Unesco
NATURE & RESOURCES, Volume 26, Number 3, 1990
Parthenon Publishing

DB # 5474
general #

NATURE & RESOURCES

Water quality and availability

About the cover

The Aral Sea is a tragic example of what can happen with poorly planned or implemented schemes to divert water for agricultural development or other purposes. Better management can protect existing industries and the communities that depend on them while introducing sustainable development activities designed to *valorize* or make the most of local resources.

Nature & Resources is published quarterly: in English, French and Spanish by The Parthenon Publishing Group, Carnforth, United Kingdom; in Arabic by the Unesco Publications Centre, Cairo; in Chinese (ISSN 1001-0947) by the Commission for Integrated Survey of Natural Resources, Academia Sinica, Beijing; and in Russian (ISSN 0207-8937) by Progress Publishers, Moscow, on behalf of the USSR National Commission for Unesco and the USSR State Publishing Committee

Subscription Information

Nature & Resources is published quarterly and can be ordered from The Parthenon Publishing Group at the following rates:

1 year	£25 for individuals
	£50 for institutions
Single issue	£8

As a special introductory offer all subscribers in 1990 will receive the Journal *post free*.

(Special arrangements for readers in developing countries; consult Unesco)

Nature & Resources is also available in French and Spanish language editions from The Parthenon Publishing Group at the same subscription rates.

ISSN 0028-0844

Correspondence to:
Editor, Nature & Resources, Unesco,
7 place de Fontenoy, 75700 Paris, (France)

Composition by Ryburn Typesetting Ltd
Printed in the United Kingdom by
The Amadeus Press Ltd

Published on behalf of Unesco by

The Parthenon Publishing Group
International Publishers in Science, Technology & Education

Casterton Hall, Carnforth
Lancs, LA6 2LA, UK

120 Mill Road, Park Ridge
New Jersey 07656, USA

Unesco NATURE & RESOURCES, Vol. 26, No. 3, 1990

NATURE & RESOURCES

Water quality and availability

International news and information concerning environmental activities, natural resources research, conservation, disaster reduction and Unesco programmes in these fields

CONTENTS

Editorial

Water was one of the four elements of the ancients, but it is more than just one of the basic resources of civilization: it is the life-blood of all living organisms on earth. The attitude of humanity to water depends on its abundance: if plentiful, it is accepted by some as a gift of God, freely available whenever and for whatever purpose needed; if scarce, it becomes a most valuable commodity, a matter of public concern, an issue of disputes and even fights between its users. Civilizations have displayed all shades of attitudes between these two extremes. Expansion of population, industry, agriculture and higher living standards have increased water consumption as never before: water is increasingly appreciated as a vital resource, which needs care and attention to remain available not only for present but also future generations.

Several crucial questions of water sciences are discussed in this issue of *Nature & Resources*: the availability of water and outlooks for the future; the shift of emphasis of hydrology with regard to environmental management and the changing role of the hydrologist; the ever increasing importance of water quality management; the impacts of human changes in humid tropics on the water balance of the earth; and the water problems of large urban settlements.

These papers illustrate some of the preoccupations of the hydrological profession, which is apparently entering a stage of rapid change and re-evaluation. At the recent symposium of Unesco's International Hydrological Programme (IHP), new trends in hydrology were expressed through adjectives such as environmental, atmospheric, ecological, diagnostic, etc. The proliferation of different concepts seems to underline the lack of a general and coherent theory. We have tremendous knowledge on hydrological processes of different space and time scales but lack a link between them. The development of coupled cognitive models for hydrological, geochemical and biological processes is needed in order to upgrade our understanding of environmental mechanisms and to shape it into an advanced science, which should be the basis of intelligent decision making in water and environmental management.

Such preoccupations, concerns and challenges are well reflected in the present phase of the IHP, which is carried out under the title – *Hydrology and Water Resources for Sustainable Development in a Changing Environment.* Water management should rely on ecologically sound, economically viable, technically feasible and socially acceptable measures. As in the past 25 years, the IHP continues to contribute to unite international efforts in facing these challenges for the benefit of present and future users of global water resources.

András Szöllösi-Nagy
International Hydrological Programme

M.M. Holland, W. Rast and S.-O. Ryding

Water quality management

Introduction

Human development is rapidly becoming limited by increasing pollution of air and water. One aspect of water pollution, eutrophication of lakes and reservoirs, ranks as one of the most pervasive water quality problems around the world. Eutrophication refers to the excessive nutrient enrichment of water, which results in an array of undesirable symptomatic changes including nuisance production of algae and other aquatic plants, deterioration of water quality, taste and odour problems, and fish kills. In spite of efforts by governments at many levels to control the causes of eutrophication, water quality has continued to deteriorate in many streams, lakes, reservoirs and coastal areas around the world.

The role of the policy-maker often focuses on the development and implementation of management strategies and/or control programmes for dealing effectively with environmental issues such as eutrophication. Indeed, effective environmental management usually requires substantial recognition that an environmental problem exists in the first place, as well as sufficient support to formulate and implement a corrective policy. Yet, because of both public and political pressures, decisions sometimes have to be made in a relatively short time frame, regardless of the state of scientific knowledge on a specific item of concern. Development of strategies to combat the detrimental impacts of eutrophication is no exception to this fact (Rast and Holland, 1988). Indeed, the policy-maker often will be confronted simultaneously by advisors and supporters who argue that immediate action is vital, as well as by those who contend that corrective efforts should be delayed until more is known about the extent and severity of the problem and the most desirable measures to treat it. Therefore, responsible officials must attempt to balance the need and desire for immediate action against the need for further study.

This paper incorporates the need for balance in evaluating the potential impacts of human activities and pollution control programmes on the environment. The approach outlined here (Figure 1) is sufficiently general that it can be applied, with minimal modification, to the assessment and management of other environmental problems. Ryding and Rast (1989) provide more details in their volume of Unesco's Man and the Biosphere (MAB) book series. In addition, the MAB programme has recently published *Eutrophication management framework for the policy-maker* as MAB Digest Number 1 (Rast et al., 1989).

Identify eutrophication problems and management goals

The effects of eutrophication are considered negative in many places around the world, and often reflect human perceptions of good versus bad water quality. Excessive algae and aquatic plant growths are highly visible, and can interfere significantly with the uses and aesthetic quality of waterbodies (Table 1). One consequence of such growths can be the production of taste and odour problems in drinking water drawn from a lake or reservoir, even though it may be treated and filtered prior to use. The water treatment process itself can become more expensive and time-consuming for eutrophic waters and water transparency may be greatly reduced. As algal populations die and sink to the bottom of a waterbody, their decay by bacteria can reduce oxygen concentrations in bottom waters to levels that are too low to support fish life, resulting in fish kills. Such oxygen-deficient conditions can also result in excessive levels of iron and manganese in the water, which can interfere with drinking water treatment. There are also negative

Dr Marjorie M. Holland, *Director, Public Affairs Office, Ecological Society of America, 9650 Rockville Pike, Suite 2503, Bethesda, Maryland 20814, United States of America.* **Dr Walter Rast**, *U.S. Geological Survey, 8011 Cameron Road, Austin, Texas 78753, United States of America.* **Dr Sven-Olof Ryding**, *Federation of Swedish Industries, P.O. Box 5501, S-114 85 Stockholm, Sweden.*

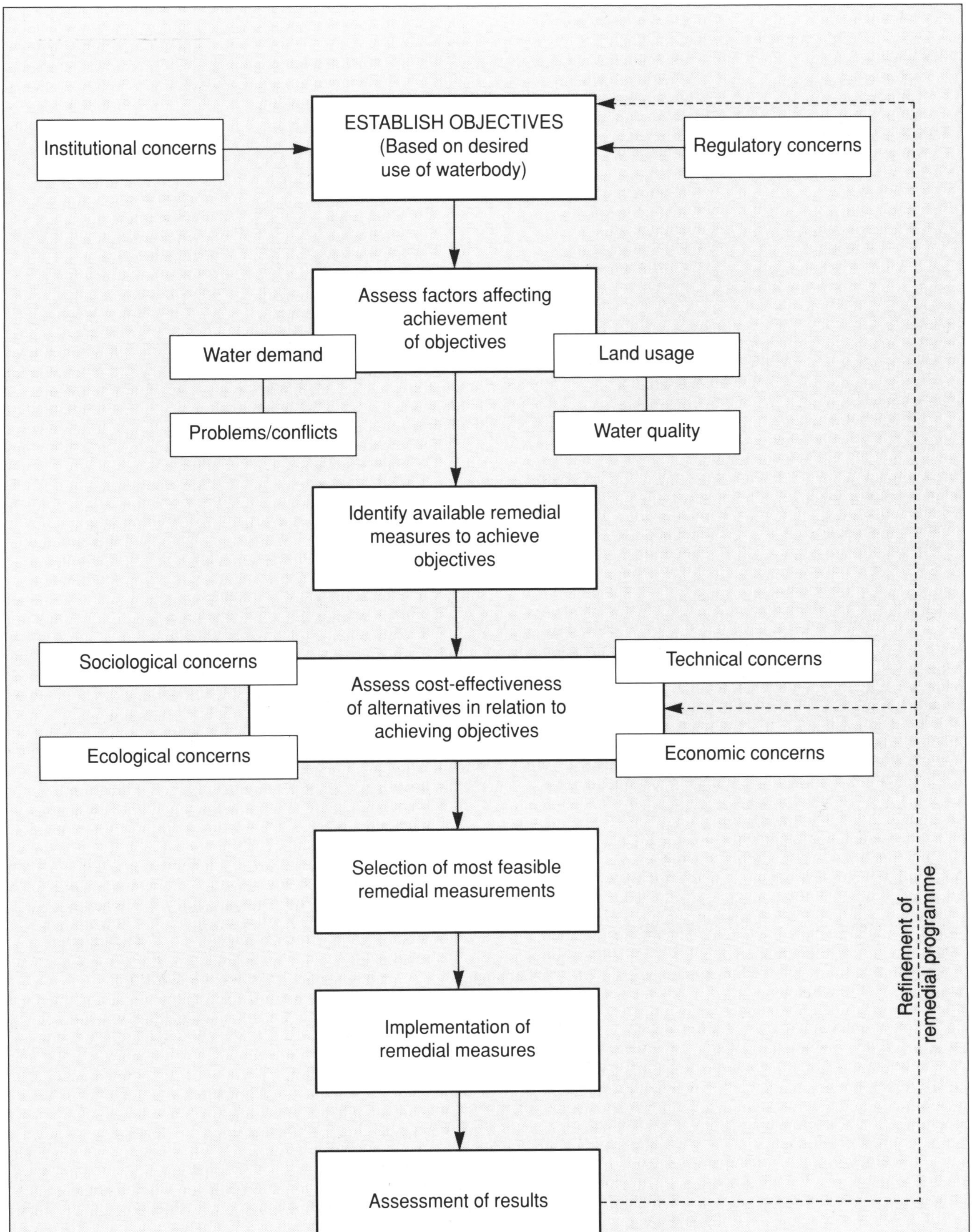

Figure 1 *Sequence of decisions to be made in the development and implementation of eutrophication control programmes. Source: redrawn from Ryding and Rast (1989).*

Table 1 ***Trophic criteria and their responses to increased eutrophication***[1].

Physical	*Chemical*	*Biological*[2]
Transparency (D) (e.g. Secchi disc) Suspended solids (I)	Nutrient concentrations (I) (e.g. spring maximum) Chlorophyll *a* (I) Electrical conductance (I) Dissolved solids (I) Hypolimnetic oxygen deficit (I) Epilimnetic oxygen supersaturation (I)	Algal bloom frequency (I) Algal species diversity (D) Phytoplankton biomass (I) Littoral vegetation (I)[3] Zooplankton (I) Fish (I)[4] Bottom fauna (I)[5] Bottom fauna diversity (D) Primary production (I)

1. (I) signifies that the value of the parameter generally increases with the degree of eutrophication; (D) signifies that the value generally decreases with the degree of eutrophication.
2. The biological criteria have important qualitative (e.g. species) changes as well as quantitative (e.g. biomass) changes, as the degree of eutrophication increases.
3. Aquatic plants in the shallow, nearshore area may decrease in the presence of a high density of phytoplankton.
4. Fish may be decreased in numbers and species in bottom waters (hypolimnion) beyond a certain degree of eutrophication, as a result of hypolimnetic oxygen depletion.
5. Bottom fauna may be decreased in numbers and species in high concentrations of hydrogen sulphide (H_2S), methane (CH_4) or carbon dioxide (CO_2), or low concentrations of oxygen (O_2) in hypolimnetic waters.

(Modified from Brezonik, 1969; Taylor et al., 1980; O. Ravera, personal communication, EURATOM, 1984; M. Straskraba, personal communication, Czechoslovak Academy of Science, 1985).

potential health effects, especially in tropical regions, related to such parasitic diseases as schistosomiasis, onchocerchiasis and malaria. Each of these diseases can be aggravated by cultural eutrophication, which can enhance the appropriate habitats for these organisms. The primary exception to these negative aspects is the use of the eutrophication process to enhance the production of aquaculture.

Why is eutrophication a problem?

The main objective of traditional water pollution control efforts was to clean up raw wastewaters and gross industrial wastes, which are potential sources of pathogens and toxic materials. However, since treatment of such effluents is becoming more common, especially in industrialized nations, the environmental impacts of other types of pollution in the drainage basin have assumed greater importance in recent years. For example, pollution from non-point sources (urban and rural runoff) is now being seriously considered in the development of effective water pollution control programmes. Indeed, there is a definite, continuing need to develop an integrated view of land, atmosphere and water interactions in the drainage basin, as they relate to the assessment and treatment of cultural eutrophication.

From a practical perspective, scientists have accumulated considerable evidence linking accelerated lake and reservoir eutrophication to the excessive input of aquatic plant nutrients from point and non-point sources in the drainage basin. Consequently, nutrient loading concepts are frequently used in the assessment of nutrient control measures.

Establishment of eutrophication management goals

The designation of unacceptable versus acceptable water quality can be based on the intended use or uses of the water resource. That is, water quality management goals for a lake or reservoir often reflect the major purpose(s) for which the water is to be used.

Obviously, there are water quality conditions to be avoided because of their interference with water uses. Ideally, for example, a lake or reservoir used as a drinking water supply should have water quality as close to an oligotrophic state as possible, because this would ensure that only a minimum amount of pre-treatment would be necessary to yield water suitable for human consumption. The level of phytoplankton (and their metabolic products) in the waterbody should be as low as possible to facilitate this goal. Further, if the water is taken from the bottom waters of a lake during the summer (usually the period of maximum algal growth), it should be free of interfering substances resulting from decomposition of dead algal cells.

Although humans can use water of a range of qualities, there is a desirable or optimal quality for virtually any type of water usage. Although not quantitative in nature, a summary of intended water uses, and the optimal versus minimally-acceptable trophic state for such uses, is provided in Table 2. A prudent approach in setting eutrophication management goals is to determine the minimum water quality and trophic conditions acceptable for the primary use or uses of the lake or reservoir and attempt to manage the waterbody so that these conditions are achieved. In a given situation, if the primary use of a waterbody is hindered by existing

Table 2 *Intended lake and reservoir water uses as related to trophic conditions.*

	Trophic state	
Desired use	*Required*	*Still tolerable*
Drinking water production	oligotrophic	mesotrophic
Bathing purposes	mesotrophic	slightly eutrophic
Low-water improvement		
with long distance supply line	—	mesotrophic
without long distance supply line	—	slightly eutrophic
Fish culture		
salmonid waterbodies	oligotrophic	mesotrophic
cyprinid waterbodies	—	eutrophic
Providing process water	mesotrophic	slightly eutrophic
Cooling water production	—	eutrophic
Water sports		
(without bathing)	mesotrophic	eutrophic
Landscaping in recreation areas	—	slightly eutrophic[1]
Irrigation		
(by means of channels)	—	strongly eutrophic
Energy production	—	strongly eutrophic[2,3]

1. Within the scope of landscaping, a eutrophic state caused by the natural ageing process, can even be desirable.
2. Without consideration of the eventual water quality requirements for the receiving canal.
3. Not valid for river plants, which may be impaired by macrophyte and algal growths.

(Adapted from Bernhardt, 1981)

water quality, this signals the need for remedial or control programmes to achieve the necessary in-lake conditions.

Who should be involved in addressing the problem?

The role of governments Because a range of different government and economic conditions exists around the world, it is difficult to provide general guidelines regarding the role of government in environmental protection efforts that will cover all possible situations. Virtually all nations also contain some type of civil service infrastructure which, if properly used, can be an effective instrument with which to address governmental concerns. Nevertheless, not all concerns identified in this paper will receive the same degree of attention in all countries, because of differing governmental priorities and national perspectives.

Because the selection of effective eutrophication control measures usually requires consideration of a number of scientific/engineering, socio-economic and political factors, a multidisciplinary approach is highly desirable. Eutrophication policy and management decisions usually are best made in consultation with individuals with expertise in several areas, including wastewater treatment engineers, chemists, agricultural experts, hydrologists, limnologists and economists. In addition, the advice of legal, health and planning experts can be extremely valuable in the development of effective eutrophication control programmes.

The role of the public If public perceptions are sought, a readily usable forum for obtaining this viewpoint should be clearly identified. One example is the creation of a citizens' advisory committee. Such a committee can provide additional insight about the extent of a given eutrophication problem, and what the social and political consequences might be if the problem is left uncorrected.

As an example of the potential benefit of public input, actual water quality data from a lake may be scarce at the beginning of a control programme. In such cases, narrative descriptions of prior conditions, remembered by elder citizens and leaders, can be used as an initial reference point against which the potential effectiveness of a control programme can be assessed. Such interactive communication can have at least two beneficial effects: (1) knowledge gained through lifetime observations of a waterbody can be documented for use in developing management programmes, and (2) persons encouraged to participate in the development of a programme are more likely to become advocates of it.

Knowledge gained in this manner by governmental personnel can be disseminated among the general population, preparing them for more informed future judgements and actions. In some developing countries, where financial constraints may limit the use of large structural solutions to eutrophication problems (e.g. municipal wastewater treatment plants), the government may wish to make maximum use of community-based information and educational programmes on eutrophication control measures, especially those in which the public can most directly participate. In such cases, a communications specialist can be a valuable asset.

Assess the extent of available information

Before a eutrophication monitoring or management programme is developed, one should attempt to determine the full scope of the problem. Previous studies and relevant case histories should be reviewed prior to development of a management programme. Likely sources of such information include drinking water and wastewater treatment agencies, universities and other types of research centres (including national, regional and local government laboratories), and the scientific and engineering literature dealing with aquatic ecosystems.

Reasons for collecting adequate monitoring data include the following:

- establishment of past and present baseline conditions, in order to document the problem, and to provide a reference against which progress can be assessed;
- identification of significant information gaps; and
- development of cost-effective monitoring programmes.

Necessary information for assessment and control of lake or reservoir eutrophication normally includes such items as the depth, volume and water-flushing rate, the in-lake concentrations of nutrients and algae, the occurrence of nuisance growths of algae and other aquatic plants, the occurrence of oxygen-depleted bottom waters in the lake and related fish kills, the annual nutrient loadings to the lake, and the population and land-use characteristics of the drainage basin.

If existing data are not sufficient to provide the necessary information for assessment or management purposes, it will usually be necessary to implement a drainage basin and/or in-lake monitoring programme. An initial monitoring programme can be modest, and designed to allow progressive expansion and revision to meet changing needs. Ryding and Rast (1989) provide detailed information on developing effective in-lake monitoring programmes, as well as methodologies for determining the nutrient load. In addition, Cale and McKown (1986) present a methodology for estimating the anticipated costs of monitoring programmes.

Data and documentation should be sufficient to warrant corrective measures. There probably will never be sufficient scientific understanding to convince every technical expert that a given management action is the ideal or timely one to be taken. New knowledge inevitably raises new questions. Nevertheless, if the policy-maker delays implementation of any corrective actions until *all* questions are completely answered, the problem can become extremely difficult to correct.

Identify options for management of eutrophication

Should one treat the causes or the symptoms?

Eutrophication control programmes can be directed towards treating either the basic causes or the symptoms (e.g. reducing aquatic plant nutrient inputs from the drainage basin versus periodic harvesting of excessive aquatic plant growths). In some cases, a combination of the two will be most useful. Control programmes can also focus on treating point sources or non-point sources of nutrients. Examples would be limiting 'pipeline' nutrient inputs from municipal wastewater treatment plants and controlling runoff from farms and urban areas, respectively. Further, the programme can be either structural or non-structural in form (e.g. building a municipal wastewater treatment plant versus changing agricultural fertilizer application practices). Nevertheless, the basic approach should be tied as closely as possible to the overall eutrophication management goals.

It is usually most effective to treat the underlying and most readily controllable causes of eutrophication, rather than merely alleviate the symptoms. In most cases, this means reduction or elimination of the excessive nutrient inputs that stimulate the excessive growths of aquatic plants in the first place. This approach will work to eliminate the basic problem, and usually is the most effective strategy over the long term.

The alternative strategy, treating the specific symptoms of eutrophication, is the logical and perhaps only option if the costs of treating the basic cause (excessive nutrient inputs) are too high, or if additional treatment is necessary in a given case. Other possible reasons for using this approach are the absence of an institutional framework for treating the cause or an inability to formulate and/or implement an effective management programme directed towards external nutrient reductions. In such cases, various 'in-lake' treatment options can offer temporary relief in varying degrees from the symptoms of eutrophication.

Consider full range of available control options

Reduction of nutrient inputs The first control priority usually is to reduce nutrient inputs to the waterbody from the sources in the drainage basin that contribute the largest quantities of the 'biologically available' forms of the nutrients (Rast and Lee, 1978, 1983; Lee et al., 1980; Sonzogni et al., 1982). The control effort can be directed to both the point (pipeline) and/or non-point (diffuse) nutrient sources in the drainage basin. For example, human and animal wastewaters contain large quantities of phosphorus and nitrogen in chemical forms easily used by algae and other aquatic plants. Treatment to reduce the level of the nutrients in these wastewaters is usually a cost-effective approach to keep them from reaching surface waters (Ryding and Rast, 1989).

