Symposium on Water Resources Management

with the Views of Global and Regional Scales

SHIGA PREFECTURAL GOVERNMENT

UNITED NATIONS ENVIRONMENT PROGRAMME

INTERNATIONAL LAKE ENVIRONMENT COMMITTEE

November 18-20, 1991, Otsu, JAPAN

Organized by
United Nations Environment Programme
Shiga Prefectural Government
and
International Lake Environment Committee

Symposium on Water Resources Management

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Duration:

November 18-20, 1991

Venue:

Lake Biwa Research Institute

Organized by:

United Nations Environment Programme (UNEP)
Shiga Prefectural Government
and
International Lake Environment Committee (ILEC)

In association with:

Ministry of Foreign Affairs, Japanese Environment Agency,
United Nations Centre for Regional Development (UNCRD),
Japan Society on Water Environment (JSWE),
Overseas Environmental Cooperation Center (OECC),
Kansai Economic Federation, Shiga Economic Federation,
International Water Resources Association (IWRA) and
Japan Association for Hydrology and Water Resources (JSHWR)

Proceedings

of

Symposium
on
Water Resources Management

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held in Otsu, Japan, November 18-20, 1991

Edited and Published by:
International Lake Environment Committee (ILEC)

FOREWORD

Excessive human activities and rapid development in many water resources around the world are recognized to be increasingly threatening both water quality and quantity and the environment of these resources.

Demands for more irrigation schemes, increased used of fertilizers and pesticides, clearing of forests in upper watershed areas, release of untreated domestic and industrial sewage are causing environmental damage to water resources such as lakes, rivers and groundwaters. Moreover, many well-intended development projects have adverse repercussions, including forced re-settlements of large populations, the spreading of water-borne diseases and eutrophication, and disruption of eco-systems and freshwater fisheries. Many conflicts, on the one hand between upstream and downstream areas, on the other hand, between different sectors of the society, have erupted. These developments made clear that new and integrated approaches are needed to reconcile conflicting interests on how to use water resources in a sustainable way.

A "Symposium on Water Resources Management with the Views of Global and Regional Scales" was convened, organized jointly by UNEP, Shiga Prefectural Government and International Lake Environment Committee in Shiga, Japan in November 18-20, 1991. During the Symposium, special focus was placed on the sustainable development of water resources. The proceedings in which the outcomes of this symposium are compiled, should appeal to a wide range of readers varying from concerned citizens to experts engaged in the management of water resources. It is hoped that all concerned readers will find these proceedings useful in their daily activities.

Sveneld Evteev
Assistant Executive Director
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A HOLISTIC APPROACH TO ENVIRONMENTAL ASSESSMENT OF WATER DEVELOPMENT PROJECTS

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INTRODUCTION

Interest on the environmental impacts of water resources development has increasingly become an important consideration since the late 1960s. Generally, as in all other environmental areas, interest of the general public on this issue peaked around 1972-73 and then gradually started to decline steadily for nearly the next decade and a half. The overall interest in the environment in general, and water resources in particular, was rekindled again in the late 1980s. Environment at present has become a key political issue in many major national fora, especially in most developed countries and a few select developing countries. Equally, it now occupies a central place in the agenda of many recent national and international fora. While it is likely that the public and thus political, interest on the environment will ebb and flow with time, it is equally clear that certain threshold of interest is likely to be maintained permanently. This threshold is likely to be somewhat higher than what existed in the early 1980s. The days when engineers could design, construct and operate major water development projects, without explicit consideration of social and environmental factors, can now be considered to be history in most countries. In others, a certain amount of lip service to environmental preservation is still being given, but it is highly likely that formal and real consideration of environmental factors even in such countries will become a reality in the foreseeable future.

This, however, should not be construed to mean that engineers completely neglected environmental impacts of water development projects in the past, but rather that they considered only certain specific impacts like development of salinity and waterlogging due to poor irrigation management practices and unsatisfactory resettlement of people who were forced to move because of the inundation due to newly constructed reservoirs. A comprehensive and integrated environmental and social impacts analysis was generally missing.

It should be further noted that this situation was not unique to the field of water resources development. No comprehensive environmental and social impact of any type of major development project was carried out anywhere in the world during the pre-1965 era. The techniques for environmental impact assessment (EIA) were developed only during the post-l965 era, and in fact the term EIA itself gained widespread use in some countries only during this period.

While interest in the environmental and social aspects of water development is unquestionably a positive development, and in our view a step in the right direction, we would argue herein that the following critical issues significantly constrain the effectiveness of impact analyses as they are carried out at present. These are:

- i) limited frameworks used for environmental assessment;
- ii) absence of any integrative methodology; and
- iii) lack of adequate knowledge.

This, however, does not mean that these are the only major issues that are worth considering, since there are other important considerations as well. However, all these issues simply cannot be discussed here because of lack of time and space.

LIMITED FRAMEWORKS USED FOR ENVIRONMENTAL ASSESSMENT

The various frameworks that have been used for environmental impact assessment have changed only in some minor ways during the past two decades. While such techniques were acceptable and even laudable in the 1970s, they are certainly out of date at present. Significant changes and modifications are essential in our current environmental assessment framework if they are to meet the complex needs and challenges of the 1990s and beyond. Yet, most unfortunately, water and environment professionals are continuing to use such limited analytical frameworks without asking any serious question on their overall effectiveness. It appears that we have generally accepted them as the only alternative available. Regrettably, we are not even asking the right questions, and hence, not surprisingly, the real long-term solution is currently nowhere in sight.

There are three fundamental problems with the techniques used at present for environmental impact assessment. First, at the macro level, the linkages between EIA and social and economic aspects of water development are not clear. It is fuzzy at best. Second, while considerable expertise has been developed on the application of the present EIA methodologies at the project level, commensurate progress at policy and programme levels simply has not been made. It has to be admitted that we simply do not know how to effectively carry out environmental assessments of policy and programmes, except in a very general fashion (Biswas, 1991).

Third, it is indeed a curious irony that we have spent the last two decades discussing and promoting what is not sustainable water development rather than what it is. We have almost totally concentrated our focus on what aspects cannot be sustained. By trying to define sustainable water development by only the factors that contribute to unsustainability, clearly we have focussed our entire attention only on one part of the equation, and have completely ignored the other part, which could possibly be as important as the negative ones, if not more. Sustainable water development, as it is analysed at present, focuses only on what it is not, and then tries to ameliorate these potential negative effects. This issue is not approached holistically, which should first consider what is sustainable water development, and then move on to what is unsustainable. Instead we are hung up exclusively on "how" to reduce negative impacts. We must admit that as scientists we find it very difficult to accept the present somewhat skewed approaches to environmental impact assessment.

It is worth noting that even though it is axiomatic that any significant development project would have many environmental impacts, the word "impact" in the context of EIA has developed primarily, and almost exclusively, negative connotations. While any large development project, irrespective of its nature, will have both positive (otherwise why construct them?) and negative impacts, all current analyses of environmental and social impacts generally consider only adverse impacts and their potential amelioration.

To a certain extent this overwhelming emphasis on the negative aspect of all major development projects can be rationally explained. During the 1970s and earlier, project analyses primarily consisted of technical and economic considerations: environmental and social issues were mostly not seriously analysed. Because of this general neglect, and some very visible but adverse impacts of certain development projects on the society and the environment, a movement gradually developed in the West for environmental conservation. Within a very short period, environmental protection became an important item on the political agenda in the late 1960s and early 1970s in some developed countries, primarily through the activities of environmental pressure groups and non-governmental organizations.

Not surprisingly this attitude and perception of environmental protection was reflected in the United Nations Conference on the Human Environment held in Stockholm in June 1972. A retrospective analysis of the Stockholm Action Plan, as approved by all the UN member countries, clearly indicates its negative approach to environmental management: stop all pollution steming from any development activity, stop exhausting non-renewable resources, and stop using renewable resources faster than their generation. The emphasis thus was primarily on adverse impacts of development: positive aspects did not receive much attention.

Accordingly, environmental impact analysis, which was developed and made mandatory in many developed countries during this era, was exclusively concerned with the identification and amelioration of negative impacts; positive impacts were mostly ignored. Because of this inauspicious and incorrect beginning, the term 'impact' has continued to have almost exclusively negative connotations. Sadly, this unfortunate situation has not changed over the past two decades.

Specifically, in the area of large-scale water development, another factor of this early environmental period has had a major and continuing impact on our general thinking. This was the publication of a series of articles in the popular media by the well-known journalist, Claire Sterling, on the adverse social and environment impacts of the Aswan Dam. Her well-written but not necessarily reliable commentaries caught the imagination of the general public, including many scientists, most of whom were no experts either on water or the environment. This Dam suited the times of a "small is beautiful" era very well for three important reasons:

i) It was a large dam whose completion in 1968 coincided with the newly emerging environment movement, which had started to flex its muscle.
ii) For political reasons well-documented elsewhere, the West declined to assist Egypt to construct this Dam. It was finally constructed with the assistance of the "Evil Empire," the Soviet Union, and thus became an immediate and easy target for the Western criticisms. Khruschev's personal interest in this Dam, including his presence during its opening, contributed to additional adverse "public image" of this project.
iii) In the then prevailing climate, it was much easier to severely criticize a new dam in a far country than one's own country.

Sterling's high profile concentration on the negative environmental impacts of the Aswan Dam found a very receptive audience in the West, who were already semi-convinced that all the large development projects were disasters. Her writings reinforced the prevailing biases, and helped to make the Aswan Dam a cause célèbre among the environmentalists as a shining example of a bad development project. The perception that the environmental and social costs of the Aswan Dam significantly outweighed its benefits did not change because the Egyptian scientists as well as the Government generally did not produce objective and comprehensive analyses of its total environmental impacts, both positive and negative. To the extent that the Government did, the general reaction outside Egypt was "what else would one expect from the Government that built it?" In contrast, its so-called adverse environmental impacts were well-publicized through a series of non-authoritative writings.

Thus, the Aswan Dam rapidly became a "symbol" of everything that is wrong with major water development projects. Unfortunately, to this date, this view is still widely held, and most international publications available on this subject still do not provide a reliable and objective discussion of the real benefits and costs of this much-maligned dam. Our recent reviews of the various research work done on the environmental impacts of the Aswan Dam over the past two decades clearly indicate that many "myths" now surround this Dam, which are now generally accepted as "facts," even though ex-post environmental monitoring indicates otherwise. This is because these "myths" have been repeated so many times that they are now accepted as truths! In reality, however, the Aswan has been a remarkably successful Dam, without which Egypt would undoubtedly have been in dire economic straits. It has undoubtedly contributed to some adverse environmental impacts. However, the real question is no longer whether this Dam should have been built, since without this Egypt would now be facing a continuing catastrophe, but rather what steps should have been taken to maximize the positive environmental impacts and minimize the negative ones.

In retrospect, such an unsatisfactory state of affairs had one major beneficial impact. It was made clear to the engineering profession, which dominates the water development field, that there are other important issues in water management in addition to the techno-economic analyses, which must be considered to maximize human welfare. Accordingly, environmental impact assessment, which was neglected prior to this period, increasingly became acceptable as an established procedure.

ABSENCE OF INTEGRATIVE METHODOLOGY

EIA methodologies have continued to consider only certain selected aspects of water development projects: an integrative approach has been generally missing.

While one can cite many instances of this narrow and restricted approach, only one aspect will be discussed here as an example: health impacts of irrigation projects.

An objective and comprehensive review of existing literature in this field would indicate that the main, and mostly the only issue considered, is vector-borne diseases like schistosomiasis and malaria. Irrespective of the reliability of the oft-quoted evidences for increases in water-borne diseases due to construction of irrigation projects, an issue that will be discussed later, it could be argued that the present approach is not only simplistic but also somewhat erroneous for the following reasons.

Viewed in any fashion, irrigation has to be considered to be an integral component of rural development. As irrigation practices spread, agricultural productions increase as well. With higher per capita food availability and more diversified crop production, food and nutrition levels of the local population increase as well. Creation of new employment opportunities due to intensification of agricultural and economic activities in the project areas improves the financial status of many landless laborers. The nutritional status of rural people is further improved by the availability of animal protein through increased livestock holdings and the development of inland fisheries in the newly created reservoirs.

In addition, the health of the rural populations is further enhanced due to improvements in education, energy availability, health and transportation facilities and lifestyle of women. These interrelationships are shown diagrammatically in **Figure 1**. Current EIAs, however, do not consider health impacts of irrigation in an integrative manner: only the negative impacts are analysed. This clearly cannot result in an objective and full impact assessment.

The way present EIAs are carried out has also affected monitoring and evaluation of irrigation projects. For example, irrespective of the rhetoric, not a single multilateral or bilateral aid agency currently carries out project evaluation in a holistic manner. This does not mean that if one broadens one's mind such an integrative evaluation cannot be done. Facts are clearly on the ground for any objective and perceptive evaluator to find out. Sadly they see them but they do not observe them.

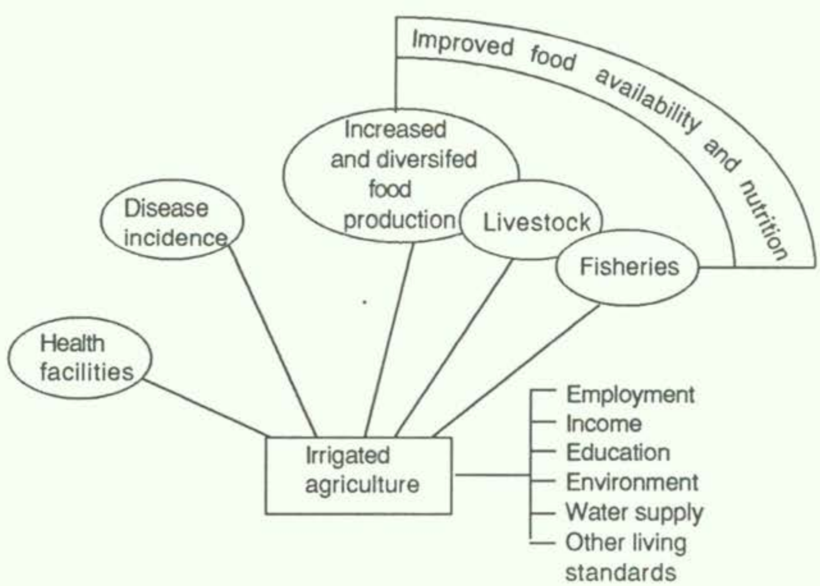

Figure 1. Interrelationships between Irrigated Agriculture and Health

It is our contention here that at our present state of knowledge we can carry out reliable and integrative environmental impact analyses, as well as evaluations of irrigation projects. For example, the evaluation carried out for a major international agency for the Bhima Project in India is a good example how such studies can be conducted (Biswas, 1987). Such an analysis, however, is generally a rare exception rather than rule.

Let us outline here just two types of major benefits which were observed at the Bhima Project, which to our knowledge have never been attributed to an irrigation project, either before or after this integrative evaluation.

First is in terms of female education. The evaluation (Biswas, 1987) noted the following:

> "One point made by several landless laborers was that, before irrigation, they had to move from one place to another searching for jobs. Thus, they could educate only one son, who was left initially with relatives, and in a few cases in hostels. Daughters invariably moved with parents from place to place, and thus were never sent to school. With the introduction of irrigation, employment opportunities near the villages have increased significantly. Now they stay in one village and find work within the village itself or neighboring areas. Because of this economic stability, for the first time they are sending their daughters to school."

We are not aware of a single EIA or any other evaluation of an irrigation project that has even cursorily considered female education as an important benefit of year-round irrigation.

Second, the Bhima evaluation further indicated that the patterns of biomass fuel utilization within the project area changed very markedly with the introduction of irrigation. Percentages of people purchasing fuelwood, or the total amount of fuelwood purchased per family, or both, in irrigated areas were significantly less than in non-irrigated areas due to three interrelated reasons:

i) higher cropping intensity as well as yields increased availability of agricultural residues, which are being used for cooking;
ii) increased livestock holding in irrigated areas produced more dung than ever before; and
iii) increases in employment opportunities and incomes encouraged people to move away from biomass to other forms of energy.

The reasons are diagrammatically shown in **Figure 2**.

This development has contributed to three major environmental and social benefits:

i) reduction in pressure on the forests in the neighboring areas;
ii) decline in time spent by women and children to collect fuelwood; and
iii) money saved by not buying as much fuelwood as before was used for other productive purposes (Biswas, 1990).

And yet, no EIA of irrigation projects has identified this type of benefit.

LACK OF ADEQUATE KNOWLEDGE

There are many areas where adequate technical knowledge simply does not exist. Equally there are areas where 'conventional' knowledge can at best be dubious and at worst totally erroneous.

There are also many areas where we are not even asking the right questions. For example, the two most widespread and important vector-borne diseases are probably malaria and schistosomiasis, but we do not know to what extent a water development project per se may increase their incidence. The problem is further complicated by the case-specificness of the answers.

An exhaustive study by the Malaria Research Centre of India has indicated that the resurgence of malaria occurred independently of the Green Revolution. There is, however, no question that irrigation, agricultural practices, rice cultivation and migration of agricultural labour have an important bearing on the mosquito vector fauna and malaria transmission (Sharma, 1987). The linkages are not clear, and there is no evidence to indicate a one-to-one relationship between irrigation devel-

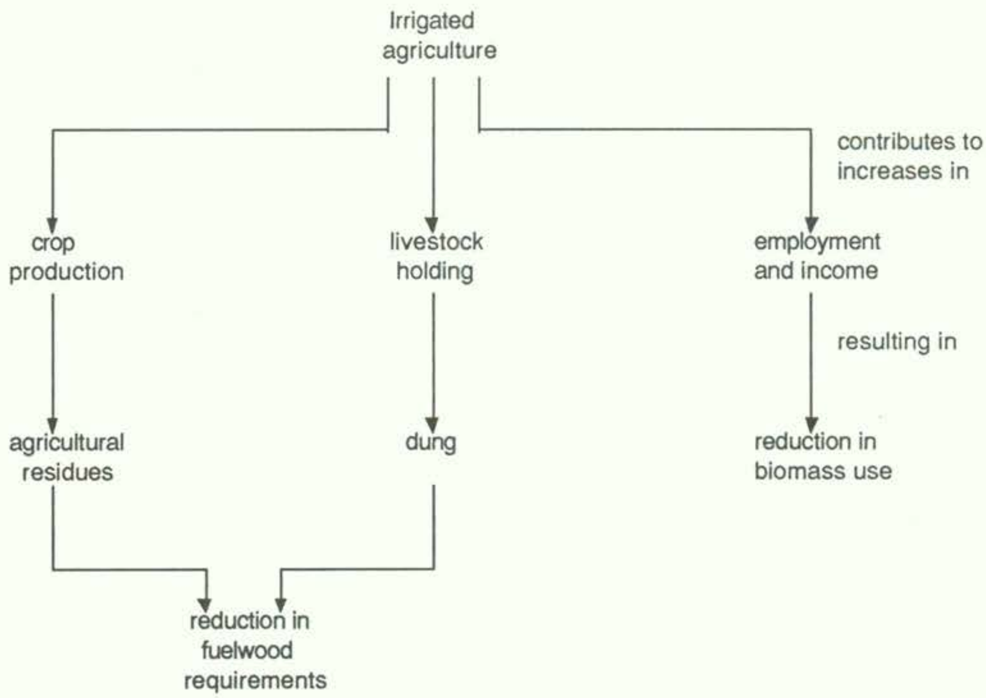

Figure 2. Impact of Irrigated Agriculture on Biomass Use

opment and additional incidences of malaria.

Figure 3 shows the district-by-district average annual parasite rate (API) between 1982 and 1984 on a rice acreage map of India. The API registers the number of malaria cases per thousand population in one year. It is found that for large parts of the country, with high acreages under paddy, malarial rates are negligible (API <0.5) or extremely low (API <2). There are some rice-growing areas where the incidence of malaria is moderate (API 2 to <10) or high (API >10). There does not appear to be any specific relationship between the area under rice cultivation and API: other parameters appear to govern disease transmission.

There are other complex issues that need to be considered for malaria. A study of two villages in the Kano plains of Kenya, one a newly established village within the 800-hectare Ahero rice irrigation scheme and another older village nearby in a non-irrigated area with traditional mixed agriculture, showed remarkable differences in terms of different mosquito species. In the new village 65% of mosquito bites were from the Anopheles Gambiae complex (the principal vectors of malaria in tropical Africa), 28% were of Mansonia species (vectors of lymphatic filariasis and Rift Valley fever) and 5% were of the Culex quinquefasciatus variety (another vector of lymphatic filariasis). In contrast, 99% of the mosquitoes in the older village belonged to Mansonia species and less than 1% were Anopheles Gambiae. Thus irrigation can change the transmission patterns of mosquito-borne diseases. This is an especially important consideration for tropical Africa, where most of the global total of more than one million deaths due to malaria now occur (Biswas, 1986).

There is also the issue of stratification as well. Evaluation of the Bhima command area development indicates that malaria appears to be attacking women more than men (Biswas, 1987). How widespread this stratification is, in India or elsewhere, is unknown since this type of question is not being asked at present, let alone answered.

If schistosomiasis is considered, there is no doubt that the presence of an irrigation system in a developing country, with extended shorelines of reservoirs and banks of canals, contributes to a better habitat for snails than existed before construction. However, extensive studies in Egypt and South Asia now clearly indicate that maximum infection is occurring not during the irrigation phase but during domestic interactions with the canals due to normal hygienic practices, since basic facilities like domestic water supply and sanitation are lacking. Increasing the provision of piped water, installing tubewells in the rural areas, constructing sanitation facilities and increasing health education are reducing schistosomiasis incidences to such an extent that this disease is unlikely to be considered endemic in Egypt by the year 2000 for the first time ever since the Pharonic period.

Another major problem we face on how best to consider vector-borne diseases within the context of irrigation projects is the absence of an adequate number of scientifically rigorous studies. The subject is replete with poor and conflicting information, the repetition of data that have seldom been critically examined, and the elaboration of personal biases. To a certain extent international organizations have contributed, albeit not deliberately, to this sad situation. For example, the estimate of the World Health Organization that globally some 200 million people are infected with schistosomiasis has remained remarkably constant since at least 1969. UNEP has incorrectly said in the past that schistosomiasis has been completely eradicated in China. Publications of the Food and Agricultural Organization (FAO) have erroneously stated that water development significantly increases onchocerciasis, whereas all the available evidence indicates the opposite. FAO has further repeated examples of increases in schistosomiasis resulting from water development projects based on poor and somewhat dubious data that were first published in 1978. A major problem in this area is the uncritical acceptance and repetition of published information, irrespective of their poor quality. As these types of dubious data are published time and time again, they gradually gain 'respectability.'

CONCLUDING REMARKS

The main thrust of our argument in this paper is the unsatisfactory state of our current practices for environmental impact assessments and overall evaluations of water development projects. While no sane person will argue that environmental assessment is not necessary, the challenge that the water and the environmental experts are facing in the 1990s is how best to carry them out holistically and effectively. Until and unless we realize that our present practices are inadequate and unsatisfactory, we are likely to make only limited progress in the future.

