the location of the resource, while the attribute may be its quality, quantity or description.

Data base design is therefore the most important aspect of a GIS system and each database consist of two major groups of data: (1) geographical data; and (2) non-geographical data. Each of these categories has unique features and each requires specific conditions for collection, storage, analysis and management. Cartographical data are used to transfer maps into a digital form. To do this the modern computer technology uses eight different cartographical elements that may be stored in a digital form as vectors or as raster of uniform quadrants or pixels (Figures 21 and 22):

point a non-dimensional object determining geometric location in a given coordinate system;

node	a spatial type of a point, non-dimensional object identifying a connection between two other elements or an end point of a given element;
line	a one-dimensional object;
string	a series of line segments;
arc	a series of points forming a curve which can be defined by a mathematical function;

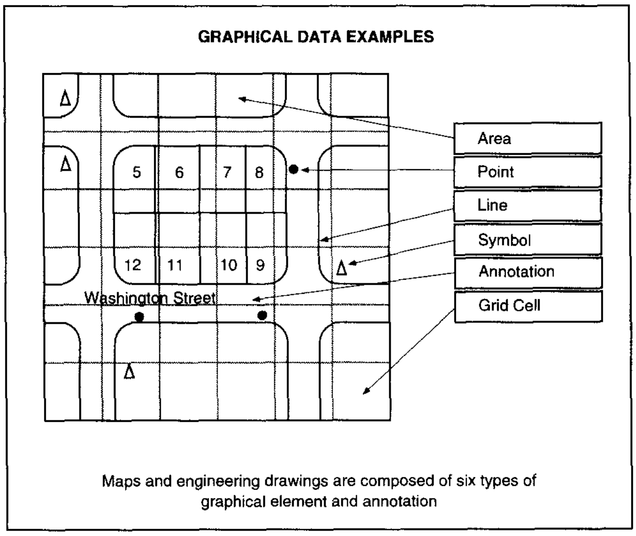


Figure 22. Maps and engineering drawings are composed of six types of elements and annotations

chain	a sequence of line segments or arches which do not cross with a node at each end;
area	a closed continuous two-dimensional object which can but does not have to include its borders; and
pixel	two-dimensional element of a picture which is the smallest possible element.

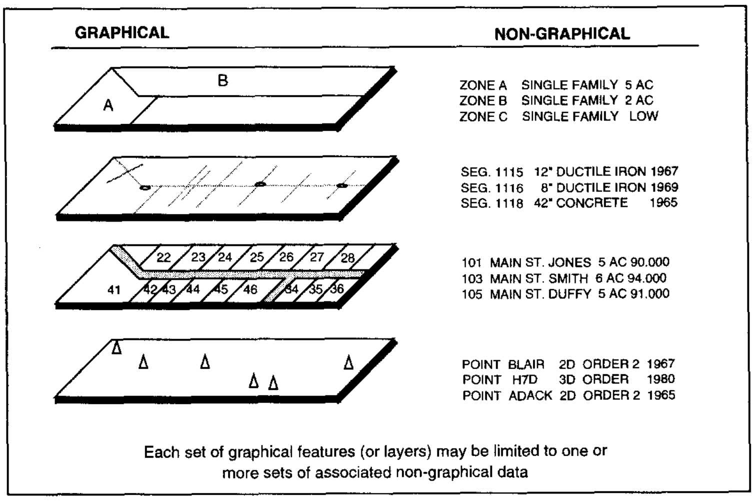


Figure 23. Graphical and non-graphical data

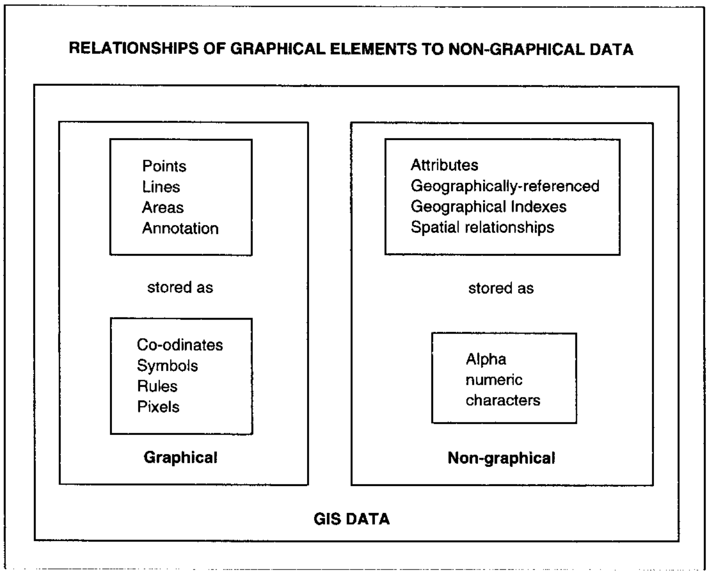
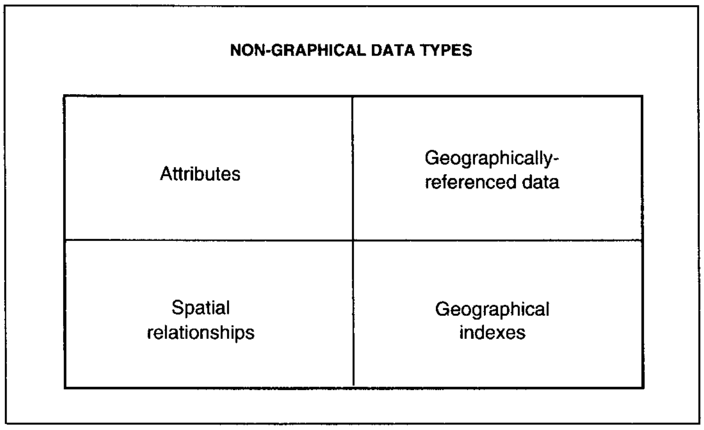


Figure 24. Graphical and non-graphical data are stored and manipulated in different formats for efficient processing

Non-cartographical data describe the characteristics of graphical elements or the occurrence and/or intensity of attributes at a given geographical location. Figures 23 to 25 give an overview of cartographical and non-cartographical data. It is important to note that careful attention must be devoted to the quality of the data to be used with the GIS technology.



NON-GRAPHICAL DATA TYPES

Attributes	Geographically-referenced data
Spatial relationships	Geographical indexes

Figure 25. There are four types of non-graphical data

When dealing with cartographical data, quality is measured by the accuracy of the location as represented on a map. Two types of location accuracy can be differentiated: relative location accuracy, which considers whether the distance between two objects on the same map is accurate; and absolute location accuracy, in which each object on the map must be correctly located in a given co-ordinate system and its location must accurately reflect the real life situation. The quality of data largely depends on the scale of the map chosen for data collection. Figure 26 shows the effect of map scale on the accuracy of data.

To develop a GIS for WRA, it is therefore necessary to first select the scale of the maps to be used in the analyses. As has been mentioned earlier, a WMUA should have an area of approximately 2,000 km^2, thus the map scale of 1:100000 is sufficient.

After procurement and transition into the GIS technology occurs, the ultimate success and the ability of the system to provide the decision makers with quality information depends, in part, on the quality and usability of the data that resides in the system.

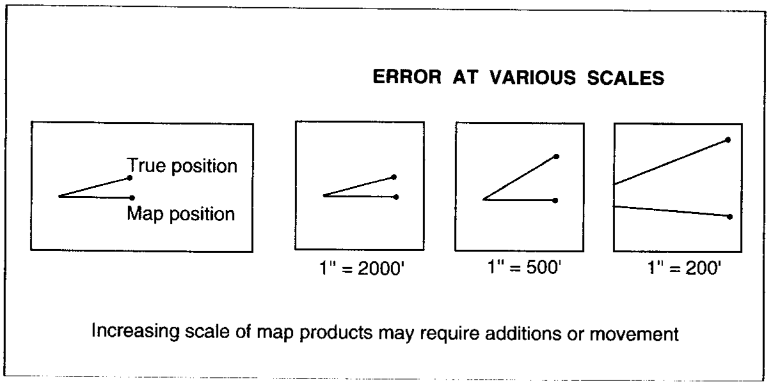


Figure 26. Error at various map scales

A systematic approach to GIS implementation involves assessing user needs and requirements, developing the database design around these needs, and testing the design in a pilot study before full implementation. Some of the major factors that influence GIS system design include the data needs of the applications that will be developed, and the availability, format and integrity of the existing data required to support these applications. In addition, the design process must anticipate the needs for updating and maintaining the eventual size of the database, the hardware platform and its configuration, the number and sophistication of the users and the organisational structure of the users, including budget and management support.

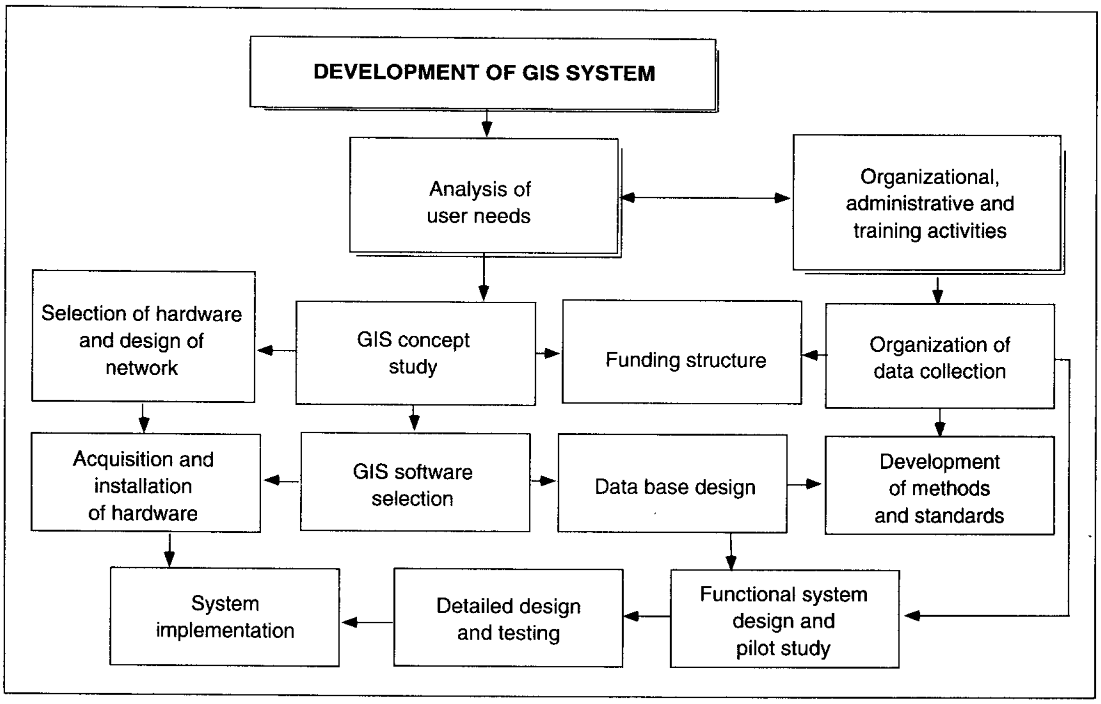


Figure 27. Development of a GIS system

Whether one deals with a small or large organisation, GIS system specification (initial identification of requirements and constraints) should be completed. This step can be simple or complex, informal or formal, but it must be done. The database design that results from this step will be based on real needs and the final database will support, more efficiently, WRA in the future.

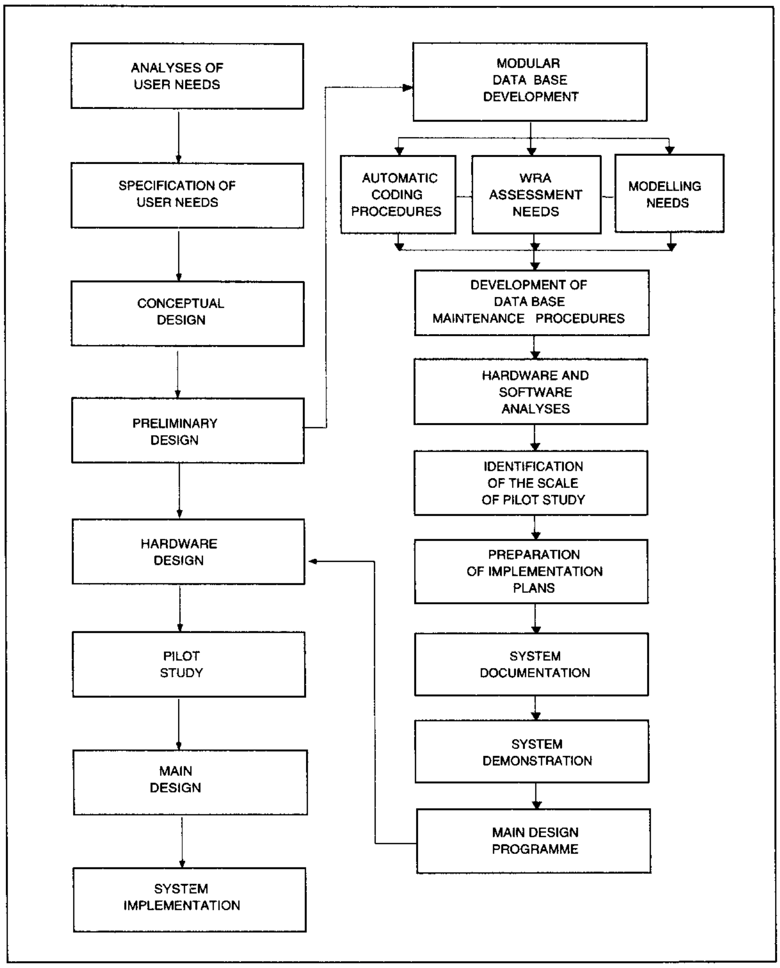
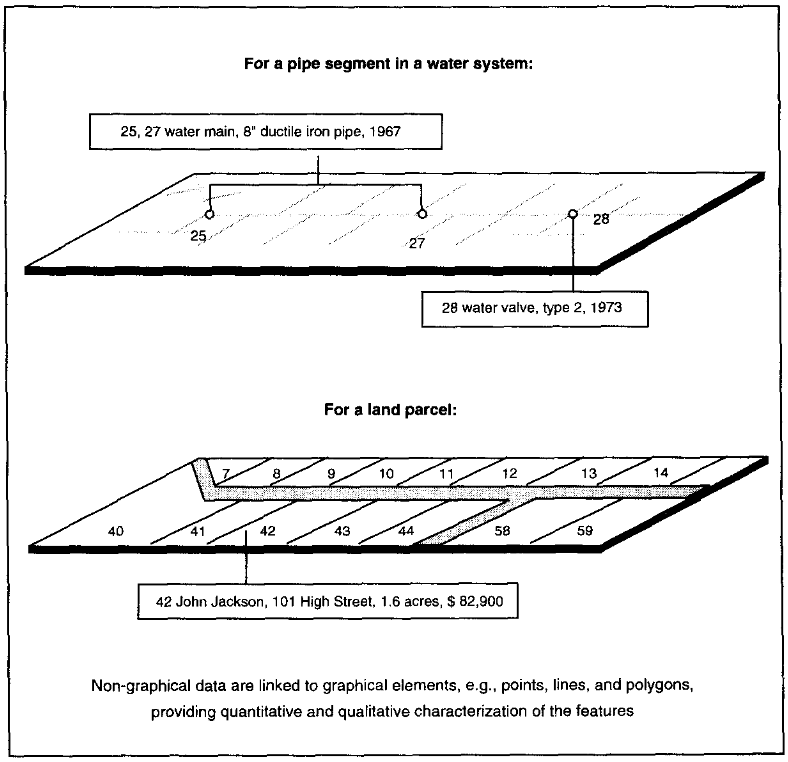