In-lake control measures Examples of in-lake methods include the harvesting of aquatic plants, the use of algicides, in-lake nutrient inactivation or neutralization, artificial oxygenation of bottom waters, dredging or covering of bottom sediments, increasing the water flushing or circulation rates, and 'biomanipulation' (Cooke et al., 1986; Ryding and Rast, 1989). Although such measures are usually less effective over the long term than external nutrient control programmes, they do offer an effective means of combating, at least temporarily, the negative impacts of eutrophication.

The option of doing nothing The environmental, social and economic consequences of doing nothing should also be considered prior to evaluating eutrophication management options, and even in deciding whether or not to implement such programmes in the first place. The consequences of doing nothing offer a basis for comparison with the potential impacts of initiating control programmes.

An inevitable consequence of human settlement of a drainage basin is a deterioration of water quality in the drainage basin over time, especially if such deterioration continues to be ignored. An untreated waterbody exhibiting eutrophication symptoms sufficiently severe that control programmes are being considered will probably become even worse over the long term. This can necessitate even more expensive control programmes at a later date, as well as the loss of an increasing number of water-use options. Further, although cultural eutrophication is largely reversible, a lake cannot deteriorate indefinitely without diminishing the chances for a timely and successful rehabilitation.

Analyse costs and benefits of alternative strategies

Consider relative costs of control options

The costs of specific eutrophication control options vary substantially. The costs of phosphorus removal at municipal wastewater treatment plants, for example, will vary as a function of the treatment process used, the age of the plant, the number of people served, etc. Non-point source control measures also exhibit a wide range of costs and effectiveness. However, the long-term costs of some non-point source measures can be minimal (e.g. sound land-use practices). Furthermore, some non-point source control measures can actually result in monetary savings over the long term, even considering the initial costs of implementing the programmes. It was determined in the North American Great Lakes Basin that beyond a certain advanced degree of point source control, it was less expensive to implement some non-point source control measures than to implement further, more stringent point source control measures (PLUARG, 1978; Johnson et al., 1978). In addition, some non-point source control measures can be relatively simple in concept, an example being the application of fertilizers in quantities adequate for plant needs. Applying fertilizers in excess of needs can result in nutrient transport to surface waters via agricultural runoff.

Compare available resources and management goals

There is little practical value in designing or developing a substantial eutrophication control programme if the available resources or administrative structure are not adequate to carry it out. Consequently, such resources should be identified and compared with the needs of the task to be undertaken. They would include such items as technical expertise, financial resources and human resources. The initial control programme should be designed, and have sufficient scope, so that it has a realistic chance of achieving its management goals.

Compare available resources and expected benefits

The most effective approach to alleviate the negative impacts of eutrophication is usually to treat the most readily controllable cause of the problem – the input of excessive quantities of phosphorus and/or nitrogen. The control programme should be directed towards the major sources of these nutrients in the drainage basin, especially human and animal wastes (including municipal wastewater effluents and drainage from large animal feedlots). Non-point sources, such as runoff from urban and agricultural lands, also offer important nutrient control targets.

Changes in land-use practices offer a largely non-structural way of reducing nutrient loads associated with runoff. However, the implementation of some non-point source methods may require basic public education and/or a change in public attitudes. For example, farmers located a long distance from a lake may not recognize their role in causing or promoting nutrient runoff to the lake. Thus, they understandably may resist the suggestion that a change in fertilizer practices or methods of ploughing can help reduce the nutrient load to the lake, especially if the suggested changes are more expensive or time-consuming than current practices or if no direct benefit to the farmer can be demonstrated. As suggested by PLUARG (1978), such individual efforts may not seem impressive when viewed individually, but can be very significant on a cumulative scale.

Cost–benefit analysis

For maximum public acceptance of environmental protection programmes, the scientist or engineer cannot ignore economic and political realities, in favour of a solely technical approach. Likewise, the policy-maker or manager cannot ignore environmental and engineering considerations. In fact, because of the tremendous growth in the size, scope and expenditures of central governments, the reaction in some countries has been a reluctance to fund new environmental protection programmes without a thorough social and economic analysis of them (in addition to environmental impact assessments).

One approach often used to assess the desirability or 'worthiness' of alternative management programmes is a 'cost–benefit analysis', which has its basis in a branch of economic theory called 'welfare economics'. In the broadest sense, cost–benefit analysis means a comparison of all the positive and negative elements of a decision, even if not all of them are measurable in strictly monetary terms. However, in practice, cost–benefit analysis usually means a comparison of the financial gains realized and the costs incurred for a particular programme or activity. If a value unit (e.g. dollars) is spent in a way that generates more wealth than is sacrificed, the overall social welfare is increased. Thus, if the 'price' of a necessary or desirable activity (e.g. eutrophication control) does not exceed the expected benefits (e.g. enhanced water quality or water uses), it is usually considered desirable to proceed with the project. Thus, a policy-maker using cost–benefit analysis is usually asking whether or not the expected benefits of a eutrophication control programme are worth the investment of public funds.

Unfortunately, a significant shortcoming of a strictly monetary-orientated approach is that it is usually done under the implicit assumption that a positive benefit:cost ratio alone is sufficient rationale to proceed with a given programme or activity. However, while the 'cheapest' solution to a eutrophication problem may be economically pleasing, it may also be environmentally short-sighted. This is because some eutrophication control programme elements may not be easily quantified, or else can be quantified only in an artificial or unrealistic manner. Examples include cultural values, the long-term sustainability of natural resources, political realities, societal and/or governmental structure and stability, and the national or regional distribution of wealth. Because of such realities, the 'logical' solution to an environmental problem is not always the most socially acceptable one.

Thus a strictly monetary-orientated cost–benefit analysis may preclude realistic consideration of the long-term environmental, social and/or public health consequences of a given control programme. For example, if one cannot assign a realistic monetary value to the desirability of maintaining a particular fish species or the achievement of enhanced water quality, such factors may be ignored as a benefit when compared to the use of a water resource for industrial purposes or municipal waste assimilation. Non-scientific concerns may also require explicit consideration in development of effective eutrophication control programmes.

One can use cost–benefit analysis in a somewhat different manner in assessing management alternatives. By comparing the expected benefits of alternative control programmes, one can attempt to select the most preferable option in a given situation by: comparing the benefit:cost ratios of alternative programmes and levels of expenditure; by comparing the absolute values of the expected benefits of alternative projects, using a fixed level of monetary and other resources; or by determining the minimum cost programme for achieving a specific goal or benefit.

Analyse adequacy of legislative/regulatory framework for eutrophication control programmes

Institutional concerns

The legislative and regulatory frameworks for addressing eutrophication should be examined as a necessary component of an effective eutrophication control programme. There is little point in developing a complex monitoring network, for example, if the legislative or regulatory framework for implementing or enforcing control programmes does not exist. Conversely, a well-formulated statute is of little value if the necessary monitoring or pollution-alert network for determining compliance with the statute is inadequate.

It is usually most efficient at the central government level to assign environmental programmes to a single agency structured to manage multiple environmental concerns (e.g. air, water and land resources), than to create a separate governmental unit to deal with each problem as it arises. Furthermore, the agency or institution responsible for carrying out such programmes should be clearly identified. The public may have concerns or suggestions about various aspects of eutrophication, but be frustrated by the lack of a clearly identified and readily accessible forum for expressing such concerns to the policy-maker or administrator.

An effective eutrophication control programme may also contain elements, or be involved with problems, which overlap political boundaries and/or governmental agency concerns. If there is an existing agency with which a new control programme is compatible, that agency is the logical one to carry out the new function. However, care must be taken to prevent a new programme from being assigned to an existing governmental unit having a conflicting purpose or goal. For example, an agency responsible for promoting commercial fisheries (thereby interested in enhancing the overall productivity of a waterbody) is not necessarily the best agency to be given the task of protecting a lake as a drinking water supply (for which increased algal production is not desirable). The optimal water quality for these two uses is markedly different. If a central agency is charged with programmes that have conflicting purposes, much effort can be expended in resolving the conflict rather than addressing the problem, and one purpose may advance at the expense of the other.

If it is necessary to create a new programme for the management or control of eutrophication, a definite term for its existence should be specified. Approximately 5 to 10 years would be a reasonable period of time, after which it would either be terminated or re-enacted. Even though this provision creates some risk that a beneficial agency or programme might be terminated, this limited term provides an incentive for governmental accomplishment, mandates timely attention by the policy-maker and/or the public, and provides an opportunity for necessary updating and refinement.

Regulatory concerns

Lengthy, complex, detailed regulations should be discouraged, if not prohibited, because of the potential difficulty both in understanding and administering them. If a new statute cannot be implemented because of unrealistic components, not only is achievement of the worthwhile objective delayed, but respect for the timely compliance with laws is also generally eroded. Over the long term, an orderly progression in statutory complexity and development, from one legislative session (or its equivalent) to another, is preferable to the confusion that can result from attempting to accomplish too much, too soon with too little information, staff and money.

Initial regulatory statutes should contain provisions for securing sufficient data and knowledge useful for periodically re-evaluating a eutrophication control programme. In the United States, for example, many environmental improvement programmes began as attempts to assist states, regions, counties or cities in understanding and addressing their specific needs. Such assistance as training grants to prepare technical staff, money for personnel, assistance to develop monitoring networks, support for students to secure advanced degrees in colleges and universities, and research grants to study the issues and problems, contribute to future refinements in the regulatory scheme. It also furthers our general scientific understanding of the complexities of the eutrophication process.

Select control strategy and disseminate summary to affected parties

General considerations

Present scientific knowledge is not sufficient to be able to offer a single, completely fool-proof eutrophication control programme for <u>all</u> cases. Nevertheless, present knowledge is sufficient to develop a generalized approach which, if used in conjunction with an adequate monitoring programme and continuing scrutiny of the measured data, will usually work in the majority of cases. The use of statistically analysed data bases and derived quantitative relationships allows for the development of a reasonable, generalized approach for attempting to assess and control eutrophication of lakes and reservoirs.

Although the most feasible control option can vary from location to location, it is generally believed that control of external nutrient inputs (especially those of phosphorus) represents the most effective, long-term strategy to control eutrophication of both natural lakes and reservoirs. Nevertheless, it is important to be realistic in selecting specific control measures, both in terms of how much reduction in the phosphorus inputs can be expected and how much such control measures will be likely to cost. An unrealistic management plan can undermine popular support for phosphorus control efforts if it is observed that the plan will not achieve the desired phosphorus control goals, or that it is inappropriate from the point of view of cost-effectiveness.

Water quality as related to desired water use

A logical approach for establishing an effective eutrophication control programme is to determine the necessary water quality and/or trophic conditions for a desired water use (or uses), and design the programme to achieve these necessary conditions.

If a waterbody has one primary use, the control measures for achieving the necessary water quality can be based on this single use. Where there are multiple competing uses for the same waterbody, determination of the desired water quality can be based on the single use of highest priority. This use may require the highest standards of water quality in some situations, while less stringent water quality may be sufficient in other cases. Thus, decisions on a

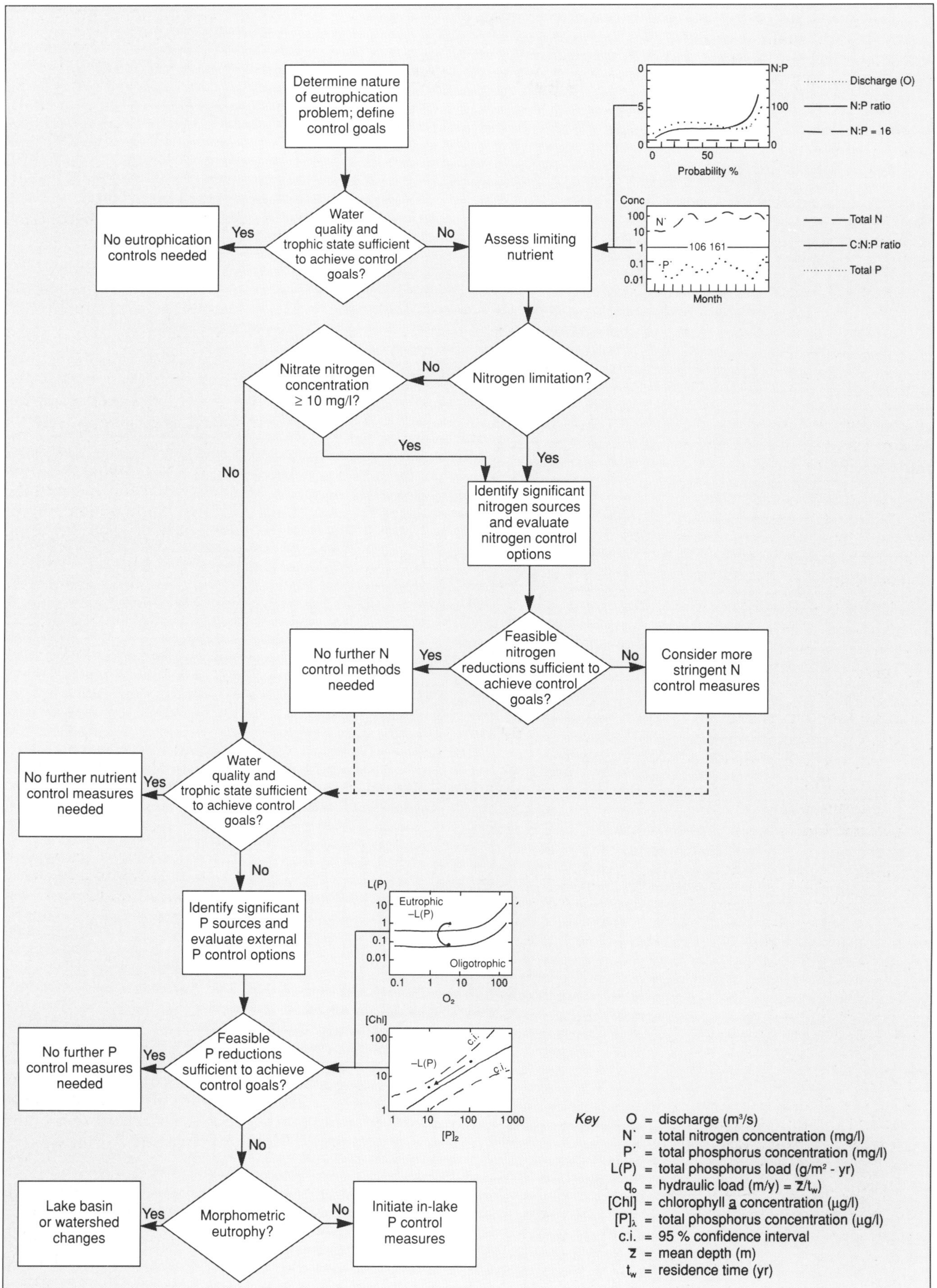

Figure 2 *Simplified, generalized approach for selection of eutrophication control measures. Source: modified from Uhlmann (1984) and Ryding and Rast (1989).*

primary water use of a waterbody used for multiple purposes are best made on the basis of specific knowledge of the lake or reservoir in question.

A simple approach for selecting a eutrophication control programme

A logical sequence of decisions to be made by a water manager is outlined in Figure 1. Nevertheless, the final decision on an appropriate control strategy should be based on a combination of relevant social, technical, economical and ecological aspects. It is also very important to set up a responsive monitoring programme both for defining the necessary pre-treatment condition of the waterbody and for properly evaluating the final outcome of the remedial measures enacted.

It is best to start with a simple approach, and then add more detail and complexity as further knowledge and experience are gained. In this way, one can build on one's successes and generally reinforce one's goals. A simplified and practical approach for selecting appropriate eutrophication control measures is outlined in Figure 2, with the answers to key questions dictating the direction to be taken (Ryding and Rast, 1989; Rast et al., 1989).

This approach relies primarily on the control of phosphorus and nitrogen inputs to a lake or reservoir. The eutrophication models presented in Figure 2 focus on the nutrient status of a waterbody appears to be appropriate for both temperate and tropical lakes and reservoirs, and for sub-arctic lakes (McCoy, 1983; Rast et al., 1983; Smith et al., 1984). Thornton (1980) and Thornton and Walmsley (1982), for example, have applied the statistical phosphorus loading models of the type developed by Vollenweider (1976) and concluded that they generally work for assessing African lakes, although the boundary phosphorus concentrations denoting the transition between mesotrophic and eutrophic waterbodies may be too low to describe tropical lake systems accurately.

Other practical considerations

As a practical matter, a lake or reservoir usually does not respond instantaneously to a eutrophication control programme, especially one based on reducing the external nutrient input. Rather, there is usually a time interval between the implementation of the control programme and the observable results in the waterbody, which represents the time necessary for a waterbody to flush itself, or otherwise neutralize the effects of its internal store of nutrients, following implementation of a control programme based on reducing the external nutrient supply to the waterbody. In contrast, in-lake methods, such as harvesting aquatic plant growths, may show smaller or no lag periods, since this latter approach directly addresses the symptoms of eutrophication, rather than the underlying cause. However, as noted earlier, the symptoms often reappear within a short period.

Summarize desired control strategy

Once a specific control programme is selected, it is useful and desirable to develop a detailed working plan in order that regulators, implementors and all other interested individuals/agencies will have adequate documentation of the tasks to be undertaken, and the goals and objectives to be met. Such an approach will usually work to foster co-operation, rather than confrontation, among governmental units and between governmental agencies and the public. As a minimum, the working plan should identify the specific goals of the control programme and the obligations of the governmental agencies involved.

To foster a greater understanding of the complexities of the eutrophication process, and the public's role in both causing and mitigating its negative impacts, a clearly articulated education programme can be valuable. Such a programme can be administered by a governmental unit, a concerned community group, or the public education system. It should include a periodic evaluation of the general effectiveness of the implemented control programme (based on collected monitoring data), and interactive communication between governmental officials and the public. It can also be the basis for development of periodic progress reports to all interested parties.

Post-treatment monitoring

In order to obtain sufficient information for a judicious selection of eutrophication control measures, extensive studies of the chemical and biological conditions of the waterbody of concern and its tributaries are usually required. Upon completion of such studies, after control measures have been planned and carried out, one may then conclude that further studies are not necessary. Such a conclusion is false. Even after eutrophication control programmes have been initiated (e.g. reducing the nutrient influx), post-treatment studies should be continued for at least 5 more years. This should be done to compare the condition of the waterbody before and after the start of eutrophication control measures, and to ascertain whether or not the results expected from model calculations have actually been achieved. Only then can one be certain the corrective action taken was correct and that the monetary investment was a financially responsible one. Post-treatment monitoring and evaluation also provide valuable information to others concerned with similar eutrophication management problems, and help guide future efforts, such as building the information and experience base for improved lake and reservoir management technology.

References

BERNHARDT, H. 1981. Reducing nutrient inflows. In: Rast, W.; Kerekes, J.J. (compilers) *International Workshop on the Control of Eutrophication*, pp. 43–51. Laxenburg, IIASA.

BREZONIK, P.L. 1969. Eutrophication: the process and its modeling potential. In: *Modeling the Eutrophication Process*, pp. 68–110. Gainesville, Department of Environmental Engineering, University of Florida; Washington, D.C., Federal Water Quality Administration, U.S. Department of Interior.

CALE, W.G.; MCKOWN, M.P. 1986. A cost analysis technique for research management and design. *Environ. Management*, **10**, 89–96.

COOKE, G.D.; WELCH, E.B.; PETERSON, S.A.; NEWROTH, P.R. 1986. *Lake and Reservoir Restoration*. Stoneham, Massachusetts, Butterworth Publishing Company. 392 pp.

JOHNSON, M.G.; CONNEAU, J.C.; HEIDTKE, T.M.; SONZOGNI, W.C.; STAHLBAUM, B.W. 1978. Management information base and overview modelling. Windsor, Ontario, Pollution From Land Use Activities Reference Group (PLUARG), International Joint Commission. 90 pp.

LEE, G.F.; JONES, R.A.; RAST, W. 1980. Availability of phosphorus to phytoplankton and its implications for phosphorus management strategies. In: Loehr, R.C.; Martin, C.; Rast, W. (eds.), *Phosphorus Management Strategies for Lakes*, pp. 259–308. Ann Arbor, Michigan, Ann Arbor Science Publishers.

MCCOY, G.A. 1983. Nutrient limitation in two arctic lakes, Alaska. *Can. J. Fish. Aquat. Sci.*, **40**, 1195–202.

PLUARG (Pollution From Land Use Activities Reference Group). 1978. Environmental management strategy for the Great Lakes ecosystem. Windsor, Ontario, International Joint Commission. 115 pp.

RAST, W.; LEE, G.F. 1983. Nutrient loading estimates for lakes. *Am. Soc. Civil Engr., Env. Engr. Div.*, **109**, 502–17.

RAST, W.; HOLLAND, M.M. 1988. Eutrophication of lakes and reservoirs: a framework for making management decisions. *Ambio*, **17**, 2–12.

RAST, W.; JONES, R.A.; LEE, G.F. 1983. Predictive capability of U.S. OECD phosphorus loading – eutrophication response models. *J. Water Pollut. Cont. Fed.*, **55**, 990–1003.

RAST, W.; HOLLAND, M.M.; RYDING, S-O. 1989. Eutrophication management framework for the policy-maker. Paris, Unesco. (MAB Digest 1), 83pp.

RYDING, S-O.; RAST, W. (compilers). 1989. *The Control of Eutrophication of Lakes and Reservoirs*. Paris, Unesco; Carnforth, Parthenon Publishing. 314 pp.

SMITH, V.H.; RIGLER, F.H.; CHOULIK, O.; DIAMOND, M.; GRIESBACH, S.; SKRABA, D. 1984. A manual for eutrophication control in the subarctic. Ottawa, Department of Indian and Northern Affairs. 32 pp. (Environmental Studies No.33).

SONZOGNI, W.C.; CHAPRA, S.C.; ARMSTRONG, D.E.; LOGAN, T.J. 1982. Bioavailability of phosphorus inputs to lakes. *J. Environ. Qual.*, **11**, 555–63.

TAYLOR, W.D.; LAMBOU, L.R.; WILLIAMS, L.R.; HERN, S.C. 1980. Trophic state of lakes and reservoirs. Vicksburg, Mississippi, U.S. Army Corps of Engineers. 15 pp. (Technical Report No. E-80-3).