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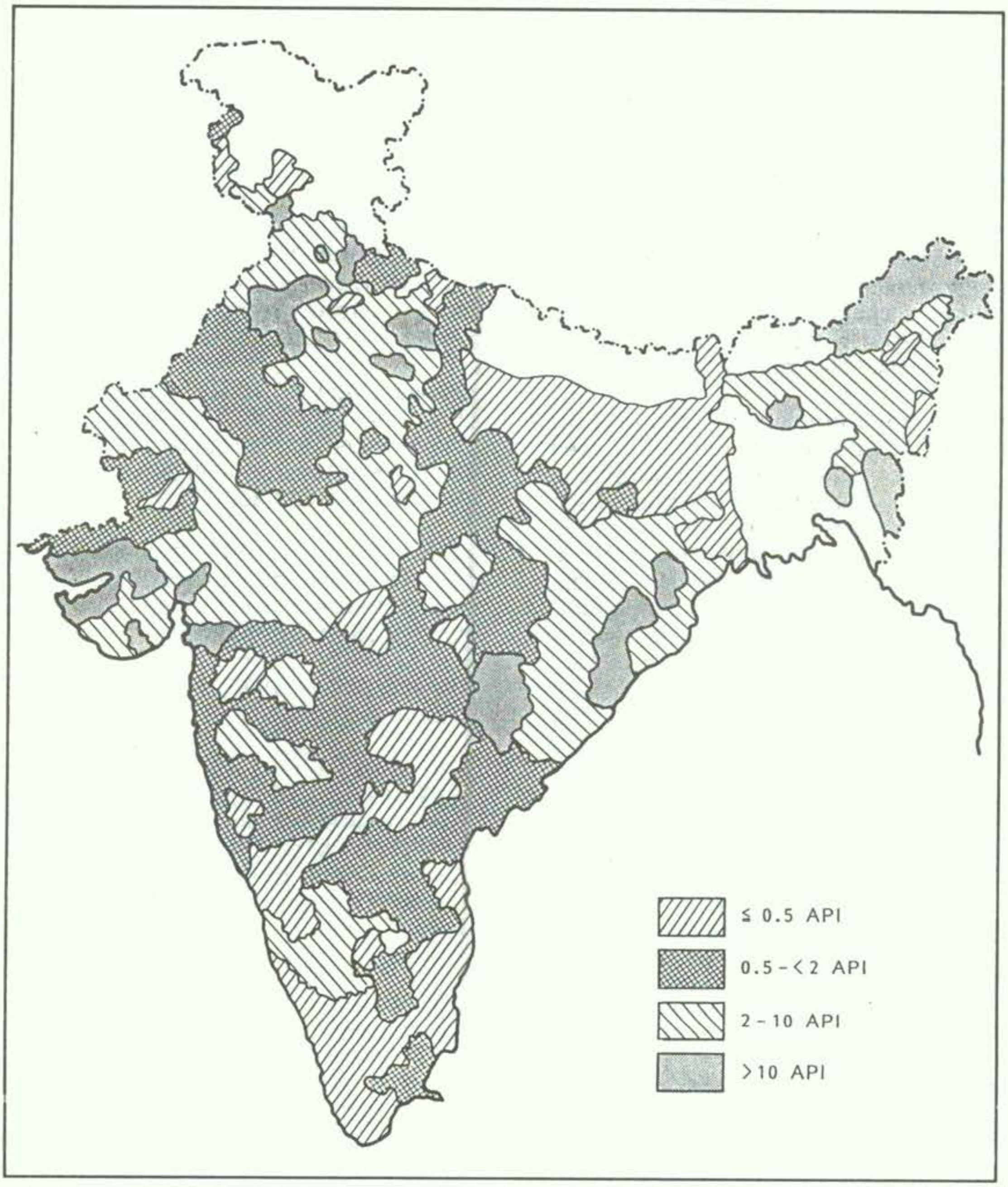

Figure 3. The Relationship between Area under Rice Cultivation and Average API, 1982-84.

COMPREHENSIVE DELOPMENT OF LAKE BIWA

By

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Thank you very much Mr. Chairman. Distinguished guests, Ladies and Gentlemen. I have the pleasure of introducing to you an outline of the Lake Biwa Comprehensive Development Project (LBCDP) and of sharing with you some of my observations on the implications of the Project with respect to the theme of this Symposium, water resources issues of regional and global scale.

My presentation will be based on the two distributed papers, one on the Evolving Issues in the Management of Lake Biwa - Yodo River Basin, and the other on LBCDP itself. For the sake of simultaneous interpretation, I will follow as much as possible my prepared text which is based on the two papers. I make use, with acknowledgement, of the OHP slides of figures and tables, many of which come from the existing materials on LBCDP prepared by the Shiga Prefectural Government, Ministry of Construction, and the Water Resource Development Corporation.

The view expressed by me, however, does not represent the official view of any of the above-mentioned government bodies.

As you have seen in the video presentation, LBCDP involves such project categories as nature and environmental conservation, flood control and water resources development. An array of large-scale component construction works, costing billions of dollars to the region and the nation, have been and will continue to be undertaken till the end of 1996 when the term of the project period is to terminate.

In the limited time I have for describing this momentous and complex undertaking, I would like to divide the presentation in three parts, the first being the description of Lake Biwa - Yodo River Basin system, the second being the description of the development of the concept of LBCDP, and the third being the description of the emerging issues of LBCDP.

First, I would like to describe the unique geographical feature of the Lake Biwa - Yodo River Basin and the upstream - downstream relation with respect to water resource development of Lake Biwa.

1. LAKE BIWA - YODO RIVER BASIN

Lake Biwa, Japan's largest freshwater lake, is situated in the upper most reach of the Yodo River Basin and occupies one sixth of the prefectural territory of Shiga. In the downstream reach of the basin are such metropolises as Kyoto and Osaka and other suburban municipalities, collectively referred to as Keihanshin Area (**Figure 1**).

Some 400 rivers and streams flow in the lake, but there is only one natural water course flowing out of the lake, Seta River, and two canals carrying lake water to Kyoto. The lake serves as a source of domestic and industrial water for both within the lake catchment area and the downstream population and industrial centers in the Keihanshin Area. It also serves for irrigation of paddy fields in the lake basin flat lands and for hydropower generation at some distance downstream of the outflowing river.

As the lake catchment area constitutes 96% of the prefectural land, Lake Biwa has been the most important natural asset for the prefecture. The Shiga residents, therefore, have had special attachment to the lake throughout history because of their dependency on the lake for fishing and transportation.

In the past century or so, the water use pattern has changed significantly due to various water resource development activities. The two canals linking the lake and Kyoto were constructed in 1890 and 1912, respectively. The City of Kyoto, therefore, has had direct access to the lake water unlike other downstream metropolises.

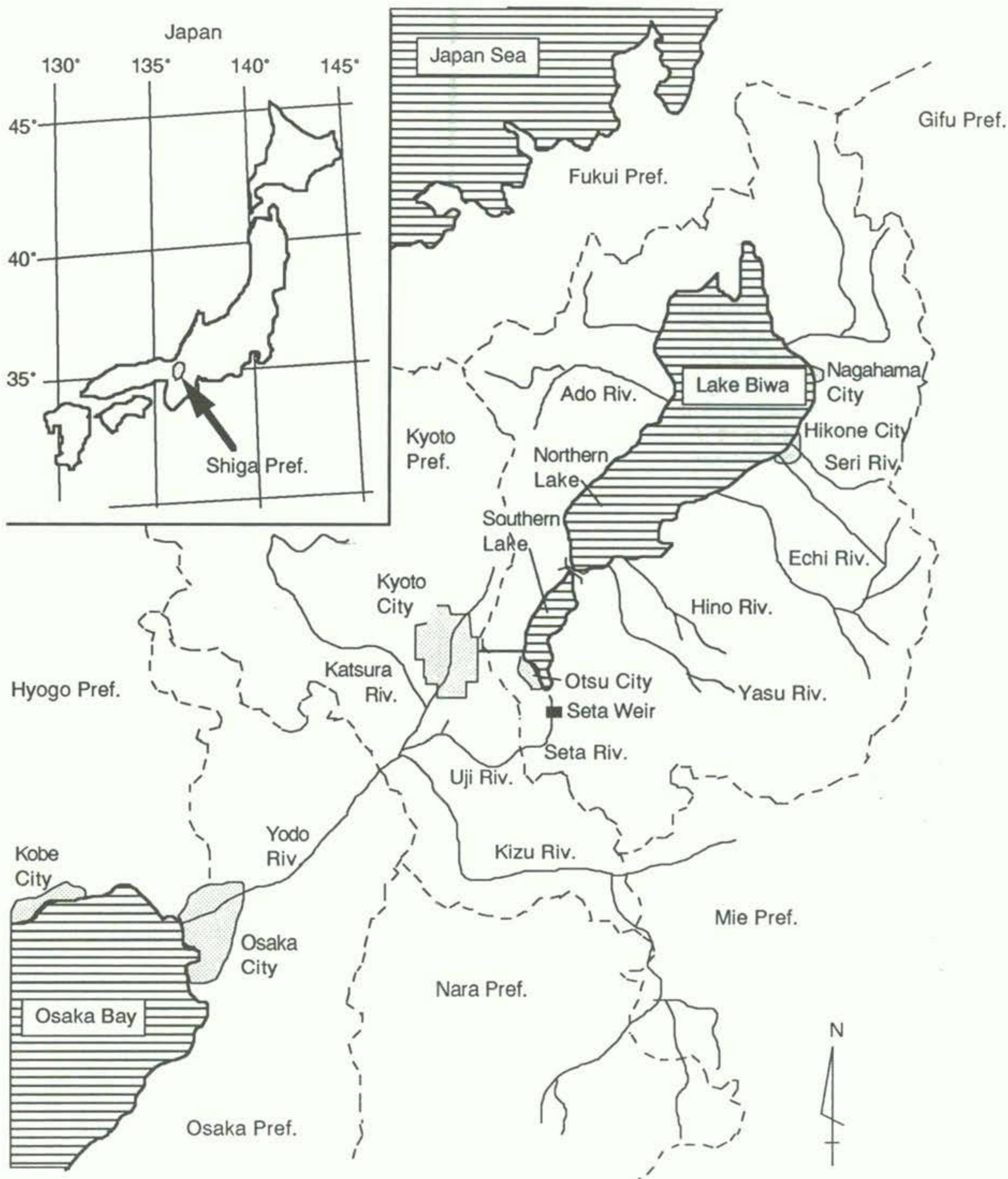

Figure 1. Lake Biwa and the Yodo River Region.
Source: "Lake Biwa", Shiga Prefectural Government, 1991

The Seta River stretches down to the prefectural boundary between Shiga and Kyoto. Within Kyoto Prefecture, it is called Uji River. Uji River is met by Kizu River and Katsura River at the Kyoto-Osaka Prefectural boundary, and the downstream stretch from this point is popularly called the Yodo River. The flow contribution to the Yodo River of the Uji, Kizu and Katsura River are, respectively, 64%, 18%, and 15%.

The official designation of the whole of the Yodo-Uji and Lake Biwa water bodies is the Yodo River System. Its total catchment area, as referenced at Hirakata, some 20 km upstream of the river mouth, is 7,281 km^2. Its annual average flow, high flow and low flow are, respectively, 177.6 m^3/day, 226.8 m^3/day, and 117.0 m^3/day.

At present metropolitan regions of Osaka, Kyoto and Kobe depend almost exclusively on Yodo River industrial and municipal water supplies. This being the case, Lake Biwa accounts for water supply amounting to 20 billion tons/year serving as many as 12 million people living in Keihanshin Area including Shiga. The Lake pollution, therefore, has been serious concern not only for those living around the lake but also to those receiving water from Yodo River.

The history of Lake Biwa and Yodo River water management was that of conflicts of interests and their resolution between Keihanshin Area downstream, particularly the Greater Osaka Region, and Shiga Prefecture upstream. For centuries the communities in the immediate surroundings of Lake Biwa had experienced many severe floodings of their agricultural fields before the government finally agreed approximately a century ago to a major dredging work of Seta River at the outlet of the Lake, in combination with the construction of Seta Weir, the only artificial water flow control facility of the lake outflow which is located at a few kilometers downstream from the lake outlet.

The Weir, constructed in 1905 and renovated in 1961, controls the lake water level and discharge rate to Yodo River. The flood frequency and the flood damage in the lake catchment have been reduced drastically after the weir construction (**Figure 2**).

The demand for water, particularly for industrial uses, began to increase sharply as the country entered the era of economic growth a decade or so after the end of the War. In the downstream stretch of Yodo River, the Hanshin Industrial Belt established in prewar years began to thrive with unfulfilled thirst for more water (**Figure 3**).

Exploitation of groundwater soon became constrained due to competition of use among industrial establishments and to land subsidence caused by overdraft of water. Industries were then forced to look for alternative sources of water. Domestic water supply needs also began to increase in the Yodo River ares after such suburban cities joined Osaka for gaining access to the Yodo River water.

The Japanese economic growth having gained momentum by the mid-1950's, there were surging interest in development of a comprehensive development plan of Lake Biwa water resources by the downstream population and industrial centers. After nearly two decades of political pressure put on Shiga Prefecture, consisting of demand by the downstream interests and the initiatives by the national government ministries, Shiga Prefectural Government finally agreed to a scheme for comprehensive development of Lake Biwa.

Now I would like to discuss the conceptual basis behind the development of the basic framework of Comprehensive Development.

2. THE CONCEPT OF THE COMPREHENSIVE DEVELOPMENT PLAN

2.1 The Conceptual Basis of the Comprehensive Development Project

The exploitation of water resources of Lake Biwa would bring about socio-economic benefits to the downstream Osaka and Kobe regions in the form of urban and industrial development. Shiga Prefectural residents, on the other hand, feared that it might mean simply to give in to the downstream demands for additional water with no direct benefit out of the transaction.

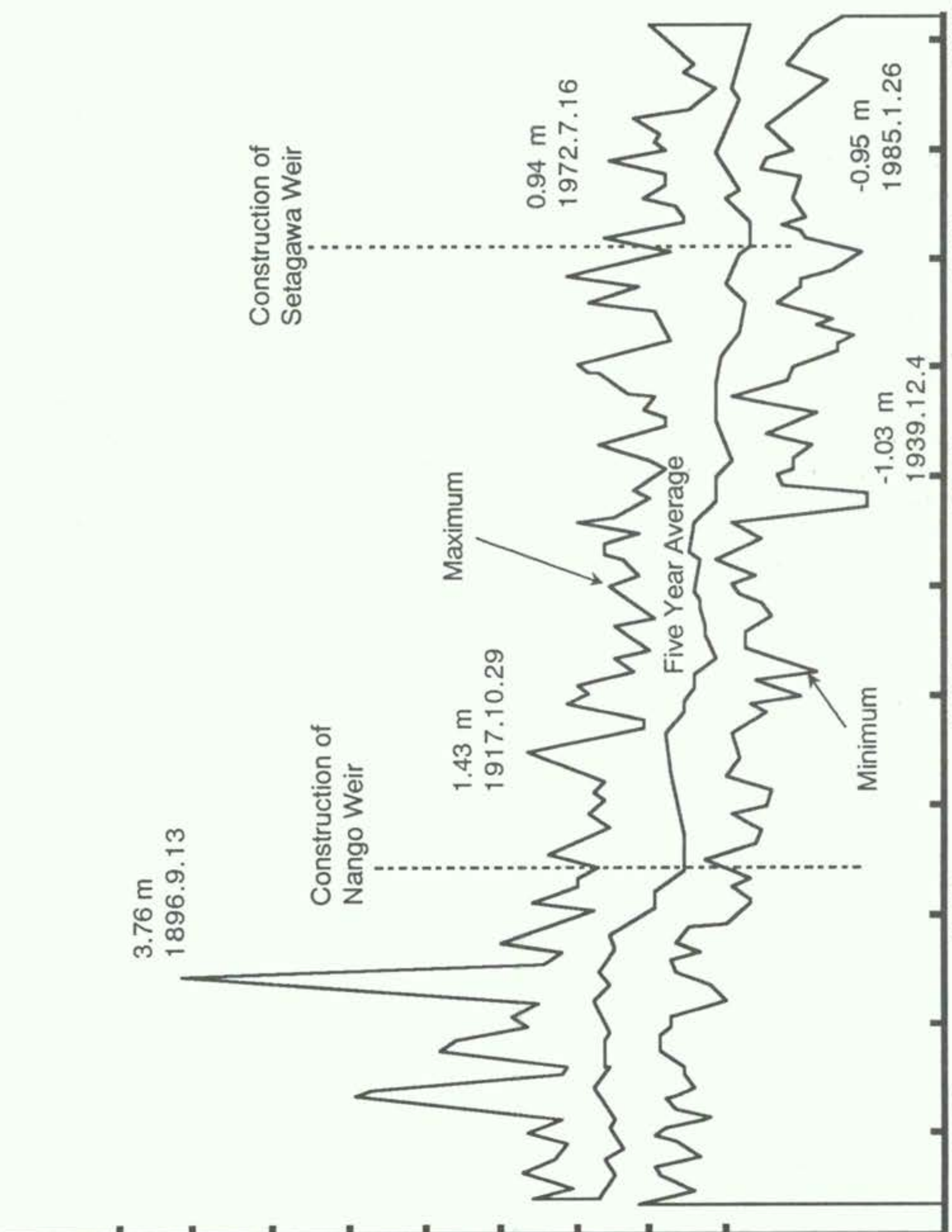

Figure 2. Change of Water Levels in Lake Biwa

Source: Development of Lake Biwa, nurturing its environment
The Water Resource Development Public Corporation
Lake Biwa Development Division, No date

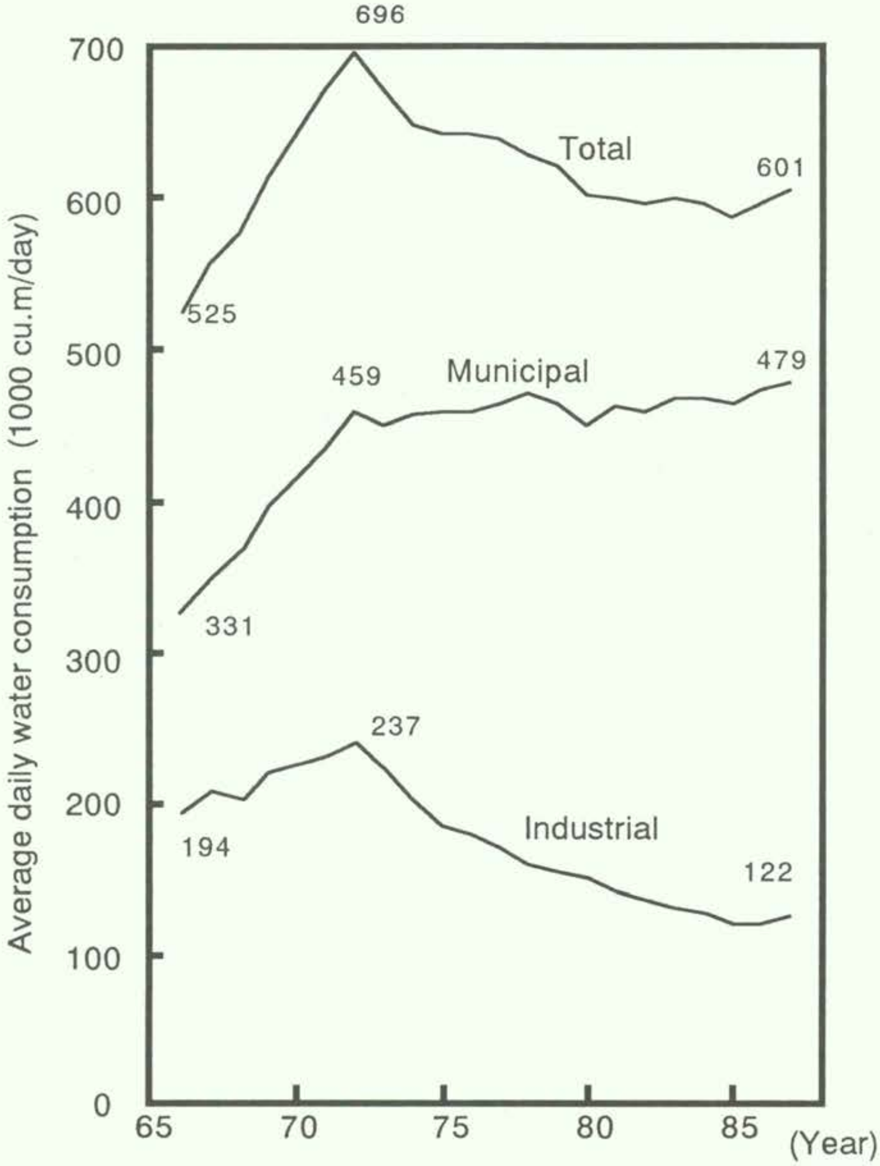

Figure 3. Trend in Water Consumption in the Downstream of Yodo River Basin
Source: Teruyuki Shimazu, "Mizushigen no Kaihatsu wa Hitsuyo ka", Gijutsu to Ningen, Vol. 18, No. 12, 1989

They were more likely to suffer from additional discharge of lake water through the Seta Weir, as it would necessitate alteration of existing, or construction of new, lakeshore facilities for coping with the lowered water level. The underlying concepts in the comprehensive development plan were, therefore, based on the observations that;

(a) since those living around Lake Biwa have historically been making a livelihood out of the Lake, the Lake ought not to be considered as a mere impounding structure as a dam.

(b) the lowering of water level, therefore, ought to be kept within a limit considered reasonable to those immediately being affected.

(c) the exploitation of additional water resource of Lake Biwa, ought not benefit only those who make direct use of it downstream but also those who suffer upstream due to lost opportunities.

The balancing of the conflicting interests of Shiga Prefecture upstream and Hanshin Region downstream required the development of a concept totally new to the water resources management policy-making institution.

The consensus consists of the following basic principles:

(a) The Comprehensive Development Project will have in it two major components, one being water resources development and the other being regional infrastructure development particularly for communities around the lake.

(b) The Comprehensive Development Project will be funded in large part externally both by the national government and the downstream local governments.

(c) The Comprehensive Development Project being a regional mega-development project with national implications, it will be drafted by the Prefectural Governor of Shiga and be approved by the Prime Minister of Japan.

The Project was designed to consist of three categories of component projects, namely those designed to contribute to the conservation of Lake Biwa environments, to mitigate against flood and coastal erosion, and to facilitate the downstream municipalities and industries the use of additional 40 m^3/s of water.

2.2 Outline of the Lake Biwa Comprehensive Development Project

The basic objective of this Project was to promote development of the Keihanshin region by providing additional water, and to improve, at the same time, the socioeconomic status of the Lake Biwa watershed communities. However, such a mega-development project would have not only regional implications but also national implications. In particular, there would be a need for a cost-sharing scheme involving national as well as downstream local governments so that the heavy financial burden on the upstream local governments could be lightened.

With such considerations in mind, the "Special Measures Act for Lake Biwa Comprehensive Development" was enacted in June 1972. The major features of this act may be summarized for each of the 12 articles of the Act as stated in the provided text.

Table 1. Special Measures Act for Lake Biwa Comprehensive Development

Article 1	The purpose of this law
Article 2	The particulars of development and conservation projects
Article 3	Procedures to be used for decisions and revision of the plan
Article 4	Preparation of a yearly plan for individual projects
Article 5	Responsible agencies
Article 6	Cooperation among the concerned bodies
Article 7	The measures for restoring the living conditions of local people
Article 8,9,10	The involvement of the national government
Article 11	The proposed scheme for cost sharing
Article 12	The establishment of the Lake Biwa Administrative Fund

As stated in Article 3 of the Special Law, the Lake Biwa Comprehensive Development Project was drafted by the Governor of Shiga Prefecture and was approved by the Prime Minister. The particulars of this Project were set in accordance with the basic policy which emphasizes the importance of the preservation and development of Lake Biwa and its catchment area.

The Project also provides for appropriate administration of facilities to be constructed, sound management of Lake Biwa and its shorelines, and appropriate operation of of the Setagawa Weir.

The project plan, which determines the outline of component projects, set forth the purpose, volume and particulars of each of the 21 projects for local area improvements.