Figure 28. Data base and GIS system design procedure

10.3 What needs to be designed

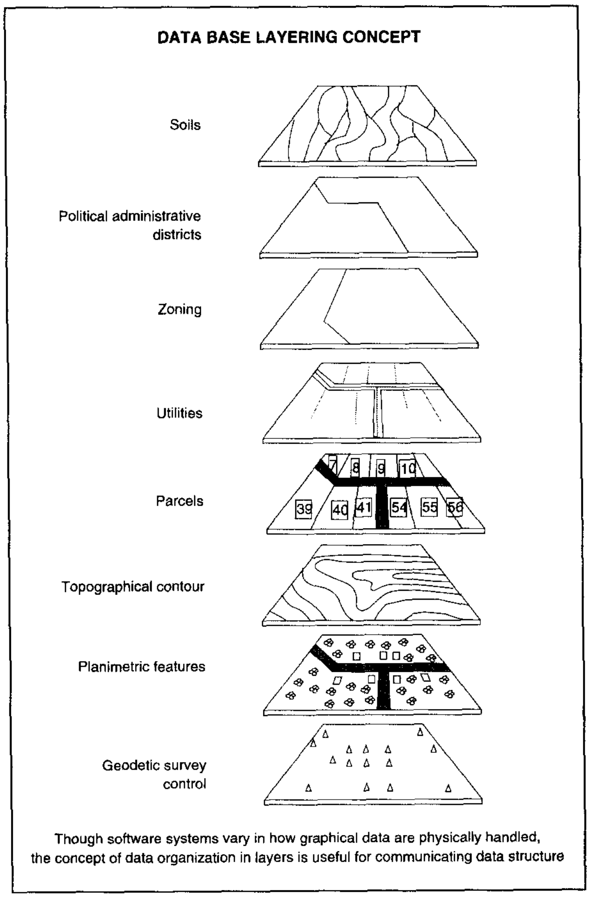
The sequence of activities in the development of a GIS system is shown in Figure 27 and a typical database design procedure is shown in Figure 28. In this guide, we will discuss only the primary parts of the design procedure as they relate to a GIS for WRA. The five primary components in this context are:

- cartographical layers;
- feature attribute tables;
- lookup tables;
- annotation series of layers; and
- tiles with relational indexes.



Non-graphical data are linked to graphical elements, e.g., points, lines, and polygons, providing quantitative and qualitative characterization of the features

Figure 29. Map features and attributes



Though software systems vary in how graphical data are physically handled, the concept of data organization in layers is useful for communicating data structure

Figure 30. Data base layering concept

Integration of attributes (Figures 29 to 30) ensures high performance, particularly for operations dealing with updating and spatial clipping. In developing a GIS system for WRA it is necessary to implement a highly-structured process and to include all the components of the water resources management balance (Figure 31). In the design stages it is important to realise that the design process is iterative. Data base design is the foundation of the whole system and the cost of development and maintenance very much depends on an efficient database design.

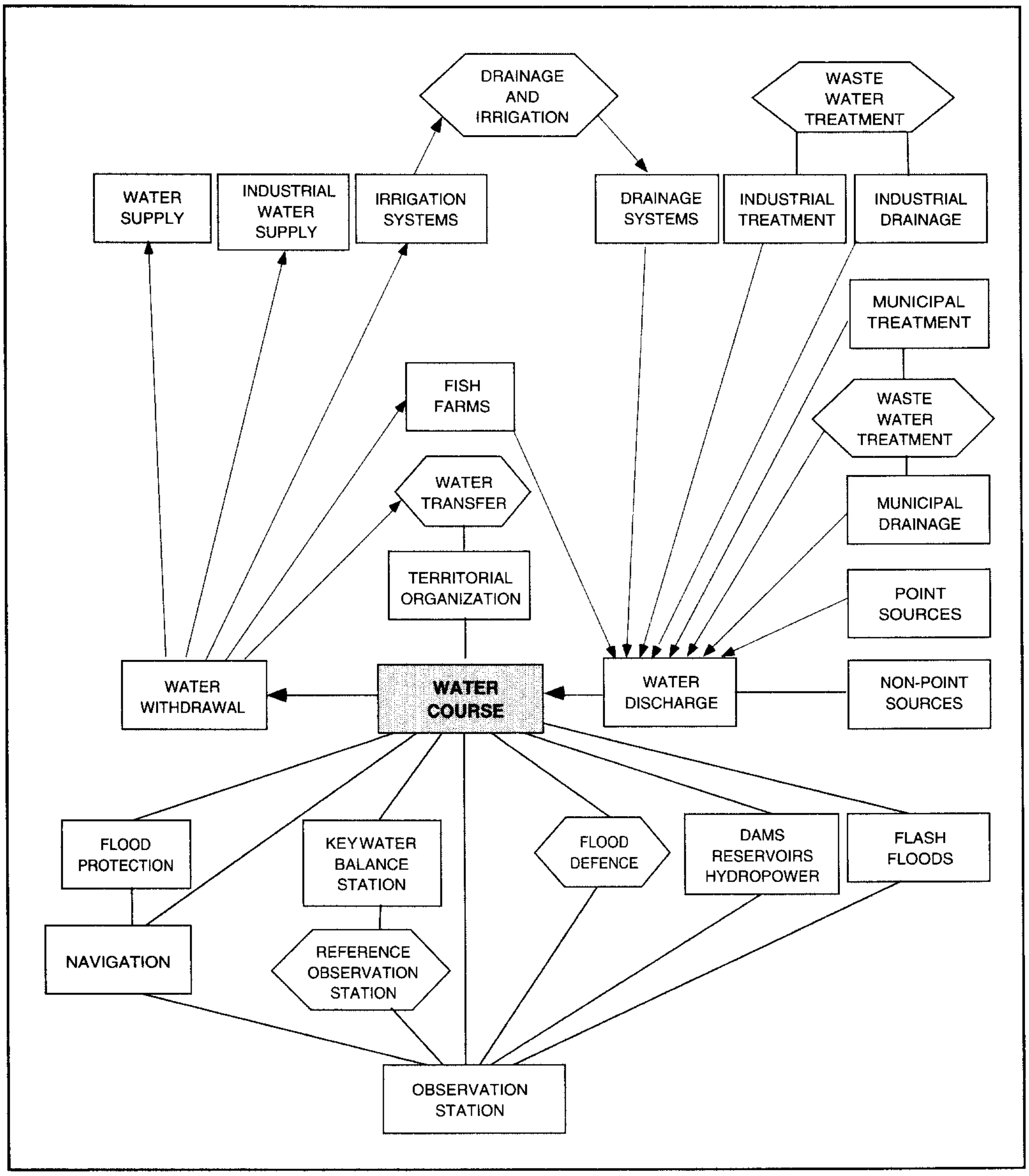


Figure 31. Components of the WRA data base for GIS implementation

The whole process of database design must be well documented and should include a standard terminology and a thesaurus which form an integral part of the database. Besides these, the documentation should contain diagrams and descriptions of the concept and the content of each cartographical layer, of the source of data for each layer, and of the data collection procedures.

10.4 RDBM system and documentation

Another major component of a true GIS is the relational database management system (RDBM). Many powerful and efficient database management systems are available in the marketplace, such as ORACLE, INGRES, Informix, SYBASE, and DB2. Ease of data exchange between these systems and the inherent product flexibility makes it possible for users to manage their data in multiple databases, while retaining full transparent access across those databases and among different machines.

A true GIS has a relational database interface that allows users to access information directly from the GIS. Because of this flexibility, users are not restricted to any particular or proprietary database model, database management system, or hardware technology. It is difficult to overstress the importance of adequately documenting the database design and subsequent implementation efforts. As a minimum, documentation should include a comprehensive data dictionary with descriptions of all items and codes for each layer. The data dictionary should be implemented on line and linked directly to the database.

Beyond the data dictionary, documentation may also include diagrams and discussions explaining the concept and content of each layer and map library, data sources for all layers and attributes, and implementation procedures including processing tolerances.

10.5 Pilot study

WRA database design and implementation, more often than not, require modifications when tested under production conditions. As a result, a pilot study is strongly encouraged. Pilot studies in this case are the implementation of the database design, sometimes referred to as a prototype, over limited geographical areas. They yield several benefits, including the following:

- testing of the physical database design performance;
- development of procedures for performing tasks under production conditions;
- identification of obstacles to system implementation;
- development of specifications for contracting data collection and loading efforts; and
- yielding timely results or products for management presentations and gaining continued management support.

If the design process has been followed carefully and if sufficient attention has been given to documenting each design stage, the pilot study should operate with few complications. There are, however, a few further guidelines to be followed:

- a sample site should be representative of the entire study area, exhibiting a full range of complexity;
- applications should be well defined and should be completed over a 3-6 month period;
- a peer review of the results should be carried out with major users of each layer and application type; and
- peer review comments should be documented and integrated in the final database design.

10.6 Layer design

When developing a GIS implementation for WRA, there should be three basic layer types and two variations. Basic layer types are polygons (WMUA, WRAUA, watersheds, sub-regions, regions etc.), lines (streams, street center lines etc.), or points (RDCS, point sources etc.; see Figure 31). Variations on these layers include network coverages that contain polygons and lines (such as rivers, roads and blocks) and link coverages containing lines and points (such as river confluences, and stream networks). Many factors influence which data sets should be combined into layers. Two of the most important are data to data relationships and data to function relationships. There are four principal methods for capturing data to data relationships:

- pre-automated data preparation (where data are integrated into one layer before digitising;
- creation and use of templates;
- automatic snapping of one feature to another; and
  copying and moving features from one coverage to another.

The establishment of procedures that manage and update these relationships automatically is both important and possible, and should be considered at the design stage. Some types of geoprocessing applications in an organisation may dominate others. The database design should reflect these priorities through well-defined data-to-function relationships.

10.7 Standards are a key to successful implementation of GIS

In the WRA and GIS world, industry-standard equipment is critical. This is because each user site has tailored its computer system to its particular needs by combining personal computers, workstations, minicomputers, mainframes, and a wide variety of peripherals. Without industry standards it is often difficult, and sometimes impossible, to tie these diverse elements into a cohesive, cost-effective computer network.

Proprietary systems, which do not adhere to industry standards, are problematic. For example, it may not be possible to run a certain kind of software or link a particular type of computer, plotter, or printer to such systems. An open system adhering to standards has far fewer limitations and enables users to maintain maximum flexibility in configuring their computer environment.

Adding new equipment to a proprietary system can also be expensive. Even though a new system may be more powerful than the existing system, the cost of implementing it may not be worthwhile, especially if the older, but still useful, equipment is made obsolete. When that happens, the original investment in the equipment is lost and users must be retrained on a new system. The overall costs of such a move makes many users think twice before moving to a proprietary system.

As information technology develops, we expect that a more open environment for creating integrated solutions will emerge. There will be growth in the recognition that specialised technologies should be used for what they were designed for and linked to other tools that have similar special purpose missions. Mainframe and mini computers, workstations and personal computers, can all work together and perform what they do best with modern hardware networks.

10.8 Hardware, software and operating systems

It is also important that hardware and software to be used for WRA satisfy certain general standards. This is important due to a fact that different groups of users will have different hardware and software platforms at their disposal but should nevertheless be able to use the system with ease. Detailed discussion about these standards is beyond the scope of this guide and the reader is referred to literature on the subject.

The trend in operating systems is towards the UNIX operating system. Because UNIX is now becoming a standard among most of the major manufacturers of hardware systems, the databases that are used by these systems can now be shared because of the communication protocols that are available.

10.9 Communications networking software

One of the major components of distributed network architecture is the communication hardware and software that actually tie the different system components together. Typically this is based on the Ethernet backbone which allows for the transfer of data and the application software from machine to machine. A number of communication protocols has also recently emerged, including the following:

- TCP/IP (Transport Control Protocol/Internet Protocol) - a very popular communications protocol on which NSF and many other useful network tools are built.
- NFS (Network File System) - a high level network service that provides transparent access to files on other disks located throughout the heterogeneous network.
- NCS (Network Computing System) - a network tool that allows an application to share the computing resources located throughout the network.

These communication protocols make it possible to have a database completely stored on, for example, a file server, while all other workstations in the system (almost independent of the manufacturer) can directly access these files. In other words, a parcel map stored on a file server can be readily accessed, displayed, and manipulated by another workstation that is hooked up to the network.

10.10 Tying it all together

The capacity to combine all of these technologies provides users with capabilities that heretofore did not exist. The idea of one central database that is non-redundantly stored and, thus, available to all users is becoming more of a reality. Geographical databases can now be maintained on distributed networks and those users who are responsible for their particular map and database components can still maintain those maps and administer them on their own file servers; yet individual users or multiple users who have requirements to use those data can share those databases across the network.

Although the technology exists today for the implementation of GIS technology across distributed architecture, this is not necessary for those in charge of the WRA who require effective information processing. At least as important as the actual hardware and software, are the issues of database design, database implementation, and organisational structure and co-ordination.

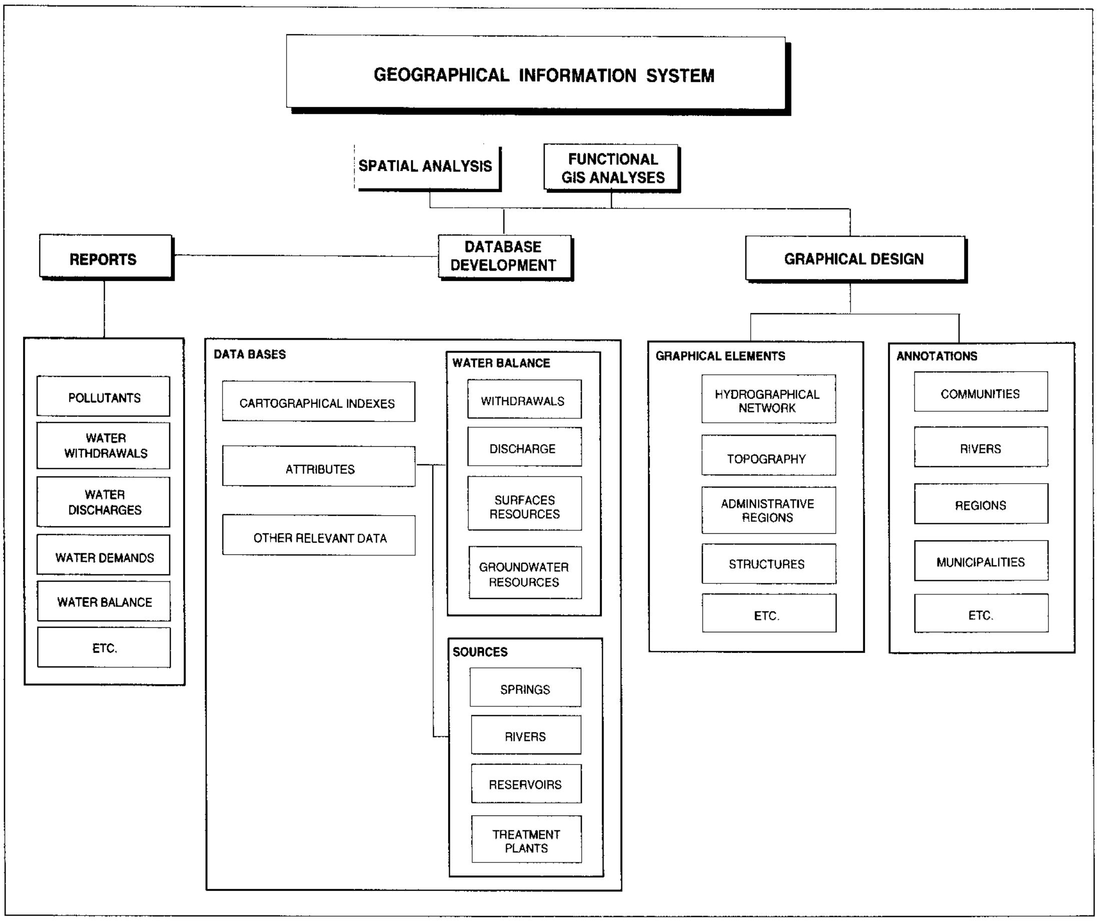


Figure 32. GIS for WRA schematic representation

The issues of database design and database organisation are critical to the ultimate success of the GIS. The issues of who is responsible for the management and maintenance of a database, especially when it is implemented on a distributed architecture, become critical aspects of the success of the system. All these issues must be thoroughly analysed before system implementation and should be designed into the total system structure. It is important to prototype the project using the technology which has been chosen and to test the database design and database management schema, prior to heavy investment in equipment. Through a pilot project, critical issues relating to database design and to technology implementation can be evaluated and reviewed, and improvements and adjustments can be made for the final implementation.