THORNTON, J.A. 1980. A comparison of the summer phosphorus loadings to three Zimbabwean water-supply reservoirs of varying trophic states. *Water SA*, **6**, 163–70.

THORNTON, J.A.; WALMSLEY, R.D. 1982. Applicability of phosphorus budget models to southern African man-made lakes. *Hydrobiologia*, **89**, 237–45.

UHLMANN, D. 1984. Evaluation of strategies for controlling eutrophication of lakes and reservoirs. *Int. Revue ges. Hydrobiol.*, **67**, 821–35.

VOLLENWEIDER, R.A. 1976. Advances in defining critical loading levels for phosphorus in lake eutrophication. *Mem. Ist. Ital. Idrobiol.*, **33**, 53–83.

M. Falkenmark

Environmental management and the role of the hydrologist

Introduction

Three main categories of environmental problems now tend to dominate international discussions: water pollution, earlier concentrated in the industrialized countries but now rapidly spreading throughout the Third World; desertification, here used in the sense of semi-arid land degradation, generated by various activities; and tropical deforestation which is causing severe erosion and soil fertility degradation in the humid tropics. The fact that all three categories tend to produce similar end results in terms of higher order disturbances of ecosystems has helped the diffuse and vague concept of 'environmental effects' to survive. Whether such absence of conceptual development has been wise or not is in itself a thought-provoking issue.

Other environmental problems are already in the pipe-line, including climate change generated by greenhouse gases accumulating in the atmosphere; and water-scarcity in semi-arid regions. The latter endangers both self-sufficient food production in densely populated rural areas and generates severe water supply problems in areas where population pressure is becoming unmanageably high.

Hydrological phenomena are profoundly involved in all these different categories of environmental problems. In spite of this, past discussions regarding environmental problems have tended to be largely dominated by biologists and chemists as hydrologists tended to stay outside the discussions. When asked for advice they have been approached basically as experts on dispersion phenomena or on the river flow available for dilution of wastewater. The reason for this bias towards chemistry and biology is the tremendous interest in explaining the end effects of environmental disturbances rather than their causes and the processes that result in biological end effects.

Professor Malin Falkenmark, *Swedish Natural Science Research Council, Wenner-Gren Centre, Box 6711, S-113 85 Stockholm, Sweden.*

When hydrologists address environmental issues, they generally refer to the environmental impacts produced by such interventions in the landscape that are necessary for development of water resources. When thinking about sustainable development, hydrologists have tended to focus on how water resources development may be achieved in a sustainable way. A fundamental perspective thus escaping the interest of hydrologists is the involvement of water phenomena in sustainable land-use development or their role in defining environmental sustainability. The fact that water is the blood and the lymph of the biosphere has been severely neglected in the past. The absence of hydrologists when discussing Third World development has indeed made it possible to neglect altogether the fundamental fact that practically all life-support systems are water-operated; even worse, it has concealed from high-level attention the alarming threat developing from population pressure on finite water resources.

Today's environmental problems

Environmental problems may be of very different origin. In industrialized countries the dominating origin tends to be a careless output of pollutants to the air, water and soil. Due to water's very particular characteristics in terms of dissolving capacity and chemical reactivity, together with its general mobility and fundamental involvement in all life processes, pollutants are easily transported along hydrological pathways. Consequently, water quality deterioration is reflected in ecological effects on flora and fauna.

In the tropics and subtropics, environmental problems have mainly been related to the very much greater environmental vulnerability due to the extreme climate in terms of both heat and rainfall intensity. Any carelessness in human interaction with the environment is easily reflected in disturbance of productivity. The soil is easily eroded when exposed to high-intensity rainfall, and the heat easily contributes to chemical crusts reducing the permeability of the soil surface, thus making it infertile. Either there is too little water in the root zone to allow biomass production, or there is too much water resulting in the leaching of nutrients.

In the general debate on what measures should be taken in order to address the different problems related to human interaction with the environment, two measures have attracted most of the attention: environmental impact assessment on a project level, and the reduction of pollution by the treatment of wastewater from households as well as industry.

The rapidly growing scale of problems related to the environment makes it urgent, however, to start developing a long-term strategy for environmental management. Efforts to reduce the problems of a forced interaction between a rapidly growing human population and a vulnerable natural environment in the tropics and subtropics still remain only a wish.

The recently started debate on sustainability is a first step towards long-term environmental management. Three dimensions of sustainability have to be distinguished: environmental, economic and socio-cultural sustainability. The first one, environmental sustainability, is a necessary – although by no means sufficient – condition for the other two. It is evident that in a time perspective of 10–50 years, people cannot survive in an area where the environment is not able to produce the different products they depend on for food, water and energy.

In order to support a growing population, people are forced to manipulate the natural environment. They remove vegetation and replace the cover in other forms; rearrange the flows of water; regulate risks and natural hazards of various kinds. Due to the integrity of the water cycle and to the involvement of water in life processes, side-effects are unavoidable: they are the apparent price to be paid for the desired benefits.

By introducing environmental impact assessment as a tool in planning such manipulations, such secondary effects may be predicted and minimized. But this has to be complemented by the formulation of a forward-looking strategy of environmental management: what unavoidable effects have to be accepted, and which ones are definitely unacceptable for the simple reason that life will not be sustainable for future generations in the area should they be allowed to materialize?

When analysing the environmental problems of today we may distinguish between different categories. In an earlier paper (Falkenmark, 1989a), I distinguished between three categories in terms of environmental manipulations:

(1) introduction of chemical substances in the biosphere, disturbing water's chemical composition and producing higher-order effects on flora and fauna, increasingly also human health;
(2) intervention with soil and vegetation, disturbing water's partitioning between the vertical and horizontal branches, and/or the soil permeability, producing chain-effects in the water cycle disturbing a whole array of water-related phenomena, many of them reflected in higher-order effects on flora and fauna; and
(3) use of natural resources, such as water or hydropower, disturbing water pathways or river profiles, producing chain-effects and consequential effects on a whole array of water-related phenomena, and in the end reflected in higher-order effects on flora and fauna.

Environmental problems of tomorrow

The United Nations Environment Programme (UNEP) and other institutions are regularly producing overviews of environmental problems and tendencies. Even if there are encouraging efforts to control certain pollution types and a large public concern, the general situation is characterized by a poor understanding of the key causes, and processes involved, and particularly how to reverse them. There is in general more talk than action, and during all this talking, problems just continue to grow not only due to continued carelessness in practices made possible by misleading economic assessment methods, but also as a consequence of fundamental natural laws at work. Leading scientists in their frustration speak of themselves as Cassandras (Hardin, 1988).

If we turn our interest to the future, what environmental problems may we expect? Basically, the preconditions for human life will be changing for several reasons:

- feedback from environmental impacts already manifested on ecological systems, such as chemical bombs (Stigliani, 1988), already polluted aquifers, or soils rendered infertile by acid rain, pesticides, etc.;
- overstressed water systems in areas where population pressure is too high for people to be able to satisfy their water needs (Falkenmark et al., 1989), which limits the potential for water-dependent long-term development;
- increased general vulnerability due to overpopulation of areas with vulnerable soils in semi-arid marginal areas or in the humid tropics;
- climate change to be felt both as changed conditions for plant growth and as changes in the recharge of aquifers and rivers.

The greenhouse effect may fundamentally alter the hydrological cycle. Changes in the general wettening of the continents will be propagated into endless changes of water-related phenomena. Consequences will be felt both through altered land-use determinants and through altered possibilities to use water in rivers and lakes. Table 1 gives an overview of some main implications of such water-related disturbances.

Even when looking beyond the initial transient phases of climate change, the hydrological effects of climate change may be expected to develop in a step-wise manner. In the first phase, any new climate pattern will be acting on the present vegetation. Due to the fundamental role of the land–water interaction, it may be hypothesized that the effect causing major concern will be plant growth disturbances in semi-arid regions (water-limited), whereas under sub-humid and humid conditions (well-watered), effects reflecting changes in the hydrological partitioning may cause greater concern.

In the longer term perspective, plant cover itself will be expected to change. The time delays involved will differ between different species. Later on, the permeability of soils would also change, producing feedbacks on the partitioning of incoming precipitation (Karavaeva and Mandych, 1989). These will be reflected in second-generation changes in the hydrological responses.

In a forward-looking perspective, preventive measures are to be preferred to merely environmental monitoring and repairing activities. What is needed is the development of a long-term strategy for environmental management. Given the wide involvement of water functions in the operation of the biosphere, human dependence on manipulating the natural environment in order to produce food, fodder, fuelwood, timber, etc., and the integrity of the water cycle, the challenge is to develop methods for the successful management of such fundamental interactions.

Three facts make it essential to see water and land as closely interacting resource systems in developing such management: land use depends on water; water is consumed in plant production; and environmental feedbacks are generated by the combined effect of parallel water functions and water cycle integrity.

Table 1 ***Implications of water-related disturbances (+ indicates wetter conditions, – indicates drier conditions).***

	Land			*Rivers and lakes*			
	Soil moisture	*Groundwater*	*Surfacewater*	*Flow*	*Carrier of effluents*	*Water bodies*	*Water depth*
	agriculture forest products buildings roads	rural water supply local irrigation	urban activities	water supply hydropower irrigation	sanitation industrial wastewater disposal	fishing recreation	navigation
Problems encountered							
+	reduced fertility	water logging building damages	urban storm runoff problems erosion	failing flow control flood problem		erosion/sedimentation increasing currents flushing of lake phosphorus	floodings inundation
–	drought crop failures	drying wells increased pumping costs foundation problems subsidence		water deficiencies reduced hydropower production	reduced dilution aeration problems unsafe for bathing	changing fish populations reduced water removal	collapsing navigation system reduced traffic
Mitigating engineering methods							
+	drainage	drainage	urban drainage	flow control		river training	increased levee height reservoirs
–	irrigation	deeper wells		water transfer schemes	flow control waste treatment aeration	dredging	flow control barrages sluices dredging

In developing the long-term management of such interactions, water, land use and environmental feedbacks have to be seen as components of a single integrated system (see Figure 1).

The involvement of hydrological processes

Pollution

Hydrological processes are deeply involved in the movement and dispersion of water-soluble pollutants. To understand the water quality genesis and the way pollutants may behave the hydrologist has to work together with geochemists (Falkenmark and Allard, 1988). The hydrologist may make predictions regarding possible pathways along which pollution may be transported; on particularly vulnerable parts in a landscape where groundwater pollution may be a risk; on the possible water transit times both along water pathways below and above the ground from waste deposits and downstream of wastewater outlets; on the build-up of pollution in lakes and reservoirs due to water exchange limitations in these systems; on the time needed to flush out a polluted water body once the input has been closed down, etc.

Manipulation of soil/vegetation

Apart from land degradation, microclimate change may be induced by changes in the regional return flow to the atmosphere (Salati and Vose, 1984). Basically, any manipulation with the partitioning mechanism of incoming rainfall taking place in the upper soil would be expected to produce consequences on the generation of flood flow, on groundwater recharge, and on the yield and seasonality in the river. Underground pathways may

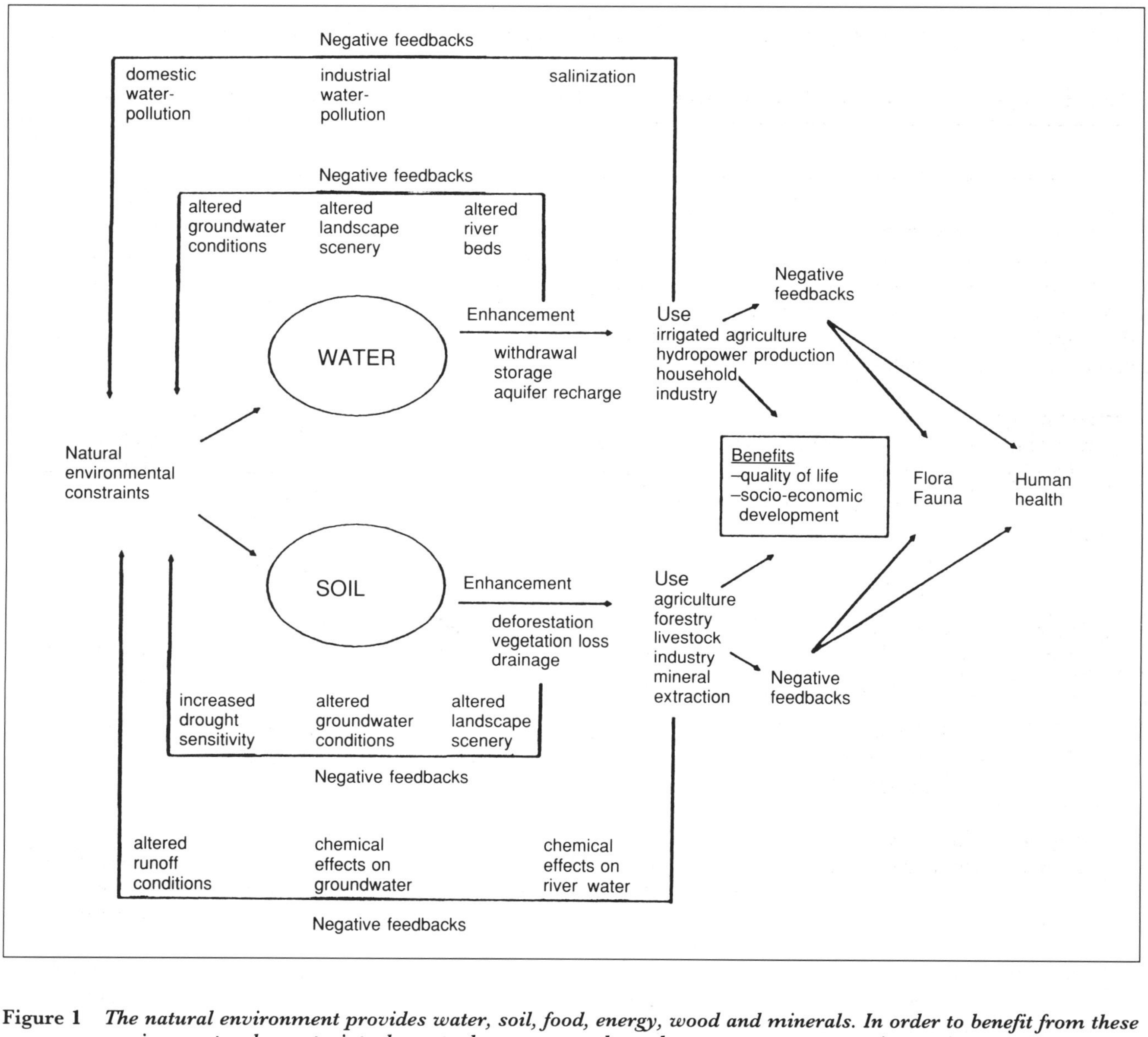

Figure 1 ***The natural environment provides water, soil, food, energy, wood and minerals. In order to benefit from these resources, various natural constraints have to be overcome by enhancement measures, increasing availability and productivity while reducing obstacles. When such measures interfere with complex natural systems, negative feedbacks are produced, accompanying the intended positive effects.***

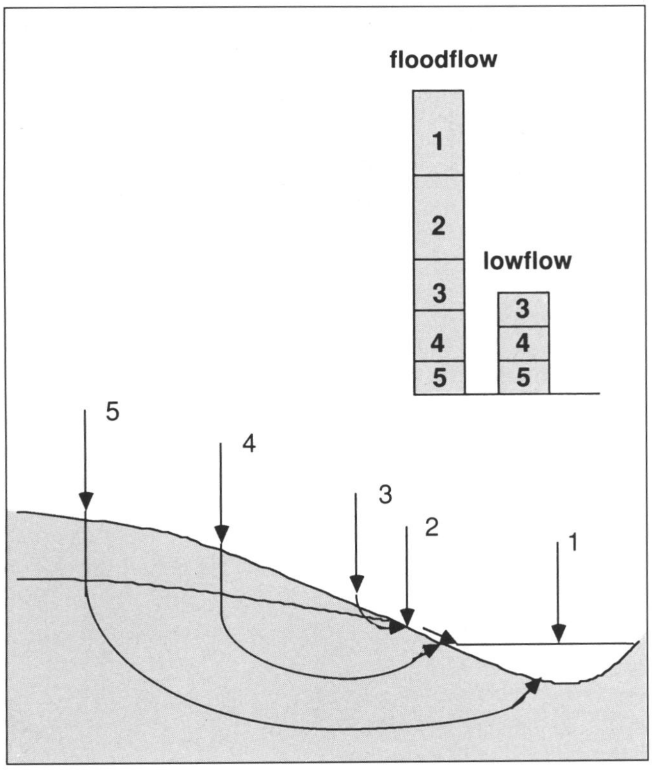

Figure 2 ***River water is a composite mixture of water fractions appearing in continuously changing proportions, arriving at the river along different pathways and therefore having a different chemical history. Above, water pathways and river water components in a humid temperate environment; Below, composition of river water in terms of water fractions; 1, net precipitation over the river surface; 2, net precipitation over the valley bottom; 3, runoff from precipitation over the foothill region; 4, runoff from precipitation over the midslope region; and 5, runoff from precipitation over the hilltop region.***

also be influenced together with the transit times and, consequently, the final mix in the river at different seasons of water fractions arriving along different pathways, and as a result the chemical composition of the water accumulating in the river (Figure 2).

The past debate on human manipulation of vegetation in semi-arid climates has suffered severely from the absence of hydrologists. For one thing, as formulated by Nelson (1988) 'the term desertification is in itself becoming desertified'. The term is widely used as a sort of synonym for land degradation in arid climates, whether caused by overgrazing or fuelwood harvesting on arid flatlands; by treefelling on slopelands; or by mismanaged irrigation systems developing salinization and water logging (Mabbutt and Wilson, 1980; Heathcote, 1980). From a hydrological perspective, desertification on semi-arid flatlands is the result of reduced infiltration, which may be generated in several different ways, as illustrated in Figure 3. On semi-arid slopelands, erosion is a fundamental mechanism. In both cases, soil and water conservation are fundamental measures to protect ground cover and stimulate biomass production in the future.

The problem of how to cope with general water scarcity in these regions also needs the support of hydrologists, able to address not only the permeability problems of relevance to soil conservation, but also the whole issue of water conservation, of assessing root-zone water availability and its vulnerability to interannual rainfall variability, etc. The short-term solution to environmental management in this region is to develop ways of striving towards best possible use of local rain; of integrated land and water conservation and management; of water-balance-based planning for optimal land use. The necessary basis is, of course, an expanded form of water resources assessment, adding to present practice in the temperate zone, the above-mentioned attention to soil moisture and its variability.

In the humid tropics the delicate balance is a nutrient balance, not a water balance. Vegetation is growing under unlimited conditions and hydrological phenomena are related to nutrient leaching, erosion and recirculation of atmospheric water. The interaction between vegetation and the water cycle is also taking place on a larger scale. As the return flow to the atmosphere changes with deforestation activities, the atmospheric water flux pattern may alter, influencing precipitation in areas downwind of the manipulated region.

Use of natural resources

Water is involved in one way or another in most exploitation and use of natural resources. When minerals or fossil fuels are being exploited the ground has to be manipulated, producing effects on groundwater recharge, drainage and quality. When water is being exploited, groundwater aquifers and rivers are being manipulated in their functions as sources for water supply projects. As a consequence, water flow is being manipulated. After use, the wastewater flow is generally disposed of in a totally different place, which adds to the effect of general flow remodeling. When hydropower is being exploited, the river channel is generally remodeled altogether and the water flow is directed along other routes. Flow control is often organized as an additional measure in order to reduce flow seasonality, the major work field for hydrologists at present.

When looking towards the future in the search of probable tasks for tomorrow's hydrologists, water scarcity-related problems have to be addressed. These and other problems are expected to develop wherever the population pressure on a finite and limited water supply continues to grow. As a result, hydrologists will have to cope with a variety of more or less intricate hydrological problems.

One category of such issues will be the increasingly complex water problems in areas around growing

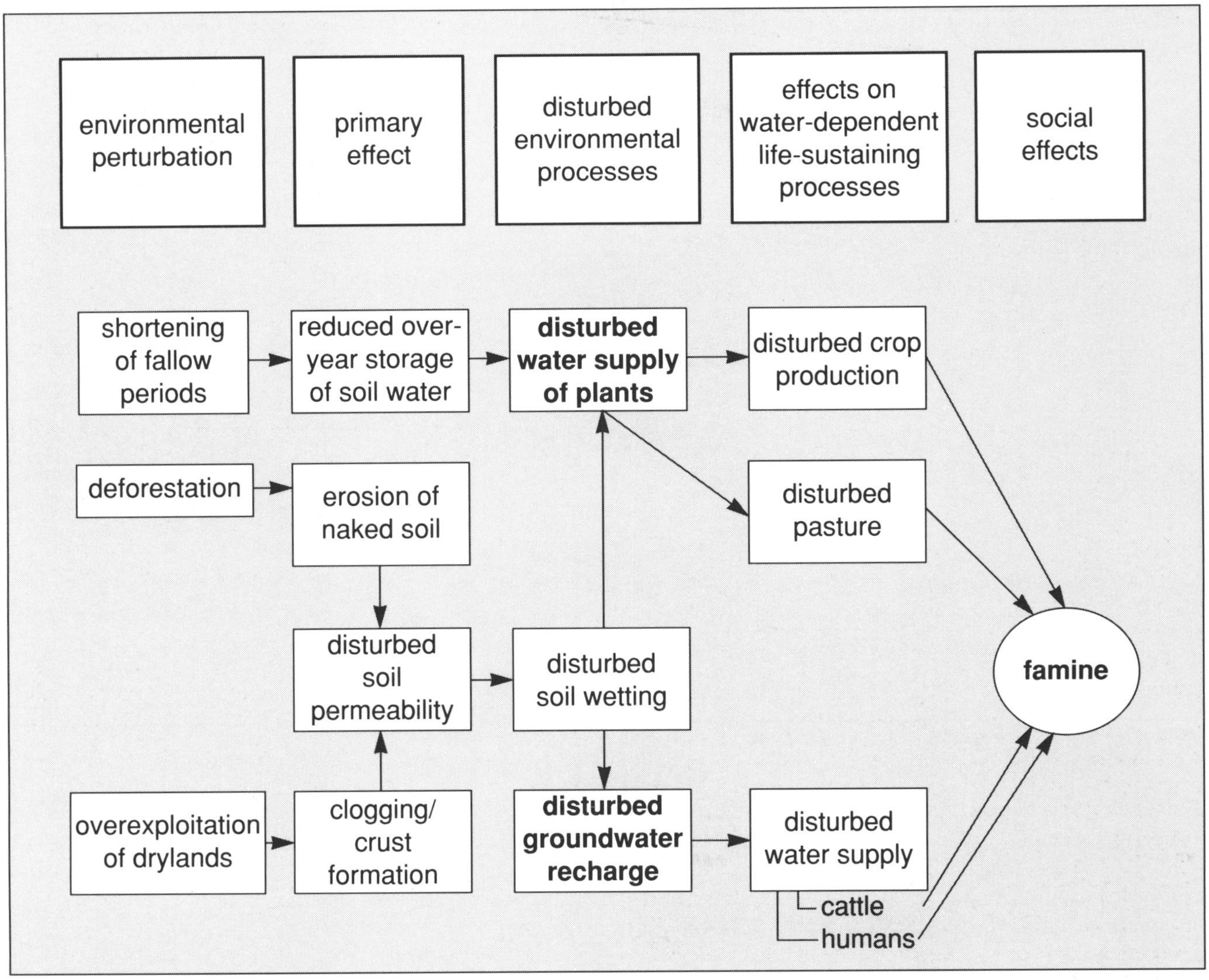

Figure 3 ***A number of processes related to poor land management tend to produce desiccation of the landscape, contributing to crop failure and local famine.***

megalopoles, trying to secure the urban water supply and wastewater handling. In trying to get a first idea of the problems encountered it is necessary to distinguish between urban areas in upstream as opposed to downstream locations, and in arid as opposed to humid climates. The main problems tend to look quite different in these different cases, but the assistance of hydrologists will be needed throughout. The urban area has evidently to be seen in its regional context, especially as local food and vegetation production in the surrounding rural area will also depend on reliable access to water, thereby competing with other water needs for city activities.