Table 2 Component Projects in Lake Biwa Comprehensive Development Plan
Source: Shiga Prefecture

(Million Yen)

Projects Component	Planned Cost (1971 price)	1972-1981 Cost (price of year)	1982-1991 Cost (1981 price)	1972-1992 Cost (unadjusted sum)
A. CONSERVATION				
A-1. Water Quality				
a. Sewage System	59,000	99,633	257,940	357,573
b. Nightsoil System	2,938	9,268	4,262	13,350
c. Stockbreeding Waste Management	-	-	2,163	2,163
d. Rural Sewage	-	-	20,000	20,000
e. Refuse Disposal	-	-	16,423	16,423
f. Lake Surveillance System	-	-	841	841
A-2. Conservation				
a. City Parks	2,775	686	7,400	8,086
b. Natural Parks	4,832	505	1,621	2,126
c. Acquisition of Conservation Areas	3,650	566	1,632	2,198
d. Roads	62,863	60,575	111,331	171,906
e. Ports and Harbors	7,193	35	4,321	4,356
A-3. Conservation Total	143,251	171,268	427,934	599,202
B. FLOOD CONTROL				
B-1. River-related				
a. Rivers	47,330	46,649	68,975	115,624
b. Dams	20,200	10,424	71,090	81,514
c. Erosion Control	22,509	15,793	35,347	51,140
B-2. Catchment-related				
a. Afforestation	14,393	25,875	27,131	53,006
b. Mountain Management	20,320	20,118	18,947	39,065
B-3. Flood Control Total	124,752	118,859	221,490	340,349
C. WATER UTILIZATION				
C-1. In-Prefecture Use				
a. Water Supply	20,446	63,650	15,379	79,029
b. Indust. Water Supply	5,920	10,447	7,978	18,425
c. Land Improvement	54,117	74,755	143,080	217,835
C-2. Fishery				
a. Fishery	5,118	3,254	5,046	8,300
b. Fishing ports	1,033	1,455	255	1,710
C-3. Water Util. Total	86,634	153,561	171,738	325,299
D. DOWNSTREAM USE				
a. Flow Control and Water Management	72,000	118,305	141,695	260,000
GRAND TOTAL	426,637	561,993	962,857	1,524,850

These are to be carried out mainly by the municipalities in Shiga, Osaka and Hyogo Prefectures and the prefectural governments themselves in pursuant to 3 major guidelines of the basic policy. The water resources development projects and the Lake Biwa flood control projects are to be conducted mainly by the Water Resources Development Public Corporation.

2.3 The Extension of the Terms of the Special Measures Act and the Revision of the Project Plan

This act, enacted in 1972, had a limited validity period of 10 years and was to be terminated in March 1982. However, due to the rapid change in social and economic conditions of the nation during the 10 year period, the Lake Biwa environment and the situation surrounding the Lake Biwa Comprehensive Development also changed, resulting in emergence of various problems not adequately taken into consideration at the time of enactment.

In particular, because of the decelerated growth of the Japanese economy since the first oil crisis in 1973, the public investment were severely curtailed, and the LBCDP had achieved only 40% of the goals stated in the Project plan at end of March 1982.

Furthermore, the Lake Biwa water quality deteriorated much more rapidly than being anticipated earlier (**Figure 4.**), necessitating the implementation of remedial measures by revising the original component projects.

The major incidents of significance during this period are listed chronologically as follows:

1973 The sudden hike in international petroleum price (the first Oil-Crisis) and its severe impacts on the Japanese economy

1976 The environmental impact study conducted on the construction of an artificial island in the southern end of Lake Biwa for siting a wastewater treatment plant

A litigation against the implementation of LBCDP submitted to Otsu District Court House

1977 The first sighting of the freshwater red tide (confirmed annually since)

1979 The Eutrophication Control Ordinance enacted for the first time in Japan by Shiga Prefecture

1981 Taste and odor problems associated with Lake Biwa water became highly noticeable

The Shiga Prefectural Government thus consulted with the concerned national government agencies for an extension of the validity period of the act and the revisions of the plan as follows:

* To extend the validity period of the special act for additional 10 years for the completion of the initially planned projects.
* To revise the project plan by adding water quality management projects.
* To maintain the current special financing measures for project implementation.

At the national assembly in December 1981, the requests by the Shiga Prefectural Government as stated above were approved nearly in whole, and the "Partially Revised Special Measures Act for Lake Biwa Comprehensive Development" was enacted, promulgated and put into force in March 1982.

Four additional categories of projects were added to the original 18 categories, which include construction of agricultural and dairy waste management facilities, rural community wastewater treatment systems, solid-waste management systems, and water quality surveillance and monitoring systems. The total expenditure swelled from the original 426.637 billion Yen to 1,524.85 billion Yen.

In addition, there arose a need for renewed efforts for coordination between upstream and downstream local governments, and a consensus reached in May 1982 stipulates the following basic agreements.

* To establish a forum of joint study on the management of water quality of Lake Biwa - Yodo River Basin
* The joint financial obligation of the downstream governments was determined to be 36.0 billion Yen.
* To extend the payback period for the 5.0 billion Yen left over from the previous years for an additional 10 years.
* The actual release of the additional flow of Lake water, amounting to 40 m^3/sec, would begin only after the compensatory works have been completed.

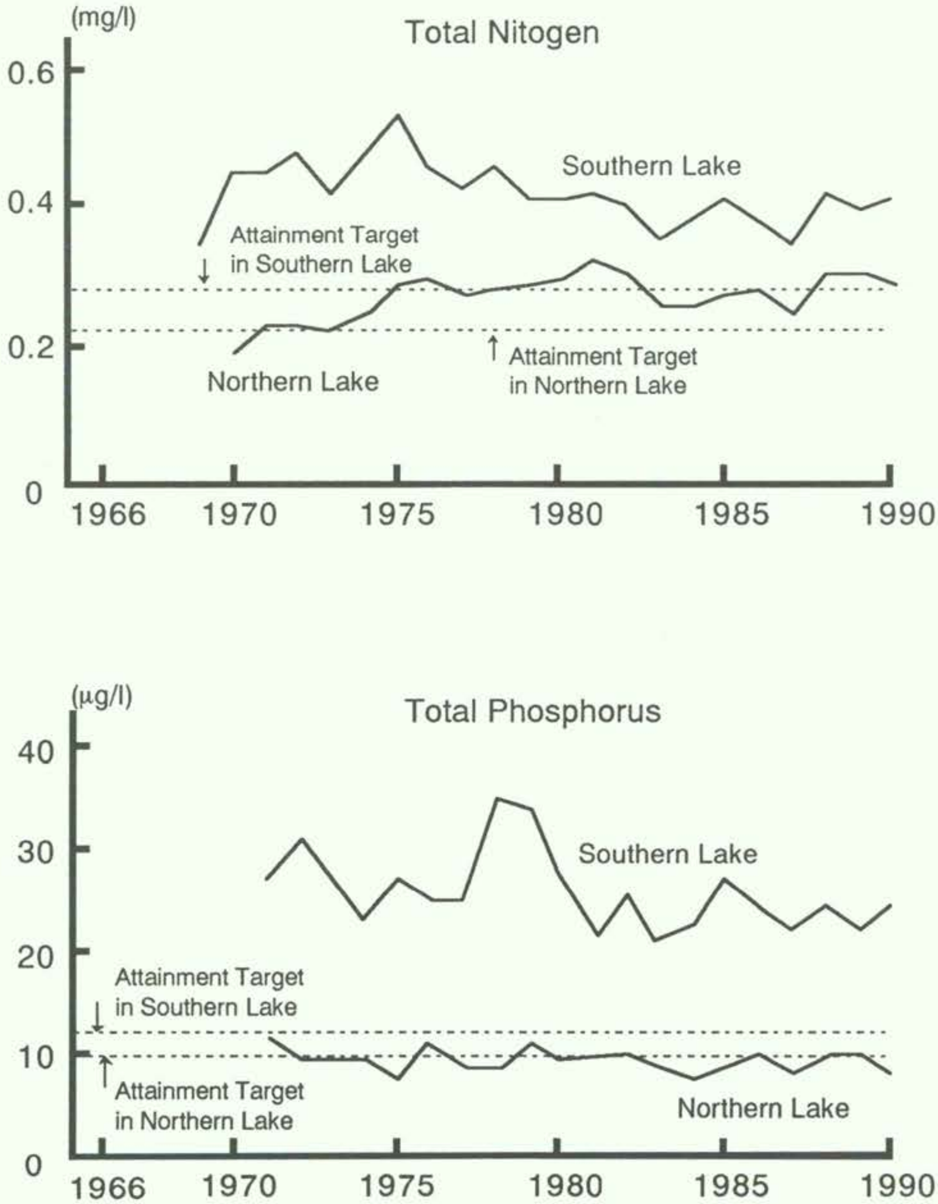

Figure 4. Annual Change in Water Quality of Lake Biwa.
(Mean values at 48 sampling stations.)

Source: Shiga Prefectural Government, "White Paper on the Environment of Shiga Prefecture", 1991

3. THE EMERGING ISSUES

The terminal year of the Comprehensive Development Project as specified in the Special Act is 1992, and the component projects are at various stages of completion. Those projects pertaining to increasing the flow through the Seta Weir down through the Seta, Uji and Yodo Rivers are reasonably close to be completed in time. The progress in compensatory public works component projects for infrastructure development, however, has been less than satisfactory. A great deal of efforts are needed for implementation the remaining portion of the projects, and for instituting transitional measures such as extending further the Project period.

Shiga Prefectural Government, the downstream governments and the national government have been reported to have agreed to extend the term of LBCDP for another 5 years till the end of 1996, so as to have the remaining projects to be completed. In the meantime, Shiga Prefectural Government will take a transitional measures to release, steadily, 27 m^3/sec of lake water down through the Seta River and hence to the Yodo River. Nonetheless, the original and the most important aspiration of the Comprehensive Development Project, the management of lake water for flood and erosion control and for flow augmentation to satisfy downstream demands, is about to be realized.

The Lake Biwa Comprehensive Development Project also takes special note of the fact that there would be a need, respectively, for;

* proper operation and maintenance of the facilities constructed in connection with the Project,
* introduction of better lakeshore management schemes,
* establishment of the operation rule of the Seta Weir for controlling the lake water level,
* acquisition of additional funds for managerial undertakings hitherto unaccounted for in the project funds.

The conservation of the Lake Biwa environments at the completion of the Comprehensive Project would not be adequate with only such provisions as stated above. The management of water-environment of Lake Biwa has entered a new era. The concern for the conservation of water quality has become more and more serious today as compared to the earlier days of the Comprehensive Development. There is emerging realization that there would be a need for a more encompassing concept of management of Lake Biwa and Yodo River System particularly for countering deterioration of water quality of the Lake at a rate which seems to be much more accelerated than before.

Now, I would like to share with you some of my own observations on the implications of this Development Project, keeping in mind that the approach taken to realize this project and many of the issues raised in the process of implementation, I am sure, will have significant bearings on conceptualization of similar development projects to be undertaken in other (particularly developing) countries in the coming years.

4. OBSERVATION

(1) My first observation is with regard to the historical timing of conceptualization and implementation of the Project.

LBCDP was conceptualized at a time when Japan was undergoing phenomenal economic growth. There was tremendous development pressure and momentum building up in the nation for water resources, and at the same time, mobilization of financial resources to such a massive project appeared not so difficult. Given the pressing needs for water resources by the downstream population and industrial centers then, the issue at that time was, as far as I could tell, when to launch the project and how politically satisfying arrangements could be arrived at among the upstream, downstream and national interests. Probably, it would not have been possible to realize this Project at any other time than in the early 1970's, and any other form than the current form, compromising downstream interest in additional water resources with upstream interest in regional development, and compromising resource development with environmental conservation.

The implication here is that this generation will enjoy the satisfaction for having accomplished the project, but at the same time it will have to bear the responsibility for the consequences of the decision, be they newly generated economic benefits, costs for restoring the disturbed integrity of the ecology, or any other kinds not properly accounted for today.

(2) My second observation pertains to the long duration of the project implementation.

A complex development project such as LBCDP takes sometimes decades to complete. As the social and economic situations change over the project duration, sometimes very drastically, the nature of the project will have to be modified with additional costs of adjustments. In the case of LBCDP, they were incrementally reassessed and readjusted, while maintaining the basic framework of the Development Project. The societal needs for the water have changed, the environment and the ecology of the Lake have changed, and the level of awareness of the public of the value of the Lake have also changed. Facilitation had to be made, more for some and less for others, to accommodate for these changes.

The implication here is that the project with long implementation duration will require timely reevaluation and necessary modification, and facilitation to such modifications will require substantial additional financial commitments. Sometimes such reevaluation may call for fundamental change in the original concept of the plan.

(3) My third observation is with respect to the concept of basin-wide water management.

One of the subjects attracting growing interest among water management specialists today is an approach called the basin-wide water management. In the case of Lake Biwa, it would be the management of the whole of the Lake Biwa - Yodo River Basin as a single unit. How does LBCDP come into picture in this respect? Simply stating, the upstream and downstream jurisdictional entities in the Lake Biwa - Yodo River Basin have conflicting interests in the management of water quantity on the one hand and non-conflicting interests in the management of water quality.

As for water quantity, the conflicts are softened through monetary transactions for undertaking compensatory public works, the very basis of LBCDP. As for water quality, the conflicts do not exist in the sense that everyone wants lake water quality improved, and it costs money to do so. The problem is that we don't know how much it will cost and who will have to bear the cost. Parts of the expenditures of water quality improvement are defrayed through the natural and environmental conservation component of LBCDP. Although the original expectation was that the amount of investment under this category would be sufficient for realizing significant improvement in the Lake Biwa water quality, it has not proven so yet.

In addition to the environmental conservation component of LBCDP, the prefectural government of Shiga has always wanted downstream government to join in creating the water quality conservation funds specifically aimed at accelerating the improvement of water quality of Lake Biwa through such activities as controlling nutrient runoff into the lake. They have not yet come to terms with such an arrangement as I understand. Why? Because it is difficult to determine precisely how much is needed for the funds.

Let us dwell on this issue for a moment. If we confine the scope of water quality improvement just to water supply, the justification for the need for such conservation funds may prove difficult. The downstream communities can get clean water by resorting to improved treatment technology for much less than what they may have to contribute to the funds to improve the lake water quality itself. If, on the other hand, we note the fact that the lake has been sustaining growing development pressure of all kinds coming from the entire Keihanshin District, and the fact that a broad spectrum of intangible benefits has to be past on to the entire population in the basin over many generations to follow, then it would not too much to ask for the downstream governments to join Shiga Prefectural Government to bear the burden of the enhanced clean-up efforts.

The implication here is that the emerging structure of the basin-wide water resource management would be dictated by the capability of the jurisdictional entities to adjust to the emerging factors in water quantity and quality, many of them unknown at the time of the inception of the Plan.

(4) My last observation pertains to the assessment of benefits and costs of the Project accruing to the future generations.

LBCDP being such a massive project having trans-generational implications, the full benefits and costs accruing to the future generation in the Lake Biwa Basin have yet to be assessed. It is not known if the society would become mature enough to accept the concept of environmental and water resource sustainability to the extent of making further efforts to reduce water consumption, or if it would simply let the supply dictate the demand for more water. Would the future generations hail this generation for having implemented the plan? Would they lament the disturbed ecological integrity in the Lake Biwa environment? Would they say that they would have done the same to develop Lake Biwa, or would they say that they would have done otherwise?

Implication here is, if for nothing else, we will have to monitor the lake, monitor the watershed, monitor the socio-economy of the region, and monitor the whole environment surrounding the lake, to facilitate future generations not only to assess the Project in retrospect, but also to take whatever measures deemed appropriate and necessary then to develop and conserve Lake Biwa and its environment. The Lake Biwa Research Institute at which we gather today is mandated to contribute to such an important undertaking.

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THE JAPANESE CONTRIBUTION TO THE PROMOTION OF LARGE-SCALE WATER RESOURCES DEVELOPMENT IN DEVELOPING COUNTRIES

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PREFACE

In connection with the recent gulf war, Japan has contributed quite a lot of money. Nevertheless, she has been criticized by both the USA and Europe for her rather passive attitude, partly because her remittance was made a little too late. As a result, vigorous discussions have been taking place in the Diet whether or not Japan should cooperate more positively with the United Nations Peace Keeping operations.

On the other hand, the USSR has been dramatically reforming itself since this summer, and thus the interest of thoughtful people in the world, including the Japanese, has been focussed on changes in "the east-and-west relationship."

Under these international circumstances, an early October newspaper reported that the total contribution of Japan's ODA in 1990 became accounted as World No. 2 next to the USA, with the amount of 9 billion US dollars.

In my personal view, although both the future of the Gulf area and the economic and technical assistance to the USSR and East Europe are very important issues, the solution of "the south and north problems" must be viewed as a more important, everlasting fundamental issue. I believe that the utmost efforts should be made to try to cope with the ever increasing population growth in the world, particularly in the developing world, and to maintain or even raise peoples' living standard. I also do believe that, as a peace-loving nation, the best way for Japan to contribute to the world would be to endeavor to drastically increase the amount and to improve the quality of the pure ODA (which has no connection at all with military affairs) for the benefit of developing nations in the south.

Furthermore, it is my belief that the ideal of ODA should be to make efforts to realize the well-balanced expansion and development of human society by implementing large-scale developments in various selected areas on our globe, while rendering assistance in medium and small-scale development to meet the domestic and/or regional requirements in each of developing countries for their own benefit.

I will now introduce several large-scale development projects, particularly in the area of water resources development in developing countries, about which projects the informed Japanese people have been frequently discussing in recent years.

I will then touch on some of the anticipated problems to be encountered in carrying out such large-scale development. Finally, I will talk of my own recent reflections regarding the so-called "development"; What ought to be the most important viewpoint for the future large-scale development in the world headed for the 21st century?

GIF (Global Infrastructure Funds)

In 1977, a noteworthy movement took rout. In that year, a movement to set up the Global Infrastructure Funds was initiated by the people engaged in Japan's private sector with a genuine aim to eradicate poverty and hunger worldwide and to promote a peaceful construction of the global community. Many people in Japan and elsewhere supported the concept. As a result, the GIF Research Foundation Japan was established in Autumn, 1990, with the support of the Federation of Economic Organizations of Japan.

In the GIF Tokyo Conference held in March, 1991, several topics on the GIF concept were addressed, which included;

- the construction of the Kra Canal in Thailand
- the Himalayan super-scale hydropower generation
- the revitalization of rain forest areas
- the revitalization and preservation of ecologically devastated areas in the Central Asia

All of them are large-scale development schemes which pose many difficulties in their planning and implementation.

RECENT TRENDS IN THOUGHT IN JAPAN'S OFFICIAL CIRCLES

In parallel with the above mentioned motion, official circles in Japan have initiated several research groups for the development of super-scale infrastructure projects which had been thought even by the people involved as being simply day-dreams and out of the question.

While the Ministry of Agriculture, Forestry and Fishery initiated an ambitious greening-of-the-desert-concept in West Africa, the Ministry of Construction established in 1988 an ad hoc committee named the Global Super Infrastructure Project Study Committee chaired by Dr. Saburo Ohkita, a famous international economist and the former Foreign Minister.

The committee was composed of officials and scholars related to the ODA. After discussion, the Committee decided to select projects based on the following criteria:

- the influence of the development should extend to either a number of countries or to a very broad area.
- its realization is considered to be beyond the capacity of countries concerned due to economic and/or technical reasons.
- the projects should be more or less several billion US dollars in scale.
- the project should not cause any drastically detrimental environmental effects.
- the consent of the local government(s) to the Japanese government's cooperation is a prerequisite.

In the light of the above criteria, the following projects were selected as the most appropriated example;

- the Ganges-Brahmaputra water storage, diversion and long transmission project
- the Kra Isthmus canal project
- the Gibraltar Strait interconnection project
- the improvement of the environment in desert area

Among the above 4 projects, the first and the forth ones are related to the large-scale water resources development about which I am speaking today. I will then briefly explain about the Japanese development concept on the Ganges-Brahmaputra.

GANGES-BRAHMAPUTRA WATER STORAGE, DIVERSION AND LONG DISTANCE TRANSMISSION PROJECT

As everybody knows, the two gigantic rivers which traverse the Indian Peninsula vertically and horizontally connect at their downstream and penetrate Bangladesh. The western and the southern parts of India often suffer from a water shortage, while the eastern part is frequently flooded.

The Global Super Project Committee of the Japanese Government Ministry of Construction has formulated a gigantic development scheme by which the present maldistribution of water in India could be overcome and, at the same time, a huge hydropower generation would become available. The scheme is to build two large dams at the Assam Gorge on the Brahmaputra River to store the huge volume of flood water and to generate power of some 10 million kW, and also to build a long canal to interconnect the Brahmaputra at Dhuburi City and the Ganges at Patuna City, and, furthermore, to transfer the river flow of the Ganges towards rivers in the west and also towards rivers nearby Madras in the South of India through super-scale long waterways.

The biggest problem of the gigantic scheme is that it requires a huge investment. In addition, the foundation of the proposed two dams would be vulnerable to frequent earthquakes, and, the trapping of sediment by the dams would cause undesirable influences in the river channel. In addition, seawater intrusion at the estuary would be aggravated. Moreover, resettlement may affect some 3 million people, while people living at the downstream area of the Brahmaputra and the Ganges may suffer from a water shortage during the dry season after the completion of the long distance canal.

Last year, the Ministry of Construction dispatched to India a civil engineer who had worked for the programming of the project to find out the reaction of the Indian Government. The Indian Government explained that they are planning to build the Dihang Dam just upstream of the Assam Valley (See **Figure 1**.) to decrease the number of expected resettlers. The government also expressed its wish to request Japanese assistance for the development of the Kosi High Dam Project (See **Figure 1**.) on the Kosi River, a tributary of the Ganges in the territory of Nepal rather than the Assam Dams Project. Regarding the planned long distance canal projects, the Indian Government replied that both the interconnection of the two big rivers and the construction of a long canal along the Indian Ocean (See d-2 plan in **Figure 1**.) would be possible but another project which aimed to transfer the flow of the two rivers to the west was not considered.

Based on the above information, the Japanese Ministry of Construction is now intending to continue the review of the projects with the GIF Research Foundation.

Next, I will briefly explain about some aspects of large-scale development program on the mainstream of the Mekong River for which I have been involved and have made efforts for many years, particularly about a large-scale dam project which has long been discussed among the people concerned in the Lower Mekong River Basin.

DEVELOPMENT OF THE MEKONG

The Development of the Lower Mekong River Basin (within the territory of Thailand, Laos, Cambodia and Viet Nam) (See **Figure 2**.) was promoted by the bilateral aid of the developed countries and also by the multilateral aid through the UN Mekong Committee which was established in 1957 with the support of the UN ECAFE (at present, the ESCAP). The USA, Europe and Japan cooperated with the Mekong Committee for this study and the development, but almost all remarkable activities of the Committee were virtually stopped in 1975 (due to the end of the Viet Nam War and the subsequent Cambodian issue), and only some of the developed countries have been rendering assistance on a bilateral basis.

In June this year, Prince Sihanouk sent an official letter to the Interim Mekong Committee, expressing Cambodia's willingness to rejoin the Committee. On the other hand, China (a part of which is located in the northern part of the Mekong River Basin) restored diplomatic ties with Thailand, Laos and Viet Nam and sent observers to the General Session of the Interim Mekong Committee. In other words, it is likely that the programming of the whole river basin development (not the Lower Mekong River Basin only) will soon become possible.