Problems arising in the design and implementation phases of the GIS system must be resolved efficiently. The role and responsibility of each component of the system must be clearly defined. Since WRA may be carried out over wide areas, it may be necessary for the GIS system to be implemented as a distributed system, with each center or network of centers having a clearly-defined role.

Organisational structure must be developed in such a way so as to provide users with easy access to the data and the system in general. At the same time, users should know who is responsible for collecting and entering data and how these data are expected to behave when the system is in use.

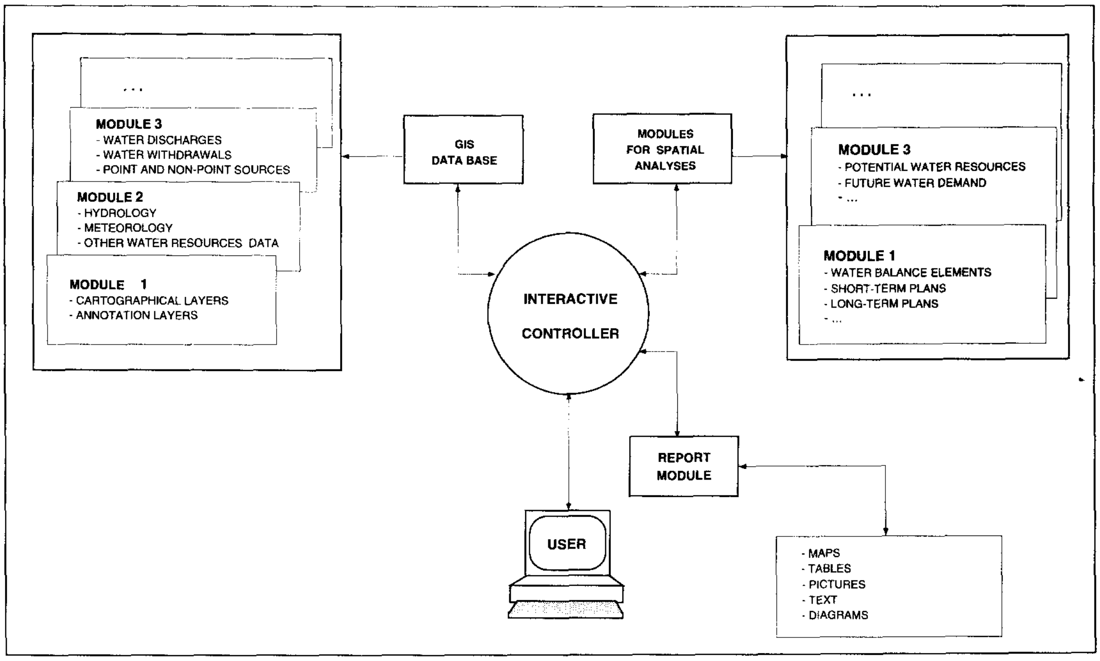


Figure 33. WRA GIS user interface and modular structure example

Figures 32 and 33 show a typical overview of a GIS system for WRA and a general user interface and procedure for accessing data. The system must be modular and easy to use. Hypertext and hypermedia concepts should be integrated as much as is possible to help design an adequate menu system for user access (see Figure 34).

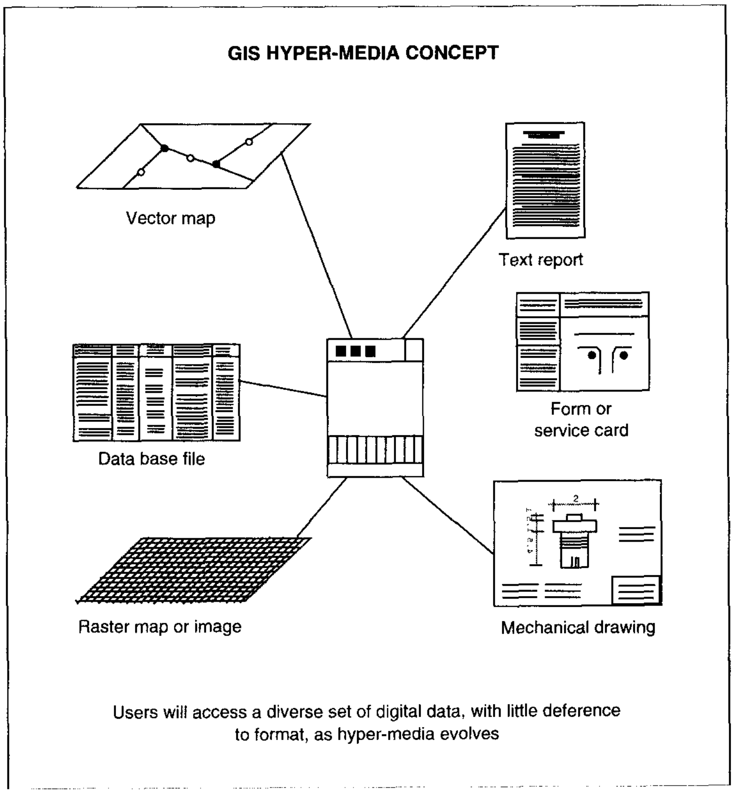


Figure 34. GIS hyper-media concept

11. Economic and environmental considerations in water resources assessment

11.1 Introduction

As is clear by now, water resources assessment is one of the basic planning tools for managing water resources. On the basis of such assessments thousands of decisions affecting the quality of the natural environment and the use of rapidly diminishing natural resources are made. The wisdom of decisions will be determined by the care and the methods we use to evaluate the alternatives. Organising, evaluating and interpreting information about the consequences of alternatives which are formulated on the basis of the WRA are the subject of this section.

Technical people working on water resources assessment should know the basics of the evaluation process so that they can provide the necessary information to decision makers. We address the evaluation process from the economic and environmental point of view and only in general terms. The reader is referred to a significant body of literature for more detailed aspects of these topics which we have summarised here.

Economic and environmental evaluations of public actions (almost all water resources development actions) available today range from non-existent or haphazard works to systematic and technically competent documents. Since the 1950s there has been a strong worldwide trend towards a more thorough assessment of public actions. As a result several evaluation methodologies have been developed of which cost/benefit analysis (CBA) has been the most notable. These methods help to clarify and to summarise, for decision makers, the complex considerations of proposed actions. Some of these methods have become elaborate technical procedures that themselves are difficult to understand for all but the trained analyst.

The technical style of evaluation that is prevalent in water resources management today contrasts sharply with the various styles of discussion and debate that dominated the field in past decades. The style of the past can be characterised as utilising broad, integrated, and shared knowledge that was implemented by the process of discussion, debate and compromise. In contrast to this, the technical style that many advocate today can be characterised as utilising deep, fractionated, unshared knowledge, implemented by written reports. A proposed public action is most often scrutinised in detail by highly-structured and quantifiable procedures made possible by advances in water resources assessment.

Clearly many of the problems in water resources today are the result of environmental rather than economic considerations. These problems are thus more complex, requiring careful analysis by trained technical experts. Increasing specialisation and the "knowledge explosion" seem to have put the average adult out of touch with the evolving body of scientific knowledge.

These factors, and others, have contributed to the changing style of evaluation. Whether they have necessitated the change, however is a different matter. There is no question that systematic evaluations are desirable, but there is evidence of growing discontent over the highly technical approach taken by most of the currently used evaluation methods, especially so when dealing with "intangible" environmental considerations.

11.2 Evaluation methods

Most proposed water resources development actions are complex, entailing many potential consequences of interest and concern to the public. To understand their possible implications as a whole is very difficult, and therefore a systematic evaluation of them proceeds, analytically, by dividing the whole into parts; each part being identified as a specific impact.

The number of separate impacts to be identified in an evaluation can be quite large. Various beneficial and adverse impacts should be listed separately and then further subdivided according to the time periods in which they occur and to the groups which they influence. Considering the potentially large number of impact types, time periods, people or interest groups, and alternatives, the bits of information can be sizable.

When information on a proposed public action is as detailed as this, decision makers should be able to gain keen insights into proposed actions advantages and disadvantages. However, it is also evident that to form a judgment on the desirability of a proposed action, decision makers and citizens face a difficult task in acquiring a holistic view from the many component pieces.

This is the "evaluation dilemma". To understand the implications of a proposed action by dividing the impacts into many component parts, requires that evaluators synthesise the parts into an understandable whole, if they are to arrive at a satisfactory judgement.

To eliminate the analytical step of the evaluation process is obviously not acceptable. Thus, a solution must focus on the means of synthesis. The ideal solution would be to devise a formula or equation that can summarise all the different components of impact into a single score or grand index to which a simple criterion can be applied for accepting or rejecting a proposal. Many evaluation methods attempt to meet this presumed ideal.

11.3 Trade-off and commensurate units

The notion of a trade-off is fundamental to evaluation. When comparing two alternatives, it is almost always the case that each has certain advantages over the other. By selecting one, we gain the advantages it provides but forego the advantages of the other. The beneficial and adverse effects of each alternative reveal the trade-offs that must be made, implicitly if not explicitly, in the selection process.

Evaluators with a strong quantitative orientation recognise that it is impossible to assess a trade-off that is not described in commensurate units. Such an impossibility becomes clearer when one agrees that an analysis must be confined to the scientific realm of objective proof. When dealing with qualitative aspects of resources assessment, their quantification may provide units that can be treated mathematically, but in no way does it make a judgment more accurate or more objective. Putting a value on qualitative components by creating a number scale for assessing qualitative factors is simply a way of summarising an evaluator's impression, or feeling, in a single indicator.

Another misleading assumption about trade-offs, advanced by conventional economic thought, is that everything is tradable. That a person will sacrifice anything if the price is right, is an unfortunate idea. There are, however, many people who live by personal, moral, and religious standards that are central to their existence and would not give them up for any price. Still, the objects of these standards might be tradable in the context of public decision making, where some values are inevitably sacrificed in the process of serving others.

11.4 Measuring ratings

Several distinctions can be made among the different methods used for measuring rating. One is the source of rating, which could be expert judgment, market prices, and a measurable physical characteristic. Another distinction is the measurement unit: money, points (or votes), and energy are the three most frequently used units.

The usual methods used for rating make a distinction between four types of rating: simple, constant "value weight", scaled "value weight" and rescaled impacts.

In most situations today, evaluation is properly seen as a process that is included in design and post-design assessments. Not so many years ago, evaluations were conceived as strictly post-design studies. The designers and engineers developed a detailed plan for solving a problem: then the evaluators entered the scene to calculate the consequences of the plan so that an accept or reject decision could be made. Today, of course, the situation has changed. Plans that took years to develop are scrapped, new designs are developed from scratch, and occasionally projects are even halted during construction (as was the case of the Gapchikovo-Nagymarosh Dam). This change in attitude has necessitated bringing the formal evaluation process into the design phase of planning and, furthermore, into the assessment phases that precede the planning.

Fundamental to this new way of thinking is that a variety of potential planning solutions should be generated before any evaluation takes place. An initial list of options, which usually includes the no-action alternative, can be quite long, so the first step in formal evaluation is to screen all but the few ideas most likely to yield acceptable solutions. Naturally, when an initial list of alternatives is long, the amount of time that can be devoted to screening each idea will be quite limited, so evaluators must often rely on judgments. In water resources projects, this is where WRA comes into play. WRA provides the data necessary to make "informed" judgments. The data are provided in a way that the evaluator can comprehend allowing the required judgments to be made using criteria which are more likely to ensure sustainable and environmentally-sound water resources development.

After a list of alternatives is narrowed down a few design considerations, the post-design phase can begin. In this phase more careful attention should be given to the full range of potential impacts, and scientific procedures for estimating impacts and WRA can be used more fully. The mathematical descriptions for the four types of ratings mentioned earlier are given below.

Mathematical description of the four types of ratings
Simple rating:

$$r_1 + r_2 + ... + r_n \tag{21}$$

Constant value weight:

$$w_1 I_1 + w_2 I_2 + ... + w_n I_n \tag{22}$$

Select value weight:

$$\sum_{i=1}^{n} \sum_{j=1}^{m} w_{ij} I_{ij} \tag{23}$$

or

$$\int w_1 I_1 dI_1 + ... + \int w_n I_n dI_n \tag{24}$$

Rescaled impact:

$$w_1\left[S_1^{w*}\left(S_1^{w}\right)_1 - S_1^{H*}\left(S_1^{H}\right)_1\right] + ... + w_n\left[S_n^{w*}\left(S_n^{w}\right)_n - S_n^{H*}\left(S_n^{H}\right)_n\right] \tag{25}$$

where

r_i	rating assigned to impact i (beneficial impacts are assigned a positive r and adverse impacts a negative r);
I_i	the magnitude of impact i, defined as $S_i^w - S_i^R$;
S_i^w	the state of characteristic i with the implementation of the subject action,
S_i^R	the reference state for characteristic i;
w_i	the value weight assigned impact i (desirable impacts have a positive w and adverse impacts a negative w);
I_{ij}	the magnitude of impact i for increment j;
w_{ij}	the value weight assigned to the increment of impact i; and
$S_i^*\left(S_i\right)_i$	the state of characteristic i rescaled in units of S^*(a single functions is used to transform all measures of characteristic i).

Table 11 summarises the characteristics of the evaluation methods usually used in water resources planning: cost-benefit analysis, the planning balance sheet, the goals achievement matrix, energy analysis, environmental evaluation system etc. In this guide we provide a brief review of the two most widely-used methods of evaluation in the field of water resources. The first is the cost benefit analysis approach which is economic by nature and the second, the environmental evaluation process relating to environmental concerns. Also considered is a recently-developed approach termed, multi-criteria analyses.

Table 11. Characteristics of the evaluation methods

	Cost-benefit analysis	Planing balance sheet	Energy analysis	Environm. evaluation system	Judgmental input matrix
Type or measure:					
technical				•	•
non-technical	•	•	•		•
either					
Method of estimating impact:					
scientific	•		•		
judgmental					•
either		•		•	
Determining of ratings:					
Source					
expert judgment		•		•	•
market prices	•	•			
physical characteristic			•		
not specified					
Measurement unit					
money	•	•			
points or votes				•	•
energy			•		
Type of rating					
simple					
constants value weight			•		•
scaled value weight	•	•			
rescaled impacts				•	

11.5 Cost-benefit analysis

Cost-benefit analysis (CBA) is an evaluation methodology in which impact is measured using non-technical terms and is estimated principally by scientific methods. Its most distinctive characteristic is that the ratings represent estimates of the monetary value of an impact. CBA uses scaled, or weighted, values that are derived from market information about the expressed demand for goods and services.