Water-cycle integrity – a new focus

The tremendous complexity of water-related phenomena tends to involve severe communication problems, especially between environmental experts and decision-makers. In the past, hydrologists have largely been absent in this dialogue.

There are indeed occasions when various linkages in the environmental system at large will have to be understood by the policy-makers. When addressing environmental problems in the future, hydrologists will therefore have to equip themselves with effective tools in order to be able to communicate crucial messages to policy-makers. Particularly important to transmit is a basic understanding of the integrity of the water-cycle and the main consequences of that integrity. The environmental management strategy called for will depend on a general understanding among policy-makers that any disturbances within the water cycle will be propagated onwards in that cycle. A general acceptance of the integrity of the water cycle is therefore crucial for the development of any advance (*ex ante*) strategy on interaction between people and the environment. Only in this way can unavoidable effects of interventions be balanced against benefits needed for human livelihood, including the problem of endangered species.

In communicating the water-cycle integrity, a set of matrices may be useful in visualizing the ways in which various processes and phenomena interact.

Table 2 ***Perturbations/disturbances of different global system components and the changes in various environmental properties generated by those disturbances.***

	Atmospheric		*Terrestrial*					*Aquatic*			
Changed environmental property	*air temp.*	*air quality*	*impermeable surface*	*soil structure improvement*	*vegetation*	*fertilizer*	*chemicals dry waste*	*groundwater withdrawal*	*river water withdrawal*	*wastewater*	*river works*
Precipitation	❍										
Soil fertility	*	❍	❍	❍	❍	❍	❍				
Groundwater recharge	*		*	❍	❍						
Groundwater quality		*				*	❍				
River flow	*		*	*	*			❍			
River extremes			*	*	*						
River quality		*				*	*			❍	
Water levels	*		*	*	*			❍	❍		❍
Sediment yields					❍						
Water temperature	❍										
Estuary quality		*				*	*			*	

❍, first-order effect; * second-order effect due to water cycle continuity.

This has earlier been demonstrated in the field of atmospheric chemistry by Crutzen and Graedel (1986). I recently developed the same idea to demonstrate linkages in the land–water system, based on a set of sub-matrices (Falkenmark, 1989b). The first one links sources of perturbations to disturbances generated in hydrological processes; the second links the disturbance of one hydrological process to other secondarily disturbed processes; and the third one links disturbance in any hydrological process to changes generated in crucial environmental components of interest to policy-makers and the general public. In a final, summarizing matrix, the changes caused in such environmental components of general interest are linked back to the original sources of perturbations that were producing those changes (see Table 2).

The soil provides a key zone in the terrestrial phase of the water cycle. Indeed, the processes in the upper soil determine not only the amount of water remaining for groundwater recharge but also its quality, the runoff formation and to a certain extent even the pathways followed by the water through the catchment to the river, and consequently the quality of the river water. At the same time, the soil productivity is directly dependent on the soil moisture conditions.

The importance of this soil–water interplay implies that water and soil have to be treated in an integrated way. An environmental matrix on water should, in other words, also include soil- and land-use phenomena. The water-cycle continuity implies that a change in a primary hydrological process is propagated through a sequence of water-cycle steps, producing changes also in secondary hydrological processes. The criteria followed in selecting processes and disturbances for the matrix set-up resulted in the following relevant processes:

- soil: wetting and nutrient supply
- groundwater: recharge and quality
- river flow: formation and quality.

The perturbing activities were then selected among those influencing fundamental hydrological processes (precipitation, water attraction capacity of the atmosphere, infiltration, percolation down the soil profile, underground pathways of water, water quality genesis processes, etc.).

Broadening the focus of hydrologists

Today most hydrologists tend to be serving the engineering part of society, and therefore concentrate on the subsectors of river hydrology and technical hydrology. Unfortunately, this bias of hydrologists for the different subsectors of hydrology (Figure 4) is also mirrored in the general understanding of what hydrology stands for.

Also contributing to the biased understanding in society on the quite limited field of expertise of hydrologists is the 'centrifugal force' acting within the different subsectors. Most of the subsectors of hydrology are focusing on the interaction between mobile water and a specific part of the geosphere–biosphere. By this interaction the particular subsector

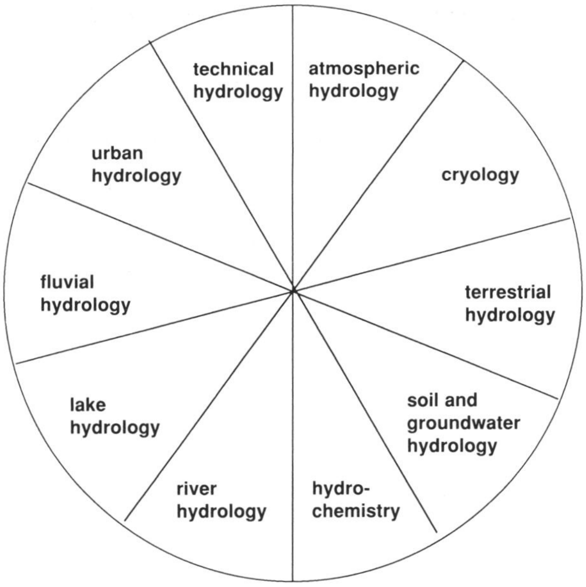

Figure 4 ***Main subsectors of modern hydrology according to Natural Science Research Council in Sweden (NFR 1986).***

of hydrology is closely linked with neighbouring fields of science: the groundwater subsector to geology, the soil moisture subsector to ecology and pedology, the hydrochemistry subsector to limnology and geology, the hydrometeorological subsector to meteorology, etc. The consequence is that hydrology has a tendency – although being the unifying science addressing the multitude of phenomena in the water cycle – to be subject to some sort of imminent centrifugal force, causing its subsectors to merge into neighbouring fields of science. As a consequence, many subsectors are in fact seen as belonging to those sciences rather than to hydrology. Field hydrometerology is the classical example.

Hydrological phenomena are evidently at work in the development of environmental problems belonging to the first category; the introduction of chemical substances into the biosphere. Basically, moving water and its biogeochemical environment tend to form a multicomponent system, which is quite complex. While moving through the root zone, water interacts with two main subsystems:
- the organic components in the root zone, which provide carbon dioxide and humates to the passing water, turning it aggressive; and
- the mineral system, which contributes weathering products but temporarily also minerals available through ion exchange.

The outcome of these interactions is water, the crucial characteristics of which are the acidity/alkalinity and the redox potential. In combination, these two basic characteristics determine the principal behaviour, respectively, of metals and organics, i.e. whether they are mobile or immobile along the water pathways towards the discharge areas.

In order to be able to address future environmental problems related to water quality, it will be important to be able to distinguish between different possible causes of quality change. In the past, there has been a natural tendency to explain quality changes as due to changes in the input of chemical substances into the water system. Changes in the quality of the composite mix of water fractions that constitute the flow in a river channel may, however, have other possible explanations. It may, for example, be due to changes in the water partitioning of rainfall, in preferred pathways, in altered transit times, in landscape changes reflected in altered relations between recharge and discharge areas, etc. This complexity makes it important that the new breed of hydrologists includes experts in such phenomena.

As already indicated, hydrological phenomena are also at work in the second category of environmental problems, i.e. those related to human interventions with soil and vegetation. The processes taking place at the interface between plant, water, soil and atmosphere control have three main phenomena:
- return flow to the atmosphere, relevant for atmospheric climate models;
- water partitioning at the ground surface and the recharge of the root zone with water accessible to the vegetation, relevant for vegetation models; and
- production of freshwater, recharging terrestrial water systems (rivers, aquifers), relevant for hydrological models.

A close link exists between photosynthesis and evaporation. Eagleson (1982) has hypothesized that plant communities developing in an area are basically the result of an evolutionary orientation based on a long-term strategy that differs between well-watered as opposed to water-limited conditions:
- under well-watered conditions, there is maximized biomass productivity under given radiation and heat energy constraints;
- under water-limited conditions, canopy density minimizes the moisture stress in the root zone under the given climate and soil conditions. The stomatal regulation operates in order to compromise between the risk of losing water and the need to take in carbon dioxide as raw material for photosynthesis.

In the landscape, water is continuously on the move. Within temperate-zone hydrology, precipitation enters the soil on the hilltops and along the slopes, and reappears in local hollows where wetlands are formed, and along foothills and valley bottoms, where water courses are fed. This water-related structure is of fundamental importance for ecosystems, characterizing an area. One reason is that the water has quite different chemical characteristics in the recharge and discharge areas. In the former, the content of dissolved solids is low, in the latter it is high as a result of chemical interaction between the moving water and the geological surroundings along the water pathways through the underground landscape. This general flow pattern is reflected in the composition of plant communities in different segments of the landscape as shown by van der Heijde (1988). Forest damage in acidified areas is thus first seen in hilltop and upslope locations.

It is evident that neither problems related to land degradation in the tropics, arid as well as humid, nor the impact on landscape ecology from climate-change-induced hydrological shifts will be adequately treated unless ecologists and hydrologists start working together. In so doing they will have to overcome two main communication barriers: the perception differences regarding the involvement of water in the biomass production process, and the differences in scale of their respective mental images (Falkenmark, 1989c).

The third category of environmental problems is the one that has attracted the main interest of hydrologists in the past. The area will no doubt be expanding although important changes in the general perspective may be called for. In their past work in the water supply fields, water resources engineers have, for instance, been applying the traditional approach from the temperate zone, generally well endowed with water. They have been asking 'how much water do we need and where do we get it?' As water scarcity rapidly expands in the Third World, a reverse approach will be necessary: 'how much water is there, and how should society best benefit from it for socio-economic development?'

This means that engineers will have to broaden their understanding in terms of the scale of interest, not only so that the local project level is also looked upon from a regional perspective, but also so that they broaden their understanding of the implications both of differences in hydroclimate and differences in terms of locations in the landscape (upstream/downstream; slopelands/flatlands). Finally, they will have to broaden their focus in order to get rid of the often exposed 'hydroschizophrenia', reflecting an insufficiently developed realization of the functional link between water in aquifers and water in rivers. In temperate climates, most water in the river has earlier passed through the underground landscape in the catchment basin.

Conclusions

Hydrologists have, unwittingly, been isolating themselves from other environmental scientists in the past. This is probably a main reason why water-related phenomena have been receiving such neglected treatment in the understanding of environmental problems. In particular, this isolation has made possible the still remaining dichotomy between water quantity and quality issues, although criticized as unsound for at least a decade.

When addressing the environmental problems of tomorrow, hydrologists must enter the scene of environmental management. What we need is a new generation of hydrologists interested in the interactions between the moving water and the surroundings through which it passes: both the interaction with plant growth and the reflections of different plant strategies in hydrological phenomena; the interaction with the biogeochemical environment and the reflection of that interaction in a continuously changing chemical composition of the water; and the way in which river water constitutes a mix of water fractions all arriving along different pathways and with different chemical histories. As the relative proportions between the various components tend to vary with the seasons, hydrologists are important team members in deciphering the large chemical fluctuations observed in water-quality monitoring.

The changing preconditions for life give particular stress to the need for a new breed of hydrologists. They are fundamental team members everywhere where the challenges of such changing preconditions are to be addressed: in the integrated planning of land use and water resources, motivated by the fact that most of the water in the river has already passed through land and carries the chemical response from that journey; in Third World development under the conditions of water scarcity where the challenge is the best possible use of local rain, arrived at through a water-balance-based planning for optimal land use; and in meeting the challenges of climate change, which will be felt by society primarily through water-related phenomena and effects propagated as a consequence of water-cycle integrity.

There is also a need for new interdisciplinary breeds of professionals able to bridge both the present gap between ecohydrology and landscape ecology, and the gap between geochemistry and terrestrial hydrology.

The above conclusions have important implications for the training of hydrologists and environmental professionals in general. In the Western world today, most hydrologists are engineers trained in a specialization at technical universities, generally sanitary engineering or civil engineering. In few countries has it been possible to study hydrology separately at the university, Scandinavia and the USSR being important exceptions. Moreover, hydrology being based on physical sciences has made it particularly difficult in the past to combine the study of hydrology with chemistry or biology.

It is fundamental that the need for new breeds of hydrologists be seriously addressed so that adequate training can be organized to produce the army of water professionals needed all over the world and in particular in Third World countries. The fact that these countries have been sending their gifted students to universities in the temperate zone has left them without tools to address the particular problems of the tropics and subtropics, whether humid or arid. It is self-evident that the hydrologists needed in these zones have to be trained in tropical hydrology, not in temperate zone hydrology.

References

CRUTZEN, P.J.; GRAEDEL, T.E. 1986. *The Role of Atmospheric Chemistry in Environment-Development Interactions.* Sustainable Development of the Biosphere. IIASA and Cambridge University Press.

EAGLESON, P.S. 1982. Ecological Optimality in Water-limited Natural Soil-Vegetation Systems. *Water Resources Research,* Vol.**18**, No.2.

FALKENMARK, M. 1989a. Water – The Multidimensional Resources, The Predictable Carrier of Solutes, and The Active Link to Ecosystems. Stockholm, Swedish National Council of Building Research. (In press).

——. 1989b. Global-change Induced Disturbances of Water-related Phenomena – The European Perspective. Laxenburg, International Institute for Applied Systems Analysis. (Collaborative Paper CP-89-1).

——. 1989c. Hydrological Shifts as Part of Landscape–Ecological Impact of Climate Change. Lunteren Conference on Landscape–Ecological Impact of Climatic Change.

FALKENMARK, M.; ALLARD, B. 1988. Water Quality Disturbances of Natural Freshwaters. In: O. Hutzinger (ed.), *The Handbook of Environmental Chemistry,* Vol. 5, Water Pollution. Springer Verlag. (In press).

FALKENMARK, M.; LUNDQVIST, J.; WIDSTRAND, C. 1989. Macro-Scale Water Scarcity Requires Micro-Scale Approaches. Aspects of Vulnerability in Semi-Arid Development. *Natural Resources Forum,* **13**, (4), pp. 258–67.

HARDIN, G. 1988. Cassandra's Role in the Population Wrangle. In: P.R. Ehrlich and J.P. Holdren (eds.) *The Cassandra Conference, Resources and Human Predicament,* pp. 6–16. Texas A&M University Press.

HEATHCOTE, R.L. (ed.) 1980. *Perception of Desertification.* Tokyo, United Nations University. (NRTS-10/UNUP-190).

HEIJDE VAN DER, P.K.M. 1988. In: Scales and Global Change: Spatial and Temporal Variability in Biospheric and Geospheric Processes, SCOPE 35

KARAVAEVA, N.A.; MANDYCH, A.F. 1989. Impact of Climate Changes on Soils and their Water Regime. Lunteren Conference on Landscape–Ecological Impact of Climatic Change.

MABBUTT, J.A.; WILSON, W. (eds.) 1980. Social and Environmental Aspects of Desertification. International Geographical Union – United Nations University. (NRTS-5/UNUP-127).

NELSON, R. 1988. Dryland Management: The "Desertification" Problem. Washington, D.C., World Bank. (Working Paper No.8).

NFR 1986. *Hydrologins nya Ansikte* (New Face of Hydrology), Natural Science Research Council, Sweden.

SALATI, E.; VOSE, P.B. 1984. Amazon Basin: A System in Equilibrium. *Science,* **225** (4658), 131.

STIGLIANI, W.M. 1988. Changes in Valued "Capacities" of Soils and Sediments as Indicators of Nonlinear and Time-Delayed Environmental Effects. Laxenburg, International Institute for Applied Systems Analysis. (Working Paper WP-88-38).

SZESZTAY, K. 1979. Evapotranspiration Studies for Estimating Man-Influenced Streamflow Patterns Under Arid Conditions. The Hydrology of Areas of Low Precipitation. pp. 197–204. Proceedings of the Canberra Symposium. Wallingford. (IAHS Press. IAHS-Publ. No. 128).

J.S. Gladwell and M. Bonell

Water-related problems of the humid tropics

Introduction

World population may reach 6.5 billion by the year 2000, with the most rapid increases probably being in Africa (75%); Latin America (65%); South Asia (55%); and East Asia (24%). Much lower rates of increase will be experienced in the developed world, e.g. USA (17%); USSR (18%); and Europe (7%). It is estimated that countries within the humid tropics will represent almost 50% of the total world population by the year 2000 and this proportion will continue to rise in the twenty-first century.

Certainly this means that we must think very carefully in terms of sustainable development, which implies development that meets the needs of the present without compromising the ability of future generations to meet their own needs. This means minimizing any adverse impacts on the quality of the atmosphere, water and the terrestrial environment in general. It is evident, however, that adverse international trade patterns, combined with the urgency for new capital inflows to service the debt, are encouraging unsustainable development policies and practices concerning water management in developing nations of the humid tropics. This is further aggravated by economic, social and political changes that lead to a rapidly growing urban population.

All members of society must realize that the environment will only be protected if we give it outstanding organizational, technical and legal efforts, and take a close look at what we are doing to ourselves. It is not necessary to take on an anti-development bias; in fact, we absolutely should not. However, if we consider only short-term futures there will inevitably be conflicts between development and the social–environmental aspects. On the other hand, if we give greater consideration to longer term integrated management (with careful thought to socio-cultural aspects of water use as well as those of the environment), environmental and cultural aspects become two of the most important considerations rather than being points of conflict.

Perhaps one of the most useful contributions scientists can offer is to make available to the various parties involved the maximum amount of relevant information in well-digested and constructed formats. There is certainly a need to identify what needs to be done, and whose responsibility it is to either do it or help in getting it done.

Water problems of the humid tropics

In spite of having all that water, or perhaps because of it, the humid tropics have water problems that need to be looked at seriously. Besides the overall need for human-resource development, some of the most urgent hydrological and water-resource management problems are addressed below. All are important and all need support.

Population, food and agriculture

Because of the increase in population, there will be a consequent increase in demands on water and land resources for food production. Unless carefully planned, this will inevitably lead to the degradation of such resources and to declines in agricultural productivity. Although the Green Revolution increased food production in some regions of the developing world, in other areas food production has not kept pace with population growth.

Dr John S. Gladwell, *Senior Programme Specialist, International Hydrological Programme, Division of Water Sciences, Science Sector, Unesco, 7 place de Fontenoy, 75700 Paris, France.* **Dr Michael Bonell,** *Reader in Physical Geography and Director, Institute for Tropical Rainforest Studies, James Cook University, Townsville, Queensland 4811, Australia.*

The most precarious area is the Wet–Dry Tropical Zone, where rainfall is insufficient under any form of land use to give a good reliable vegetation cover and erosion losses in excess of 100 tons per hectare per year are common. Since natural soil production is only about one ton per hectare per year, the lifespan of soil in these regions can be measured in terms of tens of years rather than hundreds. With a large proportion of soil nutrients concentrated in the top 20 cm, an inevitable decline in productivity will follow.

Much of the existing land now under agriculture in the humid tropics is already deteriorating due to inappropriate soil and water management. Loss of topsoil by erosion is the most widespread form of degradation, but other problems include salinization, compaction and waterlogging. These reduce productivity and jeopardize long-range sustainability. The future must lie in considering intensified production on existing good agricultural land, rather than simply expanding agricultural activities into previously unused (often because of lower potential) but ecologically extremely important areas. Apart from advances in agronomy, improved management in soil and water conservation through improved irrigation, drainage systems and erosion controls, is vital to increasing productivity.

Some of the main issues in need of better understanding include:

(1) the problem of surface and subsurface water quality and erosion/sediment consequences resulting from land-use conversion to different agricultural practices (e.g. various soil tillage practices, erosion control such as terracing, and multi-cropping);
(2) the problems and opportunities of agroforestry and inter-cropping with food crops for reducing erosion; and
(3) the smooth topography of the flatlands of humid tropics, which encourages intensive agricultural activities including hydraulic works for drainage, flood control and irrigation.

The socio-economic and cultural factors involved in the control of water resources in rural areas and their effects on erosion/water-quality management also need to be addressed.