Two big international projects are under serious consideration by the Mekong Committee at this moment. One of them is the Pa Mong dam project, the implementation of which has been expected by the Committee to become the first dam built on the mainstream of the Lower Mekong. But the project which is under consideration is not the high-dam scheme proposed by the Japanese Government Survey Team in the early 1960's but the far lower one. The largest problem of the Pa Mong dam project development plan is inundation. It is anticipated that some 40,000 people would have to be evacuated from the proposed reservoir-site even in the case of the Low Pa Mong Dam plan. Therefore, many people including the King of Thailand have opposed the dam construction. (When Japan first proposed the higher dam plan, the number of resettlers was anticipated as 250,000.) The present development plan includes the lower dam so that the expect-

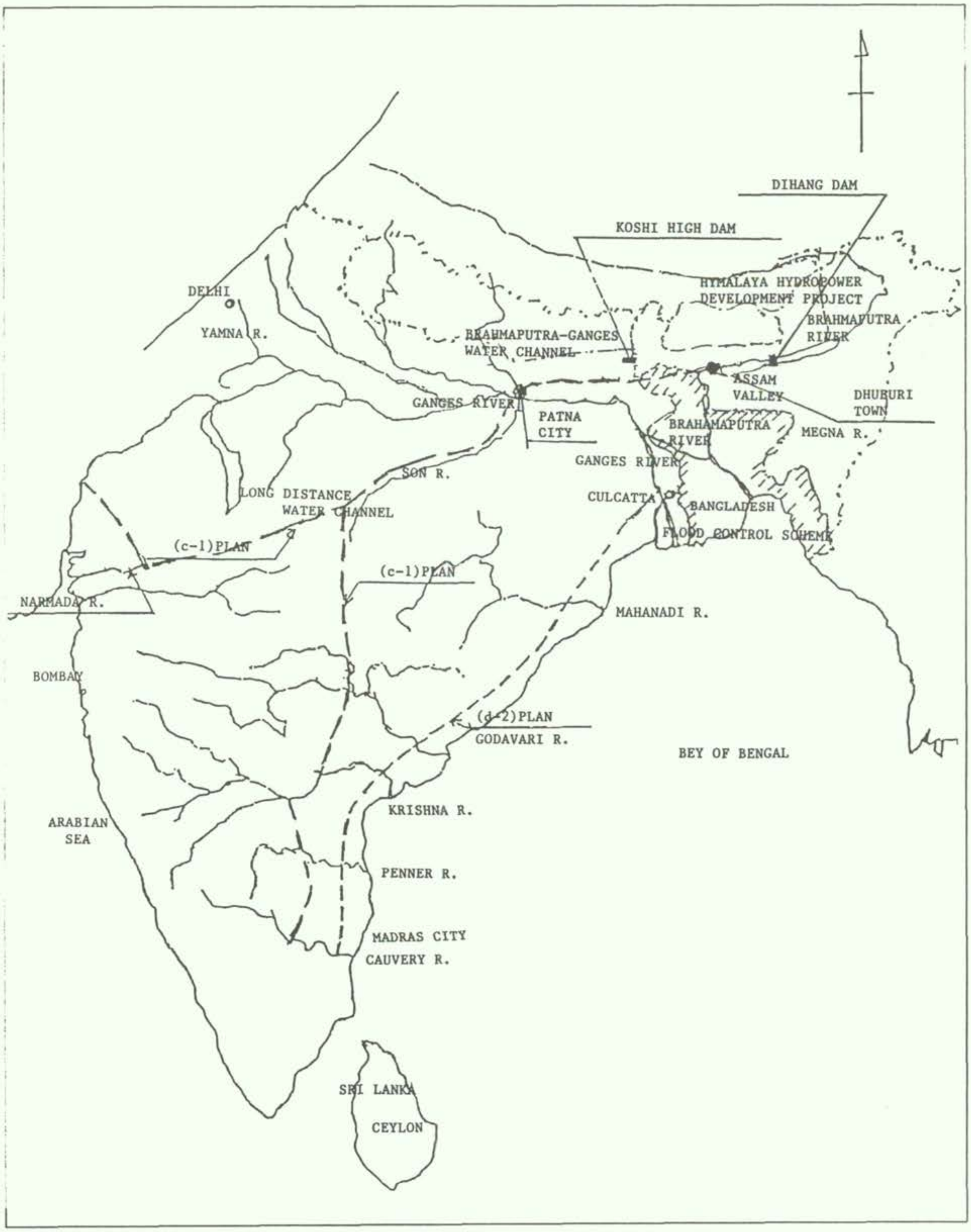

Figure 1. Location Map of Ganges - Brahmaputra Water Storage, Diversion and Long Distance Transmission Project.

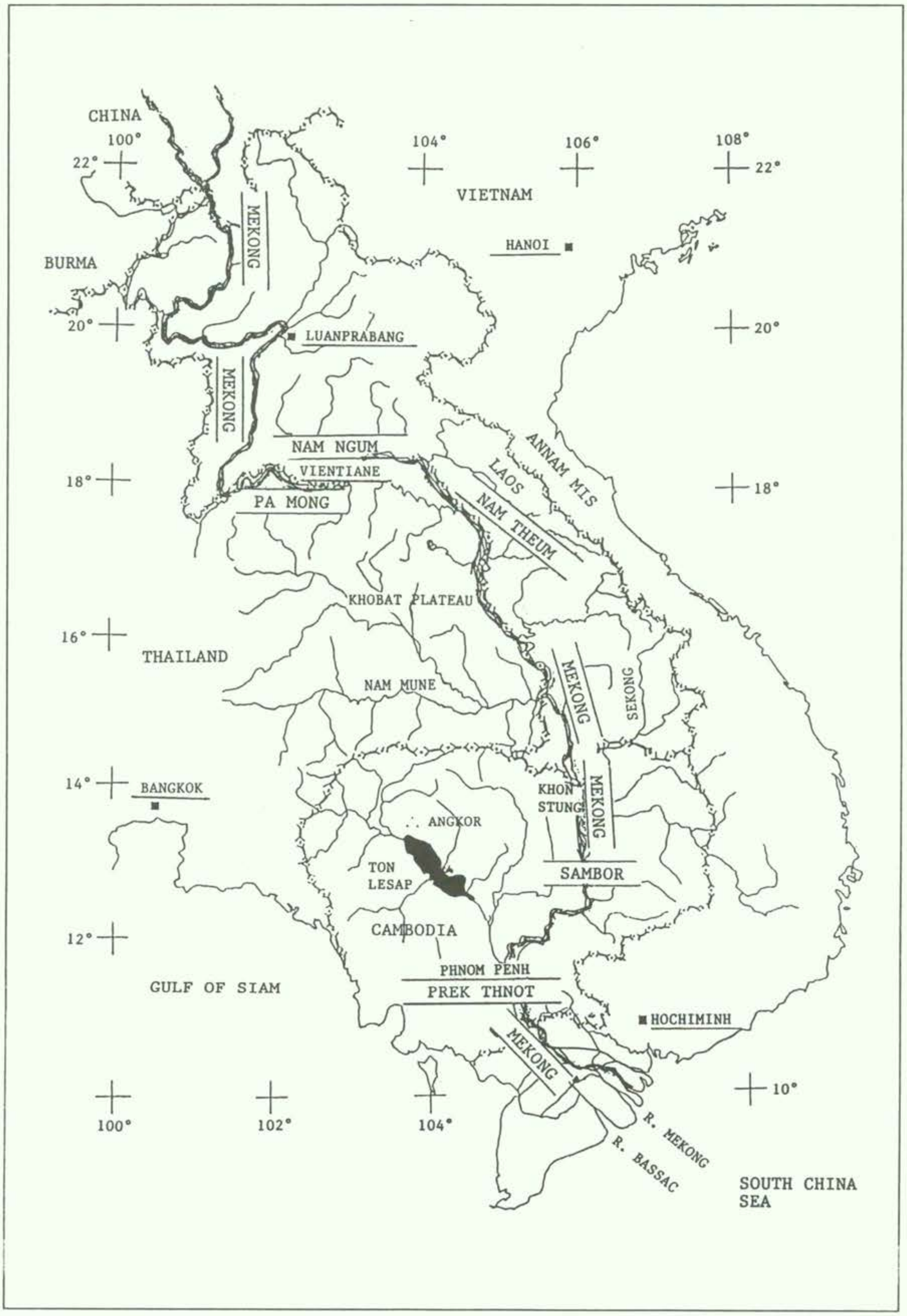

Figure 2. Lower Mekong River Basin

ed merit is much smaller and consequently the project has lost its appeal to a great extent.

The large scale development of the Mekong River Basin has been deferred for a long while. However, the Peace Conference on the Cambodian issue held in Paris at the end of October this year was successfully over, and the world is now convinced that reconstruction of the devastated land will soon be started. It is therefore certain that Japan will take a leading role in the cooperative activities. As it is believed that the Basin is blessed with a very high hydropower potential (of some 2 million kW) as well as an irrigation possibility (of more than one million ha for high yield rice production), we should keep a watchful eye on it to see how and when the comprehensive development could be resumed.

PROBELMS TO BE CAUSED BY LARGE-SCALE WATER RESOURCES DEVELOPMENT IN THE DEVELOPING COUNTRIES

As mentioned, I am quite convinced of the necessity of large-scale water resources development in the future. But I cannot deny that it would eventually involve a number of problems such as inundation and other environmental problems I have already reported.

Six years ago, I wrote a thesis which is entitled "Environmental Influences of Dam Construction on Nature and Society". In the Introduction, I wrote as follows:

What care should be taken by engineers and staff engaged in the development of dams in the third world, where circumstances are different from those in the developed countries both in nature and in society? And, what would be the appropriate way(s) to promote and attain well-balanced social development, while respecting the natural environment? In an effort to answer these questions, I have clarified the differences and the similarities as well as the grades of importance in the natural and social environmental effects resulting from the dam construction on the rivers in Japan and in the middle and lower reaches of rivers in tropical continents.

For the study, I reviewed studies on various environmental influences of dam construction in Japan and compared each one of them with available reports on the influence of the Aswan High Dam construction, and others, and also with data and studies of those in the Lower Mekong Basin in the planning of which I was involved for many years.

Omitting details of the comparison study, the conclusion of my thesis was summarized as follows:

1. The environmental influences of large-scale dam construction are different from each other, due to the differences of the region.
2. There are differences in climatic and morphological conditions as well as in the social circumstances and structures between rivers in Japan and rivers in tropical continents.
3. The important environmental issues noticed by the comparison study are as follows:

(a) In Japan

(1) The Impact on Nature

Sedimentation
Turbidity
Land collapse around reservoirs
River-bank erosion and river-bed change
Water temperature change
Influences on fish

(2) The Impact on Society

Resettlement
Change of discharge
Protection of relics

(b) In the Tropical Continents

(1) The Important Threats to Nature

Eutrophication
Influences on fish
Seawater intrusion
Influences on wildlife

(2) The Important Problems for Society

Delta problems
Resettlement
Water-related diseases

Taking into account the main theme of today's symposium, I will briefly explain the following important items:

(1) Eutrophication

Generally speaking, dams in Japan (which lies in the temperate zone) are built in remote mountainous area so that problems caused by nature do not seem very serious. However, along with the modernization of community life in the upstream area as well as the surrounding areas, some lakes have started suffering from a certain eutrophication due to many artificial causes such as fertilizer and agricultural chemical run-offs, the inflow of industrial waste and domestic sewage, etc.

In flat tropical continents, on the other hand, man-made lakes often suffer from eutrophication due to natural phenomena such as high temperature and the inflow of natural nutritious organic gradients from upstream and surroundings of the lakes. They also suffer due to the tilling and grazing in some areas. When trees are left standing and untreated within reservoirs after the completion of dams, as frequently happens in the case of tropical countries, they further aggravate the eutrophication. Also, Water hyacinths and other algae often proliferate within reservoirs, and they evapotranspire from their leaves and interfere with water circulation.

(2) Influences on Fish and Wildlife

In the case of Japan, dam construction often encounters local peoples' opposition due to the fact that it would upset customary fishing activity, particularly of ayu, i.e., sweetfish which is a favorite food fish in this country. The provision of fish-ladders beside the dam is rarely successful. However, when one breeds fish suitable for the reservoir conditions, one can certainly get economic profits.

Dam construction in tropical continents particularly influences wildlife, in general. The fringe effects brought by the reservoir creation are generally favorable to both animal and plant life. Animals gather around the man-made lake and enjoy propagation owing to the stabilized water circumstances. What should be taken care of, however, is the existence of illegal hunters. Regarding fish, the dam construction heavily obstructs migratory fish, and the eutrophication menaces lake fish. However, fish breeding in man-made lakes brings successful fishing on and around the lake. It should be noted, however, that the number of fishermen should be limited.

(3) Water-related Diseases

Since Japan lies in the temperate zone and has a sound public health program, there seems to be fewer problems. However, in tropical continents, disease germs proliferate mostly in water. People suffer from poverty and are ill-fed, so that there is quite a high probability of infection. Furthermore, unfortunately, the number of medical doctors is small with insufficient hospital facilities and medical supplies. The most important water-related diseases are malaria and schistosomiasis among others. People who are engaged in dam construction in tropical continents should fully accumulate thorough knowledge of these diseases and utilize such knowledge in the programming of dam construction and also for the operation of reservoir(s).

(4) Resettlement

The need to relocate or resettle people from dam and reservoir area is the biggest headache to the planner of dam construction. In comparison with broad and flat tropical continents, Japan is generally densely populated and narrow, where the acquisition of alternative land is difficult and the compensation for the relocation is very high. Therefore, large scale construction seems almost impossible in Japan.

In tropical countries, on the other hand, local governments often hold strong power. Under such circumstances, it is not impossible to expect to move people and resettle even in the case of large dam construction. So far, however, resettlement planning by local governments has been sometimes woefully inadequate. Complete and meaningful surveys are urgently needed. The selection of resettlement area(s) should be much more carefully made. More efforts also should be made to promote the vocational training of resettlers. Guidance to help such local people to cope with new, unfamiliar livelihoods is also needed to avoid social problems.

In the future, the most important key for the realization of a large scale dam project in a developing country is certainly to carry out a well-planned long-term resettlement program before the construction is begun. In my view, such resettlement programs should be closely coordinated with neighboring regional or city development plans as much as possible.

FUTURE PROSPECTS FOR LARGE-SCALE WATER RESOURCES DEVELOPMENT PROJECTS

There still remain a number of untouched large dam-sites in developing countries in the south. For example, the dams mentioned above on the Ganges-Brahmaputra and the Mekong as well as several projects in Africa such as a super-scale dam project in the Congo Basin in Zaire. Another example is the Stiegler's Gorge Dam project on the Rufiji River in Tanzania for the plan of which I once worked for two years.

Needless to say, the development of a dam can generate huge tremendous energy, modernize agriculture, provide water for domestic and industrial use, improve navigation in some cases and control floods. On the other hand, if the planning and execution are carefully done, fewer adverse environmental effects on nature and society will be produced than any other means of power development. The one exception is the inevitable resettlement problem.

Professor Frank Davidson of MIT in USA is a man who has been regarded as a spiritual supporter to us promoters of super-scale projects. I received a letter from him the other day. Regarding my letter on the Ganges-Brahmaputra Project, he wrote:

"How much I would like to hear your views on the idea to ship the power by microwave or laser relay satellites to Japan and other customers."

You realize, of course, that we would certainly encounter several problems if we construct any huge dam project. However, at the same time, we could say that we would be able to draw in the sky a magnificent rainbow of dreams which could be actualized in the next 21st century!

SOME PERSONAL VIEWS AND PRIVATE THOUGHTS

I am convinced that the large-scale development of dams should be and will be implemented in various parts of our globe in the future. On the other hand, I also believe that the medium- and small-scale dams, powerhouses and irrigation facilities which would meet urgent regional requirement in each part of the developing world should be constructed in parallel, as I have already mentioned. As a matter of fact, I myself have been endeavoring to assist in the development of a small hydropower station in Laos, while attending the Global

Super-Project Committee of the Construction Ministry.

I would venture that both "big schemes" and "smaller schemes" have to be developed for the sustainable expansion of human happiness. In the 2lst century, water resources development should be made deliberate and orderly insofar as possible, in an effort to keep appropriate balance among "big," "medium" and "small."

Nevertheless, I have a somewhat different thought in my mind, something which is quite a departure from what I have so far mentioned. I have acquired some fears or doubts regarding the planning of the development of projects to try to so-call "modernize" a developing country.

The other day, the 7th World Congress of the IWRA was held in Morocco, and, taking the opportunity, I made some short trips from Rabat, the capital city to Fez and to Marrakech, both of which are well known as ancient Moroccan cities. What deeply impressed me there was that traces of traditional, even medieval times have still remarkably remained, here and there, in the local peoples' livelihood in both cities. It seemed to me (a complete outsider passing through) that the people of Morocco have still been enjoying quiet, tranquil, even poetical lives conveyed since old times, apart from waves of the western civilization, either in the cities or in the local farm villages. There, the water and the air seemed to be beautiful and the sky was shining. Traditional culture was still alive in their everyday life.

I reflected on the busy and clamorous life which I left in Tokyo. In fact, what does the "civilization" mean, with which Japan has pursued since the Meiji era? In exchange for life's convenience and amenities, the Japanese people seem to have almost completely lost the calmness of their old community while the people of Morocco continue to enjoy tranquil, happy home lives! Moreover, the Japanese have been tormented by the feeling of incessant frustration and irritation!

I had so far become convinced of the necessity to promote the planning of the large-scale water resources development among extremely primitive societies such as in the Lower Mekong Basin and East Africa. Yet, suddenly, I came to reflect anew on the "merits and demerits" of our "civilization", our "modernization" and our "value judgement" (all of which have been related to my past efforts to promote water resources development and through which I have formed my own life-creed).

How important it is to do our best to protect ourselves against the destruction and devastation of the "good, old spiritual soil", while promoting large-scale development! Unfortunately, I have no answer for how to maintain this ideal while engaging in large-scale development. Nowadays, people often talk about "preservation of environment". However, thinking about the way to "cautiously protecting and bringing up the human mind in one hand, while trying to sustain the prosperity of our global society as largely and firmly as possible on the other hand" seems to me to be the incomparably important in securing a bright future for mankind. This will be our ideal to pursue in the 2lst century. In a sense, Japan must be qualified as one of the most suitable countries to be a conduit for such ideas, because Japan stands between "the Orient" and "the Occident", not only geographically but also spiritually.

GROUNDWATER QUALITY MANAGEMENT MODELS: AN OVERVIEW

By

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INTRODUCTION

A groundwater aquifer is a multipurpose resource system. The aquifer may be used for water supply purposes or may possibly act as a long-term storage reservoir for future water resources development. On the other hand, a large variety of pollutant can enter and contaminate groundwater. Many of them originate from man's use of water and others by introducing into the groundwater, directly or indirectly, undesirable constituents. Irrigation and exploitation of groundwater in coastal aquifers belong to the first category; and sanitation, disposal of wastes, application of fertilizers and some other activities belong to the second. Use and reuse of water for domestic, industrial or agricultural purposes results in the discharge of liquid or solid wastes into the geologic environment. The main goal of the groundwater hydrologist, water resources engineer or planner, who deals with the groundwater system or with a water resources system of which groundwater is a component, is the "Management of Groundwater System".

Groundwater management has historically been based on the safe or sustainable yield of the aquifer system. Over the past two decades, the management of groundwater resource has shifted from simple water balance models to mathematical simulation models. The simulation models have been used to predict the variation in the hydraulic head distribution and mass concentrations resulting from alternative planning, operational or developmental policies. These simulation models are used to predict saltwater intrusion, land subsidence, and groundwater contamination in confined and unconfined aquifer systems.

The management of groundwater quality is a difficult task, complicated by the range of criteria and by the difficulty in understanding the scientific processes occurring under ground. The management of groundwater quality depends upon four primary factors: (1) the range of alternative decisions that are feasible, (2) the criteria by which the success of a management program is measured, (3) the system dynamics that describe the change in concentration of contaminants over time in response to management decisions, and (4) the constraints that are imposed on management and on the dynamics of the system. Both simulation and optimization models have been used in the analysis of groundwater quality management problems. To evaluate alternative management decisions a simulation model is recomputed for each alternative considered. The results of alternative strategies are compared in terms of criteria used and accordingly, appropriate management decision is made. On the other hand, optimization models use a mathematically based search procedure to find the policy that maximizes the criteria without actually simulating the model for every possible alternative. This review on groundwater quality management models deals with the combined use of optimization methods and simulation models which simulate groundwater hydraulics and groundwater solute behavior by solving the governing partial differential equations. Of particular interest are the uses of linear and quadratic programming along with numerical simulation. This approach of mathematical programming provides a powerful practical tool for evaluating management alternatives.

GROUNDWATER QUALITY MANAGEMENT MODELS

Groundwater quality management models combine techniques of aquifer simulation and optimization to identify viable planning strategies for problems involving contaminated aquifers. The strategies typically involve the optimal placement of wells and determination of pumping rates so that certain desirable features occur, such as removal of contaminated groundwater. The idea is to formulate the management problem as one with an objective (or with multiple objectives) usually involving the minimization of cost and/or risk. The objective contains decision variables, such as local pumping rates at wells, that are of key interest to the hydrologist involved in aquifer management. In addition, there are physical, regulatory, economic, political and logistical constraints. The physical constraints include equations that represent the simulation of aquifer behavior such as hydraulic head and contaminant concentration redistribution over space and time. That is, these models include the simulation model as a component. Regulatory constraints usually maintain contaminant concentrations within water quality standards and hydraulic heads within desirable ranges. Additional constraints keep specific variables of the management design within certain limits, such as upper bounds on pumping at certain wells, specific local demands on water supply, or restricting wells to certain locations. Together the objective(s) and the constraints constitute a simulation-management problem that is solved using methods for large scale linear and nonlinear optimization.

There are two main approaches to linear simulation-management models. First is the embedding approach in which the discrete numerical approximations of flow equation or solute transport equation serve as algebraic constraints in the mathematical program. Adaptation of this method for transient problems would be difficult because the constraints representing contaminant transport simulation are nonlinear. Moreover dimensionality problem limits the use of this method for large scale analysis. In the second approach transport simulation for linear systems can be included in the management model using a response matrix approach which relies upon linear superposition of unit responses. The linear response matrix is developed using a simulation model before execution of the management model. Again for transient system, say in the case of aquifer reclamation study, a response matrix can not be developed a priori because the system is nonlinear. In order to include a representation of contaminant transport behavior in the management model constraints, the simulation model is linked to the optimization system as an external independent module.

PROBLEM SPECIFICATION

Models have been used for a range of problems related to groundwater quality management. Three main categories are (a) aquifer remediation, (b) control of non-point source contamination (especially from agricultural chemicals), and (c) salinity control. Each of these problems differs from one another in terms of the types of analysis needed for evaluation.

Aquifer Remediation

Simulation models of the transport of contaminant through the groundwater are widely used to estimate the likelihood that a specific engineering design for remediation will be successful. For this problem the major decisions to be made involve the means of removal of the contaminant from the subsurface and the procedure for disposal once it is above the ground. Options include: (a) extraction pumping of contaminated water and its subsequent treatment in a water purification plant, (b) removal or incineration of contaminated soil and (c) injection of substances (i.e. oxygen) into the soil to promote biodegradation. The engineering design decisions associated with the pump- and -treat option (a) concern the locations of wells and the rate at which water is pumped from each of them. For option (b) the decision focuses on the amount of soil to be removed and its location and on the means for disposing of the soil. For (c) the location of wells for injecting substances and the rates for injecting such substance are the issues. For degradation of some substances it is necessary to alternate pulses of oxygen and methane and the timing of these pulses is the concern.

Numerical models (usually finite element or finite difference models) are used to estimate the impact of alternative engineering decisions on contaminant concentrations of the groundwater over the years of the remediation project. The use of optimization models for pump-and -treat remediation has been proposed. The advantage of the use of optimization methods over trial and error simulations is that the former can search rapidly over thousands of alternative possible engineering plans. The disadvantage is that they are computationally more complex and require a sophisticated understanding of the optimization algorithm. Optimization procedures have been developed that consider constant pumping rates as well as time-varying pumping rates.

Control of Non-Point Sources of Groundwater Pollution

Aquifer remediation focuses on situations, usually poorly designed hazardous waste disposal sites, where a concentrated amount of a contaminant has entered the groundwater. Because the contaminant is concentrated, efforts to remove it are determined to be worthwhile. However, for many "non-point" sources of pollution, the contaminant is spread in smaller concentrations over a larger area. For this type of situation, remediation is prohibitively expensive, and management usually focuses on preventing the contaminant from entering the saturated zone. This goal is especially difficult to achieve for substances like agricultural chemicals that are legally applied to the soil surface or incorporated into the root zone.

Simulation and optimization models are widely used to study alternative management practices to prevent pesticides and fertilizers from entering the groundwater. One of the major issues with pesticides is the large number of them in use, and the difficulty of obtaining adequate data to calibrate and validate the models for the literally thousands of chemicals licensed to be used as pesticides. Similar models have been developed to determine the amount of nitrogen that can be expected to reach groundwater. In addition to their role in assessing the fate and transport of agricultural chemicals, models are also useful in developing ways to reduce the use of these materials. Simulation and optimization models have been used to reduce the amount of pesticide used to maintain adequate crop yields.

Salinity Control

One of the most widespread water quality problems is the presence of excess salinity, which is harmful to people and to crops. Salinity control is directly related to water use and hence is a part of water resource planning. Simulation and optimization models have been used to assess the alternative ways in which water resources can be used to provide adequate water for drinking and irrigation and simultaneously to prevent salinity build up. Stochastic analysis of these problems is important since variability in water supplies is devastating to crop production. The utilization of groundwater in coastal areas is constrained by the extent of saltwater intrusion in aquifers. A series of numerical simulation models have been developed for the analysis, prediction and control of saltwater intrusion.