The monetary value of a beneficial impact is called a "benefit" and that of an adverse impact is called a "cost". If the sum of the benefits exceeds the sum of the costs, it is presumed that the proposed action should be adopted. It the opposite is true (costs exceed benefits), the action should not be adopted. An advantage of CBA over other evaluation methodologies is that no additional analysis is required to derive ratings for some of the important adverse impacts because they are measured directly in dollars, a term that is readily understood by everyone (rather than being a technical measure that only specialists can comprehend).

CBA is probably the most frequently used systematic evaluation method and clearly has the most fully-developed theoretical foundation. Yet this foundation for the most part, remains scattered throughout the welfare economic and micro-economics literature. Thus, it is very difficult for the vast majority of those who must make decisions on the basis of CBA to become familiar with the theoretical strengths and weaknesses of the methodology. The purpose of this and the following chapter is to provide a theoretical overview of CBA including its underlying assumptions.

11.5.1 Theory of measuring benefits in perfect markets

A CBA analyst typically tries to measure benefits using market information on the prices and quantities of goods and services to derive demand curves, which are scaled or weighted values expressed in monetary units. Theory suggests that the accuracy of market information will depend on whether or not market conditions approximate the perfect market ideal. Although the actual market, in general, does not approximate the ideal, sometimes the analyst can draw information from specific sectors that do. Even if the information obtained comes from highly imperfect markets, the analyst may be forced to use it because it is the only information that is available. Thus the theory on measuring benefits in perfect markets is the usual basis for benefit measurement.

The theory of consumer choice states that a consumer's utility will be maximised when the marginal utility (that is, the change in utility) derived form the last dollar spent on each good consumed is the same for all goods. The logic behind this equality is that if the marginal utilities from the last dollar spent on each good were not the same, consumers could increase their total utility by reducing their purchases of items for which the marginal utility (from the last dollar spent) is relatively low and increase his purchases of items for which it is high. These substitutions will be halted when equality is reached.

It cannot be stressed too strongly that the market price represents the maximum willingness-to-pay *only for the last unit consumed.* This can be understood graphically by reference to a demand curve (Figure 35). An individual demand curve traces a consumer's maximum willingness-to-pay for each unit of some object good or service for a specified period of time. A demand curve is usually downward sloping to the right indicating that the more one has, the less one is willing to pay for an additional unit. This follows, of course, from the law of diminishing marginal utility.

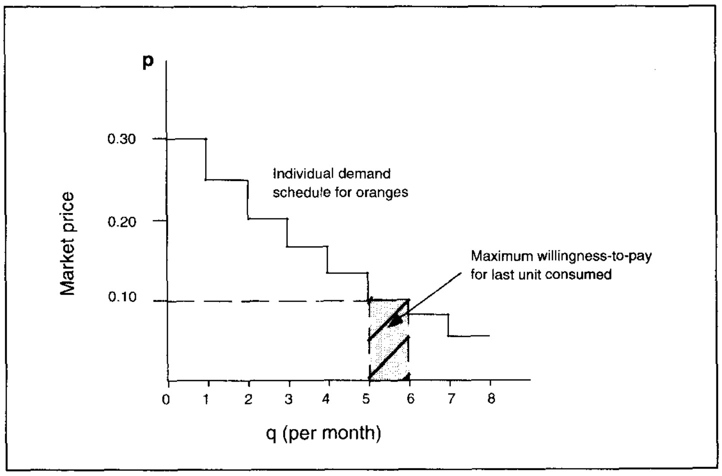


Figure 35. An individual's demand "schedule"

By definition there is no price discrimination in perfect markets; therefore everyone can buy an item for the same price. It follows then that, if the ratio of prices is equal to the ratio of marginal utilities for one consumer, as already established, it will be equal to the ratio of marginal utilities for all consumers. However, this does not mean that prices are good relative measures of the marginal utilities of different consumers because the marginal utilities of some consumers for *all goods* may be higher than others.

The willingness-to-pay for large changes should be estimated by reference to the full sweep of the demand curve rather than to a single point on it. The benefit of a large change is represented by the area under the demand curve, bracketed by the quantity change. The logic of this relationship is best understood by examining the willingness-to-pay for each of the 6 items separately. The willingness-to-pay for the first item is 30 cents, and the area under the demand curve between the quantities 0 and 1 is equal to 30 cents (that is, it is a rectangle with a height of 30 and a width of 1; 30 x 1 = 30). The willingness-to-pay for the second item is 25 cents, the area under the demand curve between 1 and 2 being equal to 25. Similarly, the willingness-to-pay for the third, fourth, fifth, and sixth items is 20, 17, 14, and 10, respectively. Thus, the benefit of all 6 items is equal to $ 1.16, corresponding to the area under the demand curve between 0 and 6.

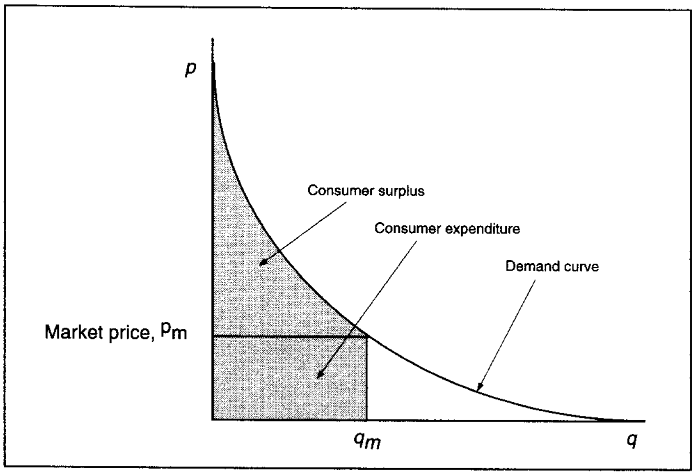


Figure 36. The areas under the demand curve showing consumer expenditure and consumer surplus

A few examples will help to clarify how the willingness-to-pay criterion can be used to measure the benefits of a proposed action. These examples make reference to market demand curves rather than individual demand curves, which have been the subject of the previous illustrations. A market demand curve is the total of all individual demand curves (Figure 36). It measures the total quantity of a particular good that would be purchased at each price *by all people* in the marketing territory. Alternatively, it can be described as showing the maximum willingness-to-pay for each unit offered to the consuming public, without reference to who buys which unit.

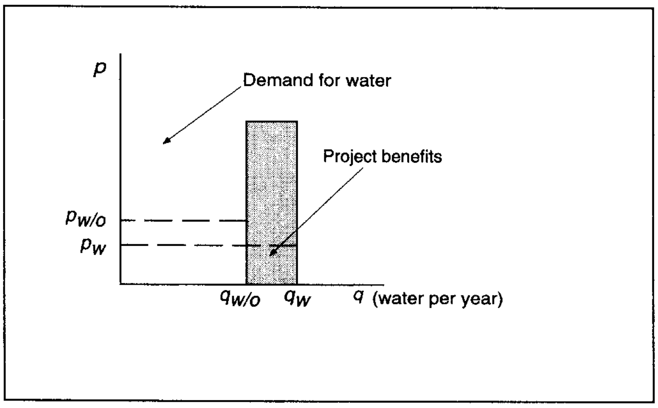


Figure 37. Benefits of a project that reduces the price of water

The subject of the first example of measuring benefits is a project that reduces the cost of water for municipal supply, enabling the public water company to reduce the price and increase the quantity of water (Figure 37). The annual benefits of water *without* the project are measured by the area under the demand curve between the quantities 0 and $q_{w/o}$; the annual benefits of water with the project are measured by the area under the demand curve between the quantities 0 and q_w. The benefits of the project are equal to the difference between the two, which is indicated by the shaded area. It can be noted that the smaller the change in price and quantity resulting from the project, the closer $p_{w/o}$ will reflect thebenefit per unit of the additional quantity. This observation coincides with the previous point that the market price measures the benefit of the last unit, and justifies the use of the market price to evaluate small changes.

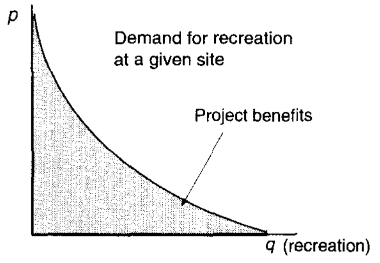


Figure 38. Benefits of a project that provides a new recreation opportunity

The second example is a project to develop and operate a new recreation facility that will be available to the public at no charge. The benefits of the project are measured by the total area under the demand curve in Figure 38.

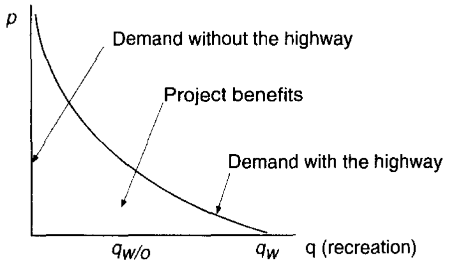


Figure 39. Benefits of a project to construct a highway that would lead to an existing recreation facility

The last example is the development of a new highway that reduces the travel time to an existing regional recreation facility. The benefits of recreation *without the highway* are measured by the area under the demand curve without the highway (Figure 39). The benefits *with* the highway are measured by the area under the demand curve with the highway. The benefits of the highway are measured by the difference between the two areas, shown as the shaded area.

Some public actions create consumer benefits indirectly, by enhancing production opportunities. Examples include water projects that increase the supply of irrigation water and projects where power plants provide additional electricity to industry. The basic principle for measuring benefits described above applies to these cases also. The increased output of consumer goods (and services) attributable to the change in production opportunities is valued by reference to the market demand for the goods.

If the change is comparatively small, the market price of the good can be used to approximate the consumer benefit. For example, if a water project provides additional water to farmers, enabling them to expand rice production, the value of the irrigation water can be approximated by the market value of the additional rice (less the extra production costs), provided the change in rice output is small compared to the total market volume of rice. However, when the change is relatively large, the benefit is better measured by reference to the demand curve for the good.

11.5.2 Theory of measuring costs in perfect markets

All projects require the use of scarce resources which, if not used in the subject project, would yield benefits in alternative uses. The cost of these resources, sometimes referred to in economics as the "opportunity cost", is their value in the highness valued alternative use. Therefore the cost of a resource used in a project is the maximum willingness-to-pay for it in another use.

If the lost opportunities for the resource are concentrated in one or a few alternative uses, resulting in a large change, the cost of the resource should be measured by the reduction in the areas under the demand curves for the alternatives.

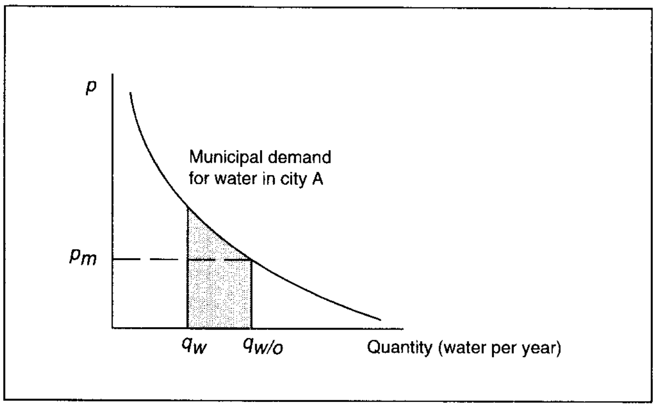


Figure 40. The opportunity cost of water for one alternative

If the lost opportunities for the resource are widely diffused among many alternative uses, resulting in very small changes for each use, then the cost of the resource can be closely approximated by its market price. For example, in evaluating a proposal for strip mining of coal, we may wish to establish the opportunity cost of the large quantity of water necessary for land reclamation. If the use of the water were restrict its use for only one alternative, say the municipal supply of a single city, the impact could be relatively large (Figure 40). In this case the market price, p_m, is well below the average value of the water withheld from the city (that is, the quantity between g_w and q_w/o). However, if the use of the water for land reclamation precluded its use for four other alternative uses, and is evenly spread among these alternatives (Figure 41), the market price for each use closely approximates the average value of the foregone water for each.

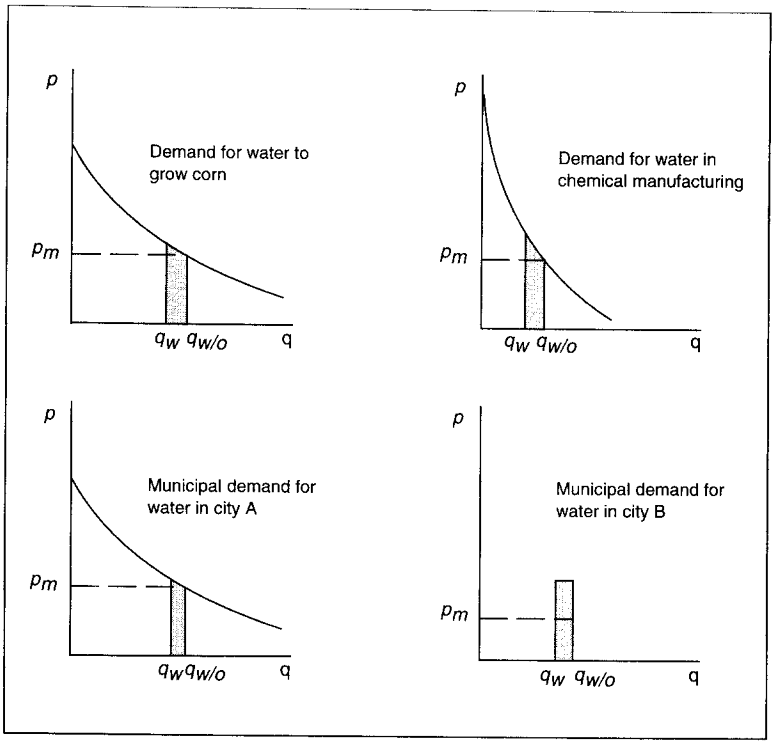


Figure 41. The opportunity cost of water for four alternatives

Estimating the cost in the case of large changes can pose serious operational problems of identifying alternative uses and estimating the demand curves for each. Fortunately, this is seldom required because most resources have many alternative uses. Therefore, even if a large quantity of a resource is used in a given project, the effect on each alternative is generally very small. Thus the opportunity cost of a resource can usually be measured by its price in the marketplace when conditions approximate perfect markets.

It is important to note that in some situations cost should be measured by the willingness-to-accept-compensation, rather than the willingness-to-pay. This is proper whenever the cost is the loss of something *to which a person has a right.* For example, if a person has the right to freedom from excessive noise in his home, then the cost of excessive noise created by the operation of a nearby airport should be measured by this person's willingness-to-accept-compensation for it, not willingness-to-pay. The difference is more than one of semantics, because the willingness-to-accept-compensation is usually larger, and may be a great deal larger, than the willingness-to-pay.

11.5.3 Summary and critique of CBA

CBA, usually represented as a comprehensive evaluation methodology, attempts to solve the evaluation dilemma by calculating a grand index of the social welfare implications of proposed actions. This is only partially true with regard to environmental problems and WRA , as we shall see later on. The ratings that form the index are measured by the willingness-to-pay criterion. Benefits are measured by reference to market information on the willingness-to-pay to acquire desired items and avoid undesired items. Costs are measured by market information reflecting the willingness-to-pay and occasionally by the willingness-to-accept-compensation for resources sacrificed and undesired items received.