Population, forest conversion and reforestation

While forests are very often a crucial element in the protection of watersheds from erosion, in preserving water quality, and in climate control, the growing population in tropical areas is forcing their continued destruction for agricultural expansion, the growing world timber trade and domestic fuelwood demand. Forest clearance has already attained devastating proportions, amounting to 11 million hectares per year. Tropical forests in Central America, for example, have been reduced by 38% and in Africa by 23% in the last 30 years alone. It is expected that 40% of the remaining 1,680 million hectares of 'closed' forest within the developing world will have disappeared by the year 2000. Most of the destruction will be in the Amazon and Indonesia, but by that time forests in Equatorial Africa will hardly exist.

Apart from population pressure, the principal underlying causes of tropical forest removal include rural poverty and low agricultural productivity, inequalities in land tenure, under-investment in forestry, ineffectiveness of forestry agencies and lack of integrated planning of forestry, agriculture and energy.

The effects of large-scale forest clearance for the timber trade, especially when that land is converted for the implementation of extensive cash crop estates, livestock ranches or subsistence agriculture, need to be addressed in terms of:

(1) radiation and water balance changes (especially surface and subsurface water transfer on slopes and river systems) and the role of atmospheric recycling of evaporated water vapour in assessing the effects of large-scale forest conversion; and
(2) erosion/sedimentation processes and water quality changes on both slopes and river systems resulting from forest burning, and deforestation for permanent conversion to agriculture, particularly at the sensitive time of first conversion.

In order to contain forest removal, some humid tropical countries have prioritized goals towards agroforestry through rehabilitating seriously degraded, deforested drainage basins and towards fuelwood and industrial forestry from plantations of selected tree species. The impact on the water balance and water quality by implementing such forest management practices must be addressed.

Rural/urban issues, water treatment and health

By the year 2000, the urban population is expected to reach 51% of the total (see Table 1). The urban population of the world will have increased almost two and a half times during the period from 1970 to 2000. It is important, however, to be aware that the urban population grows differently in various parts of the world. Looking again at the projected trends in more developed countries, we can see that the urban population may grow from 717 million in 1970 to 1,174 million by the year 2000. By contrast, the urban population in less developed areas may increase from 635 million in 1970 to 2,155 million by the year 2000.

The combined effects of population growth, urbanization and industrialization adversely affect the hydrological response of these areas and cause various

Table 1 *Urban and rural populations, 1965 to 2000.*

	Year				
	1965	*1970*	*1980*	*1990*	*2000*
Urban population (millions)					
World total	1 158	1 352	1 854	2 517	3 329
More developed regions	651	717	864	1 021	1 174
Less developed regions	507	635	990	1 496	2 155
Rural population (millions)					
World total	2 131	2 284	2 614	2 939	3 186
More developed regions	386	374	347	316	280
Less developed regions	1 745	1 910	2 267	2 623	2 906

environmental impacts, most of which will be negative. Changing the natural environment into an artificial one results in quantitative and qualitative changes in the water cycle. Urban drainage, being a part of this cycle, is related to the urban hydrological system in a very complex way. As a result, the planning of urban drainage systems (as an example) must not only look at the linkages to other urban planning efforts, but it should also be integrated with the planning of other aspects of urban water resources such as water supply, wastewater treatment and use of the receiving waters. Understanding the linkages between all of these aspects is important.

Health status is generally accepted to be one of the most sensitive indicators of social and economic conditions. About 11 million children under 5 years of age die every year in the developing world from malnutrition and infectious diseases. Of that total it has been estimated that about 55% can be attributed to diarrhoeal diseases from poor quality water. In fact, about 80% of tropical diseases are said to be water-related and can be attributed to poor or non-existent sewage treatment and lack of safe drinking water. Poor drainage also furnishes breeding grounds for mosquitoes and encourages the spread of malaria.

In 1980 only about 75% of urban communities in the developing world had access to a reasonable water supply and 50% to sanitary facilities. In rural communities only about 33% had access to good water and 13% to sanitary facilities. Despite an international effort to reverse those figures, after 10 years the total number of people without these facilities is larger than when it began.

Rivers and lakes

Reservoir construction for water harvesting or large-scale power generation, and water supply from small reservoirs at a farm scale, have produced a number of physical, ecological and socio-economic conflicts, as well as management problems between upstream and downstream water users. Such issues have been further aggravated by subsequent changes in the water quality of artificial and natural water storages induced by upstream agricultural, forestry and municipal practices. Some of the physical, environmental and socio-economic issues relating to water impoundments in need of study include the following:

(1) the influence of reservoirs on micro- and meso-scale weather and climate, referring particularly to changing rainfall patterns;
(2) sedimentation rates in water bodies and downstream effects of artificial impoundments on sedimentation;
(3) eutrophication of large surfacewater bodies resulting from upstream municipal/industrial sewage; agricultural practices such as water transport and concentration of agrochemicals, nitrogen and phosphorus from animal feedlots; and poor forestry practices such as burnings and clearings increasing sediment transfer and deposition;
(4) the need for a better understanding of water quality processes in both terrestrial and aquatic ecosystems of watersheds, and their application in decision-making for environmental planners;
(5) problems of effective integration of upper watershed management with downstream construction and operation of water control infrastructure such as reservoirs; and
(6) the problem of effective incorporation of environmental, social, cultural and institutional aspects into the water management process.

Interaction between ocean–atmosphere–human activities

The management of water resource-related activities depends very much on changes in climate, reflected in the changing distribution of rain and mountain snowfall. The humid tropics are commonly subject to the extremes of flood and drought identified with changes in the atmospheric circulation which transports both energy and moisture, and anomalies in sea surface temperature. Because these regions contain such a large proportion of the earth's population, any changes in the ocean–atmosphere regime could have correspondingly large impacts on human affairs. A much better understanding, for example, is needed of the El Niño–Southern Oscillation Index, at the interface between the ocean, atmosphere and terrestrial environment relevant to humid-tropical hydrology and water-resources management.

Tropical islands

The geographic limitations of water resources on tropical islands and the potential for a variety of water management conflicts as a result of their small size, warrants tropical islands being treated as a separate practical issue. Many of the problems noted above will occur on tropical islands. Other pressures such as saltwater intrusion from over-pumping of groundwater as well as other problems of physical water management often need special treatment.

A need for action

Because the problems are so complex, the institutions, organizations and individuals interested in their solutions must be provided with scientific perspectives so that they can make their choices knowledgeably. Long-term planning must be encouraged as the basis for any strategy for sound water management and its ecological implications. The provision of scientific information as one part of the total bank of knowledge required for decision will hopefully alleviate the tendency to postpone real policy actions (both in the developing and in the developed countries) to a point where they will be less effective, more difficult and more expensive to put into practice.

In order to assist in the development of its themes on the humid tropics the International Hydrological Programme of Unesco, in conjunction with the United Nations Environment Programme (UNEP) and twenty-one other organizations held a colloquium (International Colloquium on the Development of Hydrological and Water Management Strategies in the Humid Tropics, Australia, 1989) to consider the special hydrological and water management problems and issues of the humid tropics. Scientific, technical and institutional topics, as well as human resource development and the transfer of knowledge and technology, were considered. The immediate outcome was a report that reviewed in some detail the problems and issues. A book giving the scientific backgrounds upon which the decisions were based is under preparation.

Strong concern for the future of the humid tropics region was expressed at the colloquium. It was concluded that there is real cause for alarm. These feelings were based upon an extensive review of the present and predicted future conditions within countries of this vital region.

Furthermore, it was noted that the humid tropics play a pivotal role in the maintenance of the global hydrological cycle, which determines the capacity of the world to continue to support the agriculture, industry and infrastructures of all countries. The participants also stressed that there are a number of misconceptions concerning the characteristics of the water balance and water resources of the humid tropics because it is perceived that this region receives a greater proportion of rainfall and energy than the temperate and arid zones. They emphasized that it is vital that the real situation within the humid tropics be recognized by the world community and that appropriate actions be taken to ensure the sustainability of the hydrological systems which exist and the human developments which depend upon them.

In this respect, it was concluded that the following underlying factors should be stressed:

- the rainfalls which occur in the humid tropics are intense and highly variable in space and time;
- climatic, vegetation and soil conditions are radically different from those of the temperate zone, requiring the development of research and technology programmes specifically directed to the humid tropics;
- the natural ecosystems established throughout this zone have evolved to withstand such variability and to protect the soil mantle from the severe potential erosion hazard of high rainfall intensities experienced;
- unplanned land-use conversions, often following major deforestation from logging operations, have led to many serious problems of erosion and sedimentation;
- the nations of the humid tropics zone are almost exclusively developing countries;
- within these countries pressures are building to a point where land and water resources in many areas will become inadequate to support the population even at existing levels of economic development;
- these countries also suffer from relatively uncontrolled urbanization resulting in increased problems of water supply and sanitation necessary for proper maintenance of healthy conditions; and
- the viability of land and water resources is being put at risk through legitimate policies designed to meet the needs for food and economic development.

In general it was felt that the capacity of countries of the humid tropics to respond to these challenges is hampered by a number of inadequacies in our knowledge of the natural systems which exist in the region and in the present attitudes to the preparation and implementation of management policies.

It was the consensus of the colloquium that if the disadvantages are to be overcome, the following steps should be taken:

- research efforts into all aspects of the hydrological cycle within the humid tropics should be strengthened and encouraged, particularly at catchment scale;
- particular urgency should be given to the research needs of urbanized areas with respect to the hydrology and water quality (pollution control and potable water supply), namely data collection, processing and modelling, and water management;
- long-term monitoring of rainfall, climate and streamflow within the basin systems of the region should be continued and extended, taking care to match these programmes to the capacities of the countries involved;
- integrated watershed/river basin planning at both an international and regional level must be developed and policy decisions co-ordinated;
- education opportunities must be expanded and curricula designed to respond to the needs of managers who can interpret conditions and implement policies across a range of disciplines;
- institutional arrangements for regional and worldwide co-ordinated co-operative research, education and training, and other aspects of knowledge and technology transfer between and among the countries of the humid tropics and other warm humid regions should be developed;
- international agencies with responsibilities in water resources and related questions should further develop collaborative mechanisms and activities in support of the developing countries within the humid tropics as a matter of urgency; and
- within the scope of the bilateral and multilateral aid programmes directed to countries of the humid tropics, greater emphasis should be given to assistance in all fields associated with water-resource assessment, development and management.

G. Lindh

The need for integrated water management in large urban areas

Characteristic features of the global water situation

Before going into the problems of water management in large urban areas and their possible solutions, a look at the unprecedented growth of these areas as well as at the global water situation might be in order. In fact, one of the main concerns of this article is the growth of fairly new urban areas as seen in a historical perspective. It should be emphasized that new, large urban areas developing in the Third World do not seem to contribute to a global convergence of the urban form as is known in the Western world. It is important that we realize that the world's large urban areas do not conform to one and the same pattern.

Water is very unequally distributed over the world and many countries are in water-deficient zones. This precarious situation prevails both in some highly developed countries, such as the western part of North America and the central parts of Australia and in many less developed ones, for instance in Africa. Countries like Tunisia, Israel, Libya, Saudi Arabia and Kenya today face a situation which may very soon become critical. The reason for this is partly the population increase, partly the misuse of water. Population increase is not to be dealt with here. Instead, concentration on the possible courses is emphasized for the future water crisis, which may partly be ascribed to the management of water in urban areas.

On a global scale, about 70–80% of all water used is for irrigation with an average efficiency of about 40%. Indeed irrigation is a very wasteful use of water compared to some industrial uses where 90% may be re-used. Moreover, irrigation projects call for very competent management including well-trained farmers so as not to spoil arable land through salinization and waterlogging. The amount of irrigated land lost every year is at least 200,000–300,000 ha. Unskilled management of irrigation projects also means increased salt content of wells, and consequently deterioration of the water quality. More well-known is the deterioration effect due to discharge of wastes into water courses without any treatment. It should be underlined that reduced water quality also implies a decreasing availability as there is a close relation between the quality and quantity of water.

Another aspect to keep in mind is the environmental impact caused by the misuse of water. Such impacts may be directly recognized but often this is not possible because they may appear within a long chain of consecutive events depending on time as well as spatial factors. Time is very often an important factor since the final consequences may be hidden for a long period, creating a false sense of security as to future adverse effects. This is very often the case with leaching from sanitary landfills, which will manifest itself perhaps only after the lapse of many years.

In many countries where water is a scarce natural resource, e.g. the Maghreb, Saudi Arabia and Israel, a consciousness of these problems has certainly developed. This is also clearly reflected in the 5-year plans for many countries, but there we also find difficulties that may make the good intentions come to naught. Such obstacles may be the lack of economic resources, trained engineers and workers, etc. In other countries, this awareness seems to be either non-existent or suppressed by competing goals because of the difficulty of comparing non-monetary quantities. This is by no means unusual in countries with frequent changes in government. Dealing with water problems in such a manner reveals that water is more or less regarded as a free commodity instead of using its real cost.

Professor Gunnar Lindh, *Department of Water Resources Engineering, Lund Institute of Technology, University of Lund, Box 725, S-220 07 Lund, Sweden.*

Unprecedented growth of large urban areas

At the beginning of the century, there was no city with 5 million inhabitants, in 1950 there were six, in 1980 twenty-six, by the year 2000 we may expect sixty and, in 2025 there may be ninety cities with 5 million inhabitants or more. One remarkable feature of the development of these large urban areas is the rate of growth. It took Paris about a century to expand from half-a-million inhabitants to say 3 million, but in the Third World corresponding growth has taken place within only one generation. As will be shown below, this rapid growth has created problems that make decision making and management very complicated.

By the year 2000, about 50% of the world population will be living in so-called 'primate cities'. Such a city might not always be the largest in terms of population nor the capital of the country. The determining factors are rather its economic, cultural, political and infrastructural characteristics. Very often the activities of a primate city are more closely related to other urban areas in foreign countries than to the country itself. Sometimes the growth of primate cities may lead to a critical situation.

Mexico City has often been mentioned as a primate city that has caused some national problems. The city has grown from 1 million in 1930 to 15 million in 1980 and is expected to have 25 million inhabitants by the year 2000. It has been claimed that 'the cost of supporting Mexico City may be exceeding its contribution in goods and services: the nation's economic locomotive is becoming a financial drain'. Considering especially the water sector, the unique position held by Mexico City can also be seen from the fact that residents in this city pay only 20% of the real costs of the water supply. Thus, water in the city is subsidized, that means a deliberate change of priorities that may prevent a more well-organized use of water for other purposes.

It seems reasonable to assume that an understanding of the dynamics of a growing urban area must form the basis for a successful analysis of urban water problems. The characteristic feature of such dynamics is related to the migration from the surrounding rural area to the city. Usually, men leave the rural area first, in search of better job conditions, thereby leaving their families behind in the villages. In Africa, more and more young women have also been joining the men in the move to the cities, many of which now grow by 10% or more each year. This means that the number of inhabitants will double in less than 10 years. In Latin America, country women work in the households of better-situated families while their own families remain in the villages. In Asia, the migration that started several decades ago consists of family groups now populating the squatter settlements. For a great many people this way of living is preferable to the village life they left.

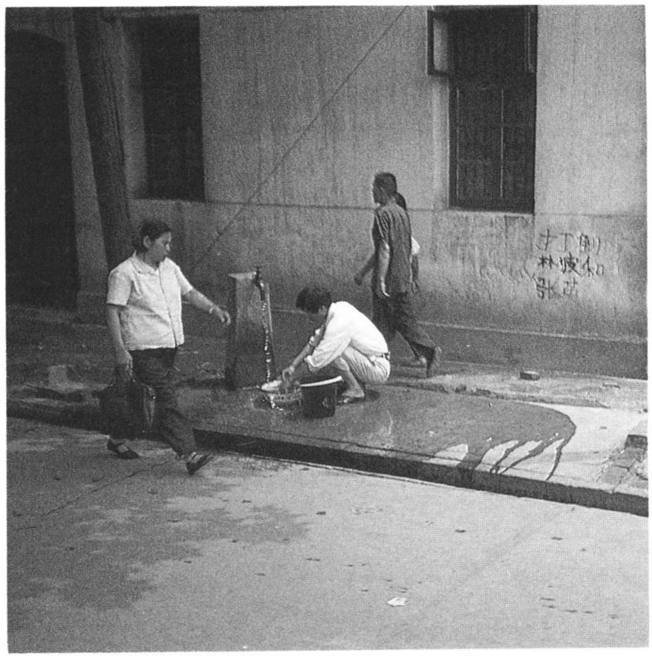

Figure 1 ***Providing potable water to city dwellers is often a difficult task, especially in developing countries with rapidly increasing populations and per capita demand.***

Many water problems have to do with the settlements of the immigrants. In most large cities in the Third World we find peripherally located shanty towns, which are considered illegal by the city authorities who do not feel obliged to provide them with water, drainage, sanitation facilities, public transport and primary health care. Shanty towns are often in areas which are unsuitable for commercial development. The worse the environment, the more likely the landowner will allow the immigrants to stay. In these shanty towns water may be sold by vendors who charge the buyer ten to twenty times the price paid by middle- or upper-income residents for a piped water supply. The water may also be contaminated. The lack of sewage systems and waste-disposal services provides fertile conditions for vermin infestation and disease. In general, there is overcrowding and a total lack of privacy and the climatic situation causes the houses to be cold in winter and hot in summer. Mexico City may again be mentioned as about 1.5 million people live on a drained lake-bed, Texcoco, which is tormented by sand storms during dry periods and is like a bog during wet periods.

Another type of slum is rather more central, in or near the city core. The houses in such areas are more like the Western inner-city slums, populated by low-income people because the previous tenants have moved to better housing in the suburbs. However, the new immigrants have to accept a lower standard in the central slums because now several families are constrained to live in a space formerly occupied by only one. As a consequence, for instance, sewage or piped-water facilities will be of a lower standard because they have not been improved to meet the greatly increased use. In some countries there are also 'custom-built' houses constructed by the private sector to meet the increasing migration to the city. Here, too, sanitary facilities, water supply, etc., are generally inadequate. In Bombay about 1.5 million people live under such conditions in houses constructed between 1920 and 1956. Another example may be taken from Hong Kong where it is not uncommon for fifteen to twenty people to live in a three-roomed apartment, constructed between 1955 and 1970.

Another feature of large urban areas is the distribution of city dwellers. One of many reasons for this may be that, because of the areal growth of large urban areas, new immigrants must travel even longer distances to reach their work place in the central part of the city. This implies increasing costs for transportation and for that reason workers have sometimes been forced to move from a location in the periphery to slums in the centre. Consequently, the need for houses in the centre will increase and, as we know, this will mean a decline in the standard of living.

This picture of the Third World is by no means exaggerated, but it must also be said that there are indications of improvements in the living conditions for urban immigrants. A fundamental condition is the replacement of outmoded and inappropriate laws to allow a more appropriate, broad-minded view of immigrants. The change of attitude, seeing them as a resource rather than a burden, has meant a public response to the urgent needs of urban immigrants, including those who cannot immediately pay for housing. The basic idea, therefore, is to offer a general infrastructure, consisting of roads, water supply, sanitation, electricity and other services, etc. Of course, this implies public support intended to encourage immigrants to build their own houses. A very interesting and positive feature of this new attitude is the fact that it is often based on a more active contribution by women.

A new attitude to taking care of immigrants will at least fulfil two demands. One is to create a much more vital urban society, and the other is to offer the opportunity for a much more productive life that will give rise to a higher degree of individual and social well-being.

Main reasons for water problems in large urban areas

A growing large urban area is by no means a unique phenomenon in the Third World. Moreover, it is difficult to draw any conclusions from experiences with large cities in the more developed countries because it seems that the development patterns of large urban areas in the Third World are not similar to those of cities in the industrialized countries. In fact, urban areas in the Third World very often consist of two parts, one representing the development of a traditional rural society where the social relationships characteristic of the village appear to predominate, and the other a city more like a Western one with its characteristic social features.

Water problems in a large urban area cannot be analysed without paying due attention to the relationships that really exist between the water sector and other urban sectors. Migration to urban areas is not a new phenomenon. What is new is the increased stream of people who for several reasons are attracted by the city. However, very often city authorities are not prepared to meet this new situation because they do not have the necessary flexibility to adjust to it. Moreover, authorities may adopt a purely economic attitude, strictly calculating the revenue of investing in even the most basic needs of such an unwanted group. However, whether this migration occurs or not, there exists a very important interplay between the rural areas and the city itself that must be taken into account in the planning process. In fact, it has been strongly emphasized by many that urban–rural linkages play a paramount role in indicating the vulnerability and sustainability of large urban areas. As a corollary of this we may say that emerging water problems are due to escalating conflicts developing between different parts of the metropolitan area. The situation is certainly very often aggravated because city authorities do not always possess the awareness needed to recognize that severe problems may be hidden in rapid societal development. The goals and objectives must also be broken down into manageable concepts, suitable for planning. One may apprehend that few urban organizations, whether in developed countries or in less developed ones, possess this capacity. Today it is well known that the best approach to planning implies the adoption of an integrated or holistic way of solving the problems.

A very common problem is the leakage of water-supply pipes and sewage systems, due to their age. This may be attributed to the corrosion of pipes, ground movements caused by over-exploitation of groundwater, heavy traffic, etc. There are some very good examples of such defective water-supply systems. One may be taken from Cairo where very rapid population growth has forced the city to find methods to increase the supply of potable water. However, when checking the water system about 10 years ago, it was found that out of 2.5 million cubic metres of drinking water delivered each day from the water works, only about 50% reached the customers. The rest was lost by leakage. The situation became even more aggravated when it was recognized that the sewage system was in no better condition than the water-supply system.

In fact, most urban areas have been confronted by similar incidents. This has to do with the simple fact that modern buried pipes have a length of life that is usually not more than 100 years. So there is a need for continuous repairs, even if locating leaking pipes is a rather difficult task. Another aspect of this upkeep has to do with the fact that the yearly expenditures for repair sometimes are about 1 per thousand of the costs of replacing the whole system. At this rate, it would take 1,000 years to repair a system that is expected to last only 100 years.

There are other problems that may partly be classified as caused by the ageing of the technical installations. An example would be the sewage network of Calcutta, which was designed in 1910 in order to serve the relatively wealthy municipal area. Today, the same system is used by a population about twice the size. Moreover, there is a discrepancy between the core area of the city and other parts of the metropolitan area. It may be added that although considerable improvements in wastewater discharge have been made, maintenance of the facilities has remained poor. A large sewage treatment facility has remained idle because house connections have not yet been made and Calcutta water supplies have never been metered on a significant scale. The same can be said about Bangkok where about 70% of the water meters do not function. This breakdown of the metering system is characteristic of many large cities in the Third World because of consumer resistance to user charges. This may lead to a further degradation of the distribution network and the sewage system as considerable economic support for maintenance is thus denied.