REVIEW OF MODEL DEVELOPMENT

The optimal management of groundwater quality is a comparatively new field in groundwater resources management. A detailed review of the use of optimization and simulation in groundwater management is presented by Gorelick (1983). Development of models for groundwater quality management is highlighted in this section and a review of recent work is provided. The first major area of research in groundwater quality management involved the management of pollutant source, where the objective was to optimize the concentration (or volume) of the injected waste water into the subsurface while maintaining water quality standard at well points elsewhere in the system. Willis (1976) incorporated a steady state simulation model in a management model which was aimed at minimizing costs associated with surface waste treatment processes. The simulation model accounted for advective flow and single component linear chemistry. Futagami et al (1976) presented the finite element and linear programming method in conjunction with the control of large water body pollution. Their simulation model considered both advective and dispersive solute transport.

The dynamic water quality simulation models have been combined with management techniques by Gorelick et al (1979), Willis (1979), Gorelick and Remson (1982), and Moosburner and Wood (1980). Under transient conditions the inclusion of discretized governing equations as constraints in a linear program leads to an extremely large constraint matrix. The method is not viable for real world problems. An alternative approach was the topic of Gorelick et al (1979). Their method took advantage of the mathematical structure of the transient constraint matrix to develop a recursive pollutant source management formula. Instead of discretizing the governing equations over space and time, Willis (1979) discretized the system over space alone. Analytic solutions to the resulting system of linear differential equations were included as constraints in a linear problem. The method of both Gorelick et al (1979) and Willis (1979) required special simulation model formulations as well as direct matrix inversion. Gorelick and Remson (1982) presented a simpler method that did not require a specialized numerical formulation to derive the management model. A numerical model based on the Crank-Nicolson approximation was used to generate the management model constraints in the form of a series of solute breakthrough curves at supply wells where water quality was to be maintained. The constraints formed a unit source-concentration response matrix. The linear program operated on the unit source-concentration response matrix by optimally superposing the breakthrough curves so as to maximize disposal potential over time while maintaining water quality at the supply wells.

Aquifer Remediation

Simulation models have been used to analyze the aquifer remediation problems (Osiensky et al, 1984; El-Kadi, 1988). Approaches to solve the optimal groundwater remediation problem have been treated very recently. Gorelick et al (1984) presented a general modeling approach to determine the optimal design of reclamation schemes for contaminated groundwater systems. The planning model combined a nonlinear, distributed parameter groundwater flow and contaminant transport simulation model with a nonlinear optimization method. The resulting management model enables one to consider a linear and nonlinear restrictions that include a complex, nonlinear aquifer simulation model. The objective was to minimize the total pumping while requiring that concentrations be held below specified values at specific points. They demonstrated the method with a series of steady-state plume - interception problems. Another example, for transient contaminant movement, involved the design of a remediation strategy that used four extraction and injection wells to maintain specified water quality standards at three locations down gradient of an advancing contaminant plume.

Ahlfeld et al (1986) used a formulation similar to that introduced by Gorelick et al (1984) and introduced a new formulation that explicitly requires that concentrations do not increase in the area outside the initial plume boundary. Results of computational experiments lead the authors to conclude that these approaches can be used with only a limited number of candidate wells. Ahlfeld (1990) introduced a two-stage groundwater remediation design with the objective of minimum total cost while requiring that certain remediation-design requirements be satisfied. Two-Stage remediation was defined by a containment stage and a maintenance stage. During the initial containment stage, a pumping strategy was used to remove contaminated groundwater far from the source and to produce hydraulic gradients that drew the plume back toward its source. During the second stage, hydraulic containment was continued until other means of permanent remediation could be implemented.

Non-point Source Pollution

An optimum soil and water management program should provide for a minimum of pollution into underground soil systems. Non-point source pollution in underground water may result from the runoff of fertilizers and other chemicals when applied to cropland, the wastes produced by livestock feedlots and the disposal of domestic or industrial wastes on land. Most of these pollutants are miscible with the native groundwater. A portion of the pollutants will remain in the unsaturated porous medium or root zone of the soil and due to deep percolation, a portion may also enter the saturated groundwater aquifer. The movement of these water soluble pollutants underground changes the concentration of the native groundwater, and a concentration of dissolved salts in excess of a permissible maximum creates a water quality hazard.

Models have been developed to simulate water movement and solute transport in the soil to assist in formulating optimal management schemes for environmental pollution control and for application of water, fertilizers and pesticides in agriculture. These models are basically one - or two-dimensional flow and solute transport (considering interacting solutes) models for integrated unsaturated - saturated porous medium. Some of the recent modelling studies and applications are by Huyakorn et al (1985), Khaleel and Reddell (1985), Nour el-Din et al (1987a, b) Russo (1988 a, b), Tracy and Marino (1989), and Antonopoulos and Parazafiriou (1990). Khan (1982) described a management model which considers all the important components of an irrigated system. The management model consists of an optimization model, an unsaturated zone model, and a saturated zone model. The purpose of the optimization model was to: (1) distribute the available land, surface water and groundwater resources in such a way that the net income from the firm is maximized; (2) encourage conjunctive use of surface water and groundwater; (3) maintain a proper salt balance in the system; (4) maintain a favorable hydrologic balance in the system; and (5) meet the concentration requirements of the drainage water to maintain favorable salinity in the root zone for optimum crop yield. The purpose of unsaturated zone and saturated zone models was to assess the impact of policies devised by the optimization model on the irrigation system.

Salinity Control

Salinity problems in agricultural activities have been addressed as non-point source pollution. Assessment of the impact and subsequent control measures to be taken have been analyzed through simulation studies as mentioned before. Also management models have been cited. One of the major areas of salinity control refers to the control of saltwater intrusion in coastal aquifers. The simulation models for analysis of saltwater intrusion problem can be broadly classified as based either on the convection - dispersion equation (miscible flow system) or on the sharp interface approximation (immiscible flow system). The mathematical formulation for the miscible density-dependent flow system was elaborated first by Pinder and Cooper (1970). Following this, solutions of the miscible flow model for specific problems have been presented by several authors e.g. Lee and Cheng (1974), Segol et al (1975), Segol and Pinder (1976), Huyakorn and Taylor (1976), Volker and Rushton (1982), Frind (1982) and Voss (1985). An analysis of steady flow in confined aquifer with a sharp interface approximation has been presented by Bear (1979). Approximate analytical solutions were developed describing the location of a stationary interface in a confined aquifer system. The numerical solutions have also been reported by Pinder and Page (1977) and Strack (1978) for stationary interface position. Approximate solutions for the dynamic prediction of freshwater-saltwater interface were introduced by Bear and Dagan (1964) and Dagan and Bear (1968). The prediction of saltwater intrusion in stratified coastal aquifers has been addressed by Rumer and Shiau (1968), Mualem and Bear (1974) and Collins and Gelhar (1977). Some of the recent field application studies are cited as by Chapelle (1986), Andersen et.al (1988), Das Gupta and Sabanathan (1988), and Rao and Hathaway (1989).

In planning analysis, simulation models are used to investigate how pumping or recharge alternatives affect the movement of the freshwater-saltwater interface. Because the models are predictive ones, the alternatives represent only localized solutions to the planning, design or operational problem. In contrast, optimization models identify, in the context of the system's objectives and constraints, optimal pumping and recharge schedules. An example of the optimal management of coastal aquifer system was presented by Shamir et al (1984). Linear models were used to relate the location of the interface toe and the magnitude of pumping and recharge in a multicell aquifer system. Since the hydraulics of the aquifer system were defined by linear equations, linear programming was used to identify the system trade off and noninferior solutions to the multiobjective groundwater planning problem in Israel. Willis and Finney (1988) addressed the problem of the control of saltwater intrusion using generalized flow models of the aquifer system and nonlinear programming techniques. The aquifer system's dynamics were represented by continuity equations describing the variation in the freshwater and saltwater heads. The solution algorithms were based on the influence-coefficient method and quadratic programming and the reduced-gradient method in conjunction with a quasi-Newton algorithm. The resulting optimization model and solution algorithms are applied to the Yun Lin Basin, Taiwan (Willis and Finney, 1991).

FORMULATION OF A MANAGEMENT MODEL

The conjunctive management of groundwater supply and quality is dependent on the flow and mass transport phenomena prevailing in the aquifer system. The flow and mass transport equations govern the response of the aquifer system to planning or operational policies. In the planning model these decisions are represented by the location and the magnitude of all the point sources or sinks of the problem (the pumping and injection wells). The equations of groundwater system are first transformed into a set of linear algebraic equations using numerical methods and the transformed equations are then incorporated in the management model.

Flow Equation

For unsteady two-dimensional saturated flow in a heterogeneous anisotropic aquifer the governing equation is (Bear, 1979)

$$\frac{\partial}{\partial x_i}\left(T_{ij}\frac{\partial h}{\partial x_j}\right) = S\frac{\partial h}{\partial t} + W, \quad i,j = 1,2 \qquad (1)$$

where h is the hydraulic head, L; T_{ij} is the transmissivity tensor, L^2/T; S is the storage coefficient (dimensionless); W is the volume flux per unit area, L/T (negative for recharge and positive for pumping); x_i and x_j are cartesian coordinates; and t is the time, T.

Most of the regional groundwater flow systems are of three-dimensional nature. Because of the non-availability of field information and complexity of analysis, groundwater management modeling studies have been based on one-dimensional or two-dimensional approximations. With experience gained from several three-dimensional simulation model studies, application of management models should be extended with three-dimensional characterization of the aquifer system.

Mass Transport Equation

The governing equation for unsteady two-dimensional transport with linear decay and sorption of a single dissolved chemical species in saturated porous media is (Konikow and Grove, 1977; Bear, 1979)

$$R_d\frac{\partial C}{\partial t} = \frac{\partial}{\partial x_i}\left(D_{ij}\frac{\partial C}{\partial x_j}\right) - \frac{\partial}{\partial x_i}(CV_i)$$
$$-\frac{C'W}{\theta b} - \lambda R_d C \qquad (2)$$

where C is the concentration of the dissolved chemical species, M/L^3; D_{ij} is the dispersion tensor, which is a function of V_i, L^2/T; V_i is the average pore water velocity in the direction i, L/T; b is the saturated aquifer thickness, L; θ is the porosity (dimensionless); C' is the solute concentration in a fluid source or sink, M/L^3; R_d is the retardation factor (dimensionless); and λ is the first order kinetic decay rate, 1/T. The average pore water velocity is given by

$$V_i = -\frac{K_{ij}}{\theta}\frac{\partial h}{\partial x_j} \qquad (3)$$

where K_{ij} is the hydraulic conductivity tensor, L/T. Assuming that ionic diffusion is negligible compared to the larger scale mixing processes of hydrodynamic dispersion, Scheidegger (1961) related the groundwater velocity to the dispersion tensor as

$$D_{ij} = a_{ijmn}\frac{V_m V_n}{|V|} \qquad (4)$$

where a_{ijmn} is the aquifer dispersivity tensor (fourth order), L; V_m and V_n are components of velocity in the m and n directions, L/T; and $|V|$ is the magnitude of the velocity, L/T. For isotropic media, the dispersivity tensor can be defined by two constants, a longitudinal and a transverse dispersivity. The dispersion coefficients in equation (4) reduces to

$$D_{xx} = D_L\frac{V_x^2}{|V|^2} + D_T\frac{V_y^2}{|V|^2} \qquad (5)$$

$$D_{yy} = D_T\frac{V_x^2}{|V|^2} + D_L\frac{V_y^2}{|V|^2} \qquad (6)$$

$$D_{xy} = D_{yx} = (D_L - D_T)\frac{V_x V_y}{|V|^2} \qquad (7)$$

$$D_L = \alpha_L|V| \qquad (8)$$

$$D_T = \alpha_T|V| \qquad (9)$$

where α_L and α_T are defined as longitudinal and transverse dispersivity, L.

Planning Model

The objective of the groundwater planning model is to manage conjunctively the water supply and quality resource of a groundwater basin so as to minimize or maximize the given planning objectives while satisfying the hydrologic, economic and environmental constraints of the problem. The management of groundwater quality is a multi-objective planning problem, a problem characterized by conflicting objectives, constraints and policies.

Assuming a deterministic groundwater system, a single chemical constituent and a fixed planning horizon of T* discrete time period, the objective function of the optimization model can be expressed as the weighted sum of the individual objectives (Willis and Yeh, 1987)

$$\text{Max}Z = \sum_{k=1}^{T^*}\sum_{l}\lambda_l F_l(h^k, C^k, Q_w^k, Q_r^k) \qquad (10)$$

where F_l is the l th objective of the planning problem and it is assumed that a particular objective is a function of the state variables (the head and mass concentration in planning period k) and the pumping, Q_w^k and injection, Q_r^k policies. The λ_l represents the weights or preferences associated with the planning objectives.

The management model is constrained by

(1) the hydraulic and water quality response equations deduced from the flow equation and the mass transport equation, respectively. These response equations may be expressed as

$$f^k(h^k, h^{k-1}, Q_w^k, Q_r^k) = 0 \qquad (11)$$

$$g^k(C^k, C^{k-1}, Q_w^k, Q_r^k, \hat{C}^{k-1}) = 0 \qquad (12)$$

where h^{k-1} and C^{k-1} are the head and concentration at the beginning of the k^{th} planning period; h^k and C^k are the head and concentration at the end of the planning period; and $\hat{C}^{k-1}$ is the waste injection concentration at the beginning of the k^{th} planning period, a decision variable of the problem.

(2) the water target requirements within any planning period

$$\sum_{w \varepsilon \pi} Q_w^k \geq D^k, \ \forall k \qquad (13)$$

where D^k is the assumed water target in period k; and index π defines the location of all pumping sites in the system

(3) the waste disposal constraint

$$\sum_{r \varepsilon \psi} Q_r^k \geq WL^k, \ \forall k \qquad (14)$$

where WL^k is the magnitude of waste load in period k and index ψ defines the location of injection sites in the system

(4) the maximum feasible pumping and injection rates Q_w^* and Q_r^* respectively and limiting hydraulic head level h*

$$Q_w^k \leq Q_w^* \qquad \omega \varepsilon \psi, \ \forall k \qquad (15)$$

$$Q_r^k \leq Q_r^* \qquad r \varepsilon \psi, \ \forall k \qquad (16)$$

$$h_i^k \leq h_i^* \qquad i \varepsilon \Delta, \ \forall k \qquad (17)$$

where Δ is an index set defining the control locations in the aquifer.

(5) the groundwater quality constraint introduced at each pumping well to prevent degradation of the aquifer's water supply

$$C_w^k \leq C_w^* \qquad w \varepsilon \pi, \ \forall k \qquad (18)$$

(6) the injection constraints to prevent possible clogging problems

$$\hat{C}_r^k \leq \hat{C}_r^* \qquad r \varepsilon \psi, \ \forall k \qquad (19)$$

(7) the non-negative restrictions of the decision variables

$$C^k, Q_w^k, Q_r^k, h^k, \hat{C}^k, \ \geq \ 0 \qquad (20)$$

Equations (10) through (20) constitute the mathematical model for the optimal conjunctive management of groundwater quality and quantity resources.

Computationally, the model is extremely difficult to solve for several reasons. First, the constraint set of the model is nonconvex. The pumping and injection decisions affect the velocity field and consequently, the convective and dispersive mass transport occurring in the aquifer. In the mass transport equations, these terms are multiplied by the mass concentrations. Because the constraints and the response equations are equalities, the nonconvex feasible region is restricted. The size of the constraint set may also be inordinately large because of the temporal discretization of the response equations. The discretization affects the optimality of the planning policies. Finally, if the objectives are nonlinear or nonconvex, convergence properties of solution algorithms are difficult to prove. Consequently, local solutions to the planning problem can be expected using nonlinear programming algorithm. However, there also exists the possibility of obtaining only stationary solutions to the optimization model. In this event, simulation may be a more viable solution approach (Willis and Yeh, 1987).

MODEL ERROR AND UNCERTAINTY

Models of complex systems are necessarily simplifications. Consequently, the results produced by a simulation model will be highly uncertain and give only one possible representation of the complex system of interest. As reviewed, most models of groundwater quality consider systems to be deterministic and represent only the average behavior. They either ignore model uncertainty or treat it as an afterthought. One approach to explore parameter uncertainty is to conduct post-optimization parameter sensitivity analysis (Ahlfeld et al., 1988).

Gorelick (1989) elaborated on model error and stressed on the need of incorporation of uncertainty analysis into management of groundwater quality. Various types of errors that make management models imperfect and model results highly uncertain are categorized into two groups: those associated with the simulation model alone, and those connected with the management model. First there are simulation model errors. These are of three main types: model misspecification, solution error, and errors in model parameters which include measurement errors, averaging, and extrapolation error. Often we have an inadequate concept of the processes and interactions that are of greatest importance in groundwater quality simulation (Knopman and Voss, 1987). Even if the correct concept of the active processes exists, one cannot always describe them.

Model misspecification may occur due to an incorrect concept of spatial and temporal variability of the model parameters and of the representativeness of field measurements. Models contain parameters which represent average or effective values over space and time. By representing model parameters as zonal averages much of the natural variability of groundwater transport is ignored. This creates a large source of uncertainty in using aquifer models for prediction. Models of complex aquifers will always be an imperfect description of the state of the system, including its geometry, initial conditions and boundary conditions, as well as the system stresses due to natural and man-made sources. Even if one properly conceptualizes models and translates that concept into a mathematical form, errors can occur due to one's inability to exactly solve the mathematical problem. Finally, models require data and these may be error-ridden. This source of model error will never disappear and must be accounted for through risk qualification of management designs.

The second major source of management model uncertainty stems from errors associated with the formulation of the planning model. Here either the objective or constraints may be improperly conceptualized or simplistically represented. For example, one may have represented certain constraints as linear functions when they are nonlinear. Another misrepresentation may occur when an objective is incorrectly approximated. The true problem may involve a combined objective that includes both risk and cost yet was misrepresented by a cost function alone. Kaunas and Haimes (1985), Massmann and Freeze (1987) and Wagner and Gorelick (1989) all adopted different approaches to risk-based engineering design of groundwater quality management problems. One may specify the wrong coefficient values in the management model formulation or have the incorrect demand, supply, or regulatory limits. Finally, management model results may be uncertain because the problem may have false local optimal solutions or may provide one with global optimal solutions that are not unique. In general, the errors associated with management model formulations and solutions will be less than those associated with simulation models of the physical processes. Misspecification of the objective and constraints can generally be corrected by rethinking and reformulating the problem; techniques for solution of the optimization problem are available but can require much computer time.

KNOWLEDGE GAP AND RESEARCH NEED

There is a lack of understanding of many important physical processes and systems dynamics in all of the groundwater quality areas as mentioned. Processes in the unsaturated zone, those associated with the flow of immiscible contaminants, coastal aquifer saltwater intrusion, and complex chemical interactions and phase changes have received little attention within the context of groundwater quality management modelling. Consequently, engineers and scientists have limited ability to predict the effect of remediation on fate and transport of a contaminant in an aquifer, the effect of changes in pesticide and fertilizer applications on crop yields and the effect of salinity build up on crop losses and human health.

Existing models are used in situations for which the specific models are inappropriate. Such model misspecification may lead to unreliable model predictions and highly uncertain management designs. The initial need for research lies in understanding the physical and chemical processes taking place in different subsurface environment and in developing mathematical representation of these processes. With proper understanding of system's dynamics, optimization model can then be designed, tested and further applied for mitigation studies. Field testing of simulation-optimization methodologies has been limited and results are not always presented in the scientific literature. Feedback from field investigations is essential.

It is often difficult to develop quantitative criteria by which one can adequately compare the results of alternative management decision. Economic criteria are often used but they are only one of a number of factors that are important. Other factors include public health benefits, minimization of risk, absence of a negative effect such as unemployment. There is a need to expand our understanding of the criteria by which alternative management programs should be judged, the types of constraints that need to be imposed.

There are also serious problems associated with numerical computation of the best management alternative. Simulation, especially under stochastic environment, can be infeasible to evaluate a very large number of management decisions. Optimization methods are in some cases limited because they either require a special mathematical structure or the current optimization algorithms are not computationally efficient enough to analyze the high dimensional system associated with groundwater quality management. Although groundwater quality management models have been developed for steady and unsteady cases, research is needed for solution of nonlinear groundwater quality control problems. Nonlinearities arise from management decisions that create unknown groundwater velocity fields as well as from problems having chemical interactions. Groundwater quality management models that include nonlinear constraints represent a key area of research. Such models can be used for management problems of the unsaturated zone, groundwater reclamation, complicated pollutant chemistry and coastal aquifer protection. In terms of computation, there is need to develop better ways of integrating the use of powerful computers like supercomputers with the use of the smaller machines that are easily available.

There has been very little work done in the area of uncertainty analysis associated with the groundwater quality management modelling. The only type of model errors that have received attention are those associated with model parameters, especially those related to physical flow processes. There have been no studies exploring uncertainty associated with chemical and biological process parameters and how they influence groundwater quality management. Further research is needed with consideration of model parameter uncertainty with specific focus on the spatial variability of those controlling groundwater and contaminant migration. All physical and chemical parameters must be viewed in the context of their spatial and temporal variability and the uncertainty this generates in engineering designs for aquifer management. It is necessary to integrate methodologies for groundwater quality network design, model parameter estimation, risk quantifications and management design under uncertainty so as to address the design problem based on a combination of technologies.

CONCLUDING REMARKS

Groundwater flow and mass transport models are extensively used to simulate the dynamics of aquifer system and to evaluate the long-term impact of sustained water withdrawals and the migration of chemical contaminants. Combined simulation and management models have been developed to consider a particular behavior of groundwater system and to determine the best operating policy under the objectives and restrictions dictated by the specific situation. The optimization approach to groundwater quality management offers a promising tool for assessing the impact of contaminant transported to the groundwater system, and for designing the appropriate remediation strategies for aquifer rehabilitation. Different types of management models have been developed for steady state pollutant distribution and for unsteady cases involving solute redistribution.

Groundwater optimization models have not been widely applied for the management of groundwater supply and quality. Generally, there is a lack of credibility associated with the optimal policies developed from optimization models. Water managers and engineers find it difficult to conceptualize how objectives and constraints can be incorporated in a mathematical model. This is caused in part by the lack of formal education and training in systems optimization. Public officials are often reluctant to believe the results of optimization modelling. Much greater credibility is associated with simulation models. The implementation of alternatives or policies developed from groundwater optimization models presents serious legal, economic and political decisions. Typically quasi-governmental agencies responsible for water management are unwilling or unable to address the issues and ramifications associated with optimal groundwater development and operation. Efforts must be undertaken to carry out field studies involving optimal groundwater supply and quality management. Until optimization policies can be implemented and demonstrated to have practical significance, groundwater quality simulation models will be used for ad-hoc mitigation studies.

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GLOBAL AND REGIONAL PERSPECTIVES OF EUTROPHICATION CONTROL

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INTRODUCTION, POINT SOURCES AND NON-POINT SOURCES

Eutrophication of waters is the result of an excessive emission of nutrients, particularly phosphorus and nitrogen, into rivers, lakes, ponds, reservoirs and coastal seas. Besides a natural input human activities have greatly influenced the cycling of these elements and much of the eutrophication is anthropogenic. Agriculture is the dominant consumer of nutrients. Hence the pathways of nutrients and their control originate in land use practices and the fate of the products derived from the arable land. The development of these practices and the environmental factors controlling the loss of nutrients to the water environment therefore are the focus of this paper. Thus most attention is for non-point sources.