The costs and benefits to different people are typically added without attempting to adjust for the likelihood that a dollar is valued differently by people at different income levels. Costs and benefits occurring in different years are totaled in an index of present value, utilising a discounting procedure based on the fact that people are not willing to pay as much for something received later rather than sooner. Some types of impacts have obvious dollar translations because they are regularly exchanged in markets. Others do not, so indirect evidence must be collected and analysed in order to derive some indication of their dollar value.

CBA has several important assets supporting it as a useful evaluation tool. Based on established theory of value that has been scrutinised and subjected to debate by many economists during its evolution, CBA has been adjusted to meet some of its theoretical and operational shortcomings. CBA also attempts to reflect the values of all people rather than a select few, insofar as these values are revealed by the behaviour of people in the marketplace. It does this by using impact categories and measurement units that are understandable to decision makers and to the average adult. There is an extensive body of literature on applications of CBA, covering a wide variety of evaluation problems and this serves as a valuable resource to the evaluation community.

In contrast, CBA has several important disadvantages that warrant caution in its application, particularly for water resources assessment:

1. The willingness-to-pay criterion for placing values on impacts violates the democratic principle of equality, because willingness-to-pay is greatly affected by the ability to pay. An essential value to a democratic system of government is that public issues should be settled by a political process in which each adult has an equal vote, irrespective of income, wealth, education, and other factors. In some applications the use of the criterion does not unduly violate the equality principle because the interests of different income groups are not in conflict, or because the proposed action is especially designed to deal with a social equity problem, such as poverty. However, there are many other cases in which the equality principle is seriously violated. Thus, as a general rule, the CBA approach should always be scrutinised for the likelihood of its giving insufficient attention to the values of the poor.
2. In an attempt to monetise impact, CBA has adopted a set of very technical procedure that are difficult for decision-makers and the public to understand. Thus, it is not uncommon for decision-makers and interested citizens, after having read a CBA evaluation, to find themselves in a position of either having to accept *on faith* the estimated monetary impacts or ignoring them.
3. The accuracy of many monetised environmental impacts is highly questionable due to the paucity of willingness-to-pay information about environmental issues. Usually the dollar values placed on environmental impact are only partial estimates and therefore represent minimum values, with no indication of the maximum values.

4. Some types of environmental impact have almost entirely eluded attempts to be estimated in dollars. Others frequently escape any form of quantification. Intangible impacts (with no dollar value) cannot be included in a net-benefit calculation, and therefore are given unequal treatment in CBA report. The possible consequence of this is that decision-makers and others reviewing these reports give insufficient attention to environmental issues in forming their opinions.
5. The monetisation of some types of impact is a step backward rather than a step forward. For example, there is nothing more basic to human understanding and more central to the concept of public welfare than human life. The CBA practice of converting the loss of human lives to a dollar value confuses rather than enlightens the decision-making task of forming a judgment regarding the wisdom of a proposal.
6. There is serious doubt that dollar values can or should be placed on many types of environmental, social, and political impact. Such types of impact relate to issues and problems that people do not equate with money. The willingness-to-pay criterion is useful for rating items that can be and are acquired in the marketplace, and therefore provide people with adequate experience to form good judgments regarding their dollar values. But many human values are formed totally outside the scope of the market, so people, in their roles as consumers and producers, do not confront them in such a way that their monetary equivalents are assessed.
7. The cost of conducting a CBA can be very high. One of the prime reasons is that extensive research is necessary to derive monetary values for types of impact that do not have immediate dollar equivalents. Due partly to their high cost, CBA is seldom used in local government (where a good deal of water resources assessment may take place).
8. The procedure of discounting future costs and benefits creates serious intergenerational equity problems, placing virtually no importance on long-term environmental damages and resource depletion.
9. People who live by strong environmental and humanistic values place less emphasis on making high incomes. Thus their willingness-to-pay is lower because their ability to pay is lower, which means that their views and wishes will be selectively discriminated against by CBA evaluations.
10. CBA usually is conducted by economists who tend to be more aware of and sensitive to monetary than non-monetary impacts, with the result that CBA evaluations often give insufficient attention to estimating non-economic impacts.

Certain proponents of CBA have been selling it as a completely comprehensive evaluation method, capable of incorporating in its grand index all the factors important to public decisions. This they have done, despite its many weaknesses, on the unrealised hope that further research would solve the problems. However, some of its serious limitations are inherent to its fallacious premise that all important human values can be adequately represented by money. The inevitable conclusions are that CBA is not, and cannot become, a completely comprehensive evaluation method. However, this does not mean that the method should be thrown away. Economic factors are and will always be important in decision making and CBA is well suited for addressing the strictly economic impacts of public actions.

11.6 Environmental Evaluation System

The Environmental Evaluation System (EES) is distinguished from CBA by its more quantitative orientation and by the fact that it uses a procedure called "Delphi" for systematically obtaining and processing expert judgments. Delphi was originally developed for estimating objective phenomena, so it is particularly applicable to impact estimation, but it has also been used for subjective judgments including quantification of weighted values.

We do not give nearly enough credit these days to the enormous powers and subtle qualities of the human mind. Science has a central, irreplaceable role to play in the evaluation process, but we must recognise that it often is not capable of providing the answers we seek. During the in-design phase of evaluation, when a long list of alternatives must be screened, data and budget limits permit few scientifically prepared impact estimates. And even after the alternatives have been narrowed down to a few (or one), some types of impact will continue to resist scientific estimation. Human judgments are the alternative. We recognise that the human mind is often able to make quite accurate estimates due to its marvelous ability to store and process huge quantities of information. People who have devoted much study to the functioning of a particular system (for example, ecological, economic, or social) are in a special position to judge the magnitude of impact on the system. Expert judgment has been the common means for solving the age-old problem of incomplete information and will no doubt continue to be in the future. Delphi represents a procedure for obtaining and processing expert judgments for the purpose of maximising the accuracy of the resulting estimates.

It is obvious that the rationale for an expert judgment is accuracy, so normally we would not ask a microbiologist to judge the impact of increased property tax nor a banker to judge the impact of a change in wildlife management policy. Also, considering that two heads are better than one, we should ask several experts for their judgment, when possible, rather than one. And when the opinions of several experts are quite similar, we can be more confident in using the average opinion than if they are quite different.

Not so obvious is how the *process* of acquiring judgments from a group of people affects the accuracy of the outcome. The researchers who developed Delphi have studied a variety of group decision-making situations with interesting results. For example, they demonstrated that the median of judgments made independently is more accurate than a consensus arrived at in a face-to-face meeting. Apparently, the most vociferous person at a meeting strongly influences the group consensus, but loudness is a poor indicator of expertise. In addition, if the median and the range of independent judgments are reported to the participants for reconsideration, the judgments of a subsequent round will converge somewhat. More often than not the convergence is toward the correct answer, and it will continue for several iterations, though diminishing with each round. These results explain the essential features of Delphi. Many variations are possible, but the basic steps are as follows:

- Each expert is asked for an independent opinion on one or several carefully-prepared questions without consulting the other experts.
- The median and range of the opinions are calculated and fed back to the experts for their consideration in another round of estimates.
- The process of gathering opinions and feeding back results is used for one or more rounds.
- The median of the final round is calculated as the best estimate.

The most obvious application of Delphi in evaluation problems is in estimating impact. However, the originators feel that it can also be useful in securing value judgments. Research has shown that value judgments also narrow during the iteration process, though obviously the correctness of the judgments cannot be verified.

Although the accuracy of expert judgments can be increased using Delphi, experience indicates that the added cost in money and time over less-formalised procedures is not insignificant, especially when the iteration process is repeated several times. Consequently, the use of only one or two iterations is common.

11.6.1 Description of the method

EES is an in-design and post-design method for assessing environmental and certain types of social impact of water projects. The method is intended to be *comprehensive* in its coverage of all the important environmental (but not economic) considerations, *systematic* in generating replaceable answers, and *interdisciplinary* in its use of experts from various fields.

Impact categories are preset by the EES method to be used in all applications, and each impact is estimated by scientific procedures, where possible. The rating system calculates a composite score of environmental impact by recoiling each impact and multiplying it by a set of constant, weighted values based on expert judgment. A positive net score (obtained by subtracting the adverse from the beneficial values) reflects favourably on the project, whereas a negative score reflects unfavourably.

The environmental factors are organised in four levels. The two most telling levels are environmental *categories* and environmental *parameters.* The four categories: ecology, pollution, aesthetics and human interest, are used to classify seventy-eight parameters. The parameters included are ecological parameters of population, species, habitats, and communities; pollution parameters of water, air, land, and noise indicators; aesthetic parameters of land, air, water, biota, artificial objects, and composition; and human interest parameters of educational or scientific excavations, historical trends, cultural heritage, mood or atmosphere, and life patterns. The lowest level in the hierarchy, termed environmental "*measurements*", constitutes the data used to measure the parameters.

The process of calculating the composite score has three steps. First, impact estimates are made by forecasting parameter levels with and without the subject project. For example, forecasts are prepared (with and without the project) for terrestrial browsers and grazers, pest species, water losses, dissolved oxygen, appearance of water, arificial objects, and the life patterns of people residing in the area.

The second step begins converting these parameter estimates from diverse units to commensurate units. In this step each parameter measurement is transformed by a "value function" into a measurement on an "environmental quality scale" ranging from 0 to 1, where 0 represents "extremely bad quality" and 1, "very good quality". The value functions were developed by an interdisciplinary research team using scientific information where possible but clearly incorporating value judgments as well. Many of the functions are non-linear, reflecting the fact that each unit change in an environmental parameter is not equal to every other unit change in that parameter. There are two reasons for this. First, as the natural conditions of an environment are altered, such as by an air or water pollutant, each successive increment of alteration (up to a point) has more serious consequences for the life that depends on that environment. Beyond a certain point, most of the damage has been done, so further alterations are less serious. Second, the law of diminishing marginal utility suggests that the more we have of something desired, the less we value each additional increment. Implied by this is the law of increasing marginal disutility, that the more we have of something not desired, the more we value avoiding each additional increment.

The environmental quality scale is used for measuring intangible and tangible parameters. The third and last step in deriving the composite score is to multiply each environmental quality score by a weighted value (called a "parameter importance unit") assigned to the corresponding parameter, and then total the products. The weighted values are predetermined, based on expert judgment. Proponents of Delphi recommend that weighted values should be fixed for all projects; "... if weights were allowed to vary from project to project, the assignment of weights would be the responsibility of the investigating team. Essentially, each team would have their own special weights depending on their views and background; thus results would be produced that would be extremely difficult to replicate."

Mathematically, computation of the composite score can be represented by the following equation:

$$E = \sum_{I=1}^{78} (V_{1i} - V_{2i}) w_i \qquad (26)$$

where:

E is a composite score of environmental and social impacts;

V_{1i} the value, in environmental quality units, of parameter i *with* the project;

V_{2i} the value, in environmental quality units, of parameter i *without* the project; and

w_i the weighted value (or parameter importance unit) assigned to parameter i.

In addition to the composite score, EES identifies potential problem areas by placing red flags on parameters estimated to be seriously affected by the project. For the ecology parameters, minor flags are assigned to negative changes between 5 and 10 percent and major flags to changes above 10 percent. For parameters in the other three categories, minor flags are assigned to negative changes between 10 and 30 percent and major flags to changes above 30 percent. These rules were determined from field tests of the sensitivity of parameters to change and the significance of that change. "The broad nature of the ecology category is the primary reason for the differentiation in the red flag rules. Field tests indicate that a small change in the ecological parameters was comparable in impact tolarger changes in all other parameters." The adoption of this warning system can be interpreted as a recognition that the whole is not equal to the sum of the parts, that the large adverse impacts are not adequately reflected by the points they add to the grand score and therefore should be identified for special consideration.

11.6.2 Critique of EES

EES is a thoughtfully-devised method for calculating a composite score. Its ability to incorporate non-quantifiable data in its index is a feature that distinguishes it from most other evaluation methodologies. Although designed for evaluating the environmental and certain types of social impact of water projects, EES procedures could be useful for any evaluation task. The method of rescaling impact avoids (theoretically, at least) any problems with the constant weighted values procedure, presented by the unequal value of impact increments. The warning flags are a useful supplement to the composite score, calling attention to adverse impact that deserves special consideration in project design and decision making. The fact that EES is especially sensitive to preserving ecological systems means that it is well-tailored to represent the environmental interests of future generations.

EES in its present form, however, is not without weaknesses. The impact categories are fixed, as if the same set of issues will recur for all proposed water projects, which is highly unlikely. Impact categories should be flexible, so that they can be adapted to the special conditions of each evaluation problem. Some of the impacts are defined and measured in technical terms that few citizens and decision-makers can understand.

Another weakness in EES is that the values used in the procedure for selecting the parameters, determining the value functions, and assigning the value weights provide no assurance that the interests of the broader public will be adequately considered. The weight assigned to each parameter "is an indicator of the degree to which water resource projects may disturb or enhance the dynamic stability of man's relationship with the natural and social environment", but this abstraction offers no evidence to citizens that their concerns have been incorporated into the weighted values.

Finally, one must question the usefulness of the EES composite score, measured in nominal units that have no particular meaning. Presumably, in making an accept-reject judgment, one would compare the net score (for environmental impact) to the net benefits (for economic impact). Suppose that a proposed dam scores 50 points, indicating a net adverse effect on environmental parameters, and has a potential yield of $10 million in estimated net benefits. How can one judge the trade-off between the fifty-point loss and the $10-million gain? Since the fifty points have no special significance, there is no basis for making such a comparison. One could construct studies that would provide some meaning for the points. For example, EES could be applied to past actions to derive the average dollar value of a point implied by past decisions. However, applying this value to future decisions carries the dubious assumptions that (1) we are satisfied with past decisions, (2) the values of society are not changing over time, and (3) the *average* value is an adequate indicator of the various values that come to bear on decisions.

11.7 Multicriteria analysis

11.7.1 General description of the method

While CBA and EES do not fulfill all the requirements for an evaluation of complex water resources systems, the recently-developed 'multicriteria analysis' attempts to do so. The evaluation of the different alternatives is performed using multicriteria optimisation techniques (multi-objective programming).

Traditionally, the primary objective in planning and design has been overall economic efficiency, with the goal of either maximising benefits or minimising costs. More recently, the emphasis in certain types of planning has tried to include all relevant objectives including environmental quality, social well begin, regional income redistribution, and so on.

Multi-objective problems arise in design, modelling, and planning of many complex resource allocation systems in the areas of industrial production, urban transportation, heath delivery, layout and landscaping of new cities, energy productions and distribution, wildlife management, operation and control of the firm agricultural production and government administration. The inclusion of a vector of objectives introduces a new dimension in the areas of modelling and mathematical programming.

Multi-objective programming deals with optimisation problems that have two or more objective functions. The multi-objective programming problem differs from the classical (single-objective) optimisation problem only in the expression of their respective objective functions. The general single-objective optimisation problem with n decision variables and m constraints is:

$$\text{maximise} \quad Z(x_1, x_2, \ldots, x_n) \tag{27}$$

$$\begin{aligned} \text{subject to} \quad & g_i(x_1, x_2, \ldots, x_n) \le 0, 1, 2, \ldots, m \\ & x_j \ge 0, 1, 2, \ldots, n \end{aligned} \tag{28}$$

The general multi-objective optimisation problem with n decision variables, m contents and p objectives is

$$\begin{aligned} & Z(x_1, x_2, \ldots, x_n) = [Z_1(x_1, x_2, \ldots, x_n)], \\ \text{maximise} \quad & [Z_2(x_1, x_2, \ldots, x_n)], \ldots \\ & [Z_p(x_1, x_2, \ldots, x_n)], \end{aligned} \tag{29}$$

$$\begin{aligned} \text{subject to} \quad & g_i(x_1, x_2, \ldots, x_n) \le 0, 1, 2, \ldots, m \\ & x_j \ge 0, 1, 2, \ldots, n \end{aligned} \tag{30}$$

where

$Z\ (x_1, x_2, \ldots, x_n)$ is the multi-objective function and $Z_1(x_1, x_2, \ldots, x_n)$, $Z_2(x_1, x_2, \ldots, x_n)$ $Z_p(x_1, x_2, \ldots, x_n)$ the p individual objective functions. The individual objective functions are not added, multiplied, or combined in any way (see list in Section 11.9).