The integrated systems approach

It is of paramount importance to keep in mind not only the spatial aspects but also the time history of relevant processes. This latter demand means that the planning procedure has to be executed within a certain time-horizon. This is the very opposite of an ad hoc planning model, the characteristic feature of which is the easy-going decision merely to add something to the already existing structure. In 1982, Mexico City began to extract water from a source situated 100 km away and 1,000 m below the city level. The need to augment the water supply would in the 1990s require the use of another source, located 200 km away and 2,000 m lower. It has been estimated that the expenditure for this increase of water supply would be so great that it may constrain further expansion of the city. This is certainly the result of an incomplete planning strategy, where water is one of the decisive constraints.

An important feature of the holistic planning concept is that planning and decision making is not to be decentralized in the sense that these activities should be performed on a sectorial basis. If this is done there might be a violation of the basic idea of the systems analysis approach, which postulates that the total planning result must be something more than the sum of the planning achievements. What must also be taken into account is the interacting links between sectors.

From another angle, looking at the water sector – or any other sector – in isolation might lead to a sub-optimization, if neglecting possible interaction within other parts of the whole urban area. However, there may be another pitfall when applying the holistic concept, especially in Third World countries. Such a concept could possibly be identified as the development of a macro-economic plan irrelevant to conditions in these countries because there are not enough data available. Moreover, a purely economic attitude to the planning process is not sufficient because such an approach often does not consider the extremely important relation between economic, social and political aspects.

As a matter of fact, I do not know of a complete solution to the complex planning procedure for large urban areas. However, there has been a series of very promising studies carried out within the Unesco Man and the Biosphere (MAB) Programme, prompted by the requirement for better data and information as a basis for urban planning. Such preliminary studies have been carried out for the cities of Hong Kong, Barcelona and Kuala Lumpur, to mention some of them. Perhaps the most interesting has been the study of Frankfurt-am-Main in the Federal Republic of Germany. In this study, important selected sectors of the urban area were identified and analysed as a basis for decision making. By this method we may have found some essential 'elements', in the sense of an ecological systems analysis approach. When this is achieved we have to find out what important relations may exist between these elements or sectors.

In order to incorporate the societal experience of interrelations between the sectors just identified into the natural science systems analysis concept, there have been attempts to formulate these interrelations through personal expert experiences. In fact, this approach to some extent corresponds to the use of expert knowledge in the so-called 'decision support system' method. At this stage of development, a system is created, dependent on the interlinkages of its sectors or 'elements'. It should, in principle, be possible to carry through a change of the planning goal in order to achieve a desired change of societal development by a corresponding change of the characteristic value of one or more sectors. In practice this may mean, for instance, that activities in the water sector may be changed in some manner. The important fact to remember is that this change of policy is now made in reference to what will happen to the whole system. This situation should be compared with the earlier practice, where decisions were made on a sectoral basis, regardless of the impact on other urban sectors.

One may, of course, ask what implications such new ideas will have on urban water-resource planning and especially what consequences they will have for planning and management in the growing large urban areas in the Third World. Do these ideas really contribute to a better practice in urban water planning?

As I have already pointed out, comprehensive urban water planning must be based on two important concepts. In the first place, decision making in the water sector must be carried out with due regard to the fact that this sector is related to other urban sectors. Second, the planning process must include the relevant space, which is the urban area and the interlinked surrounding area.

With this in mind, planning means identifying important sectors in the area to be considered and establishing mutual links through data information and expert knowledge. There may be city administrations that already practise this procedure. Where this is not the case, the model proposed may certainly put city authorities to a severe test, especially if a sufficiently efficient organization is lacking or if the tradition-bound bureaucracies lack the flexibility needed for dealing with the new situation. Of course, the application of the model just described will most probably require a greater economic investment, a situation that sometimes may become an impossible burden. Moreover, the decision support system will also demand more personnel, especially more well-trained administrators, in the effort to cope with inadequate time perspectives in urban planning, budgeting, financing and decision making.

For many large urban areas in the less developed countries, the reorganization of the planning function may be almost insuperable for several reasons already indicated. To my mind donor organizations will have a great mission here, just as important as giving aid to the rural communities.

I.A. Shiklomanov

Global water resources

Introduction

Although fairly reliable information is available on long-term averages of global water resources, too little is known about the causes of long-term variations and trends that result in the long wet and dry periods observed in some regions, with their repercussions on the volumes of water stored in glaciers, the ground, soil and lakes. The evaluation of global water resources has been made even more difficult because of human influences, such as the increase in the CO_2 content in the atmosphere.

The distribution of water on earth is shown in Table 1. Estimates of water stored in the ground in permafrost regions or as soil moisture and in swamps are somewhat approximate but the data on volumes of water in the oceans, lakes and reservoirs are an improvement on previous estimates.

Table 1 shows that the total volume of fresh water on earth is about 35 million km^3, which is only 2.5% of the water in the hydrosphere; moreover, most of the fresh water (about 24 million km^3 or 69%) occurs in the form of ice and snow in the polar regions.

Table 1 ***Water storage on earth.***

Type of water	*Reference area (km^2 x 10^3)*	*Volume (km^3 x 10^3)*	*Equivalent depth (m)*	*Total water storage (%)*	*Freshwater storage (%)*
Sea	361 300	1 338 000	3 700	96.5	—
Total groundwater	134 800	23 400	174	1.7	—
Fresh groundwater	134 800	10 530	78	0.76	30.1
Soil moisture	82 000	17.5	0.2	0.001	0.05
Glaciers and permanent snow pack	16 232	24 064	1 482	1.74	68.7
Antarctica	13 980	21 600	1 545	1.55	61.7
Greenland	1 802	2 340	1 299	0.17	6.68
Arctic islands	226	83	367	0.006	0.24
Mountain regions	224	41	183	0.003	0.12
Underground ice in the permafrost zone	21 000	300	14	0.022	0.86
Lakes	2 058	176	85.5	0.013	—
Freshwater	1 236	91	74	0.007	0.26
Salt-water	822	85	103	0.006	—
Swamps	2 683	11.5	4.3	0.0008	0.03
Rivers	148 800	2.1	0.014	0.0002	0.006
Water in the biosphere	510 000	1.1	0.002	0.00007	0.003
Water in the atmosphere	510 000	12.9	0.025	0.0009	0.04
Total	510 000	1 385 984	2 718		
Freshwater	148 800	35 029	235	2.53	

Professor I.A. Shiklomanov, *Director, State Hydrological Institute, USSR State Committee for Hydrometeorology and Control of the Natural Environment, 2 Linija, 23, Leningrad, 199053, Union of Soviet Socialist Republics.*

Rivers and freshwater lakes, which are among the main sources of water supply, contain only 93,000 km^3 of water, which is only about 2.7% of the total amount of fresh groundwater on earth.

The hydrological cycle and global water balance

Due to its permanent movement under the action of solar energy and gravity, water appears on earth in phases which form a cycle. The recovery periods of the various water storages vary widely: whereas on average atmospheric water is renewed every 8 days and river water every 16 days, the renewal of water contained in glaciers, large lakes, groundwater reservoirs, seas and ocean, may take hundreds of thousands of years.

The bulk of water circulation in nature involves the exchange of water between the land, the ocean and the atmosphere, through which not only the quantity but also the quality of freshwater resources is restored. Of the annual 505,000 km^3 of water evaporated from the ocean surface, about 90% returns directly as precipitation, the remaining 10% being carried to the land by air fluxes. To this amount, precipitation of continental origin of the order of 68,500 km^3 should be added. This represents an average layer of 1,000 mm of which about 35% returns to the ocean as river discharge and glacier runoff. The possible exchange of water between the atmosphere and outer space is unkown and the inflow of juvenile water from the earth's crust is only of local significance. The water cycle of the earth can thus be considered as closed, the 577,000 km^3 of average annual precipitation being equal to the annual evaporation from the ocean and land.

The above data are based on all available hydrometeorological observations, reduced to a common period (1900–1960). Where observations are inadequate or missing, indirect methods have been used. The data on precipitation from over 50,000 meteorological stations were adjusted in order to reduce measurement errors due to wind, initial moisture and evaporation. These adjustments are particularly significant at high latitudes where snow represents a large part of the annual precipitation.

Evaporation data were also corrected: for plains, the method of Budyko and Zubenok (1961) was used, which takes into account radiation, air temperature, humidity and turbulent exchange as factors determining evaporation, whereas for mountains the altitude and vertical gradients were considered by applying empirical relationships. Monthly data from 1,700 stations were used to produce maps of annual evaporation. The results compared closely with those obtained by means of the energy balance method.

The results of a Soviet study on global water resources (Anon., 1984) compared with those of Baumgartner and Reichel (1975) show that while the differences are negligible for the total land area, they can be very significant in the case of some continents. The greatest differences in runoff appear in Africa and North America (32 and 40% respectively), probably due to a gross underestimation of runoff in closed inland areas by Baumgartner and Reichel. With regards to precipitation and evaporation, the greatest differences appear in Europe. These may be due to the data corrections applied in the Soviet study.

It should be pointed out that the objectives of the two studies were different, which explains the difference in methods used. The main objective of the USSR monograph was to estimate the water resources and their variations for each continent, subdivided into a number of physiographic regions, to estimate the availability of water in various regions and to assess the present and future impacts of human activity on river runoff, which justifies the use of direct runoff observations. The study by Baumgartner and Reichel (1975) was aimed at the evaluation of global water balance components over continents and oceans. The global runoff being less than 7% of the volume of

Table 2 *Streamflow.*

Territory	*Annual stream flow* (mm)	(*km*^{3})	*Percentage of total runoff*	*Area* (*km*^{2} *x 10*^{3})	*Specific discharge* ($l\ s^{-1}\ km^{-2}$)
Europe	306	3 210	7	10 500	9.7
Asia	332	14 410	31	43 475	10.5
Africa	151	4 570	10	30 120	4.8
North and Central America	339	8 200	17	24 200	10.7
South America	661	11 760	25	17 800	20.9
Australia and Tasmania	45	348	1	7 683	1.4
Oceania	1 610	2 040	4	1 267	51.1
Antarctica	160	2 230	5	13 977	5.1
Total land area	314	46 768		149 022	10.0

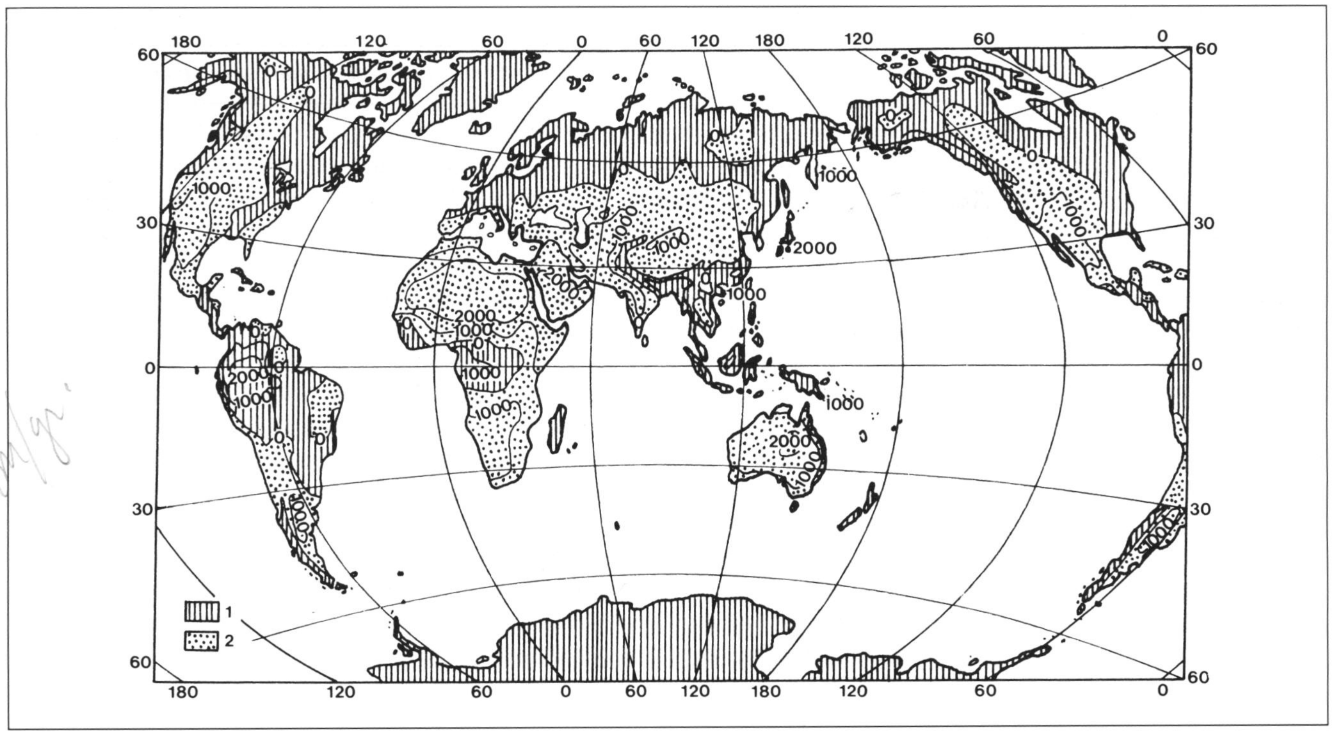

Figure 1 *Surplus (1) and deficit (2) of river runoff (mm).*

global precipitation or evaporation, it was found acceptable to evaluate it by indirect methods, thus avoiding the more elaborate use of streamflow data.

The differences in the results can be explained logically and do not challenge the value of the studies in question. They show that there remains much to be done in order to improve information on the world water balance. Recent investigations in many countries within the framework of the International Hydrological Programme (IHP) have underlined the advantages of using data from the world meteorological observation network for the determination of water balances of river basins.

River runoff and water availability

River runoff is one of the main sources of freshwater from which various water demands are being satisfied. Through its continuous renewal by the hydrological cycle, river runoff represents the dynamic component of the total water resource, as compared to the less mobile volumes of water contained in lakes, groundwater reservoirs and glaciers. The base part of the streamflow (about 25% of the total) indicates the renewable part of the groundwater resources (with the exception of aquifers discharging directly into the sea).

As shown in Table 2, global river runoff is 44,500 km^3 (excluding polar glaciers and ice). Of this volume, 43,500 km^3 flows to the oceans and the rest into endorheic areas (Caspian and Aral seas, Lake Tchad, Andean altiplano, etc.). Table 2 also shows the distribution of river runoff by continents.

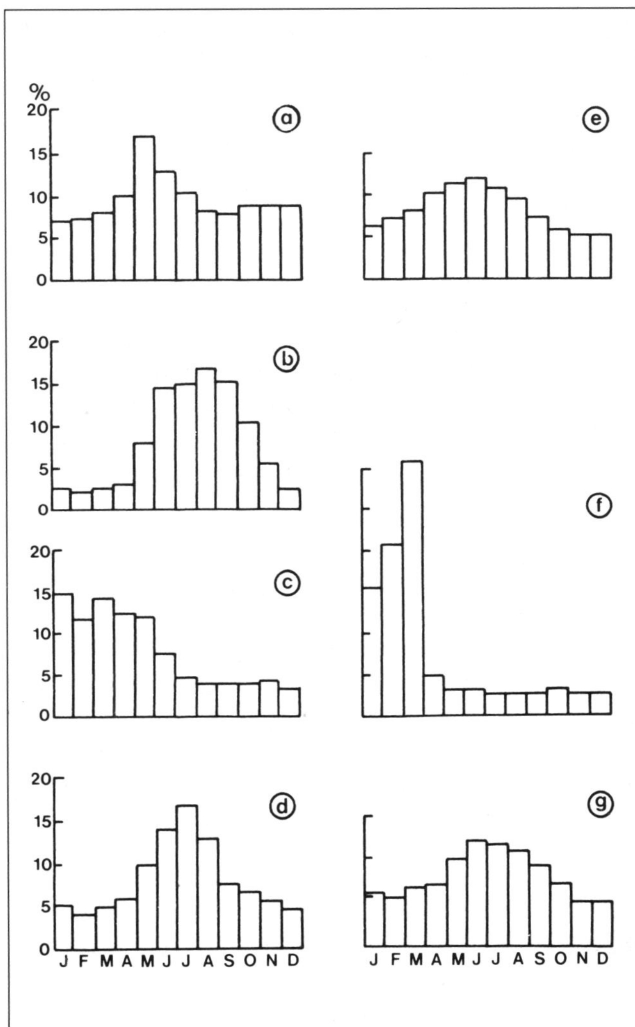

Figure 2 *Distribution of monthly streamflow in (a) Europe, (b) Asia, (c) Africa, (d) North America, (e) South America, (f) Australia and (g) all continents combined.*

Table 3 ***Water availability in some countries of the world.***

Country	Area ($km^2 \times 10^3$)	Population[1] (10^6)	Long-term mean annual streamflow (km^3)	Per unit area ($10^3\ m^3\ km^{-2}$)	Per capita ($m^3 \times 10^3$)	Percentage of world streamflow
Brazil	8 512	130	9 230	1 084	71	20.7
USSR	22 274	275	4 740	213	17	11
People's Republic of China	9 561	1 024	2 550	267	2.5	5.7
Canada	9 976	25	2 470	248	99	5.6
India	3 288	718	1 680	511	2.3	3.8
United States of America	9 363	234	1 940	207	8.3	4.4
Norway	324	4	405	1 250	99	0.9
Yugoslavia	256	23	256	1 000	11	0.6
France	544	55	183	336	3.4	0.4
Finland	337	5	110	326	22	0.2
World land area[2]	134 800	4 665	44 500	330	9.5	

1. For 1983.
2. Without Antarctica.

An indicator of water availability is the difference between precipitation and potential evapotranspiration ($P-E$). Optimum conditions exist when this difference is close to zero, or when E exceeds P by not more than 400 mm in tropical, or 200 mm in moderate climates. For the world, $P-E$ amounts to 124 mm (Shiklomanov, 1985). The variation of this index is shown in Figure 1, together with the arid zones and those with surplus water.

The temporal variability of streamflow within a year is illustrated in Figure 2 for each continent and the total land area. The distribution for smaller regions is, of course, even more irregular and varies also from year to year. The variability depends very much on the climate: the higher the aridity index, the greater the temporal and spatial variability of the available water resources in a region.

The overall availability of the water resources of a country or region is indicated by the annual (or seasonal) river runoff per unit area or per inhabitant in Table 3 for a number of countries. The decrease of per capita availability of water is proportional to the increase of the world's population: while in 1850 it was about 33,300 m^3/year, today it is only 8,500 m^3/year. The availability of water is also affected by the impact of human activity on the quantity and quality of the water resources.

Human impact on water resources

Human activities affecting the hydrological regime can be classified in the following groups.

(1) Activities which affect river runoff by diverting water from rivers, lakes and reservoirs or by groundwater extraction (water for irrigation, industrial and municipal water supply, interbasin water transfers).

(2) Activities modifying the river channels (e.g. the construction of reservoirs and ponds, levees and river training, channel dredging, etc.).

(3) Activities by which runoff and other water balance components are modified due to impacts on the basin surface (e.g. agricultural practices, drainage of swamps, cutting or planting of forests, urbanization, etc.).

(4) Activities which may induce climate changes at the regional or global scale (e.g. modifying the composition of the atmosphere by increasing 'greenhouse' gases or by increased evaporation caused by large-scale water projects).

To illustrate the above influences, reference will be made to the study of the modifications of runoff in the main rivers of the USSR which have been evaluated since 1936 and predicted for the year 2000 (Shiklomanov, 1979). Considering that streamflow was unaffected by people before 1936, the impact of human activities was assessed by comparing actual or predicted runoff, as illustrated in Figure 3 for eleven rivers of the USSR. It can be seen that the annual runoff of the rivers flowing south, other than the Volga, has decreased significantly, especially since 1955, whereas those flowing north have been much less affected. The discharge of the Syrdarya river, for instance, was reduced by about 60%. The reduction of discharge of some Siberian rivers (Ob, Yenisei and Amur) can be explained by the filling of the great reservoirs built on those rivers and the effect is therefore temporary.