Point sources of nutrients are certain industrial wastewaters and especially municipal wastewaters. A large fraction of the nutrients present in human food ends up in the sewage, which further may contain substantial amounts of phosphate originating from detergents. In developed countries the sewage is collected and treated. Nutrient removal techniques are available and include nitrification and denitrification, precipitation of phosphate and biological phosphorus removal. Increasingly these techniques are implemented but even in the developed world the percentage treated is still low. The control of point sources in most countries is the responsibility of the water sector: Public Works Departments, Water Authorities etc. Non-point sources are largely beyond the control of the water sector, but depend strongly on agricultural practices. In urban areas which are not properly sewered and where sanitation is absent or poor, also large quantities of nutrients leak into the environment. Notwithstanding an increased provision of sanitation for 300 million people in urban areas during the water decade, the fast growth of especially slum areas has caused an increase of the unserved urban population from 292 to 377 million (UNDP, 1990). Besides a serious source of waterborne diseases such unofficial settlements are large diffuse sources where per capita 1-2 grams of phosphorus and 5-10 grams of nitrogen per capita and per day are released on and in the soil, the streets, urban waterways etc. Via groundwater, run-off and also directly the surface waters will be loaded heavily in such regions.

FERTILIZER PRODUCTION AND GLOBAL CYCLING OF NITROGEN AND PHOSPHORUS

There is a relationship between the consumption of fertilizers and the population. Worldwide for the period of 1980-1987 the following approximate statistics hold: (**Table 1**.)

Especially in developed countries the use of polyphosphates as builders in detergents is another important source.

Population growth control evidently is an important factor in the limitation of further growth of nutrient consumption and discharge into the environment. The need to enhance agricultural production to feed the growing population varies over the continents and is also dependent on the level of provision. **Table 2**., derived from World Resources (1990) illustrates the large differences in fertilizer use and the rates of increase.

Although these figures are still rather global, they are consistent with the general observation that eutrophication problems are most pregnant in areas with intensive agriculture. The GEMS data-base on water quality of lakes and rivers around the world illustrates this to some extent. However, in many water systems the effects of point sources are dominant.

Table 1. Fertilizer consumption and world population.

Fertilizer consumption (Mill. Ton)	1980	1987	%increase per year
K	23.3	26.1	1.7
P	30.6	34.7	1.9
N	58.0	75.3	4.4
Population (billion)	4.4	5.1	2.4

Table 2. Fertilizer use in kg per ha cropland.

Area	1975-1977	1985-1987
World	67	91
Africa	14	19
North & Central America	84	83
South America	28	39
Asia	42	93
Europe	207	228
Oceania	34	34

The cycling of nutrients in the environment gives a clue to control measures. It is essential to discriminate between fluxes and pools. Certain pools may act as buffers in which the nutrient accumulates and may be returned for prolonged periods, even after the loading of the environment is reduced or terminated. This is particularly the case with phosphate. Actually phosphate hardly "cycles" in the environment in the sense that it is returned to the land. This is only true for the fraction of fertilizer that ends up in animal feed or human food and returns as manure or excreta on the fields. An important fraction of the phosphate in feed and food is discharged into water, either directly via a sanitation system or indirectly through run-off, leaching etc. This phosphate finally accumulates in the sediments of lakes and seas and cycles only within these water bodies by release and uptake in the biota, followed by sedimentation in detritus or otherwise. This internal loading of water bodies and the internal cycling is exactly one of the main problems of eutrophication by phosphate. Such phosphate may be used repeatedly before it finally is buried in deeper sediment layers and becomes inaccessible for algae. Phosphate also may accumulate in soils. Over-fertilization or excessive application of manure with respect to plant uptake will gradually lead to a progressive saturation of the soil matrix and a front of phosphate saturation gradually moves downward towards the saturated zone. Iron and aluminum hydroxides are the main absorbents in most soils. When the groundwater is reached such soils start to leach phosphate; due to inhomogeneous soil properties and preferential flows this generally occurs earlier than calculated on the basis of average values. In some countries the development of phosphate saturated soils acts as a time bomb for the watershed into which these fields drain.

From an ecological point of view it is important to intercept as much as possible the phosphate that ends up in manure, sewage sludge, wastewater and other end products of sanitation. By land application of this material the demand for new phosphate fertilizer is reduced. The trend towards increasing urbanization,- in 2015 half the population of the developing world is expected to live in cities-, urgently requires a much higher level of sanitation. Primarily for health reasons, but also for the protection of the (water) environment. Nearly all fast growing mega-cities lie on major rivers or coastal seas and the prospects for a proper collection of human wastes are not favorable, especially for the explosively expanding informal settlements. Presently too much of the nutrients in wastes and wastewater end up in the water by direct discharge and by run-off.

Due to the non-conservative character of nitrogen and the occurrence of gaseous compounds the nitrogen cycle involves more compartments and is more or less closed. On a world wide scale, based on the land surface, a balance of inputs and outputs (Jenkinson, 1990) gives the figures of **Table 3.**, which necessarily are approximate values.

The loss that can not be accounted for, about 11 kg/ha,yr, is probably due to denitrification. Accumulation in soils is thought to be insignificant or rather soil organic matter tends to decrease (Bolin, 1986). Already 25 % of the total input comes from fertilizer. The loss by drainage proportionally is small, but increasing. Regionally it will be much higher. Fresh waters and coastal seas receive more or less the same amounts of gaseous nitrogen compounds per ha as the adjacent land. In this respect it should be noted that the atmospheric pools of NH_3 and NOx are small, resulting in short residence times in the atmosphere and deposition mainly in the region where the gases were generated. For NH_3 this is the land (e.g. emissions from manure), for NOx combustion on land is the main source but soils and atmospheric lightning also contribute. N_2O has a very long residence time and will deposit equally over land, seas and oceans.

The regional differences in the nitrogen balance are great. In **Table 4.** a balance for Denmark, based on converted data from Schroder (1990), is presented. Denmark is the country in the EEC with the second highest fertilizer application rate, approaching 150 kg N/ha,yr for the agricultural land. The data in the table apply to all the land, as in **Table 3**.

Table 3. Inputs and outputs in kg N/ha,yr to the land surface of the earth.

	Input	Output
NH_3 exchange	2.7	3.6
N_2O	?	0.8
NOx	2.4	2.7
N_2 fixation (biol.)	9.4	(denitrific.) ?
Fertilizer	5.0	-
Run-off	-	1.3
Total	19.5	8.4

Table 4. Nitrogen balance in kg N/ha,yr for Denmark.

Import	1950	Export		Import	1980	Export	
Fertilizers	15.1	Vegetable Products	7.0	Fertilizers	87.2	Vegetable Products	7.0
Import animal feedstuff	12.8	Animal Products	4.6	Import animal feedstuff	41.9	Animal Products	14.0
N_2 fixation	44.2	Lost to environment	64.0	N_2 fixation	7.0	Lost to environment	125.6
Atm. outfall	3.5			Atm. outfall	10.5		
Balance	75.6		75.6		146.6		146.6

The increases in fertilizer application and losses to the environment are outstanding. Noteworthy is also the low return of animal products on import of animal feedstuff. In **Figure 1.** the amounts of nitrogen cycling within the Danish agriculture and the outputs in 1,000 tones per year are displayed; for clarity the inputs are left out. Including the domestic feedstuff used only 12% of the nitrogen in feed is converted into useful animal products. Actually the transport of feed across the world, frequently from developing countries to the developed world, affects the nutrient balances negatively. In the developing world a shortage exists, but nutrients are exported. In the developed world the fertilizer application rate is (far) beyond an ecologically acceptable level, but in addition to this more nutrients are imported in order to produce more meat and dairy products. Clearly the secondary nitrogen cycle through livestock and the losses of nitrogen to the atmosphere by volatilization of ammonia and the leaching of stored manure add to the environmental burden. The internal cycle of nitrogen (**Fig.1.** and Schroder, 1990) suggests that 17% of the discharge to the environment is directly due to the latter processes, whereas indirectly the leaching and volatilization from the fields partly is also due to the intensive cattle breeding.

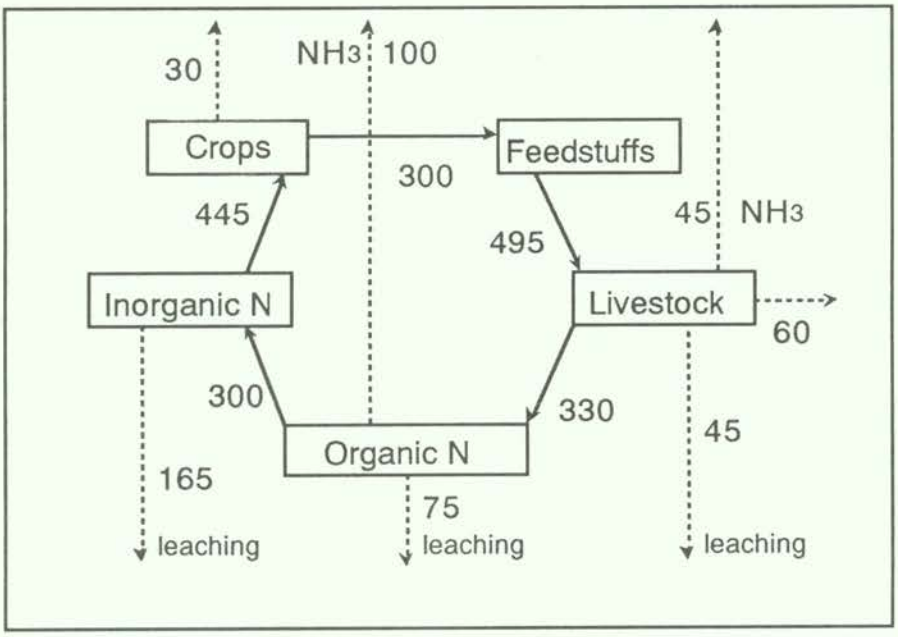

Figure 1. Internal nitrogen cycle in Danish agriculture and outputs as products and to the environment. 1,000 tons N/year

DEVELOPMENTS IN AGRICULTURE

The increasing world population requires an extension of the cropland and/or an intensification of the agricultural production on existing fields. The available cropland per capita is already below 0.2 ha in Asia and expected to decrease in the next decades (World Resources, 1990). The extension of agricultural areas takes place in regions which are generally less suitable for agriculture; the most productive soils are already heavily used in most continents, in Asia 82%. This implies clearing woods on rather steep slopes and exploiting more or less marginal land. This is practiced by people living under marginal conditions, who are the least able to do this in an environmentally acceptable way, e.g. by proper terracing and use of irrigation methods. The annual rate of deforestation is presently 1.3% in Latin America, 0.9% in Asia and 0.6% in Africa. Massive erosion and desertification are a consequence. The suspended solids content of rivers may increase 100 fold with respect to the natural level due to deforestation.

An increased application of fertilizer is to be expected and a continuation of trends as indicated in **Table 2**. All this will contribute to increasing eutrophication.

A second factor is the climatic change. The rise in temperature due to the increased concentration of greenhouse gases, among which CO_2 is the most important, will lead to enhanced growth rates of plants (Parry, 1990), especially the so-called C_3 species which have as the primary product of photosynthesis organic compounds with 3 C-atoms per molecule. These include soybean, wheat and rice. C_4 plants (e.g. maize) are less responsive. Enhanced CO_2 concentrations induce closure of the stomata in plants and concomitantly reduces evapotranspiration. Hence a reduced water requirement may be a side effect and a shift of agriculture into dryer areas may result. Further the cultivation of certain crops may be extended due to the longer growing season; for instance rice cultivation in northern Japan (Hokkaido) may double. The higher productivity is mainly allocated to plant organs with a low nitrogen requirement (roots, stems) and therefore results in a more efficient use of nitrogen in terms of N used per kg crop (Kraalingen, 1990). Further effects of global heating are the shifts in zones in which livestock performs effectively. The shift will tend away from the tropics.

Enhanced productivity may be curtailed by a lack of nutrients or of water, although the latter is only true when the availability of water is reduced. The rainfall patterns are expected to change rather dramatically with a worldwide intensification of the hydrological cycle due to enhanced evaporation rates. This also will affect leaching, run-off and erosion patterns and consequently eutrophication. Regionally the climate will become dryer.

Another global effect that does affect agriculture is the acidification. In terms of effects on eutrophication the atmospheric input of sulfates in fresh water systems may induce a substantial sediment release of phosphate (Caraco et al 1989). This is due to the conversion of iron into FeS and the release of iron-bound phosphate. The fact that fresh waters are mainly phosphate limited and marine waters nitrogen limited is probably related to the differences in sulfate content.

CONTROL OF NON-POINT SOURCES

From the foregoing it will be clear that agricultural practices will largely control the diffusive flux of nutrients into the environment. Besides birth control as an overall background aspect in all environmental problems, a number of sound practices and developments can be identified:

* application of fertilizer shortly before the growing season.
* deep placement of fertilizer
* banded or side-dress application of fertilizers
* use of coated fertilizer with a slow release rate.
* application of nitrification inhibitors, nitrate is more mobile than NH_3 or organic N.
* low input farming, which includes less reliance on fertilizers, pesticides etc.
* intercropping, especially agroforestry, which implies the alongside planting of crops, shrubs and trees, with a more efficient preservation and use of moisture, nutrients, a better soil structure and the provision of fuelwood.
* better irrigation practices, terracing, reforestation

This list is not exhaustive.

The diffusive sources related to manure and human excreta not treated in waste water treatment plants with nutrient removal, can be reduced by:

* limitation of the periods in which manure may be applied and restriction of the level of loading
* deep placement of the manure
* good housekeeping in and around stables
* conversion of surplus manure into fertilizer or better: to curtail the non-land based animal husbandry

This list is not exhaustive.

Also in the environment itself certain measures can be taken, especially with respect to phosphate, e.g.:

* internal loading in fresh waters can be reduced by chemical treatment of sediments with aluminum or iron to fix phosphates.
* Liming has the same effect, when applied as Ca-nitrate the oxidation of the sediment top layer will reduce phosphate release
* dredging of sediments
* aeration of hypolimnetic or oxygen deficient waters
* creation of wetlands along rivers and streams, which have a capacity to retain run-off and enhance nitrification and denitrification.

CONCLUSION

The perspective is that the eutrophication will continue to increase, especially in the developing world due to population growth, urbanization, increased food production on marginal lands and lack of funds and infrastructure for treatment, better land use and agricultural practices etc. Unfortunately the environmental protection plays a modest role in the short term priorities of most developing countries although the damage accepted on the long term probably outweighs the short term gains. A variety of frequently appropriate technologies is in principle available to prevent un-necessary nutrient releases or to intercept them before they diffuse into the environment. The implementation of these methodologies depends largely on the policy makers outside the water sector.

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STATE OF THE ENVIRONMENTS OF WORLD LAKES - FROM THE SURVEY BY ILEC/UNEP -

By

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ROLES OF LAKES

Freshwater is a requisite resource for human beings. In former days, rivers were the main source of water for residents of mountainous regions such as Japan, while people in plain regions used to depend on groundwater. If there was a lake with good water quality nearby, people on the lake shore, naturally enough, used water from the lake, but generally, lakes were of greater importance for fisheries and water-borne transportation than for water supply. With population increase and urban development, however, larger water sources came to be needed for city water supply, and lakes became more and more important as sources capable of providing a large amount of water. Since river water flux tends to fluctuate widely and is less reliable, man-made lakes are created by damming rivers where appropriate lakes are not found, and are used as stable water sources for municipal use, irrigation and hydroelectric power generation. Beside millions of natural lakes on the earth, the number of reservoirs of various sizes has been increasing very rapidly. Japan, for example, has some 100 natural lakes with areas wider than 1 km^2, while there are as many as nearly three times that number of reservoirs of the same size range.

Thus, lakes are now expected to serve not only for such traditional uses as fishery and transportation but also as important water sources. However, it should be noted that, unlike ever-flowing water in rivers, water in lakes remains stagnant for several months to decades, or in some lakes even longer than hundred years, and therefore tends to be easily polluted. Lakes suffer from water quality degradation, if human activities are intensified and population increases around them. Consequently, much attention has to be paid to maintaining lake environments in sound conditions in order to coexist with lakes for sustainable use of their resources. To achieve that, not only lake itself but also the area gathering rain-water into it - referred to as the catchment area - should be managed in a rational way as an inseparable system.

SURVEY OF THE STATE OF WORLD LAKES BY ILEC/UNEP

The International Lake Environment Committee Foundation (ILEC) is a non-governmental organization located in Otsu with the aim of formulating and disseminating such environmentally sound management of lakes and reservoirs world-wide. Its core is the Scientific Committee that consists of 19 experts from 14 countries and a member from the United Nations Environment Programme (UNEP). Supporting the Committee's activity is one of the main tasks of the Foundation.

Immediately after its foundation in 1986, ILEC initiated, in cooperation with UNEP, a project called the "Survey of the State of World Lakes", which aimed at collecting and compiling environmental data on as many important lakes of the world as possible to be used as the basis for the management of lakes. Efforts have been made to collect not only natural scientific data on lakes themselves, but also environmental and socio-economic data on their catchment areas. This is the first attempt of its kind ever made. The Lake Biwa Research Institute has fully supported this survey by serving as the editorial body.

The results so far obtained from the survey have been published in three volumes of the "Data Book of World Lake Environments" (1988-1990). These volumes contain sets of detailed data on 145 lakes from all over the world: 50 from Asia, 4 from Oceania, 14 from Africa, 35 each from Europe and North America, and 7 from South America (**Table 1**). The lakes belongs to 52 countries and 27 of them are man-made reservoirs, while the rest (118) are natural lakes.

Table 1 Number of lakes so far surveyed.

	Number of countries	No. of lakes Natural	Man-made	Total
Asia	11	37	13	50
Oceania	2	3	1	4
Europe	17	34	1	35
Africa	15	11	3	14
North America	2	29	6	35
South America	5	4	3	7
Total	52	118	27	145

Table 2 Size (surface area) distribution of surveyed lakes.

	Lake surface area (km^2) <100	100-250	250-500	500-1,000	1,000-5,000	5,000-10,000	10,000-50,000	50,000-100,000	Total
Asia	36	6	-	3	4	-	1	-	50
Oceania	2	-	-	1	-	1	-	-	4
Europe	17	4	5	4	4	1	-	-	35
Africa	3	-	2	-	3	3	2	1	14
North America	14	3	3	1	7	-	4	3	35
South America	3	-	1	2	-	1	-	-	7
Total	75	3	11	11	18	6	7	4	145

As shown in **Table 2**, small lakes, less than 100 km^2 in surface area, account for about 50% of the survey, simply because smaller lakes can be more easily studied and hence are richer in available data. Although there are 253 "large lakes" (larger than 500 km^2) in the world - Japan has only one, Lake Biwa - excluding man-made lakes, only 15% of these have been covered by this survey so far. The 4th volume, expected to appear in 1992 dealing mainly with lakes of CIS and Canada, will make up for this deficiency to some extent. The National Water Research Institute of Canada and the Committee for International Projects of the former USSR cooperated in preparing this volume by providing data from these two countries richest in existing lake numbers.

In addition, more condensed and largely qualitative information on some 500 lakes has also been accumulated, and is being edited to be published in another book entitled "Catalogue of World Lakes".

FIVE MAJOR ENVIRONMENTAL PROBLEMS IN WORLD LAKES AND RESERVOIRS

The data collected by ILEC indicates that various environmental disruptions are now wide-spread among lakes and reservoirs in the greater part of the continents, leading to the crisis of water resources and aquatic ecosystems. There are some common features in the disruptions which may be classified into the following five categories.

1) Lowering of lake water level due to the over-use of water from lakes and/or inflowing/outflowing rivers, resulting in a decrease in lake water volume, the deterioration of water quality and changes in lake ecosystems.

2) Rapid siltation in lakes and reservoirs caused by accelerated soil erosion resulting from the over-use or mis-use of arable, grazing and forest lands within their catchment basins.

3) Acidification of lake water due to prevailing acid precipitation, resulting in the extinction of fish and the degradation of ecosystems.

4) Contamination of lake water, sediments and organisms with toxic chemicals contained in agricultural chemicals and industrial wastes.

5) Eutrophication due to the inflow of such nutrients as nitrogen and phosphorus compounds in waste water discharged from industrial plants, agricultural lands, homes, urban and road surfaces, etc., resulting in heavy blooms of plankton, the deterioration

of water quality, the decrease of bio-diversity and, in extreme cases, the complete collapse of aquatic ecosystems.

It is impossible to discuss all these situations in detail due to time limitation; instead I will deal with some cases which are not so well known in Japan with a focus on the state in developing countries.

LOWERING OF LAKE WATER LEVEL

The worst example of lowering lake water level is the case of the Aral Sea in central Asian desert in Kazakhstan and Uzbekistan Republic, which has recently received much media attention. The Aral Sea was the fourth largest lake in the world, some 100 times as wide as Lake Biwa. The lake water was brackish with a salt concentration of one-fifth of sea water, and was fed by two tributaries originating from glaciers in the Pamir Highlands and the Tienshan Mountains. Since the 1960's, an extensive agricultural development plan was initiated in the watersheds of these rivers by taking a large amount of river water for irrigation. As a result, the river flow failed to reach the lake, which then started shrinking.

During the past 30 years, the Aral Sea has lost one-third of its area and two-thirds of its water volume, salt concentration in lake water have reached 4 times the former level and almost all native organisms have disappeared. The shore line has retreated by several tens to one hundred kilometers and ships in harbors are now left buried in desert sands. Fisheries in the lake have been completely destroyed. The pollution by agricultural chemicals and increased salt concentration in drinking water are now badly spoiling the lives of local people and their health. ILEC has been participating in an international experts meeting for preparing an action plan to cope with these problems, but it is by no means a simple task.

Symptoms caused by the subsidence of water level due to the abuse of lake water for power generation and irrigation are also known in other freshwater lakes. In many of those cases, it is noticeable that the deterioration of the water quality, especially eutrophication, took place. Future studies and more information are needed on this point.

ERODED SOIL FILLS LAKES AND RESERVOIRS

Soil erosion and resultant rapid siltation in lakes are one of the most serious disasters in developing countries. For instance, Lake Dongting, the second largest freshwater lake in China, on the middle reaches of the Chiang-Jiang (Yangtze River), receives flood water from the river every summer and is now accumulating new sediments at a rate of 5 - 6 cm per year. This means that the lake, with an average depth of 6.7 m, may be filled up and disappear within 100 years or so. This is a critical problem which may completely upset the way of life in lakeside communities.

It is said that the Chiang-Jiang has become more and more muddy in recent years as the result of increasing soil erosion in its upper reaches. I have had an opportunity to observe what is going on in Yunnan Province, one of the headwaters of the river. There , the original vegetation was the evergreen forests of oaks, Castanopsis, trees of camphor family, etc. just like those in the southwestern part of Japan, but they have been mostly turned into secondary forests of pine and bare lands which are now used as pastures. In order to increase food production to meet the ever-growing population, hill slopes are now extensively cultivated in addition to farmlands on narrow plains along valleys. Furthermore, people wants to get more cash income, since even remote rural areas have now been incorporated in the global market economy everywhere in the world. The main cash crop in Yunnan is tobacco and tobacco fields are now spreading over hill slopes further and further upwards. Reckless hill-slope cultivation has caused terrible soil erosion. Probably by the same reason, overgrazing is very often observed in pastures on slopes, where the trampling by livestock has broken continuous grass cover to result in the start of soil erosion, which may eventually leads to the collapse of whole slope in some places. Streams are always heavily loaded with muds even on fine days, flowing down continuously toward the Chiang-Jiang.

EUTROPHICATION

It may not be necessary to say much about the problem of eutrophication, since most of you are probably well acquainted with the case of Lake Biwa. The eutrophication of Lake Biwa began around 1960 simultaneously with the start of post-war economic growth of Japan. The deterioration of the lake's water quality has continued ever since, causing serious concern among 13 million people who depend on the Lake Biwa/Yodo River system for their water supply.

Observation of the changes in the plankton biomass at the center of Lake Biwa during the past 35 years indicates that the biomass in the 1980's is more than ten times as large as that in 1950. During the course of this rapid increase, clogging trouble in sand filters took place as early as in 1958 at the Municipal Water Purification Plant of Kyoto. Since 1969, unpleasant musty odors in the tap water of Lake Biwa origin became an annoyance for the users every summer. The plankton biomass peaked in the late 1970's, when the bloom of a flagellate plankton, *Uroglena americana*, appeared as "freshwater red tide". It has occurred almost every year since 1977 to 1991, in spite of all the cooperative efforts made by the residents and local government of Shiga Prefecture. Though the trend of water quality degradation was more or less leveled off, signs of the bloom of such blue-green algae as *Microcystis* and *Anabaena* - an indicator of more advanced eutrophication - has appeared since 1983.