Generally the multi-objective techniques involve: (A) generating non-dominated sets; (B) using the prior articulation of preferences; and (C) using the progressive articulation of preferences.

a) Methods for generating the non-dominated set

These techniques identify the set of non-dominated solutions within which the best-compromise solution will lie. One technique is to transform the various components into a single scalar function by weighting each of the components.

$$\begin{aligned} \text{Maximise} \quad & \sum_{k=1}^{p} w_k z_k X \\ \text{subject to} \quad & w_k > 0,\ k, x;\ x \in X \end{aligned} \tag{31}$$

The parameters (w_k) may be varied systematically to yield points that are non-dominated. solutions. A second method, the constraint method, also leads to a scalar funtion where:

$$\begin{aligned} \text{Maximise} \quad & Z_r(x) \\ \text{subject to} \quad & Z_k(x) \ge e,\ \mathit{all}\ k \ne r;\ x \in X \end{aligned} \tag{32}$$

and *e* is the lower boundary on objective *k*. By varying *e*, we can solve the equation with LP (linear programming) packages.

If we add two more methods that are described elsewhere, there are four principle methods for generating non-dominated sets:

- the weighting method;
- the constraint (C) method;
- the multi-objective simplex method of Philip; and
- the multi-objective simplex method of Zeleny.

b) Methods with prior articulation of preferences

These methods reduce the computational burden of generation techniques by an ordering of preferences before the solution of the problem. These methods can be further classified:

continuous methods	**discrete methods**
goal programming utility function assessment surrogate worth tradeoff	methods that use ordinal value functions weighted average electre

c) Methods with progressive articulation of preferences

These methods can be characterised by the following three steps: (1) find a non-dominate solution; (2) get DM reaction to this solution and modify the problem; and (3) repeat steps 1 and 2 until satisfaction is obtained. The following methods use progressive articulation of preferences:

- Step Method (stem)
- Method of Geoffrion
- Method of Lionts
- Sequential SEMOPS

11.7.2 Characteristics of water resources planning and multi-criteria optimisation methods

When conducting water resources planning and while looking for the objectives and conditions which are necessary to find the optimal solution and rank the different alternative solutions a number of methods can be used, all of which must satisfy the following conditions:

- criteria functions must be discrete and posses different units of measure;
- decision makers should be able to influence the definition of criteria functions and to understand the effects of certain criteria upon the ranking of the alternatives; and
- it should be possible to, during the analyses, change the weighting of particular criterion and evaluate the impact of the weighting co-efficients upon the ranking of the alternatives.
- with regard to the interaction between the decision maker and the multicriteria optimisation method to be used the following three possibilities should be mentioned:

- these are methods in which the preference function of the decision maker is at the same time a criterion function for the optimisation;
- two stage approach to optimisation whereby, in the first stage, one uses methods to determine a set of non-inferior solutions and, in the second stage, a final reduction to the optimal solution is implemented; and
- an iterative approach to optimisation whereby the preference structure is iteratively introduced into the optimisation procedure.

With this in mind Opricovic (1986) defined five basic relationships between the decision maker and the method of optimisation (Figure 42).

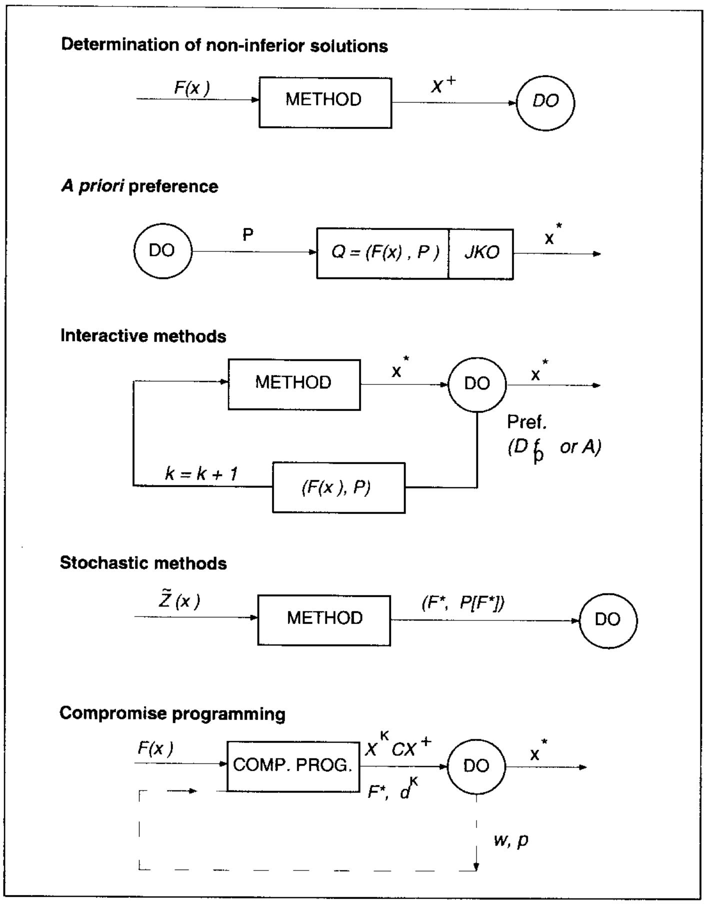


Figure 42. Methods of multicriteria optimisation

For those methods which include a predetermined preference structure the decision maker must decide on his preferences prior to the analyses and does not take part in the final decision since the solution is predetermined by the preference structure used.

Interactive methods do allow the decision maker to participate actively in the optimisation process. This may cause some problems when there is more than one decision maker, each with a different preference structure, thereby introducing conflicts of interest which are not easy to overcome. With stochastic methods the decision maker is not a part of the optimisation procedure at all.

Compromise programming overcomes these deficiencies in that it does not include a decision maker directly in the optimisation procedure, but allows for the free definition of criteria functions and weighting factors. This, in turn, generates a set of solutions which can be analysed for the effects of any given criterion on the ranking of alternative solutions.

11.7.3 Compromise programming

The decision maker is often ill-equipped to compare numerous possible solutions according to several criteria. That is why the normative method for reduced set of non-inferior solutions is needed. The use of the "ideal point" as the reference point in the criteria functions space is proposed in a few papers. Suppose that the optimal solution x_i^*, i.e. f_i^*exists, according to i - th criterion:

$$f_{i*} = \max f_i(x);\ \ i = 1,......n;\ \ x \in X \tag{33}$$

then we call the vector $F^* = (f_1^*,.....f_2^*)$ the ideal solution for the MCO problem. If there is a solution $x^* \in X$ for which $F(x^*) = F^*$, then all criteria functions have maximal values for the same solution, so that x^* could be adopted as the optimal solution of the problem.

However, such a solution rarely belongs to the admissible set x, so that we have to search for the admissible solution which is the closest to the ideal solution in the criteria space. The solutions which are closest to ideal, according to the adopted distance measure, is called the compromise solution. For measuring the distance from the ideal point, the following equation is usually used:

$$L_p(F^*,F)=\left\{\sum[f_i^* - f_i(x)^p]\right\}^{1/p};\ \ 1 \le \mathrm{p} \ge \infty \tag{34}$$

This represents the distance between the ideal point and the point $F(x)$ in the criteria space. To underline the dependence on parameter p, the metric is denoted as $R(F(x),p)$. This metric is actually the additional criterion for the MCO by the compromise programming, and is called here the function of compromise programming. The solution, $x^+(p)X$ by which the minimum of $R(F(x),p)$ is achieved, is called the compromise solution of the MCO problem, with the parameter p. In a criterion space, the compromise solution is $F(p)=(f_1(x^+(p)),.....,f_n(x^+(p)))$. The minimum achieved $R^+(p)$ for the compromise solution $x^+(p)$ is the total aberration, and f_i^* - $f_i(x^+(p))$ the i - th individual compromise aberration.

The sum $\sum_{i=1}^{n} F_i(x^+(p))$ represents the total benefit of the solution $x^+(p)$, for 1< p<∞, Instead, the following function could be used to replace $R(F(x),p)$:

$$R'(F(x),p)=\sum_{i=1}^{n}[f_i^* - f_i(x)]^p \tag{35}$$

Since $R(F(x),p)$ is an increasing function of $R'(F(x),p)$, the minimum of both functions is achieved for the same solution $x^+(p)$. The function $R(F(x),p)$ for $p = \infty$ has the following form:

$$R\ (F(x),p) = \max_i(f_i^* - f_i(x)) \tag{36}$$

The basic characteristic of compromise programming is that the solution of the MCO problem is determined by minimisation of aberration from the ideal point according to the adopted measure of distance, including all criteria.

The parameter, p, has the role of the "balancing factor" between the total benefit and maximal individual aberration. With an increase in the value of parameter p, the total benefit is decreased. At the same time, maximal individual distance from the ideal value is decreased. The small parameter p values are used when the total benefit has the advantage over single (individual) aberrations. Because of the solution monotony, at least in the first MCO problem solution iteration, the compromise solutions should be determined $x^+(1)$, $x^+(2)$ and $x^+(\infty)$, as well as the corresponding values of the criteria functions.

The given shape of the function $R\left(F(x),p\right)$ is used where the values of criteria functions can be added. However, in certain cases, they are not expressed in the same measuring units, i.e. the case of heterogeneous criteria space. To use the metric $R\left(F(x),p\right)$, a certain transformation must be introduced and the following metric is proposed:

$$R''\left(F(x),p\right)=\left\{\sum_{i=1}^{n}\left[\frac{\left(f_i^*-f_i\,(x)\right)}{\left(f_i^*-f_i^-\right)}\right]^p\right\}^{1/p} \tag{37}$$

where $f_i^- = \min_{x_\in X} \mathrm{f_i}(x)$; $\mathrm{i}=1,2,\ldots.,\mathrm{n}$. To apply this to the problem below, we must invoke a non-linear programming algorithm (or dynamic programming).

$$\min_{x\in X} R\left(F(x),p\right) \tag{38}$$

If we assume that alternative systems versus criteria array is given as a matrix with elements $f_{ij}, j=1,\ldots.,J;\ i=1,\ldots.,n$. The numerical value of element f_{ij} is the value of the i - th criterion function for j - th alternative system. For this case, consider the steps of the CP algorithm which has two parts.

Part I. *Determination of the trial compromise solutions.*

Step 1. Input of the matrix $\left[f_{ij}\right]nxJ$ weights $a_i=1$, $\mathrm{i}=1,\ldots.,n$.

Step 2. Determine the best, $f^+{}_i$, and the worst, $f^-{}_i$, value for the criterion functions from the matrix $(f_{ij})nxJ'\,f^+{}_i=$ best $f_{ij}, f_{i-}=$ worst f_{ij}, $\mathrm{i}=1,\ldots.,n$.

Step 3. Determine relative distances, d_{ij}, of objectives from the ideal point, $d_{ij}=(f^+{}_i-f_{ij})/(f^+{}_i-f_i), j=1,\ldots.,J, i=1,\ldots.,n$

Step 4. Determine $\min_j\left[\sum_{i=1}^{n}\left(a_i,d_{ij}\right)^p\right]^{1/p}$, *for* $p\in I$ where I is an integer set $[1,\infty]$, and the corresponding CP solution $x_c(p)$.

Step 5. Find the minimax solution *for* $p=\infty \min_{j\in J}\max_{i\in n} d_{ij}$

Step 6. Compare the various compromise solutions, particularly, solutions $x_c(1)$, $x_c(2)$ and $x_c(\infty)$.

Step 7. Present the results to the decision maker.

Part II. *Perform a second run of the algorithm (steps 2 to 7) only if the decision maker has provided weights* a_i, $i = 1,....,n$ *for the objectives.*

Both parts of the CP algorithm can be performed in one computer run, but we propose that an analysis of the results of Part 1 be conducted before the data are prepared for Part II. In fact, Part II can be run within the framework of sensitivity analysis.

The compromise programming technique has the following advantages over other multicriteria optimisation techniques:

- a number of evaluation parameters can be easily included in the analyses without regard to their dimension;
- the selection criteria are classified in accordance to their relative importance;
- the method ensures independence of different criteria functions;
- different ranking of criteria functions is possible;
- differential degree of criteria function development is possible depending on the alternative considered; and
- uncertainty of outcome can be included in the analyses by selection of weighting functions.

All these advantages make the ranking of criteria functions possible, thereby providing a much more objective final decision when compared to decisions obtained with other optimisation techniques.

12. References

Anonymous. 1987. Methodology for the development of a water resources balance. SAP Kosovo, "Jaroslav Cerni" Institute, Belgrade.

Anonymous. 1987. Methodology for the development of a water resources balance. SAP Vojvodina, Institute for Industrial Construction, Novi Sad.

Anonymous. 1989. Integration of geographical information technologies. *ARCNEWS.*

Aronoff, S. 1989. *GIS a management perspective.* WDL Publications, Ottawa.

Beriwal, M. 1992. Emergency operations, GIS to the rescue. *GIS World* 5(2).

Berry, J. K. 1987. Map news. Newsletter of the map analysis packages (MAP) users. School of Forestry and Environmental Studies, Yale University, Connecticut, USA. 4(1).

Briggs, D. & Martin, D. 1988. CORINE: an environmental information system for the European Community. *European Environmental Review* 2:29-34.

Briggs, D. & Mounsay, H. 1989. Integrating land resource data into a European geographical information system: practicalities and problems. *Applied Geography* 9: 5-20.

Briggs, D. 1991. GIS development for broad-scale policy applications: the lessons from CORINE. *AGI Geographic Information.*

Burrough, P.A. 1987. *Principles of geographical infromation systems for land resources assessment.* Clarendon Press, Oxford, UK.

Camarata, S.J. 1989. ESRI distributed computing; what it means for geographic information systems. *ARC NEWS* 11(4).

Cohon, J. 1978. *Multi-objective programming and planning.* Academic Press, New York.

Creveld, I. van. 1991. Geographic information systems for ambulance services. *AGI Geographic Information.*

Cross, A. 1991. Working for a safer society. *AGI Geographic Information.*

Csiti, A. 1992. Current state of municipal sewage treatment along the Rhine and Danube, *RBA Working Paper* No. 2.

Heriksen, C. 1990. ESRI local area network technology, technical overview. *ARCNEWS* 12(1).

Dangermond, J. 1990. CAD versus GIS. *ESRI.*

Dickinson, H. J. & Calkins, H. W. The economic evaluation of implementing GIS. *Int. J. Geographical Information Systems* 2.

Duckstein, L. & Opricovic, S. 1980. Multi-objective optimization in river basin development. *Water Resources Research* 16(1).

Deuker, D. 1990. Defining GIS. In: F. Kiss Guba (ed.) GIS for environmentally sound river basin development. RBA Working Report, TU Delft, The Netherlands.

ECE-UN. 1974. Rukovodstvo po Sostavlenim Vodohazjastvenih Bulansov, United Nations, New York.

Elliott, C. 1991. Store planning using GIS. *AGI Geographic Information.*

Falkenmark, M. & Lind, G. 1976. *Water for a starving world.* Westview Press, Colorado.