If the predicted streamflow is compared to the observed runoff in 1975 and 1985 (Figure 3), it can be

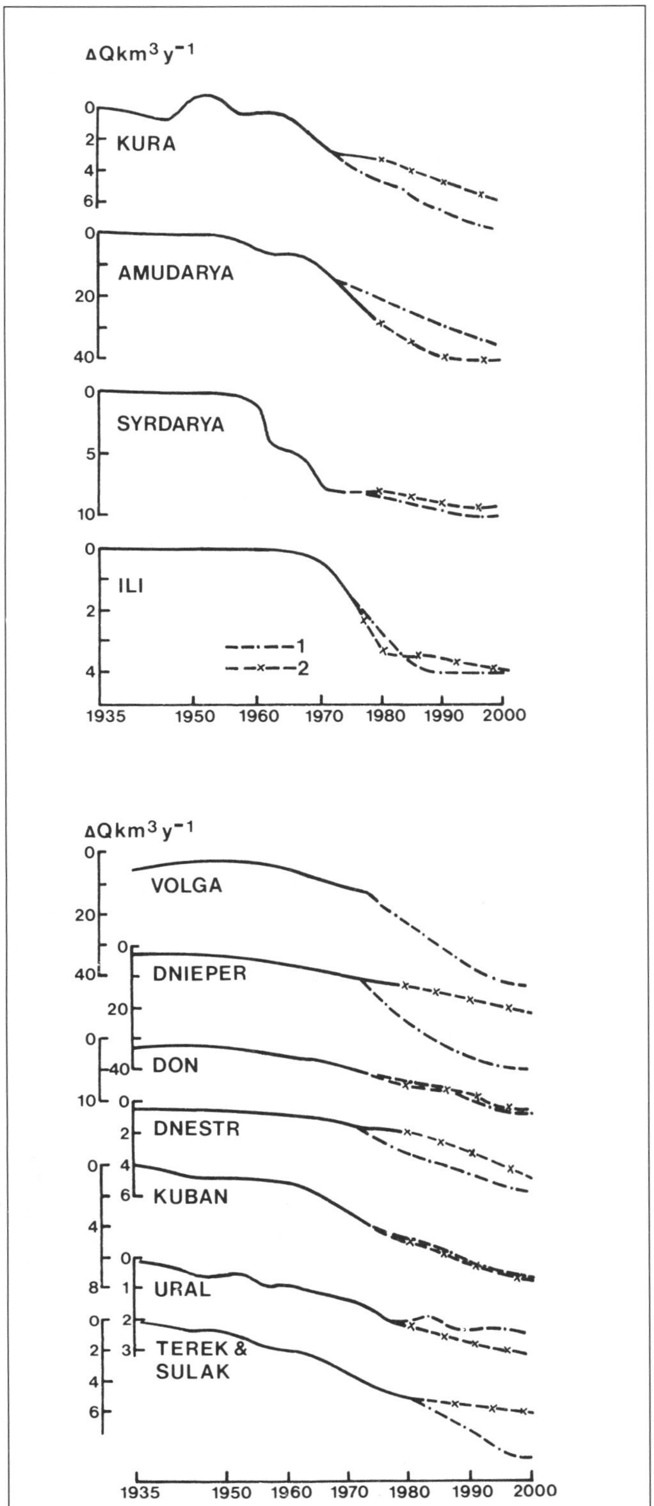

Figure 3 ***Change of annual streamflow in the USSR due to human activities. Forecasts made for average climatic conditions: 1, 1975 forecasts; 2, 1985 forecasts.***

seen that the flow of the northern rivers has been reduced considerably less than was anticipated in 1975. This is because the development plans on which the forecast was based were later revised, partly owing to the warnings about the possible consequences of the structures on the river runoff. On the contrary, the flow of the Amudarya river was reduced much more severely than predicted in 1975, because a more rational water management plan had been assumed than was actually implemented. This led to the very unfavourable ecological situation which today affects the Aral Sea.

The 1985 forecast predicted more moderate changes of the river runoff, based on a more cautious water management policy. Nevertheless, discharges of the southern rivers will be considerably reduced if the present trends of expansion of irrigated areas continue.

Impacts on global water resources

On a global scale, the main effects of human activities on water resources are related to water consumption and runoff control by large reservoirs. Other activities, such as those which affect the basin surface, only modify river runoff of smaller basins. In larger areas they often have opposing effects, cancelling each other out and can thus be neglected on a global scale.

Estimates were published recently on the development of water consumption for twenty-six regions of the world that are more or less

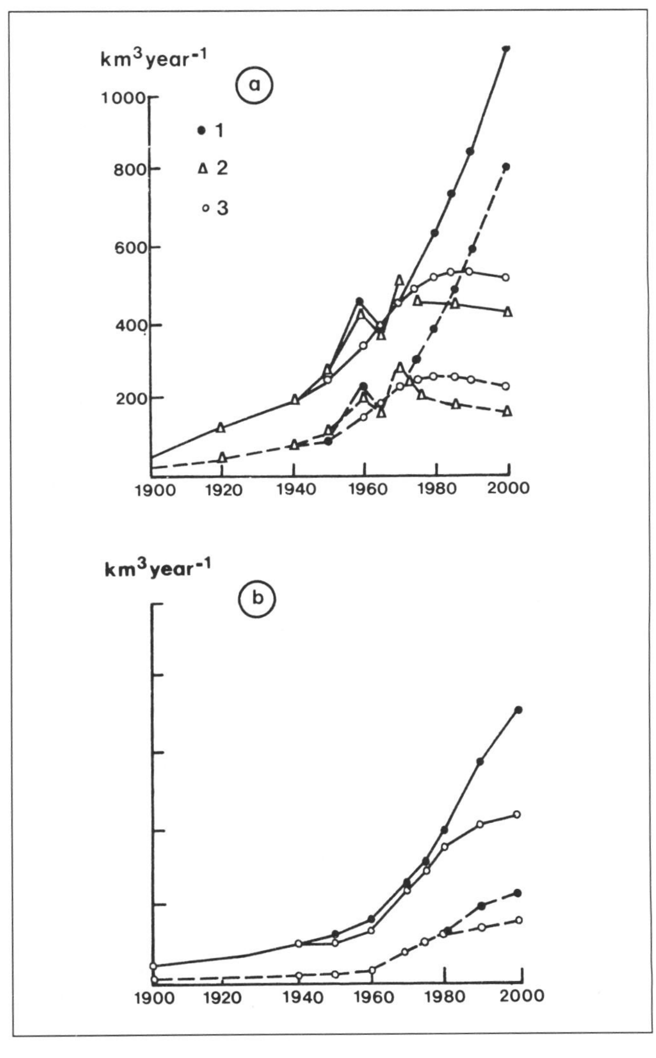

Figure 4 ***Forecast water consumption in (a) the USA and (b) the USSR according to date: 1, 1965–1970; 2, 1977–1981; and 3, 1983–1985. Total water consumption is indicated by a solid line; industrial water consumption (including power generation) is shown by a broken line.***

Table 4 ***World water demand according to use in km³/year; nos. in parentheses are percentages.***

Water users	*1900*	*1940*	*1950*	*1960*	*1970*	*1980*	*1990*		*2000*	
Irrigated area (Mha)	47.3	75.8	101	142	173	217	272		347	
Agriculture										
A	525	893	1130	1550	1850	2290	2680	(68.9)	3250	(62.6)
B	409	679	859	1180	1400	1730	2050	(88.7)	2500	(86.2)
Industry										
A	37.2	124	178	330	540	710	973	(21.4)	1280	(24.7)
B	3.5	9.7	14.5	24.9	38.0	61.9	88.5	(3.1)	117	(4.0)
Municipal supply										
A	16.1	36.3	52.0	82.0	130	200	300	(6.1)	441	(8.5)
B	4.0	9.0	14	20.3	29.2	41.1	52.4	(2.1)	64.5	(2.2)
Reservoirs										
A	0.3	3.7	6.5	23.0	66.0	120	170	(3.6)	220	(4.2)
B	0.3	3.7	6.5	23.0	66.0	120	170	(6.1)	220	(7.6)
Total										
A	579	1060	1360	1990	2590	3320	4130	(100)	5190	(100)
B	417	701	894	1250	1540	1950	2360	(100)	2900	(100)

A, Total water consumption; and B, Irretrievable water losses.

homogeneous from the points of view of physiography and economic activity (Shiklomanov and Markova, 1986). Water use in these regions was studied on the basis of data available up to 1985 on the rate of economic development, demography and climatology. For each region the total and irretrievable water losses were estimated for municipal and industrial use (power generation included) and irrigation, as well as evaporation from large reservoirs. The study covers the period from 1900 to 2000, with extrapolations early into the next century. Although data were available from many countries, where necessary, water consumption was assessed indirectly, by analogy with areas of similar physiographical and socio-economic conditions.

The most complete data were available for the USSR and the USA and the comparison of water consumption in these two countries is shown in Figure 4. The data illustrate the changes of water management in the USA: according to the first estimate (Landsberg et al., 1965), water consumption should have been about 2.5 times greater than it actually is; a major increase was predicted for industrial water supply and power generation. The approach to water management has meanwhile changed radically in the USA, with a very strong emphasis on water saving technologies, recycling, use of sea-water, replacement of extensive practices by intensive, multipurpose water management methods. This has led to a certain stabilization of water consumption, as had been forecast in 1975–1979 and later (USGS, 1984), when it was expected that the demand would become stable after 1980 with even a slight decrease forecast by the end of the century, mainly owing to water savings in industry and power generation.

Similar trends can be observed in the USSR: while in the 1960s and 1970s a total annual use of about 600 to 700 km³ was planned for the end of the century, according to recent estimates total annual water use should remain below 400–450 km³. It should be noted that, just as in the USA, in some countries of Western Europe (the Netherlands, Sweden, United Kingdom) water consumption has not increased since the 1970s, with a slight trend of decrease expected by the end of the century.

Global water consumption is, however, expected to grow in spite of its stabilization in some countries, as shown in Table 4 and this trend will probably continue into the next century. About 70% of total water use and 90% of irretrievable, consumptive use is due to irrigation.

In the future the relative importance of irrigation in the water consumption of certain regions may be somewhat less because of increased water use in industry. Evaporation losses from reservoirs will be higher than the sum of the irretrievable losses in industrial and municipal water supplies.

The balance of water use with respect to resources is illustrated in Figure 5 together with the relation between consumptive and total water use in 1950, 1980 and 2000, for selected physiographic/economic regions. Water use has increased significantly since the beginning of the century, with a maximum rate of increase in the 1950s and 1960s. The expected increase from 1980 to 2000 ranges from a minimum of 20% in North America, 32% in Europe, 70% in Africa to a maximum of 95% in South America.

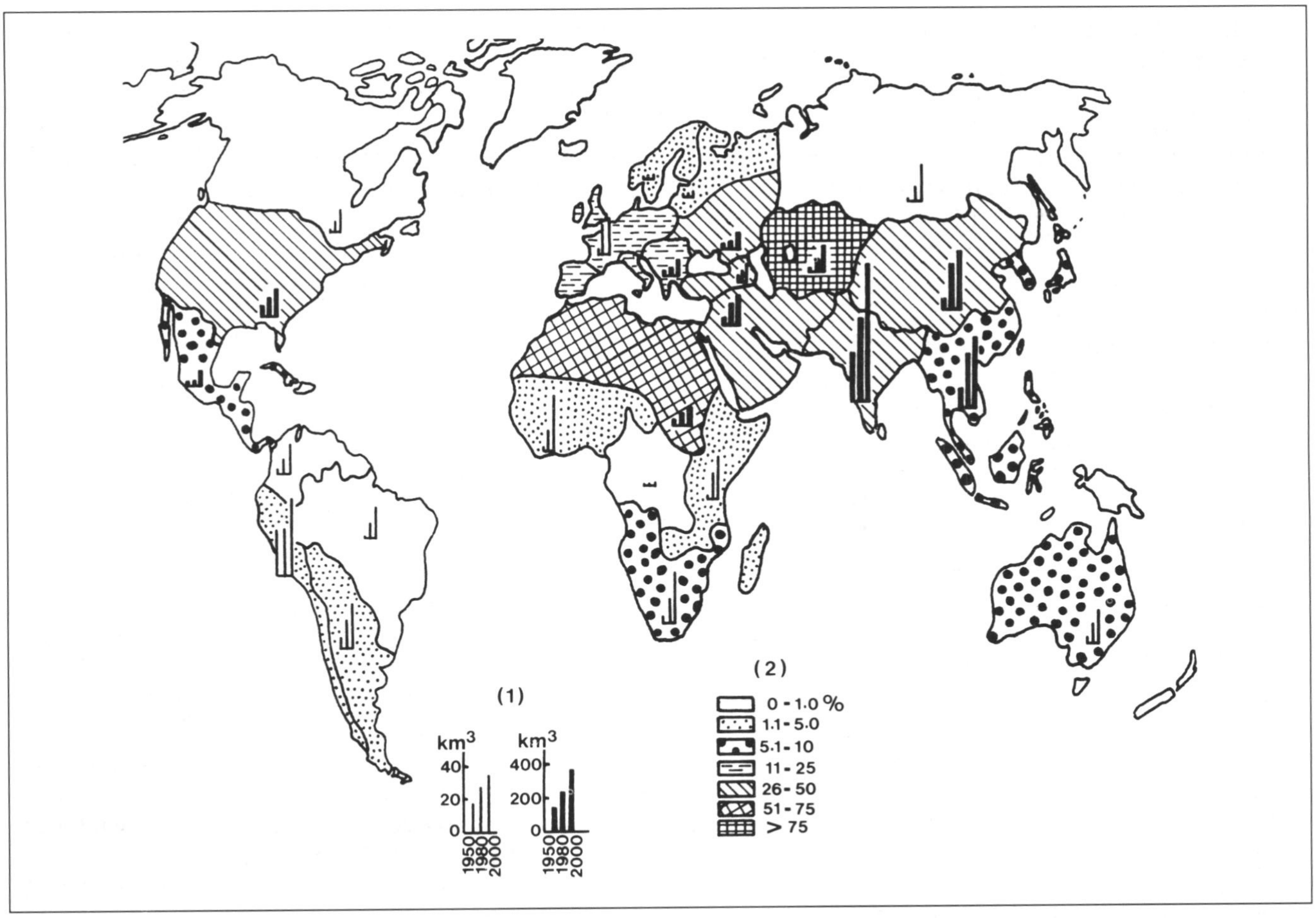

Figure 5 ***Irretrievable water losses for regions of the world for 1950, 1980 and 2000 (1) and percentage of water-resource use in the world for 1980 (2).***

Water use depends on climate, population and economic development of a region. The aridity index R_0/LP and the per capita consumption show that in arid regions economic growth only emphasizes the significance of the climatological factors, and that in such regions water shortages are imminent under the impact of social and economic development. On the contrary, the aridity index is of little significance in humid regions.

Although the global water demand in 2000 is expected to reach about 11.6% of global resources (6.5% of which is irretrievable use), these figures are already largely exceeded in some parts of the world (20–65%), and will reach 40–100% by the end of the century. In other words, in some regions the total water resources might be fully used within 10 years.

It should be noted, however, that some of the evaporated water might reappear in the same region in the form of precipitation. An analysis by the Drozdov (1972) method has shown that in some regions as much as 30–40% of the irretrievable water might return in the form of increased runoff in the same region (up to 5–13% of the total runoff). The impact of human activities on the water balance of large regions is highly complex and its study calls for international co-operation in hydrology and climatology on a global scale.

It is of interest to examine the very unequal per capita distribution of available water resources in the world (see Table 3). Relative water availability can be classified in the following seven categories: extremely low, below 1,000 m^3/year per capita; very low, 1,100 to 2,000; low, 2,100 to 5,000; medium, 5,100 to 10,000; above medium, 10,000 to 20,000; high, 20,100 to 50,000; and very high, over 50,000.

Global water availability in 1950 was medium or above medium; it was low only in northern Africa, central and southern Europe, China and southern Asia. No region was then in the very low or extremely low water availability categories. Thirty years later, northern Africa falls in the category of extremely low, while the regions of northern China and Mongolia, Central Asia and Kazakhstan belong to the category of very low. By the end of the century, the following situation can be expected: extremely low, two regions (northern Africa, Central Asia with Kazakhstan); very low, three regions (northern China with Mongolia, southern and western Asia); and low, seven regions (central and southern Europe, south of the European part of the USSR, South-East Asia, East and southern Africa). At the same time, high or very high water availability is found in northern Europe, the north of the European part of USSR, Canada, Alaska, most of South America, Central Africa, Siberia, the Far East and Oceania.

It should be noted that the biggest drop occurs in regions with lowest water availability: in the 50 years between 1950 and 2000, per capita water availability is reduced by a factor of 11 in the arid regions of Central Asia with Kazakhstan and northern Africa, whereas in regions of high water availability the reduction factor is only 1.5 to 5. The natural inequality of water resources in the world will be strongly accentuated in the future under the impact of human activities. Large scale water transfers are bound to become strategic options to be considered in the near fu'ure. It should be noted that the above values were determined assuming stationary climatic conditions, i.e. assuming that anthropogenic climate changes of global scale would remain insignificant until the end of the century.

The acuity of the present and future water shortages is caused not only by the insufficiency of water by quantity, but even more by the steady deterioration of its quality. In 1980 the amount of wastewater produced in Europe was about 308 km^3, and 440 km^3 in North America, while the world total amounted to about 1,870 km^3. A significant increase is expected by the end of the century, with the total reaching 2,300 km^3 per annum. The majority of wastewater is discharged without adequate treatment; for efficient dilution of 1 m^3 of untreated wastewater between 8 and 10 m^3 of river water are needed. Simple calculation shows that the world freshwater resources are not sufficient to dilute the untreated wastewater. Another very important source of water pollution is the excessive use of fertilizers and pesticides in agriculture. The dissolved solids content is particularly high in areas of intensive irrigation.

The control of water pollution is one of the most important aspects of environmental protection. While wastewater treatment is most widely used to fight pollution, it must be recognized that even the most efficient treatment does not protect rivers from pollution, since treated wastes also contain harmful residuals. The strategy of water conservation should thus comprise multipurpose measures, of which the reduction of wastewater production, recycling of used water and careful use of chemicals in agriculture are essential elements.

Climate change and water resources

Concern has been growing recently as regards pending climate changes attributed mainly to the increased CO_2 content of the atmosphere. The estimated increase in the last 100 years is about 22%, one-quarter of which has occurred in the last decade (Budyko and Izrael, 1987; Budyko, 1988). This may have induced an increase of the mean surface air temperatures of the northern hemisphere by about 0.5 °C in the last 100 years, of which 0.35 °C has occurred in the last 15 years only (Vinnikov et al., 1987; Jones et al., 1986). Certain calculations predict a further increase of 17–18% in the CO_2 content by the end of the century and a doubling by 2030–2050. As a consequence, mean air temperatures may rise by 1 °C (as compared to 1960) and 3–4 °C, respectively. It is significant that such changes have been predicted by two different methods: general circulation models of the atmosphere and palaeoclimatic analyses of past warm periods in the history of the earth. Increases of temperature can be expected especially in the higher and middle latitudes, and more so in winter than summer.

With regards to possible hydrological consequences, the application of the same methods has led to less conclusive and often contradictory results, as for instance as regards predicted changes of precipitation and soil moisture (Budyko and Izrael, 1987; Vinnikov et al., 1987).

Detailed data have been presented regarding the effects of human activity on air temperature and precipitation for North America and the USSR (Anon., 1988; Budyko, 1988). Soviet climatologists have prepared maps of expected changes of air temperature and annual precipitation that could be induced by a global warming up of 1 °C (by 2000–2005) and 2 °C (by 2020–2025). Increase of winter air temperature by 4–5 °C is expected on the Arctic coast and Siberia, while in the southern parts of the USSR temperature would rise by about 1 or 2 °C. An increase of 2–3 °C in summer temperatures is expected at higher latitudes, but limited to about 1 °C only in central regions. Less probable is a rise of summer temperatures in Central Asia.

The patterns of predicted changes of precipitation are much more complex: an increase of 50–100 mm in northern regions, slight decrease in central parts of the European part of the USSR and in western Siberia, and an increase up to 100 mm in the arid regions of Middle Asia and Kazakhstan seem probable (Budyko, 1988). As for the more distant future, the predictions are less reliable. Climatologists nevertheless foresee that a further rise of air temperature would result in a substantial increase of precipitation over the USSR by as much as about 100 mm on average.

Most of the researchers in the USA and Western Europe have analysed possible climate changes in certain regions or river basins by assuming hypothetical scenarios, without specifying the time when they may occur. As a rule, the scenarios were derived from general circulation models or were simply based on logical assumptions. While the scenarios are explicit with regards to the temperature increase (between 1 and 4 °C), precipitation is assumed alternatively to increase or decrease by 10 to 25 mm. In the Soviet studies, hypothetical scenarios were complemented by predictions of regional climate changes (usually for 2000–2005 and 2020–2030) based on palaeoclimatic analyses.

Studies by different authors of the influence of climate change on river runoff differ greatly and are difficult to compare (Gleick, 1988; Shiklomanov, 1989a). They agree, however, on the sensitivity of river runoff to slight modifications of climate. For instance, a rise of temperature of 1–2 °C and 10% drop of rainfall would reduce river runoff in arid regions by 40–70%, since runoff is particularly sensitive to changes of precipitation.

According to palaeoclimatological analyses (Budyko, 1988) the response of river runoff in the USSR to a global warming of 1 °C might change runoff by 3–20%, with a decrease of 3–10% in the central region of the European part of the USSR and Siberia, and a probable increase of runoff in the rest of the territory. An overall increase up to 7% of the runoff (280–320 km^3/year) could be expected, which would compensate the planned increase of water demand. Predictions for a more distant future are less reliable; nevertheless, they indicate that a larger increase of total runoff could be expected in the case of global temperature rise of 2 °C.

Climate changes are likely to be sharply reflected by the seasonal variations of runoff, particularly in regions of significant snowmelt. In this context, the Sacramento river basin in the USA was studied by Gleick (1986, 1987) whose water balance model was calibrated with a 50-year series of data; hypothetical scenarios were tested, assuming temperature increases of 2 °C to 4 °C and changes of precipitation in the range of −20 to +20%. Other scenarios were also tested with general circulation models assuming a doubling of the CO_2 content in the atmosphere. The results of the study indicate a steady increase of soil moisture in summer, a decrease of summer runoff of the order of 30–60% and an increase of winter runoff of 16–81%.

A water balance model using 10-day intervals was developed for the European part of the USSR and calibrated using a long series of data (Shiklomanov, 1989b). The model was applied to the Volga basin and to one small and two medium-sized river basins (Table 5). Climate change scenarios were derived for each basin on the basis of the climatological maps for the years 2000–2005, with an increase of temperatures ranging from 0.5 to 1.5 °C in winter, and 1.5 to 2.5 °C in summer, as well as a change of annual precipitation from −3 to +12%. The changes were mainly reflected by a significant increase of snowmelt that induced an increase of winter runoff and a corresponding decrease in spring. Typical long-term mean values of runoff for the four basins as shown in Table 5 indicate that human-induced climate changes may have a significant impact on the hydrology of river basins even as large as that of the Volga.

Forecasts of future changes of water resources attributable to human-induced climate changes are still not sufficiently reliable to be used in long-term water-resource management planning. The studies do indicate, however, that such changes would be fairly significant even in the case of slight climate modifications, and that not only river runoff, but also water demand might be affected.

Conclusions

Despite recent advances in the study of world water resources, progress has yet to be made involving the upgrading from the studying of mean values to the much more complex task of assessing seasonal variations of hydrological magnitudes, applied globally and to selected geographical and economic regions. Of particular importance is the evaluation of the impact of human activities on the hydrological cycle, an impact that is already strongly felt in certain regions.