Fortunately, the eutrophication of Lake Biwa is not as serious as in some other lakes. For instance, Dianchi, a lake about half as wide as Lake Biwa located near Kunming City, the capital of Yunnan Province in China, is suffering from extreme eutrophication, because of the untreated wastewater it receives from two million population of Kunming and a suburban industrial center consisting of some 160 factories. Up to three years ago, nevertheless, many fish pens for breeding carp were floating on the lake surface. When I visited the lake again last year, however, its vast surface was covered by dense blooms of algae like green dye and fish-breeding was almost totally abandoned because of the lack of dissolved oxygen in lake water. Nearly all the native waterweeds and some 20 species of fish had been made extinct. Millions of pond snails that died of oxygen deficit in the bottom water were floating on the surface. The ecosystem of the lake had been completely destroyed. Ironically, city water supply for two million residents of Kunming are running short, and the city has begun to take this hypertrophic lake water as a source of tap water this year. The water authority are now facing great difficulties in supplying tap water that meets the legal standards.

Such an example illustrates how important it is to prevent the advance of eutrophication beyond the stage of present-day Lake Biwa.

PRELIMINARY ANALYSIS OF THE DATA COLLECTED BY ILEC/UNEP SURVEY

Coming back to the topic of ILEC/UNEP project again, this survey is expected to continue for a few more years. Therefore, we have not yet undertaken comprehensive analyses of the data collected. Nevertheless, a preliminary analysis demonstrated some interesting relationships, which will be outlined in the last part of my speech with emphasis on water quality aspects.

Transparency is one of the most easily measurable indices of water quality and an enough number of observed values are available. It was found that the volume of lake water was most closely correlated with transparency as shown in **Figure 1.** In the figure, there is a difference of magnitude of ten million in lake volume, ranging from the world-largest Lake Baikal at the right end to very small lakes on the left end. Logarithmic scales were therefore used for both axes to incorporate such widely varying data into a graph. Although the points each corresponding to a lake are very scattered, you may see a broad positive correlation between transparency and lake volume as approximated by a dotted line in **Figure 1.** Some points far below the dotted line represent shallow, wind-swept lakes on plains such as Tai-hu (China), Lake Balaton (Hungary) and Lake Winnipeg (Canada), in which the water tends to be always turbid with suspended muds, whereas the points far above the line correspond to such lakes as Mashu-ko in Hokkaido and Lake Tahoe on the border between California and Nevada well known for their very clear water.

This positive correlation may indicate that the larger the lake volume the more resistant is the lake to the decline of transparency caused by the inflow of silt and/or eutrophication. This suggests, in turn, the importance of lake water volume as a parameter in the analysis of the relationships between water quality and the conditions of catchment land area responsible for the pollution of lakes.

The degree of turbidity can be expressed by the concentration of suspended solids (SS), or the amount of particles suspended in water. As an example, **Figure 2** shows the relationship between SS and the ratio of forest area to the whole catchment area. In the figure, closed circles represent Japanese lakes, in which a more or less inversely proportional relationship is recognized. The turbidity of lake water was found to increase significantly if the area ratio of forest came to less than 50%. However, contrary to our expectation, no clear relationship between the two variables was obtained when non-Japanese lakes shown by open circles were put together.

In the next step, parameters more closely related to SS were sought by dividing the characteristic values of catchment areas such as forest and farmland areas, population, etc. by lake water volume and converting them to specific values per unit lake volume. As illustrated in **Figure 3**, the area of farmlands - including both crop fields and pastures in this case - in the catchment area per unit volume of lake water (in terms of km^2 per million cubic meter or m^2/m^3) was the most influential factor for SS or turbidity. Thus from the global point of view, the progress of farmland development seems to be inevitably associated with the acceleration of soil erosion. It should be noted, however, that the relationship shown by a curve in **Figure 3**, is only valid for lakes under relatively moist climates with closed circles, while it is not for lakes in arid regions marked by open circles. Unfortunately, available data on SS values in lakes of arid regions were too limited to draw any conclusions.

Figure 4 shows the relationships between total nitrogen and total phosphorus concentrations in lake water, indicators of the degree of eutrophication, and the catchment area population per unit volume of lake water. Since the data are also plotted on logarithmic coordinates, the deviation of the value for each lake from the regression lines is much wider than its visual impression. Thus there are differences greater than two times in the concentrations of phosphorus and nitrogen corresponding to the same value of abscissa. Though individual lakes are no doubt influenced by specific conditions, we may assume that the population increase in the catchment area is the leading factor for accelerating eutrophication in world lakes. After the completion of this survey, more comprehensive and detailed analyses of the data are expected to identify the factors responsible for the deviation mentioned above.

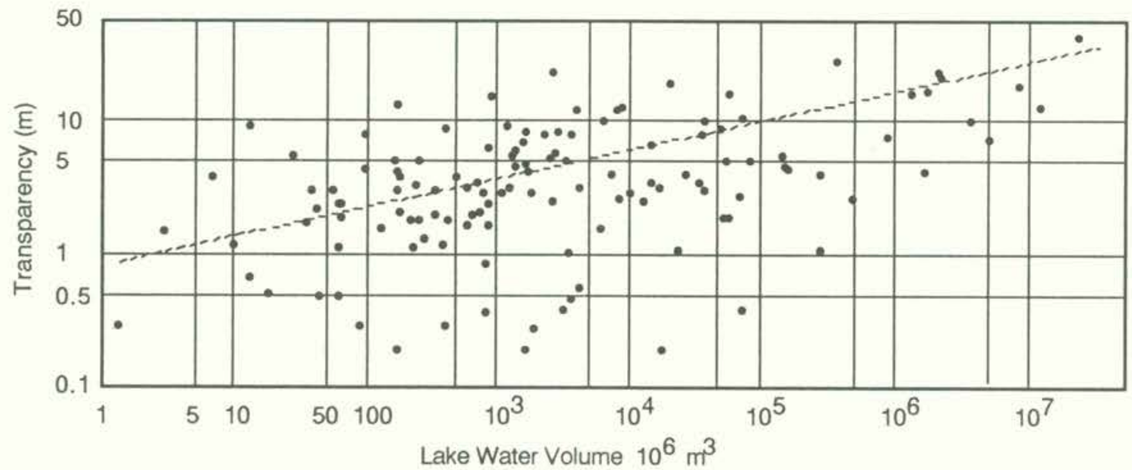

Figure 1. Relationshop between Transparency and Lake Water Volume

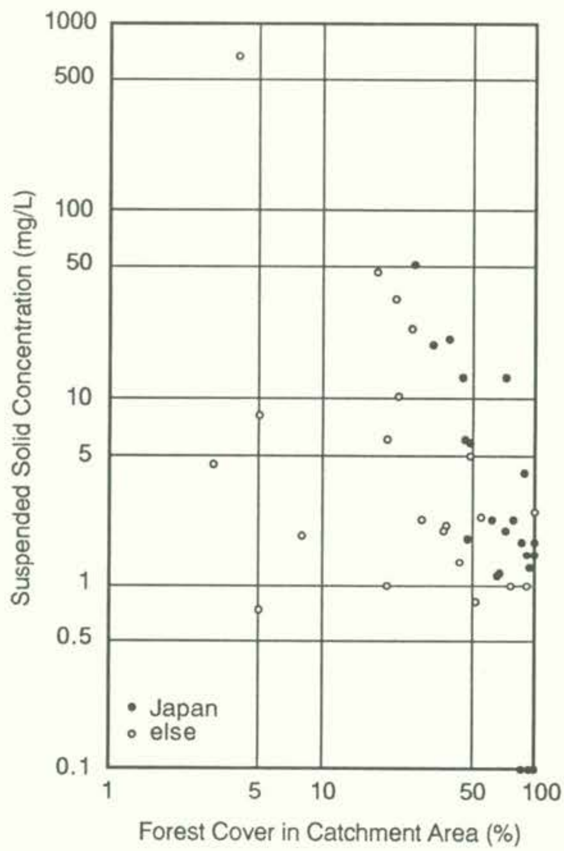

Figure 2. Relationship between Suspended Solid Concentration and Percent Forest Cover in Catchment Area

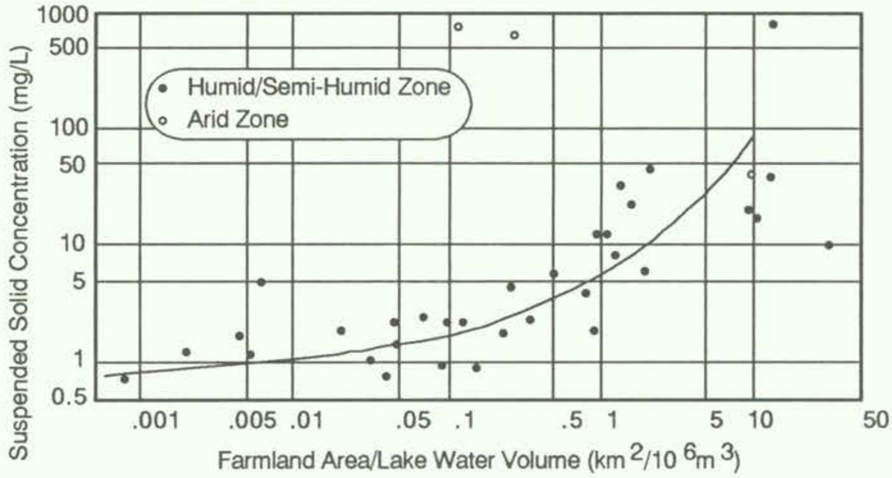

Figure 3. Relationship between Suspended Solid Concentration and Farmland Area in Catchment Area

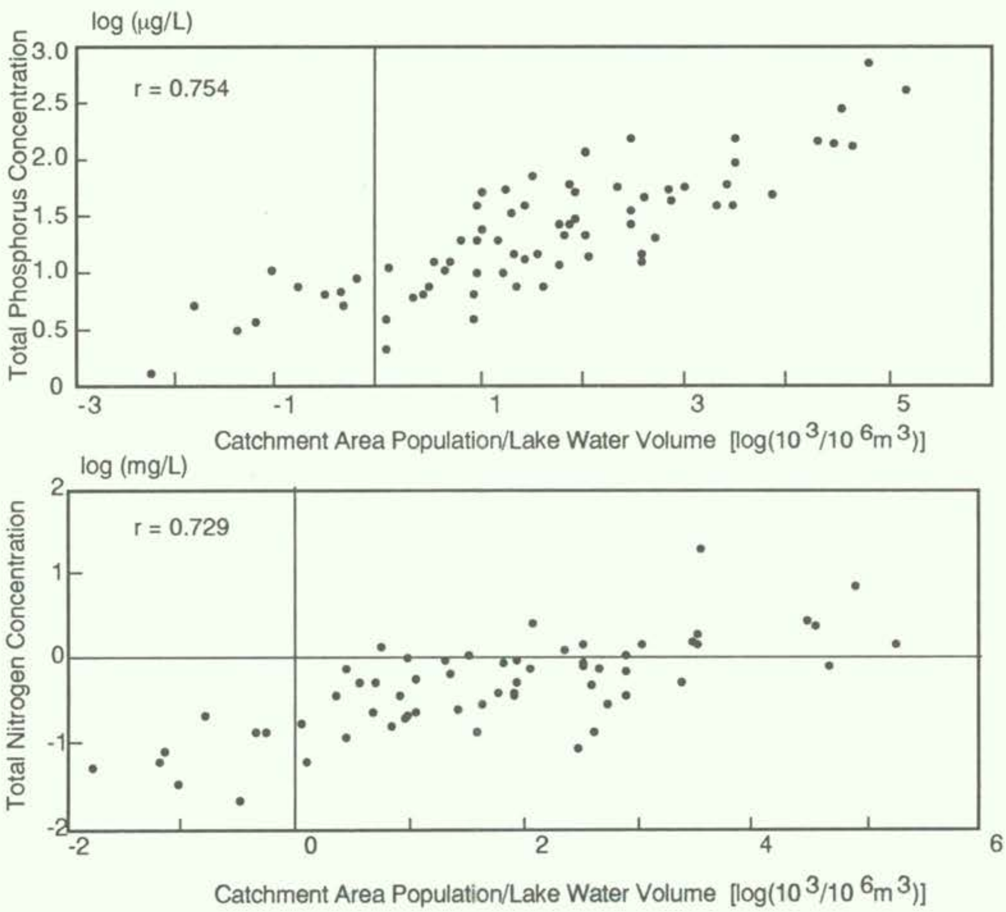

Figure 4. Relationship between Total Phosphorus and Total Nitrogen concentration and Population in Catchment Area

ENVIRONMENTAL PROBLEMS OF LARGE CENTRAL ASIAN LAKES

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In the middle of the Euro-asian continent there is the largest closed area in the world with the territory of four million square kilometers. The rivers within this area usually end up in quite a number of closed lakes. Two of them are so large that they are traditionally called as seas. The largest lakes are: Caspian Sea, Aral Sea. Lake Balkhash and Lake Issyk-Kul. Approximate morphometric data on them by about 1970 are given below:

The main feature of any closed area is that all the precipitation falling on it eventually evaporates from the area. The river run-off originating from the precipitation comes down to the terminal lakes or marshes and evaporates from them. The closed lakes are very sensitive to the changes in their water balance quickly reacting to them by altering their main morphometric parameters which manifests in the changes of the water level. Dissolved salts content in the lakes' water also quickly reacts to the water balance changes. The morphometric and geochemical variations cause many other ecological changes.

The natural variations of climate are the main reason for the alterations in the water balances of both terminal lakes and their basins. Besides, an economic activity plays ever increasing role there because if the consumptive used of water increases in the basin, less water comes to the terminal lake. Closed areas are characteristic of arid and semi-arid regions where the main use of water is for irrigation purposes which tends to grow reducing the inflow of river waters into the terminal lakes. Both development of irrigation in lake basins and, in particular, the reduction of lakes lead to serious socio-economic problems of environmental origin. In Central Asia significance of the climatic and anthropogenic factors change from place to place as can be seen from the review below.

The classic and disastrous example of the behavior of the closed lake and of the associated environmental implications is the story of **The Aral Sea**. The larger part of this paper is devoted to the discussion of the Aral Sea case.

The Aral Sea receives only two rivers, Amudarya and Syrdarya. Few more rivers, like Zerafshan, Tedzhen and Murgab, do not reach Amudarya anymore but did so in some periods during the historic time. Irrigation canals including possibly the largest in the world Karakum canal stem from the two main rivers reducing their run-off downstream. Aral Sea serves as the main (but not the only one) collector of waters in this large area.

The surface of the region gravitated to the Aral Sea is about 2 million sq.km. Approximately 70 percent of the territory belongs to what used to be the USSR. It is divided between the five Republics; each of them has recently proclaimed their independence. The rest belongs to Iran and Afghanistan.

While the population around and near the lake shores is over 3 million, its basin contains no less than 32 million inhabitants. Most of the population lives in areas of the middle reaches of the rivers where they come out from the mountains. It is an area of ancient civilizations with millennia of irrigation, the oldest one being dated back to six thousand years B.C. By the middle of this century the irrigated area in the Aral Sea basin was about 5 million hectares.

Aral Sea is situated in a very arid region with annual precipitation of about 100 millimeters. In the stripe between the plains and the mountains precipitation is between 400 and 500 mm and in the mountains, which is the zone of the river run-off formation, it is higher exceeding at some points 2000 mm. Total amount of precipitation in the Aral Sea basin is about 500 cubic km a year. The river run-off is about 120 cu.km. Out of this amount Syrdarya and Amudarya carry from the mountains approximately 110 cu.km. The groundwater resources of acceptable quality which are not connected hydraulically with the river run-off are about 45 cu.km a year.

Lake name	Lake area, in km^2	Maximum depth, in m
Caspian Sea	370,000	1025
Aral Sea	64,500	68
Balkhash	18,200	26
Issyk-Kul	6,300	702

In the historic time variations of the meteorologic and hydrologic conditions in the basin were quite large and, as a result, there were pronounced changes in the state of Aral Sea.
The water level varied within 20 m, so as it was sometime much higher and sometime lower than at the present. Rise and fall of the civilizations in the basin related to development or decline of irrigation and, hence, also influenced the state of the lake.

During a century before 1960, about half of the Amudarya and Syrdarya run-off was used for irrigation and lost for natural evapotranspiration in the middle and lower reaches of the rivers.
The other half flowed into the Aral Sea. The water level was oscillating within 2-3 m. The area of the Aral Sea was 66,000 sq.km (excluding the islands). The volume of water was 1,066 cu.km. The maximum depth was 69 m and the average depth, 16 m.
The salinity of water was about 10 g/L. These data are commonly used now as a reference point when discussing the state of the lake.

At the end of the 1950s and the beginning of 1960s the leadership of the USSR made a decision on an extensive development of irrigation in the Aral Sea basin. During 1950s through 1970s it was believed that the irrigation may become the main remedy in solving many agricultural and socio-economic problems. The Central Asia had a prominent place in this technological fix. It was expected that the expansion of the irrigated lands would bring a drastic increase in cotton production with the subsequent increment of the textile and its products. It was planned that a part of the cotton would be exported bringing hard currency into the country. It was expected also that the region would be then the main source of fruits and vegetables for the whole of the country. It was thought that a production of rice and meat would go up satisfying the demand of the region. And last, but not the least, all those developments would provide enough jobs for a rapidly growing population of the region.

In short, the expansion of irrigation in Central Asia should have brought a prosperity both to the region and to the country as a whole. It was clear to the water resources experts and, through them, to the rulers that one of the main side effects would be a deterioration of the Aral Sea. But it deemed a small sacrifice to the shiny development prospects. Any water expert in the country knew a saying of a famous Russian climatologist A.I. Voeykov published in 1908 that the Aral Sea is a mistake of the Nature because waters collected from the mighty mountain systems go finally to a sparsely populated depression and evaporate. And the common thought was that mistakes of the Nature could and should be corrected. Thus the technological fix has been combined with the narrow, sectional support from the science. Even if a comprehensive impact assessment of the development plans for the region had ever been made, it never became known either to the government or to the public. Besides, the role of the latter that time was to applaud and not to participate in the decision making.

Since the decision on the massive development of irrigation has been made, the investments in agriculture, the irrigation including, have increased drastically. For instance, in Uzbekistan, the most populated of the five Republics, in the period of 1961 through 1985 the investments in agriculture were 45 billion roubles. Out of this amount at least 24 billion roubles were spent for irrigation and related activities. With the prevailing official exchange rates these figures in the US dollars are correspondingly 64 and 34 billion. It would not be a big exaggeration to say that the investments in agriculture in the basin of the Aral Sea over the last thirty years were close to 100 billion roubles, moreover a half of it went into the irrigation. The area of irrigated lands in the Aral Sea basin has increased from 5 to about 8 million hectares now.

The consumption of water was and still is excessive because of the lack of interest in economizing it. The irrigation canals are mostly unlined. The largest one is the Karakum Canal taking about 10-12 cubic km of water a year from Amudarya River westward. It goes in many places through a sandy desert. But even where the lining was envisaged it usually has not been made because the builders after having dug a part of the conduit filled it promptly with water without putting the lining and reported on the work accomplished as it were in accordance with the design, Additional benefits for the advanced accomplishment of the construction quotas and the illegally saved materials going to the black market were the premiums for the corruption. More lining has been put, however, in the canals built more recently.

Efficiency of the irrigation systems is between 0.55 and 0.65 due to the seepage from the unlined distributing canals and a predominantly furrow method of watering. Water consumption by crops exceeds the necessary one by 150 - 200 percent. About 17 or 18 thousand cubic meters of water is spent on average per hectare of cotton (Oreshkin, 1990) and between 25 and 55 thousand cubic meters is used for a hectare of rice (Glazovsky, 1990).

In Amudarya and Syrdarya River basins a part of water once used for irrigation returns into the river and can be used again. Even keeping this in mind one can see that the development of new irrigated lands with the area of 3 million hectares would take all the water resources available by 1960 in the Aral Sea basin. With the 17 thousand cubic meters per hectare, the additional water consumption would be at least 51 cubic km a year. Taking average efficiency of the irrigation systems as 0.6, one can obtain the amount of water used by new irrigated areas as 85 cubic km per year. If we add some unknown but considerable volume lost from the main irrigation canals we could come to the figure of water consumed by the new irrigation developments. Apparently, this figure is close to 100 cubic km a year. For comparison, before 1960 the average amount of water coming annually into the Aral Sea was about 56 cu.km.

Thus, even keeping in mind that the irrigation returned waters coming back to rivers or canals are used again, no considerable inflow to the Aral Sea could be expected under the circumstances. In fact, the inflow went down to 11 cu.km by 1975 and to 0 by 1980. In the 1980s the rivers did not reach the Aral Sea every year, and when it occurred the inflow did not exceed few cubic kilometers. During the last three decades the precipitation in the basin was below average, so that about 20 percent of the inflow reduction was caused by the oscillations of climate while the main factor was the human activity in the basin. As a result, the Sea has been shrinking since the beginning of 1960s while the concentration of dissolved salts has been increasing:

Year	Water level m a.s.l.	Area thous.sq.km	Volume cu.km	Salts content g/l
1960	53.3	67.9	1,090	10.0
1965	52.5	63.9	1,030	10.5
1970	51.6	60.4	970	11.1
1975	49.4	57.2	840	13.7
1980	46.2	52.5	670	16.5
1985	42.0	44.4	470	23.5
1990	39.0	38.0	300	29.0

The former lake bottom is a salty desert or solonchaks and serves as a source of salts spread out by wind. The rest of the Aral Sea is at a brink of being divided in a more deep western part and a more spacious shallow eastern part. The North-Eastern part, so called the Little Sea, is also practically separated.

Drastic changes have occurred in the hydrographic networks in the basin of the Aral Sea. A good part of the water infiltrated into the soil in the irrigation systems and conduits appears in many newly formed lakes and marshes situated in desert. Sarykamysh Lake is the largest one collecting the water north-west of the lower reach of Amudarya River. It has an area of 3,000 sq.km and a volume of 26 cu.km. The dissolved salts content of its water is at the present 12-13 g/l. Another lake, Arnasai, is correspondingly 1,800-2,400 sq.km, 12-20 cu.km and 4-13 g/l. The Arnasai Lake collects water from the middle reach of the left bank of Syrdarya River. In the irrigated areas a new, ample network of the irrigation and drainage canals has been formed. The level of ground water has gone up drastically in many places due to the seepage. There, the salinization of soils is a real, big problem. Along the rivers, the ground water level has gone down due to the drop of the river water levels. The deltas of the two principal rivers have completely changed their regime and mostly dried up. Consequently, the unique ecosystems of the river valleys and the deltas have disappeared and many endemic species are under the danger of extinction.

Because of the agricultural returned waters the salinity in the Syrdarya and Amudarya progressively increases downstream. In the lower reaches of syrdarya the average salts content has changed from 0.8 g/l in 1960 to 2.8 g/l in 1985 and in Amudarya it has gone up to 1.7 g/l. Hence, though the rivers are currently the main source of water supply there, its quality does not meet the standards. In addition, the level of fertilizers application on the irrigated lands there exceeds 10-15 times the average for the whole of the USSR and a part of the fertilizers leaches down into the rivers. And even more, the level of pesticides application seems to be the highest in the world with the subsequent implications to the water quality in both the rivers and the Aral Sea. In the Autonomous Republic of Karakalpakya situated along the lower reaches of Amudarya, 118,000 tones of pesticides were used during the last two decades, or about 10 kilograms per person per year.

The hydrological consequences (hydrographic features, water resources and their quality) of the development strategy adopted thirty years ago could have been predicted and many of them were. Many other, mostly environmental, effects were more difficult to foresee. An aboriginous, to large extent endemic, fish fauna was adapted to the brackish water of the Sea because the fish has evolved from the freshwater species. It could survive 13 g/l but the higher salinity has killed all the fish. The fishery as the main occupation of the population around the lake has gone, along with the annual catch of 44 thousand tones of rare and valuable fish. People there have lost their main source of income.