Folke, C. & Kaberger, T. 1991. *Linking the natural environmental and the economy.* Kluwer Academic Publishers, Dordiecth.

Godwin, R. B., Foxworthy, B. L. & Vladimirov, V. A. 1990. Guidelines for water resource assessments of river basins. *Technical documents in hydrology.* UNESCO, Paris.

Goicoechea, A., Hansen, D. R. & Duckstein, L. 1982. *Multi-objective decision analysis with engineering and business applications.* John Wiley & Sons, New York.

Goodchild. M. F. 1989. Spatial analysis using GIS. Seminar Workbook, National Center for Geography, USA.

Hadley, R. F. 1985. Long-term monitoring of natural and man-made changes in the hydrological regime and related ecological environments. *Technical documents in hydrology.* UNESCO, Paris.

Haimes, Y.Y. 1977. *Hierarchical analysis of water resources systems.* McGraw Hill, New York.

Haimes, Y., Kindler, J. & Plate, E. J. 1987. The process of water resources project planning: a system approach. *Studies and reports in hydrology* 44. UNESCO, Paris.

Heywood, I. 1991. Managing our future environment: Some GIS issues. *AGI Geographic Information.*

IHP-III Project 17.1. 1988. Proceedings of the colloquium of information systems for water-related uses. *Technical documents in hydrology.* UNESCO, Paris.

IHP. 1978. Water balance of Europe: key reports of the workshop on the water balance of Europe, Varna, Bulgaria, 27 September - 2 October, 1976. *Technical documents in hydrology.* UNESCO, Paris.

IHP-UNESCO-UNEP. 1988. A worldwide surface water classification system. UNESCO, Paris.

Institute for Water Management of Hungary. 1985. National infrastructures in the field of water resources. UNESCO, Budapest.

Kiss Guba, F. 1991. GIS for environmentally sound river basin development, RBA Working Report.

Kiss Guba, F. 1991. GIS for the Rhine - Danube project. Rhine - Danube Workshop No.3, Delft.

Kiss Guba, F. 1991 River Basin Information Systems Rhine - Danube Workshop No.2, Budapest, 1991.;

Kiss Guba, F. 1992. Information on municipal sewage treatment plants along the Rhine and Danube. RBA Working Paper, No.3.

Kiss Guba, F. 1992. A tool to compare municipal sewage treatment plants. Rhine - Danube Workshop No. 4, Budapest.

Loucks, D.P., Stedinger, J.R. & Haith, Z.A. 1981. *Water resources planning and analysis.* Prentice-Hall, New York.

Major, D.C. & Zenton, R.Z. 1979. *Applied water resources systems planning.* Prentice-Hall, New York.

Miloradov, M. 1988. Danube water resources GIS: feasibility study and system design. University of Novi Sad.

Miloradov, M. 1992. Planning and management of complex water resources systems in development countries. *J. Water Resources Planning and Management*, ASCE 118(6): 603-619.

Miloradov, M., Andjelic, M. & Tomasevic, I. 1988. Development concept of a water resources information system in Vojvodina (VISV). *Vode Vojvodine*, Novi Sad 16: 1-13.

Miloradov, M. & Bozinovic, M. 1989. Osnovne metodoloske postavke za izradu vodoprivrednog bilansa vodnog podrucja. *Vode Vojvodine*, Novi Sad 17: 31-40.

Miloradov, M., Tomanic, M.v & Opricovic, S. 1990. Multicriterial analysis of a multipurpose water resources system. In: Simonovic *et al.* (eds.) Abstracts International Symposium on Water Resources System Application, Winnipeg, Canada, pp. 637—647.

Organisation for Economic Cooperation and Development (OECD). 1977. Water management policies and instruments. Paris, France.

OECD. 1985. Guidelines for evaluation of multipurpose water resources systems. Paris, France.

OECD. 1985. Management of water projects, decision making and investment appraisal. Paris, France.

OECD. 1989. Water resources management - integrated policies. Paris, France.

Opricovic, S. 1986. *Multicriteria ranking of alternative water resources solutions.* (In Serbo-Croatian) Naucna Knjiga, Belgrade, Yugoslavia.

Reynolds, J. 1991. GIS in the commercial and financial world. *AGI Geographic Information.*

Rhind, D. 1989. *Why GIS.* Birkbeck College, London.

Schultz, G. & Barrett, C. 1989. Advances in remote sensing for hydrology and water resources management. *Technical documents in hydrology.* UNESCO, Paris.

Shaw, A. 1991. Real-time vehicle tracking. *AGI Geographic Information.*

Star, J. & Estes, J. 1990. Geographical Information Systems: an introduction. University of California, 1990.

Tomlin, C. D. 1990. *Geographic information systems and geographic modeling.* Prentice Hall, Englewood Cliffs, New Jersey, USA.

United Nations. 1991. Integrated water resources planning. UN, New York.

United Nations. 1991. Legislative and economic approaches to water demand management. UN, New York.

UNESCO-UNEP. 1987. Methodological guidelines for the integrated environmental evaluation of water resources development. UNESCO, Paris.

Urenda, C. 1992. PC-Based GIS manages municipal water systems. *GIS World* 5(5).

United States Geological Survey. 1984. State Hydrological Unit Maps. Reston, Virginia.

Wisemann, R. F. & Juracek, K. E. 1992. Kansas develops decentralized GIS. *GIS World* 5(5).

WMO-UNESCO. 1991. *Water Resources Assessment.* IHP non-serial publications in hydrology, Paris.

Yapa, F. 1991. What is GIS? In: Maguiere, D.J., Goodchild, M.F. & Rhind, D. W. (eds.) *Geographical information systems, volume 1, principles.* Longmans Scientific and Technical, Harlow, U.K..

13. Appendices

The appendices to this report contain a set of data sheets for the collection of the water resources assessment data. The data sheets are given only as an example and other similar data sheets can be used. It should be mentioned that raw data sheets are not attached since they are very detailed and contain information that is necessary to compute different values that can be found in the data sheets attached (i.e. data on the chemical methods used in the water quality analyses etc.)

The first set of data sheets is used in the surface water quantity balance computations, The second set of data sheets are the corresponding sheets for the ground water quantity balance computations. A complete set of these data sheets is used for an integral water resources balance evaluation.

Water quality data sheets are also only one possible solution and modifications of the forms can be made as necessary. Care should be taken to ensure that specific water quality parameters are adequately chosen so as to reflect the actual water quality of the samples. Concentration values from these data sheets are used in tandem with the corresponding values for the quantities of water to obtain mass flow values for each particular substance. Qualitative water resource balance evaluation should be carried out exclusively utilizing mass flow and not concentration.

The third set of data sheets refers to the data which needs to be collected for non-point sources of pollution. It is also given as an example data sheet. Similar data sheets should be provided for all point sources of pollution also. Not all data is used in the evaluation of the water resources balance but it is useful for planning purposes.

Appendix A.
Data collection forms for water balance

DAILY DATA					
Day of the month	Method of flow measurement	Time of measurement	Q (m^3/s)	Daily flow (m^3/day)	Note
1	2	3	4	5	6
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
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LOGO OF THE AUTHORITY RESPONSIBLE FOR CONDUCTING WRA OR OF THE AUTHORITY RESPONSIBLE FOR DATA COLLECTION

DATA COLLECTION STATION CODE

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MONTHLY REPORT

SURFACE WATER BALANCE YEAR: ________

WMUA name: ....
WRAUA name: ....
Subregion name: ....
Region name: ....

Type of withdrawal: (circle as necessary)

1 2 3 4 5 6 7

Type of discharge: (circle as necessary)

1 2 3 4 5 6 7

Surface water resources balance equation terms. Circle the term to which this data sheet refers

Terms for evaporation and infiltration air not measured directly. They are estimated using techniques discussed in the Guide and these estimates should be entered on these sheets. For water withdrawals and water discharges each have seven categories listed below. In the specified box you should circle the corresponding number referring to the given type of withdrawal or discharge. For the method of station coding refer to the Figure 11 in the Guide. **Type of withdrawal: 1. for settlements; 2. for industry; 3. for irrigation; 4. for farming; 5. for fish farms; 6. for power plants; 7. for other demands. Type of discharge: 1. municipal; 2. industrial; 3. from cattle farms; 4. from drainage systems; 5. from fish farms; 6. from power plants; 7. from other dischargers.**

$$\sum_{i=1}^{I}(V_{ins})_i,\ \sum_{j=1}^{J}(V_{outs})_j,\ \sum_{c=1}^{C}(V_{dis})_c,\ \sum_{e=1}^{E}(V_E)_e,\ \sum_{k=1}^{K}(V_{ws})_k,\ \sum_{l=1}^{L}(V_{infs})_l,\ \sum_{m=1}^{M}(V_S)_m$$

DAILY DATA

Day of the month	Method of flow measurement	Time of measurement	Q (m^3/s)	Daily flow (m^3/day)	Note
1	2	3	4	5	6
1					
2					
3					
4					
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6					
7					
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LOGO OF THE AUTHORITY RESPONSIBLE FOR CONDUCTING WRA OR OF THE AUTHORITY RESPONSIBLE FOR DATA COLLECTION

DATA COLLECTION STATION CODE

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MONTHLY REPORT
GROUNDWATER BALANCE YEAR: __________

WMUA name: ....
WRAUA name: ....
Subregion name: ....
Region name: ....

Type of withdrawal: (circle as necessary)

1 2 3 4 5 6 7

Territorial code, enter as necessary:

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Surface water resources balance equation terms. Circle the term to which this data sheet refers

Only the water withdrawal term is measured directly. All other terms are estimated using techniques discussed in the Guide and these estimates should be entered on these sheets. Seven categories of withdrawal are possible and are listed below. In the specified box you should circle the corresponding number referring to the given type of withdrawal. For the method of station coding refer to the Figure 11 in the Guide. **Type of withdrawal: 1. for settlements; 2. for industry; 3. for irrigation; 4. for farming; 5. for fish farms; 6. for power plants; 7. for other demands**. The estimated values are based on the territory rather than a data collection station and a code of the territory needs also to be entered. Territorial coding is conducted in a manner as in Figure 11 of the Guide.

$$\sum_{p=1}^{P}(V_{ing})_p,\ \sum_{q=1}^{Q}(V_{outg})_q,\ \sum_{r=1}^{R}(V_{wg})_r,\ \sum_{l=1}^{L}(V_{infs})_l,\ \sum_{m'=1}^{M}(V_{Ssa})_{m'},\ \sum_{s=1}^{S}(V_{dao})_s,\ \sum_{t=1}^{T}(V_{dai})_t,\ \sum_{f=1}^{F}(V_{ET})_f$$

DAILY DATA

Day of the month	Method of flow measurement	Time of measurement	Q (m^3/s)	Daily flow (m^3/day)	Note
1	2	3	4	5	6
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
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21					
22					
23					
24					
25					
26					
27					
28					
29					
30					
31					

LOGO OF THE AUTHORITY RESPONSIBLE FOR CONDUCTING WRA OR OF THE AUTHORITY RESPONSIBLE FOR DATA COLLECTION

DATA COLLECTION STATION CODE

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SYNTHESIS REPORT

SURFACE WATER BALANCE YEAR: ________

WMUA name: ....

WRAUA name: ....

Subregion name: ....

Region name: ....

Type of withdrawal: (circle as necessary)

1 2 3 4 5 6 7

Type of discharge: (circle as necessary)

1 2 3 4 5 6 7

Surface water resources balance equation terms. Circle the term to which this data sheet refers

Terms for evaporation and infiltration air not measured directly. They are estimated using techniques discussed in the Guide and these estimates should be entered on these sheets. For water withdrawals and water discharges each have seven categories listed below. In the specified box you should circle the corresponding number referring to the given type of withdrawal or discharge. For the method of station coding refer to the Figure 11 in the Guide. **Type of withdrawal: 1. for settlements; 2. for industry; 3. for irrigation; 4. for farming; 5. for fish farms; 6. for power plants; 7. for other demands Type of discharge: 1. municipal; 2. industrial; 3. from cattle farms; 4. from drainage systems; 5. from fish farms; 6. from power plants; 7. from other dischargers.**

$$\sum_{i=1}^{I}(V_{ins})_i,\ \sum_{j=1}^{J}(V_{outs})_j,\ \sum_{c=1}^{C}(V_{dis})_c,\ \sum_{e=1}^{E}(V_E)_e,\ \sum_{k=1}^{K}(V_{ws})_k,\ \sum_{l=1}^{L}(V_{infs})_l,\ \sum_{m=1}^{M}(V_S)_m$$

AVERAGE WEEKLY VALUES			MONTH											
			1	2	3	4	5	6	7	8	9	10	11	12
AVERAGE	WEEK	I												
		II												
		III												
		IV												
	MONTHLY:				BIWEEKLY:						ANNUAL:			

EXTREME VALUES, M^3/S			MONTH											
			1	2	3	4	5	6	7	8	9	10	11	12
EXTREMES	MIN	Qmin												
		DATE												
	MAX	Qmax												
		DATE												

NOTES: ....

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SHEET NUMBER: ____________________

Form SWBS2, Date filled: ________________

LOGO OF THE AUTHORITY RESPONSIBLE FOR CONDUCTING WRA OR OF THE, AUTHORITY RESPONSIBLE FOR DATA COLLECTION

SYNTHESIS REPORT
GROUNDWATER BALANCE YEAR: __________

WMUA name: ....
WRAUA name: ....
Subregion name: ....
Region name: ....

DATA COLLECTION STATION CODE

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Type of withdrawal: (circle as necessary)

1 2 3 4 5 6 7

Territorial code, enter as necessary:

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Surface water resources balance equation terms. Circle the term to which this data sheet refers

Only the water withdrawal term is measured directly. All other terms are estimated using techniques discussed in the Guide and these estimates should be entered on these sheets. Seven categories of withdrawal are possible and are listed below. In the specified box you should circle the corresponding number referring to the given type of withdrawal. For the method of station coding refer to the Figure 11 in the Guide. **Type of withdrawal: 1. for settlements; 2. for industry; 3. for irrigation; 4. for farming; 5. for fish farms; 6 for power plants; 7. for other demands**. The estimated values are based on the territory rather than a data collection station and a code of the territory needs also to be entered. Territorial coding is conducted in a manner as in Figure 11 of the Guide.

$$\sum_{p=1}^{P}\left(V_{ing}\right)_p,\ \sum_{q=1}^{Q}\left(V_{outg}\right)_q,\ \sum_{r=1}^{R}\left(V_{wg}\right)_r,\ \sum_{l=1}^{L}\left(V_{infs}\right)_l,\ \sum_{m'=1}^{M}\left(V_{Ssa}\right)_{m'},\ \sum_{s=1}^{S}\left(V_{dao}\right)_s,\ \sum_{t=1}^{T}\left(V_{dai}\right)_t,\ \sum_{f=1}^{F}\left(V_{ET}\right)_f$$

AVERAGE WEEKLY VALUES			MONTH											
			1	2	3	4	5	6	7	8	9	10	11	12
AVERAGE	WEEK	I												
		II												
		III												
		IV												
	MONTHLY:						BIWEEKLY:					ANNUAL:		

EXTREME VALUES, M^3/S			MONTH											
			1	2	3	4	5	6	7	8	9	10	11	12
EXTREMES	MIN	Qmin												
		DATE												
	MAX	Qmax												
		DATE												

NOTES: ....
....
....

SHEET NUMBER: ____________________

Form SWBS2, Date filled: ________________

LOGO OF THE AUTHORITY RESPONSIBLE FOR CONDUCTING WRA OR OF THE AUTHORITY RESPONSIBLE FOR DATA COLLECTION

DATA COLLECTION STATION CODE

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WATER QUALITY REPORT GENERAL PARAMETERS

SURFACE WATER BALANCE YEAR:_____________

WMUA name: ....
WRAUA name: ....
Subregion name: ....
Region name: ....