The importance of the impacts depends not only on the scale and intensity of human activities, but also on the natural climatic variations in river basins. Long lasting dry periods create difficult and often critical situations, which give rise to increased activities in

Table 5 ***Effect of climate change on the long-term mean annual and seasonal runoff of some rivers of the USSR.***

River		*Watershed area (km^2)*	*Zone*	*Runoff (mm)*			
				Year	*Winter*	*Spring*	*Summer*
Volga at Volgograd	A	1 360 000	forest	187	22	107	58
	B		forest-steppe	165	35	94	36
Sosna at Yelets	A	16 300	forest-steppe	144	30	102	12
	B			129	53	63	13
Chir at Oblivskoye	A	8 470	steppe	47	3.0	43	1.0
	B			70	22	45	3.0
Devitsa at Nizhnedevitsk	A	76	forest-steppe	127	26	60	41
	B			112	36	41	65

A, natural conditions; and B, warming up by 1 °C.

water-resource planning and management. On the contrary, during wet periods water shortages are alleviated and as a rule water management projects are judged only from the point of view of the negative effects they may have on the environment. Such changing attitudes are particularly prominent with respect to the large-scale spatial redistribution of water resources, which must be considered as imminent in order to cope with long-term shortages of water resources in large regions. Although such measures are not popular, the question will reappear sooner or later. It is therefore necessary to prepare the scientific bases of the projects, including the prediction of possible human induced climate changes and their long-term impacts on hydrology and water-resource management.

Acknowledgments

The author is grateful to his collaborators in the State Hydrological Institute of the USSR: M.I. Budyko, V.I. Babkin, K.Ya. Vinnikov, V.Yu. Georgievski, A.V. Yezhov, V.V. Kvintradze, N.A. Lemeshko and A.I. Moiseyenko for contributing data presented in this paper.

References

ANONYMOUS. 1984. *World Water Balance and Earth's Water Resources.* L.: Gidrometeoizdat. 638 pp.

ANONYMOUS. 1988. Impacts of Climate Change on the Great Lakes Basin. United States–Canada Symposium. 209 pp.

BAUMGARTNER, A.; REICHEL, E. 1975. *The World Water Balance for Continents and for Total Land Area.* Munich, Vienna, R. Oldenburg Verlag. 180 pp.

BUDYKO, M.I. 1988. Climate at the End of the 20th Century. *Meteorologia i Gidrologia*, **10**, pp. 5–24.

BUDYKO, M.I.; IZRAEL, YU. A. (eds.), 1987. *Anthropogenic Climatic Changes.* L.: Gidrometeoizdat. The University of Arizona Press. 405 pp.

DROZDOV, O.A. 1972. Water Exchange in the Atmosphere and Possible Long-Term Predictions of its Changes. *Vodnye resursy*, **1**, 32–42.

GLEICK, P. 1986. Methods for Evaluating the Regional Hydrologic Impacts of Global Climatic Changes. *Journal of Hydrology*, **88**, 97–116.

——. 1987. Regional Hydrologic Consequences of Increases in Atmospheric CO_2 and Other Trace Gases. *Climatic Change*, **10**, 137–61.

——. 1988. Climate Change and California: Past, Present and Future Vulnerabilities. In: B. Glantz (ed.), *Societal Responses to Regional Climate Changes: Forecasting by Analogy*, pp. 307–27.

JONES, P.D.; RAPER, S.C.B.; BRADLY, R.S.; DIAS, H.F.; KELLY, P.M.; WIGLEY, T.M.L. 1986. Northern Hemisphere Surface Air Temperature Variations: 1951–1984. *Journal of Climate and Applied Meteorology*, **25**, (2), 161–9.

LANDSBERG, H.H.; FISCHMAN, L.L.; FISHER, J.L. 1963. *Resources in America's Future: Patterns of Requirements and Availabilities: 1960–2000.* Baltimore, Johns Hopkins, 1017 pp.

SHIKLOMANOV, I.A. 1979. *Anthropogenic Changes in River Water Content.* L.: Gidrometeoizdat. 300 pp.

——. 1985. Large-Scale Water Transfer. In: J. Rodda (ed.) *Facets of Hydrology*. Vol. II. pp. 345–87.

——. 1989a. Climate and Water Resources. *Hydrological Sciences*, **34**, (5), 495–529.

——. 1989b. Anthropogenic Changes of Climate. "Water Resources and Water Management Problems". Conference on Climate and Water. Vol. 2. Helsinki, Finland, pp. 310–47.

SHIKLOMANOV, I.A.; MARKOVA, O.A. 1986. *Specific Water Availability and River Runoff Transfers in the World.* L.: Gidrometeoizdat.

USGS (U.S. Geological Survey). 1984. *National Water Summary 1983: Hydrologic Events and Issues.* 984. Washington, D.C., U.S. Geological Survey Water-Supply Paper 2250, 243 pp.

VINNIKOV, K.YA.; GROISMAN, P.YA.; LUGINA, K.M.; GOLUBEV, A.A. 1987. Changing Mean Air Temperature in the Northern Hemisphere. *Meteorologia i Gidrologia*, No.1.

News

MAN AND THE BIOSPHERE PROGRAMME (MAB)

Land/inland water ecotones

A fair amount of progress was made in 1989 on the comparative study on 'Land/inland water ecotones and their role in landscape management and restoration'. This work has its roots in MAB Project Area 5, with an international workshop in Sopron, Hungary, in May 1988 providing the springboard for the preparation of a state-of-the-art synthesis, an overall proposal for future collaborative research, and the identification of initial field activities. (See the Reviews section below for details on Volume 4 of the MAB Book Series and MAB Digest No. 4).

The overall aim of the collaborative field research is to determine management options for the conservation and restoration of land/inland water ecotones through increased understanding of ecological processes. The project proposal describes the substantive research content, in terms of key questions and hypotheses to be addressed. Emphasis is given to fluvial corridors and circum-lacustrine ecotones. A 5–6-year period of research is envisaged, starting in January 1990. A Scientific Advisory Committee has been set up under the chairmanship of Dr Henri Décamps (France), to promote and co-ordinate the programme and to ensure its overall scientific quality. Close co-operation is envisaged between MAB and the International Hydrological Programme (IHP), at national, regional as well as international levels. In a number of cases, it is envisaged that contributing field activities might be undertaken under the joint auspices of MAB and IHP National Committees. Co-operation is also envisaged with a range of international non-governmental organizations, including SCOPE and the International Association of Limnology (SIL).

Parallel with the first series of national and multinational field projects, a number of regional and international workshops will address more specific topics. A working group headed by M. Zalewski (Poland) and J. Thorpe (UK) organized a workshop from 5–8 March 1990 in Krakow (Poland) on 'Fish and land/inland water ecotones'. Further information may be obtained from Maaej Kalewski, Institute of Environmental Biology, University of Lodz, ul. Banacha 16, 90-237 Lodz, Poland.

In the USA, the MAB National Committee accorded support to a workshop on 'Wetland and riparian ecotones in landscape dynamics: applying theory, data and methods' held 18–20 September, 1990 in Oak Ridge. Enquiries to Carolyn Hunsaker, Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831-6038, United States of America.

The Hydrobiological Station of Mikolajki (Masuria, Poland) will host from 20–26 May 1991 an international workshop on 'Phosphorous dynamics and retention in ecotones of temperate lowland rivers and lakes'. For details, contact Anna Hillbricht Ilkowska, Institute of Ecology, Polish Academy of Sciences, 05-092 Lomianki, Poland.

Non-point source pollution of aquatic systems

As noted below, late 1989 saw two new publication series: the MAB Book Series and MAB Digests. The first numbers in the two series resulted from a lengthy process of synthesis of existing information on the practical control of eutrophication in lakes and reservoirs. They represent the fruits of several years' work of a core editorial group, which integrated contributions from some fifty researchers and managers.

A somewhat similar process is being followed by the same core group of specialists, in the elaboration of a practical manual for the assessment and control of non-point source pollution of aquatic ecosystems. Among the issues being addressed are: the hydrological cycle and major processes affecting non-point source transport and transformation; types of aquatic pollutants, impacts on water quality and determination of critical levels; major sources (land uses) of non-point source pollutants in drainage basins and factors affecting pollutant loads; quantification of unit area loads and total pollutant loads from the drainage basin; available non-point source pollution control measures; development and implementation of a non-point source pollution control programme; identification of research needs.

The intention is that the manual will be finalized in late 1991 for publication in the MAB Book Series. A distillation for decision-makers is also envisaged in the series of MAB Digests. For substantive enquiries on the overall synthesis on non-point source pollution of aquatic systems, contact the chairman of the Scientific Advisory Committee: Dr Walter Rast, US Geological Survey, 8011 Cameron Road, Austin, Texas 78753, United States of America.

INTERNATIONAL HYDROLOGICAL PROGRAMME (IHP)

To commemorate the 25th Anniversary of the International Hydrological Decade (IHD) which later became what is now the International Hydrological Programme (IHP), a symposium was held prior to the 9th Session of the Intergovernmental Council of the IHP at Unesco. About 120 hydrologists and water resources specialists from sixty countries took part, including representatives from several non-governmental scientific and professional organizations.

In his opening speech, Dr A.M. Badran, Assistant Director-General for Science, underlined the importance of the IHD/IHP for the development of the scientific and technological bases for the rational management of water resources. He concluded that in the future, the IHP should become a point of convergence of hydrological concepts and methods as practiced in various parts of the world, of advanced research and regional expertise, of complementary scientific disciplines relevant to hydrology and water management, of the humanities and water sciences.

On behalf of the United Nations system, J.C. Rodda, Director of the Hydrology and Water Resources Department of the World Meteorological Organization, emphasized the importance of the role played by hydrology in assessing human impact on the environment. In this connection, he insisted that at the 1992 UN Conference on Environment and Development in Brazil, water issues should be voiced with emphasis.

On behalf of the non-governmental scientific organizations, Dr H. Colenbrander, Secretary General of the International Association for Scientific Hydrology, expressed his hope that in its IVth Phase the IHP will continue to focus on scientifically important projects, ensuring the transfer of knowledge and research results and the tightening of existing ties between scientists and experts of many different countries.

During the first session the history of IHD/IHP was recalled by speakers who actively participated in the programme since the very beginning. Recalling the setting up of the IHD and its later development into the IHP, Dr V.I. Korzoun drew attention to the gradual shift of emphasis from data assessment in the initial years, towards fundamental and applied research of the hydrological cycle in the later phases of the IHP, with the current programme being concerned largely with water resources management. Educational activities follow a similar pattern, technician training programmes gradually being complemented with university and other forms of higher education.

Professor A. Volker pointed out that in the 1960s, when the IHD began, both public opinion and governmental policies favoured water issues. In the course of time, these attitudes changed considerably, the increased sensitivity to environmental issues drawing public attention away from water-related engineering problems. Professor Volker concluded with the hope that the IHP would contribute to a better understanding of the complexity of the land phase of the hydrological cycle and enhance the general awareness of the significance of a good knowledge of hydrology for the management of the world in which we live.

Dr N.B. Ayibotele gave a brief account of the growing participation of developing countries in the activities of the IHD/IHP, despite the many difficulties which hinder their greater involvement. The education and training components are seen as the most valuable contribution of the IHP to developing countries. In the forthcoming years, global issues such as climate variability and its effects on hydrology and world water resources will require information from all parts of the world, and it is in the general interest to ensure that those regions which are less able, are assisted and encouraged to share in the global effort.

The initial steps taken to launch the IHD were recalled by Dr J.M. Rodier, who also underlined the differences in attitudes towards the programme: while the most developed countries favoured basic research, the developing countries felt that urgent action was needed in the field of data collection. Governments initially had different approaches to the programme which gradually gained more support as the projects developed. The speaker pointed out that information on the achievements and current efforts of the IHP is insufficient and many of its valuable publications do not get the attention they merit.

The review of the past, present and future of the science of hydrology was the subject of the second session. In his introductory paper, Dr V. Klemes raised a number of vital points which focus the present preoccupations of hydrologists and water scientists. He underlined the basic differences between hydrology as a geoscience and water resources management as a decision science, and warned of the detrimental consequences of confusing these two disciplines. Many of the basic problems of hydrology are still unresolved and the need for basic research is more acute than ever; the application of mathematical models to analyse time series of hydrological data is only a small and often misused part of the necessary scientific effort in hydrology. In the future, the scientific substance of hydrology must be reflected both in education of hydrologists and in the appreciation of hydrology as a science by water managers and decision-makers.

In the lively discussion that followed, often conflicting ideas were argued with regard to the prospects of hydrology and its relationship to water-resource management, on the use and misuse of mathematical methods in hydrological analysis, on the necessity of a balance being found between basic hydrological research and applications in water-resource management and hydraulic engineering and other pertinent questions with which hydrologists are faced.

The third session began with Dr M. Falkenmark's paper on the importance of hydrology in environmental research. This paper, which is published in this issue of *Nature & Resources*, offered an opportunity to examine the position of hydrology with respect to other environmental sciences. The paper and the subsequent discussion stressed the need for a broader view of hydrology, which in the past has mainly been concerned with river runoff and related problems.

The fourth session was devoted to the assessment of global water resources. Professor I.A. Shiklomanov's comprehensive report, which introduced the subject, is also included in this issue of *Nature & Resources*.

The paper was followed by several comments on the various aspects of the hydrological cycle and the water demand at regional and global scales. J. Margat pointed out that continental runoff cannot be identified with the concept of water resources: for instance, in some regions of the world, soil moisture is an important resource of rain-fed agriculture, whereas in general, only a part of the runoff can be considered as an effective resource. He also stated that in the last decades large scale mining of non-renewable groundwater has taken place in some parts of the world and that this trend will increase in the future. In confronting demands with resources, the scale in space is crucial, because by increasing the area under observation, the severity of regional and local water shortages is masked. Since estimates at a global scale are rather uncertain, it would be advisable to indicate their reliability by confidence intervals.

The fifth session was devoted to the role of national and international professional institutions in promoting water sciences in developing countries. The subject was introduced by Professor E.J. Plate, who pointed out that developing countries have difficulty in keeping up with the activities of the large number of professional and scientific associations, which despite the best intentions, do not contribute sufficiently to the exchange of scientific information at a global scale. He advocated the idea of linking advanced research centres and regional expertise in order to approach the world's hydrological problems. The concept was supported by several participants, from both developing and industrialized countries. Professor A.M.A. Salih drew attention to the positive experience of some specialized international professional associations, such as the International Association for Hydraulic Research, which assist national engineering institutions with the transfer of knowledge and information by means of regional conferences. He also pleaded for a responsive approach on the part of international associations with a view to assisting less developed countries, many of which have made little progress in recent years.

The highly topical problem of global climatic changes and their repercussions on hydrology and hydrological science was discussed in the last session. Dr N. Body, who underlined many of the uncertainties regarding the prediction of possible global changes, pointed out the high variability of hydrological events and the need to adopt the concept of risk in engineering design. The effect of greenhouse gases will probably be more apparent as regards the rapidity of changes rather than its overall magnitude. Hydrology would be affected indirectly through the modification of the vegetation pattern and groundwater regimes, which would be particularly prominent in arid and semi-arid regions, where a close balance exists between rainfall and evapotranspiration. In contrast to possible effects of greenhouse gases, changes due to large scale modifications of vegetation in many parts of the world are more clearly recognizable. Dr Body concluded that hydrological changes at a global scale are imminent and that the challenge inherent in that change can only be met by a better understanding of the mechanism of the hydrological cycle at temporal and spatial scales related to the world's climatic system. The combined use of representative basins and remote sensing seems to be a promising path to follow.

It should be mentioned here that the symposium offered an opportunity to the President of the IASH, Dr V. Klemes, to present the 1990 Hydrology Prize to Professor Z. Kaczmarek.

Book reviews

Naiman, R.J.; Décamps, H. (eds.), **Ecology and Management of Aquatic-terrestrial Ecotones**, Paris, Unesco; Carnforth, Parthenon Publishing, 1990, 316 pp. £35. (MAB Book Series, Vol. 4.)

This well-referenced and illustrated book comprises thirteen chapters addressing such topics as the general ecological importance of land/inland water ecotones, the use of models in examining ecotone structure and dynamics, and the influences of internal processes on maintenance of ecotones and socio-economic values of ecotones.

Rast, W.; Holland, M.M., Ryding, S.-O., **Eutrophication Management Framework for the Policy-maker**, Paris, Unesco, 1989., 83 pp. MAB Digests are available from: Division of Ecological Sciences, Unesco.

This first volume in the MAB Digest series provides (a) quantitative tools for assessing the state of eutrophication of lakes and reservoirs; (b) a framework for developing cost-effective eutrophication management strategies; (c) a basis upon which strategies can be tailored for each specific case according to the characteristics of the local area or region; and (d) specific technical guidance and case studies regarding the effective management of eutrophication. An initial discussion on the role of the policy-maker is followed by sections outlining proposed successive steps in eutrophication control. A glossary of some 150 terms is also provided.

Young, M.; Ishwaran, N. (eds.), **Human Investment and Resource Use,** Paris, Unesco, 1989, 54 pp.

MAB Digest 2 comprises suggestions for shaping future activities of research, training and information synthesis. It is designed to contribute to the growing interest in exploring issues at the environment–economics interface, particularly those concerned with the effect of the level and nature of human investments in determining the manner in which natural resources are used.

Hadley, M.; Schreckenberg, K., **Contributing to Sustained Resource Use in the Humid and Sub-humid Tropics,** Paris, Unesco, 1989, 59 pp.

MAB Digest 3 is an overview of activities within the framework of MAB relating to the ecology of humid and sub-humid tropical ecosystems, principally forests and savannas. The main aim is to provide a summary account of MAB activities on tropical forests and savannas and proposed future directions of work. As such, it should be of interest to both researchers and managers involved in the use and management of tropical ecosystems.

Naiman, R.; Décamps, H.; Fournier, F., **The Role of Land/inland Water Ecotones in Landscape Management and Restoration,** Paris, Unesco, 1989, 93 pp.

MAB Digest 4 presents proposals for a collaborative programme of research for the period 1990–1995. The overall aim is to determine the management options for the conservation and restoration of land/inland water ecotones through increased understanding of ecological processes. The digest describes the substantive research content, in terms of key questions and hypotheses to be addressed, in fluvial corridors and circum-lacustrine ecotones.

van der Made, J.W. (ed.), **Evaluation of National Guides on Methods of Hydrological Computations**, Paris, Unesco, 1989, 48 pp. Available from: Division of Water Sciences, Science Sector, Unesco. (Series: Technical Documents in Hydrology).

This document is the result of a working plan presented to the Intergovernmental Council of IHP entitled 'Methods of hydrological computations with particular reference to extreme hydrological events (flood and low streamflow)'. The working group, chaired by Dr M.F. Roche, completed a previous task of evaluation of national guides by compiling information on national and regional guides collected from Member States and reviewing them.

In this exercise, the term 'guide' was extended from its usual meaning of information and step-by-step directives to all interesting documents dealing with methods of hydrological computations. It, however, excludes documents dealing with data acquisition (including techniques of measurement and data transmission), the primary processing of data as drawing of rating curves, all matters related to water quality and sediments and all the methods for hydrological processing.

Guides before 1960 were also excluded, except for those treating important questions. Where references are concerned, the most recent guides were chosen where several exist on the same subject. Altogether 184 guides were evaluated from thirty-two countries. In addition, main guides edited by organizations belonging to the United Nations system and other international organizations are also mentioned.

Ivanov, K.; Pechinov, D. (eds.), **Water Erosion**, Paris, Unesco, 1989, 142 pp. Available from: Division of Water Sciences, Science Sector, Unesco. (Series: Technical Documents in Hydrology – IHP-III Project 2.6.)

This is an abridged version of the Proceedings of the International IHP/MAB Symposium on Water Erosion held in Varna (Bulgaria) from 19 to 24 September, 1988. It contains the key papers, as well as a state-of-the-art paper summarizing the discussions which covered five themes.

(1) Effects on soil erosion and water transport of sediments of agricultural intensification, the increase in industrial, mining and urbanization activities, and large-scale works modifying the environment.
(2) Methodologies of monitoring water erosion during various phases of the hydrological cycle.
(3) The role and the main concepts of integrated land management in combating water erosion.
(4) Socio-economic constraints and expected results of the application of comprehensive policies for soil conservation and land management.
(5) Influence of water erosion on the environment.

U. Maniak, **Model Curriculum for Short-term Training Courses for Senior Hydrology Technicians**, Paris, Unesco, 1989, 34 pp. + Annexes. Available from: Division of Water Sciences, Science Sector, Unesco. (Series: Technical Documents in Hydrology.)

The fast growing awareness of the importance of wise use of water can only be made concrete if it is supported by trained personnel that can ensure smooth management. However, most training courses have concentrated on the postgraduate or professional level leaving little room for hydrology technicians. It is to meet this need that this model curriculum for short-term training courses was designed to provide the structure for teaching basic hydrological subjects, field-work and special optional supplements. Advice is given on how to prepare, organize and execute courses and a model curriculum is attached as an annex.

N. Arnell (ed.), **Human Influences on Hydrological Behaviour: an International Literature Survey**, Paris, Unesco, 1989, 195 pp. Available from: Division of Water Sciences, Science Sector, Unesco. (Series: Technical Documents in Hydrology.)

This document was designed to survey the many studies that have taken place in IHP programmes concerning human activities on hydrological behaviour. Many of these studies have used experimental basins, and have led to major advances in hydrological science and practice. The major problem, however, is extending these results as widely as possible and transferring them to areas without information. To alleviate this problem, the International Steering committee of the Flow Regimes from Experimental and Network Data (FREND) project proposed the compilation of an international literature review of hydrological studies on the effects of human activities on water quantity and quality. It complements both the final report of the FREND project (which is available from the Institute of Hydrology, Wallingford, Oxon, United Kingdom) and the International Association of Hydrological Sciences (IAHS) proceedings of the 'FRIENDS in hydrology' conference, which provided an opportunity to discuss the results of the FREND project in a wider context.

Unesco NATURE & RESOURCES, Vol. 26, No. 3, 1990

ISSN 0028-0844

NATURE & RESOURCES

Water quality and availability

International news and information concerning environmental activities, natural resources research, conservation, disaster reduction and Unesco programmes in these fields

CONTENTS

The Parthenon Publishing Group
International Publishers in Science, Technology & Education

Casterton Hall, Carnforth
Lancs, LA6 2LA, UK

120 Mill Road, Park Ridge
New Jersey 07656, USA