Type of withdrawal: (circle as necessary)

1 2 3 4 5 6 7

Type of discharge: (circle as necessary)

1 2 3 4 5 6 7

Surface water resources balance equation terms. Circle the term to which this data sheet refers

Quality of evaporation and infiltration is not measured. Infiltrated water quality is assumed to be the same as that of the water body from which infiltration originates. For water withdrawals and water discharges each have seven categories listed below. In the specified box you should circle the corresponding number referring to the given type of withdrawal or discharge. For the method of station coding refer to the Figure 11 in the Guide. **Type of withdrawal: 1. for settlements; 2. for industry; 3. for irrigation; 4. for farming; 5. for fish farms; 6. for power plants; 7. for other demands. Type of discharge: 1. municipal; 2. industrial; 3. from cattlefarms; 4. from drainage systems; 5. from fish farms; 6. from power plants; 7. from other dischargers.** Chlorophyll and transparency are not observed for wastewaters and springs. Suspended solid are not observed for springs. The flow value must correspond to the flow on the water balance sheets, i.e. samples must be taken at the same time as flow measurements.

$$\sum_{i=1}^{I}(V_{ins})_i,\ \sum_{j=1}^{J}(V_{outs})_j,\ \sum_{c=1}^{C}(V_{dis})_c,\ \sum_{e=1}^{E}(V_E)_e,\ \sum_{k=1}^{K}(V_{ws})_k,\ \sum_{l=1}^{L}(V_{infs})_l,\ \sum_{m=1}^{M}(V_S)_m$$

No.	WATER QUALITY PARAMETER	UNIT OF MEASURE	MEASURED VALUE
1	Flow	m^3/s	
2	Alkalinity	mg $CaCO_3$/l	
3	Bicarbonates	mg $CaCO_3$/l	
4	BOD_5	mg O_2 /l	
5	Calcium	mg /l	
6	Chlorides	mg/l	
7	Chlorophyll	mg/l	
8	Colour	descriptive	
9	Dissolved oxygen	mg/l	
10	Electroconductivity	µS/cm	
11	Free ammonia	mg N/l	
12	Free CO_2	mg/l	
13	Magnesium	mg/l	
14	Nitrates	mg N/l	
15	Nitrites	mg N/l	
16	Odour	descriptive	
17	Orthophosphates	mg P/l	
18	pH value		
19	Transparency	m	
20	Potassium	mg/l	
21	Sodium	mg/l	
22	Sulphates	mg/l	
23	Temperature	°C	
24	Total phosphorus	mg P/l	
25	Total suspended solids	mg/l	
DATE OF SAMPLING:			

NOTE: ONE DATA SHEET MUST BE FILLED FOR EACH SAMPLE; STANDARD METHODS SHOULD BE USED FOR THE ANALYSES

LOGO OF THE AUTHORITY RESPONSIBLE FOR CONDUCTING WRA OR OF THE AUTHORITY RESPONSIBLE FOR DATA COLLECTION

DATA COLLECTION STATION CODE

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WATER QUALITY REPORT GENERAL PARAMETERS

GROUNDWATER BALANCE YEAR:______________

Type of withdrawal: (circle as necessary)

1 2 3 4 5 6 7

WMUA name: ....

WRAUA name: ....

Subregion name: ....

Region name: ....

Territorial code, enter as necessary:

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Surface water resources balance equation terms. Circle the term to which this data sheet refers

WQ for withdrawal and spring discharge term is measured directly. WQ for all other terms is estimated using groundwater quality monitoring stations. Seven categories of withdrawal are possible and are listed below. In the specified box you should circle the corresponding number referring to the given type of withdrawal. For the method of station coding refer to the Figure 11 in the Guide. **Type of withdrawal: 1. for settlements; 2. for industry; 3. for irrigation; 4. for farming; 5. for fish farms; 6. for power plants; 7. for other demands.** The estimated values are based on the territory rather than a data collection station and a code of the territory needs to be entered also. Territorial coding is conducted in a manner as in Figure 11 of the Guide. Not all parameters should be monitored (See Table 2 in Chapter 4 of the Guide). Flow values are determined by groundwater flow models.

$$\sum_{p=1}^{P}(V_{ing})_p,\ \sum_{q=1}^{Q}(V_{outg})_q,\ \sum_{r=1}^{R}(V_{wg})_r,\ \sum_{l=1}^{L}(V_{infs})_l,\ \sum_{m'=1}^{M}(V_{Ssa})_{m'},\ \sum_{s=1}^{S}(V_{dao})_s,\ \sum_{t=1}^{T}(V_{dai})_t,\ \sum_{f=1}^{F}(V_{ET})_f$$

No.	WATER QUALITY PARAMETER	UNIT OF MEASURE	MEASURED VALUE
1	Flow	m^3/s	
2	Alkalinity	mg $CaCO_3$/l	
3	Bicarbonates	mg $CaCO_3$/l	
4	BOD_5	mg O_2 /l	
5	Calcium	mg /l	
6	Chlorides	mg/l	
7	Chlorophyll	mg/l	
8	Colour	descriptive	
9	Dissolved oxygen	mg/l	
10	Electroconductivity	µS/cm	
11	Free ammonia	mg N/l	
12	Free CO_2	mg/l	
13	Magnesium	mg/l	
14	Nitrates	mg N/l	
15	Nitrites	mg N/l	
16	Odour	descriptive	
17	Orthophosphates	mg P/l	
18	pH value		
19	Transparency	m	
20	Potassium	mg/l	
21	Sodium	mg/l	
22	Sulphates	mg/l	
23	Temperature	°C	
24	Total phosphorus	mg P/l	
25	Total suspended solids	mg/l	
DATE OF SAMPLING:			

NOTE: ONE DATA SHEET MUST BE FILLED FOR EACH SAMPLE; STANDARD METHODS SHOULD BE USED FOR THE ANALYSES

LOGO OF THE AUTHORITY RESPONSIBLE FOR CONDUCTING WRA OR OF THE AUTHORITY RESPONSIBLE FOR DATA COLLECTION

DATA COLLECTION STATION CODE

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WATER QUALITY REPORT SPECIFIC PARAMETERS

WATER BALANCE YEAR: __________

WMUA name: ....

WRAUA name: ....

Subregion name: ....

Region name: ....

Type of withdrawal: (circle as necessary)

1 2 3 4 5 6 7

Type of discharge: (circle as necessary)

1 2 3 4 5 6 7

Specific WQ parameters are analysed only for special purposes (industrial discharges, specific requirements for water use etc.) A list provided is only for example purposes and for each particular situation a list of parameters may differ. Note that if a polluter discharges specific substances the same substances should be analyzed in samples from nearby surface and groundwater data collection stations. Seven categories of withdrawals are possible and are listed below. In the specified box you should circle the corresponding number referring to the given type of withdrawal. For the method of station coding refer to the Figure 11 in the Guide. **Type of withdrawal: 1. for settlements; 2. for industry; 3. for irrigation; 4. for farming; 5. for fish farms; 6. for power plants; 7. for other demands.** The estimated values are based on the territory rather than a data collection station and a code of the territory needs to be entered also. Territorial coding is conducted in a manner as in Figure 11 of the Guide. Not all parameters should be monitored (See Table 2 in Chapter 4 of the Guide). Flow values are determined by groundwater flow models.

WATER RESOURCES BALANCE EQUATION TERM TO WHICH THIS DATA SHEET REFERS.

Enter the term from the relevant WRB equation in the space provided. This sheet is used for all samples used for specific water quality analyses.

WATER QUALITY PARAMETER	**Unit of measure**	**Observed value**
INDUSTRIAL BRANCH	**POWER GENERATION**	
Mineral oil	mg/dm^3	
INDUSTRIAL BRANCH	**OIL EXTRACTION**	
Oil and mineral oil	mg/dm^3	
Phenols	mg/dm^3	
Volatile phenols	mg/dm^3	
Total Organic Carbon	mg/dm^3	
p i m alkalinity	nVal/dm^3	
Hardness	nVal/dm^3	
NH_{4+}	mg/dm^3	
S^{2-}	mg/dm^3	
Na^+	mg/dm^3	
Ba^{2+}	mg/dm^3	
Sr^{2+}	mg/dm^3	
Cl^-	mg/dm^3	
SO_4^{2-}	mg/dm^3	
INDUSTRIAL BRANCH	**NATURAL GAS EXTRACTION**	
Mineral oil	mg/dm^3	
Phenols	mg/dm^3	
Volatile phenols	mg/dm^3	
S_2-	mg/dm^3	
DATE OF SAMPLING:		

NOTE: ONE DATA SHEET MUST BE FILLED FOR EACH SAMPLE; STANDARD METHODS SHOULD BE USED FOR THE ANALYSES

Appendix B.
Data sheets for non-point sources of pollution

A. Drainage of agricultural and natural lands

CHARACTERISTIC	DATA TO BE COLLECTED AND INSTRUCTIONS
WMUA (Name and Code)	Enter name and code (see chapter 3) of the WMUA on which the drainage system is located. If drainage system extend over more than one WMUA fill a data sheet for each WMUA with data relevant only to each individual WMUA.
Drainage system (Name and code)	Identify the drainage system by name or a code. These can usually be obtained from the owners of the drainage system or those responsible for the system management
Area drained, ha	Enter the total area drained by the system. If the system extends outside a given WMUA enter only the area within the WMUA considered.
Receiving water body (Name and Code)	Enter the name and/or the code of the water body into which drainage waters are discharged
Location (description)	Describe the location of the discharge point, (e.g. left/right bank, submerged discharge or not etc.)
River km. at discharge point	Give river km at the discharge point or geographical longitude and latitude of the discharge point
Soil Characteristics	Briefly describe the soil at the location, repeat for each micro location
Physical	Describe the physical characteristics of the soil
Location	Give a micro location of the soil type
Moisture	Give average soil moisture content
Infiltration coefficient	Give average infiltration coefficient at this location
Soil composition	Describe soil composition at each micro location
Location	
Composition	
Land Use Crop Area covered, ha	Describe land use in the area. If the drainage system covers area under different crops give relevant data for each crop.
Vegetation (natural) Vegetation type Area covered, ha	Describe land use in the area. If the drainage system covers non agricultural area give relevant data for each vegetation type (grass, forest, etc.).
Agricultural chemical use (fertilisers, herbicides, pesticides) Type of chemical Area treated, ha Annual application rate, kg/yr-ha	Describe agricultural practices in use. For each chemical used give data on area under treatment and annual application rate.
Dynamics of discharge	Give a detailed description of the operation of the drainage system (typical distribution of discharge during the year, average annual quantities discharged, temporal variability of discharge etc.) Is the system gravitational or is pumping necessary, give maximum discharge observed, are the discharged quantities regularly and continually monitored, if so give relevant weekly or daily data for a typical year)
Discharge water quality	Give a detailed description of the quality of water being discharged. How frequently is the quality analysed, what water quality parameters are monitored, who is responsible for the water quality analysis. Does water quality vary with time, have WQ trends been observed, etc.

B. Solid waste landfills

CHARACTERISTIC	DATA TO BE COLLECTED AND INSTRUCTIONS
WMUA (Name and Code)	Enter name and code (see chapter 3) of the WMUA on which the landfill is located. If the landfill extend over more than one WMUA fill a data sheet for each WMUA with data relevant only to each individual WMUA.
Landfill (Name, code and location)	Identify the landfill by name, code, location and owner. These can usually be obtained from the owners of the landfill or those responsible for its operation
Area covered, ha	Enter the total area covered by a landfill. If the landfill extends outside a given WMUA enter only the area within the WMUA considered.
Data about the landfill Topography Total area Total volume End of use volume Depth of ground water Soil permeability	Give a detailed description of the landfill site and the relevant data on the area and volume of the landfill. Also give the data on the depth of ground water table below the landfill and soil permeability. If drainage system is installed below the landfill describe it and fill form A also.
Method of landfill operation	Describe the type of waste being disposed of at the landfill. Give data on quantities of each type of solid waste disposed of at the site per year. Provide data on compacting practice if any etc.
Solid waste quality	Has solid waste quality been analysed. If yes give the relevant results. Who conducted the quality analyses, is there waste recycling in use, what is the composition of solid waste
Data on the zone of influence	Has the impact of a landfill on ground water and surface water resources been analysed. If yes what are the results of such analyses. Are there any piezometers or observation wells in the vicinity of the landfill, if yes give data on their location, depth, age, construction, distance from the landfill, etc.
Surface water data in the vicinity of the landfill	Is there a surface water body in the vicinity of the landfill, if yes provide data on their location and distance from the landfill. Make sure nearest RDCS to the landfill are identified for each surface water body and the distances from the landfill.

C. Seepage septic tanks

CHARACTERISTIC	DATA TO BE COLLECTED AND INSTRUCTIONS
WMUA (Name and Code)	Enter name and code (see chapter 3) of the WMUA on which the septic tank is located.
Community (Name and code, location of the tank)	Identify the septic tank by name or a code. These can usually be obtained from the owners of the septic tank or those responsible for the waste water management
Daily volume discharged	Provide the data on average daily volumes of waste water being discharged to the septic tank and the population equivalent for the loading of the septic tank.
Receiving water body (Name and Code)	Enter the name and/or the code of the water body into which drainage waters are discharged
Data on the Septic tank Material used Total volume Basic dimensions Depth of ground water Soil permeability	Give basic data about the septic tank. What is it made of, what is its volume and basic dimensions (width, depth, length), what is the soil permeability below the septic tank.
Method of use Type of waste water Volume of water/day Method of discharge Sludge disposal	Give a brief description of the way in which the septic tank is used. What type of waste waters are discharged and in which quantities. Is the discharging continuous or intermittent. What is done with content of the septic tank when full, where is sludge disposed of, etc.
Zone of influence Observation wells and piezometers Surface waters	Describe the observation wells and piezometers in the vicinity if any exist. Give relevant data on their location, distance from the septic tank, construction, depth, age etc. For surface waters give the location and description of the nearest surface water body. Specify the shortest distance from the septic tank
Data on water quality	Provide the data on the water quality. Is the quality of waste water discharged to the septic tank monitored, if yes who is responsible for the monitoring and what quality parameters are being monitored. What is the average water quality for the parameters monitored and with what frequency is the quality monitored.

D. Urban runoff from non-seaward communities

CHARACTERISTIC	DATA TO BE COLLECTED AND INSTRUCTIONS
WMUA (Name and Code)	Enter name and code (see chapter 3) of the WMUA on which the septic tank is located.
Community (Name and code, location of the tank)	Identify the septic tank by name or a code. These can usually be obtained from the owners of the septic tank or those responsible for the waste water management
Water supply and sewerage data	Provide data on population connected to water supply system, number of bathrooms, number of septic tanks, number of individual water supply wells, number of wells which are being used as septic tanks, method of storm water drainage if any etc.
Receiving water body (Name and Code)	Enter the name and/or the code of the water body into which runoff waters are discharged
Data on human activity in the WMUA Agriculture Animal husbandry Small industry Farming, etc.	Provide data on major human activities in the area, number and kind of farm animals, method of manure disposal, method of manure storage, estimated annual manure production. Provide data on small industrial activity and services in the area. Give data on type of activity, number of employed staff, amount of waste water produced for each activity, water quality data if available.
Data on ground water resources	Provide data on any piezometers in the area, their depth, construction and location. Provide data on ground water levels in the area and any data on ground water quality if available, including data on the frequency of sampling.