Large changes have occurred in the environment. The direction, intensity and composition of the salts transport have modified considerably. The expansion of irrigation has lead to the increase of the salts movement mostly with the drainage run-off. N. Glazovsky (1990) has calculated that the salts transport in the Aral Sea basin has increased about two times and is now 118 million tones a year. During the last three decades a huge amount of three billion tones of salts were removed within the basin. Of this volume, 60 percent have accumulated in the nearby ecosystem, in small new lakes and marshes, 27 percent have gone to the two large new lakes, Sarykamysh and Arnasai, and only 13 percent came to the Aral Sea. Moreover, the transport of sodium, chlorine, sulfate and magnesium has increased much more than that of the other main ions like calcium or carbonate.

Wind erosion of the former bottom of the Aral Sea has increased greatly, from 50 to 360 percent in different points around the lake. The salts transport goes along with it taking away between 1,000 and 10,000 t/sq.km per annum. For the whole former lake bottom it comes to 40-150 million tones a year (Glazovsky, 1990).

Transport of salts with the drainage water, the wind and the groundwater together with the raise of the groundwater level leads to the progressive salinization of soils. Soils with a medium or high degree of salinization occupy from 35 to 80 percent of the irrigated areas in the Central Asia. The land losses due to water management activities there have reached 1 million hectares (Rozanov, 1984).

The environmental degradation, namely unacceptable drinking water quality, high salt contents of the air and, apparently, high level of the pesticides residues in the agricultural produce make direct impacts on the state of human health in the Aral Sea basin. The worst situation is where the above factors make the most unfavorable combination, that is in the lower reaches of the two rivers and around the lake.

In the lower reaches of Syrdarya River the morbidity has increased 20 times over the last 20 years. The infants mortality in a number of districts exceeds 110 per 1000, that is three times more than the average for the USSR and comparable with the figures for the least developed countries. The number of the cancer cases in the Autonomous Republic of Karakalpakya is 7 times the all-Union level. Over 90 percent of the population there suffer from anemia, the number being 60 times more than the average for the USSR. In the same

Autonomous Republic 46 percent of women have genetic disorders of different kind and in its capital, Nukus, the breast milk of all the 35 mothers sampled was unsuitable for feeding. Clearly, the area close to the lake is in the state of the environmental catastrophe and the whole of Aral Sea basin is no much better. The water level of the Aral Sea is, therefore, an indicator of the difficult socio-economic situation in its whole basin.

But perhaps, the pitiful state of the human health and the environment is compensated by remarkable achievements in the economy of the region? Not al all. The plans to convert the whole of Central Asia into the blossoming garden have failed. On the contrary, the region has been converted into the area of the cotton monoculture. The production quotas of cotton kept increasing over the years, though the export expectations were not fulfilled and even some cotton of good quality had to be imported to produce textiles. Though it has not been made public yet, there are indications that the important user of the local cotton was the military-industrial complex producing a solid fuel for missiles, gunpowder and alike. As in many other regions and cases, the decades-long military orientation of the country has brought disaster to that potentially prosperous area.

The yields and the total harvest of cotton were raising through 1960s and 1970s having increased almost twice, but from 1980 they are in decline due to the salinization of soils and the monoculture. The quality of the cotton produced is in general low.

Pesticides indiscriminately used and spread from the air over both the fields and the villages have made pronounced impacts on the health of the population. The earnings from the cotton, if they were, were not used wisely enough in the development of such social amenities as education and medical services. In addition, the students were forced to spend about two months collecting cotton at the expense of quality of their education. Not much has changed there during the last six years since the beginning of the reforms, or so called PERESTROIKA.

The region has the highest rate of population in the country but no new good lands supplied with enough water is available anymore. The developing irrigation could not absorb the growing population and the unemployment is high. Tensions between the neighboring nations grow. In a number of places the national boundaries drawn in 1920s do not adequately reflect the realities and any border change may lead to ethnic confrontation. The management of a large, multinational lake basin under these conditions would not be a simple task.

And yet, it is obvious now that the development strategy of the Aral Sea basin, which is the centre and the main part of the Soviet Central Asia, adopted thirty years ago was wrong. It has lead to the environmental catastrophe, may be the largest in the world. The strategy has proved to be unsustainable. The damage to the environment and the economy of the region assessed through the costs of the necessary corrective measures is at least 37 billion roubles (Glazovsky, 1990). A new development strategy for the Aral Sea basin is urgently needed.

The most urgent problem is an expeditious improvement of the environment for the population of the Aral Sea basin, in particular in the areas situated close to the lake. The water supply there is of the highest priority. During the last three years major pipelines of the total length of 1,900 km transporting water of acceptable quality have been built. About 300 desalinating installations have been put into operation. These actions have brought the water supply for 580 thousand people. Some improvements were made in the health service of the population. The use of aircraft to spread the most toxic pesticides is more restrained than before. Provision of food of good quality is also of high priority though a quick achievement of this goal looks dubious keeping in mind the difficult situation with the food supply in the country. The immediate actions like those mentioned above can alleviate somehow the life of the people there but would not solve the crisis.

The crisis can be solved only if the strategy of development is changed. A comprehensive, long-term programme of the land-and-water resources management should be one of the cornerstones of the strategy. It should contain such elements as dropping low productivity lands from irrigation, increase of efficiency of the irrigation systems, drastic reduction of water applied for a unit of cropland, diversification of crops and liquidation of the cotton monoculture, optimal use of fertilizers and pesticides, transition to the integrated pest management systems.

However, the strategy must go well beyond the modern land-and-water management programme. It should go to the roots of the catastrophe addressing principal social and economic problems such as the population control, the balanced ratio between the demand and supply of cotton, an appropriate structure of the crop and livestock production, development of the agricultural extension services, conversion of industry from the military production, considerable improvement of the social amenities including education at all levels and medical services. Much care should be devoted to the cooperation among the nations of the region in whatever political forms they may evolve as the only basis for the lasting, sustainable development of the rich territory which used to be called the Soviet Central Asia and where the Aral Sea basin has the central position.

It has been mentioned above that the deterioration of the Aral Sea is an indicator of the deep troubles developed in its basin. A special programme to save the Aral Sea would not reach a desirable objective while a long-term sustainable development strategy for the basin, if successful, would bring as a side effect a stabilization and even a raise of the lake water level.

Currently, however, a sustainable development programme for Central Asia is nowhere in sight. The social situation continues deteriorating and the water level of the Aral Sea keeps dropping. To stabilize it at the present level, one needs the inflow of about 35 cu.km a year. It is possible and even economically feasible to save this amount of water by implementing a part of the land-and-water management programme mentioned above. To stop irrigating 15 percent of the lowest productivity lands would save about 20 cu.km of water. Control of the water seepage from the canals and more efficient watering of crops would bring at least 20 cu.km more. One has to emphasize, however, that the technological actions must go along with the careful analysis of the socio-economic implications of such actions.

A very complex environmental catastrophe occurred in the Aral Sea and its basin is the lesson to be learned world-wide.

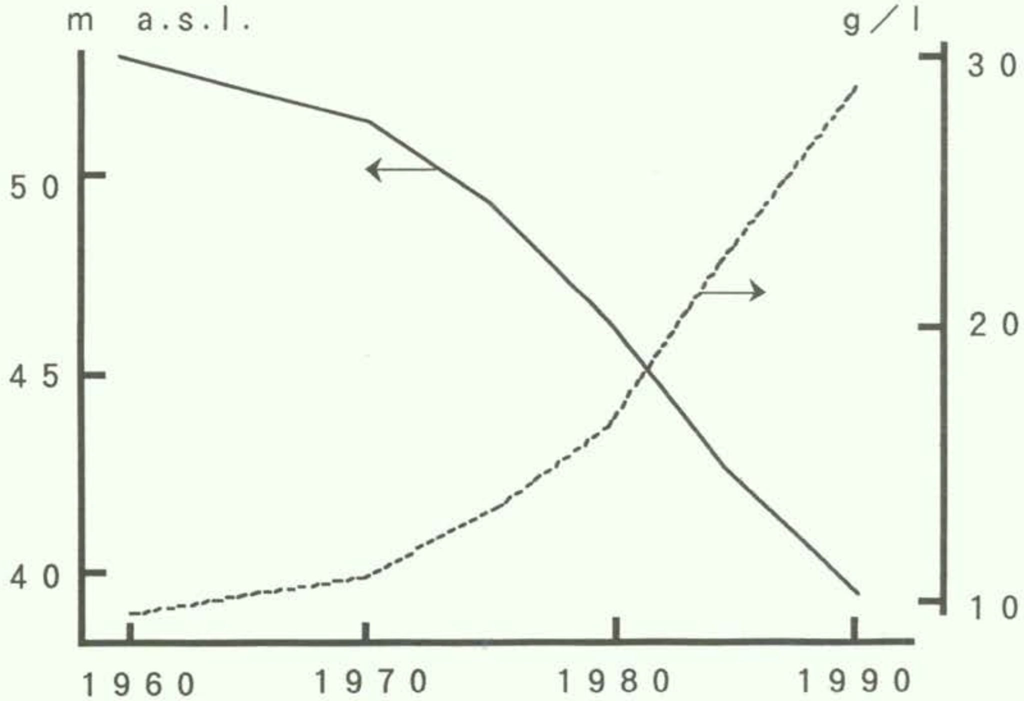

Figure 1. Aral Sea - the Water Level and Salinity

Lake Balkhash is a large and shallow lake in the south-east of Kazakhstan at 340 m a.s.l. Its area is around 18,000 square kilometers and the mean depth is only 6 meters. The western part of the lake where the main tributary, Ili River comes in is with fresh water, while the eastern part has brackish water with salinity of about 5 g/l. Upper part of the Ili basin belongs to China.

In the middle reaches of the Ili River there is Kapchagai Dam with a water reservoir. Withdrawals for irrigation both in the Chinese and the Kazakh parts of the basin together with the evaporation losses from the water reservoir are important factors in the decrease of the water inflow into the lake. The consequences are similar to those for Aral Sea, such as desiccation and deterioration of the river deltas, drop of the lake level and shrinkage of the lake area, increase of the water salinity, etc. The environmental deterioration, though, did not progress so much as compared with the Aral Sea.

While the other large lakes discussed in this paper are situated at low altitudes, the **Issyk-Kul Lake** is in Tian-Shan Mountains at about 1,600 m a.s.l. and is surrounded by the ice-capped ridges of 3,000 m and more above the lake level. The water is brackish with the salinity of about 6 g/l. Transparency of water is the highest measured in the USSR and the color of it is intense blue. No doubt, this very large lake (6,300 sq.km) is one of the beauties of the world.

Variations of the water level of the lake depend, first of all, on the regime of precipitation on the basin and the lake (Ozero..., 1978). From 1910 to 1969 the lake level fell down by 3.3 m though some smaller ups and downs have been observed during that time. From 1969 on, there was a continuation of the drop followed in the recent years by some increase of the water level. Human activity is developed mainly around the lake shore. The main consumer of water is irrigation which is developed in the Central and Western parts of the lake valley while the Eastern part has enough precipitation for rain-fed agriculture. It is doubtful that the withdrawals for irrigation play a considerable part in the regime of the lake.

The main environmental problems are associated with somewhat chaotic development of the basin. Rapid expansion of tourism is not accompanied by proper sanitation facilities. Some industry and agricultural activities also increase the water pollution. The shame is that the lake was used for a number of years as a navy test area and, hence, it was forbidden to address properly the environmental issues there. In spite of a large water volume (1,700 cu.km) the water pollution is spreading, being mainly in the coastal areas spoiling the beauty of the lake water.

The Caspian Sea is the largest lake in the world. Its area is about 400 thousand sq.km, the volume of water is almost 80 thousand cubic kilometers and the maximum depth exceeds 1,000 m. The water level is at an altitude of minus 26-28 meters. The basin of the Sea is 3.6 million sq.km.

The Caspian Sea basin has about 30 percent of the USSR population. Over 30 percent of energy is produced there, as well as a considerable part of the industrial and agricultural production. The lake itself is a source of fish including such valuable species as sturgeon. The Caspian Sea is the main, almost exclusive producer of caviar in the world. The navigation over the Sea and its principal tributary, River Volga is quite developed. There are oil fields both beneath water and near the shores.

The Caspian Sea can be divided into three main parts. The deepest southern part contains two thirds of the Sea volume. The middle part has about one third and the volume of the northern part with the depths not exceeding 10-25 m is about 1 percent of the total volume. Salinity of water changes from 13-14 g/l in the South to 1-2 g/l in the North where the main tributaries, Volga and Ural Rivers come into the Sea. Due to the shallowness of the northern part, the oscillations of the Sea level cause noticeable changes in the position of the shores.

The oscillations of the water level of this gigantic closed lake are quite considerable. There is much evidence of the large water level fluctuations in the historic past. During the five decades from 1880 to 1930 the level went down by about half meter. A very drastic drop in the water level occurred from 1932 to 1945 when it fell down by 1.85 m. This trend continued and by 1956 the water level dropped half meter more. The area of the lake decreased by 37 thousand sq.km, mainly at the expense of the shallow northern part of the Sea. The pronounced changes in the configuration of the shores could be very visible even on the small scale maps.

The drop in the water level brought many impacts on the economy and ecology. All ports had to be adjusted to the lower water level. The navigation canal in the Volga delta had constantly to be dredged. The fish spanning grounds reduced causing loss in the fish production. Salty deserts appeared in place of the lake bottom.

Between 1956 and 1978 the water level almost stabilized going down by only about 0.3 m more and reaching the point below minus 28.5 m. All sectors of economy adjusted to the new, low water level. There was, though, one major point of concern: a slight further drop of the water level by, say, 50-100 cm would dry out the main fish spanning grounds. That was the kind of a natural threshold below which a large and a valuable ecosystem of the Northern Caspian would virtually disappear.

The drastic drop of the water level was mainly ascribed to the expanding economic activities in the basin consuming ever more water. In 1973 the total water consumption in the basin was 29 cu.km a year or almost 10 percent of the total river run-off inflow and was undoubtedly to grow. It was believed that the regime of the water level and of the Caspian Sea water balance was practically completely caused by the economic activity in its basin (Shiklomanov, 1976). The forecasts gave a further considerable drop of the water level so that the Sea would be facing a major problem. Large-scale water transfers into the Caspian basin appeared among the main national water management plans (Golubev and Biswas, 1979).

However, the forecast proved to be wrong. Since the end of the 1970s the water level started to grow quickly exceeding the lowest level by about 1.5 meters. On the first of July, 1991 the level was minus 27.00 m. Apparently, the main reason for the growth was increased precipitation in the basin. The economy has to adjust again to the higher and still increasing water level. All the navigational facilities must be rearranged. Protection of the cities and other settlements are on the agenda as well as protection of railways and roads. Exploitation of the oil fields is also a problem.

Obviously, a stable water level of the Caspian Sea, no matter whether high or low, is the most convenient.

Much field studies on the Caspian Sea, some of them quite detailed, have been done during the last few decades when the lake was in different stages of its evolution. The results of these studies are very valuable now: the Caspian, due to the considerable water level increase, can serve as a large scale model to understand the natural processes and implications of the worldwide sea level rise connected to the climate change.

To sum up, the closed areas have a special set up of environmental problems where changes in the lakes serve as a good indicator of the natural and socio-economic processes in the basin. However, due to individuality of each lake and its basin the resultant problems are quite different from place to place. The study of the closed lakes of the world seems to be a promising area of further international research.

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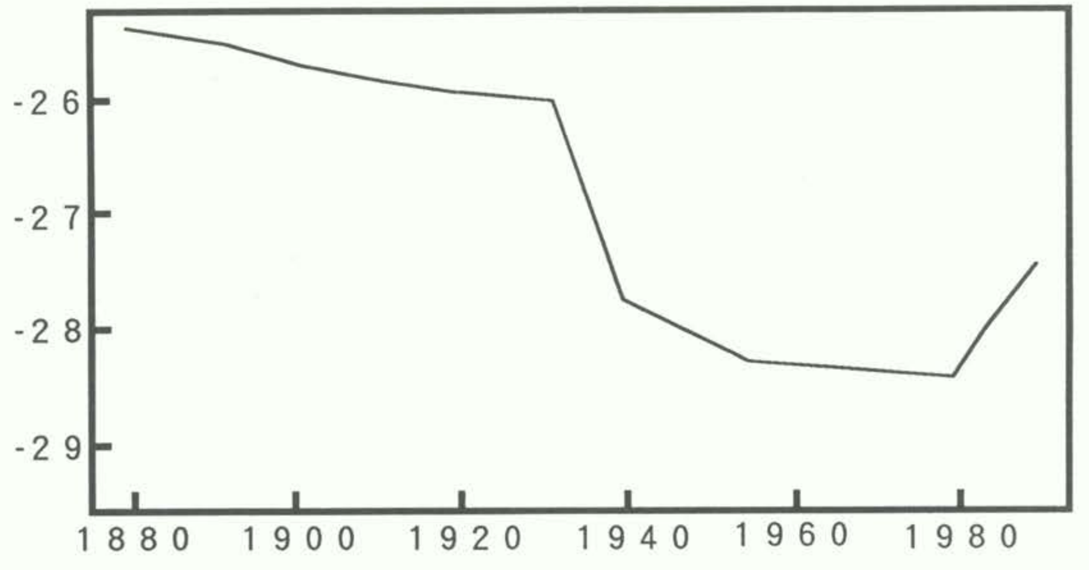

Figure 2. Caspian Sea - the Water Level

THE INTEGRITY OF THE ENVIRONMENT AND WATER MANAGEMENT CASE IN ARID AND SEMI-ARID ZONES IN AFRICAN SOUTH OF THE SAHARA

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1.INTRODUCTION

The integrity of the environment in the African arid and semi-arid zones, South of the Sahara, have been witnessing over the last two decades disturbing symptoms of degradation. The persistent drought spells that continue to hit the area have dramatized the situation to the stage of famine and collapse of the environmental fabric of the area. The state of population poverty in these areas and lack of basic human needs including food, water supply coupled with the absence of sound environmental management that characterized this fragile topical environment are directly responsible for this situation.

The anti-thirst campaigns launched in these areas during the late sixties and early seventies associated with growing population and animal pressures and ill - conceived plans to settle the nomads have brought with it critical environmental consequences as a result of tree felling, over grazing and exhaustive agricultural and land-use practices. These included loss of arable lands to deserts, declination of fertility and increasing food gap reaching the stage of famine and collapse of the system.

2.THE ENVIRONMENTAL FABRIC OF ARID AND SEMI-ARID ZONES

The patterns of the fabric of the arid and semi-arid areas should first be viewed within the total environment of the African continent and its ecosystems.(**Figure 1**.)

Africa lies almost symmetrically about the equator and apart from its northern tip and the cape region in the south it straddles the tropical and sub-tropical belts. This unique location have characterized the continent climate, vegetation sequences, soils and its socio-economic patterns and life styles.

Apart from the winter rain confined to the two tips, the continent rainfall is influenced by the arrival time, duration and intensity of the interconversion zone (ITCZ). This zone migrates annually between the tropics about six weeks behind the sun. As of this we observe near the equator (6°N to 6°S), the passage of the ITCZ twice a year resulting in distinct peaks of rainfall. Apart from coastal and topographical effects there is a clear distinction into zones of seasonal rainfall all running approximately parallel to the equator to the Sahara desert in the north and Kalahari desert in the south. The extent of the Saharan desert area, the largest in the world, is influenced by the land mass to the east, while the Kalahari is much restricted in area because of the coastal influence and the easterly rain bearing winds from the Indian ocean.

The zones outside the equatorial region are characterized by drought that last two, three and finally four seasons. This simple patterns of the annual rainfall show some departures especially in the eastern part of the continent, which is generally drier except in the extreme south. The high lands of Ethiopia, Kenya and Tanzania have some areas of relatively high rainfall on windward slopes and dry patches in the leeward slopes. Despite the regular annual migration of the ITCZ, it is to be observed that most rainfall comes in the form of heavy showers and have a very uneven distribution in both space and time.

Out of the estimated annual volume of rainfall in Africa of 20700 x 10^9 m^3, 87% of it occurs between 15°N and 20°S of the equator and 75% of this volume is lost by evaporation. About 90% of the run-off of the continent is restricted within 10°N and 20°S of the equator. An interesting feature to be observed is that north and south flowing rivers and streams to the arid and semi-arid zones constitute 19% of the total run-off. The north flowing rivers concentrate mainly in the Nile basin and constitute

4% of the total run-off of the continent. The Nile, the Senegal and the Niger and Lake Chad, are perennial sources of water, transcending the semi-arid and arid zones, the rest of the streams and wadies are seasonal running during the rainy seasons in spades resulting from the semi-arid showers and most of their flows are lost by evaporation or percolates away into the sand dunes and partly into deeper strata.

No quantitative evaluation of the ground water resources of the African continent can be ascertained due to the absence of adequate knowledge and data on renewable recharge which generally insignificant compared with the ground water storage. But generally aquifers with interstitial porosity exist in the extensive sandy areas, alluvial fill, coastal sedimentary basins and sand- stone formations. Aquifers with fracture and channel porosity exist in the limestone formations in northern Africa in addition to localized formations of little porosity.

Proceeding outwards from the evergreen rain-forest, the sequence of vegetation follow the trends of water deficiency and duration. We find the semi-evergreen rainforest, the Savannah grasslands, the semi desert vegetation and finally the desert.

The continent soil zones are very much influenced by climate, vegetation cover and topography. Tropical soils in the abundant vegetation areas particularly the evergreen rain-forest are low in nutrient cycles as the majority of the nutrients are held in the biomass rather than the soils. As long as the system remains closed, the nutrient cycle remains undisturbed. When the cycle is disturbed by forest clearance for farming, logging or over grazing loss of nutrient become very high.

Black cotton soils or tropical black clays are found in areas of low relief and associated with grass vegetation and they are not very fertile. These soils are common in the basin of the upper Nile.

In areas of less rainfall are a group of reddish - chestnut soils succeeded by reddish brown soils in the drier areas. The Sahara and Kalahari deserts are characterized by stony and sandy soils and include extensive deposit of blown sands. In many cases these soils revealed surprising fertility on irrigation.

It is to be observed however that the tropical soils are generally suspectable to erosion cycles associated with the climatic and topographic conditions. The erosion is emerging as a serious problem as a result of human and animal pressures on soil vegetation cover and deforestation.

The arid and semi-arid zones are shown in **Figure 2**. They are Sandwiched between the humid and desert zones. Assemblage is given in **Figure 3.** (Hecstra 1988 Productivity, Lessons from the Sahel). The arid zone have annual rainfall varying from 150-350 mm with 50% to 100% variability and the wet days range between 30 to 70 days. With this clear water scarcity the area is not suitable for crop production except in very limited land depressions which have some accumulation of sub-surface water. This zone is a potential area for wet season grazing by nomads and the soil is enriched by the animal cycle within it. The dominant animals include camels and long-eared goats. The traditional water management in this zone include the provision of shallow wells and man made ponds for catching rain water which are the only means for supplying drinking water as the dry season progress. These sources normally dry up before the start of the next rainy season. The settlement round these water points are temporary camping style settlements as the nomads conduct their movements to potential grazing fields.

Over the years and with the introduction of new water supply points particularly boreholes under the anti-thirst campaigns, this system started to break down. The camping style settlement, gradually changed into permanent village settlements. These in turn gradually expanded and subjected the system to increasing human and animal pressures beyond the resource capabilities including water, vegetation and tree cover.

The semi-arid zone is divided into three sub-zones. The dry boundary, the semi-arid zone proper and the humid boundary. The rainfall in the dry transitional boundary varies between 350-450 mm and the wet season range from 70 to 100 days and the rainfall variability range from 50% to 70%. Short cycle crops are generally cultivated in this zone including ground nuts, sorghum and water melons. Fallows are very common on these areas and the fallow-crop ratio is rather high (4:1) and extremely important for the maintenance of soil fertility. Timely sowing is important but there is always risks for repeated sowing due to high variability of the rainfall. This transitional area provides important grazing potential and settlement services centres for the

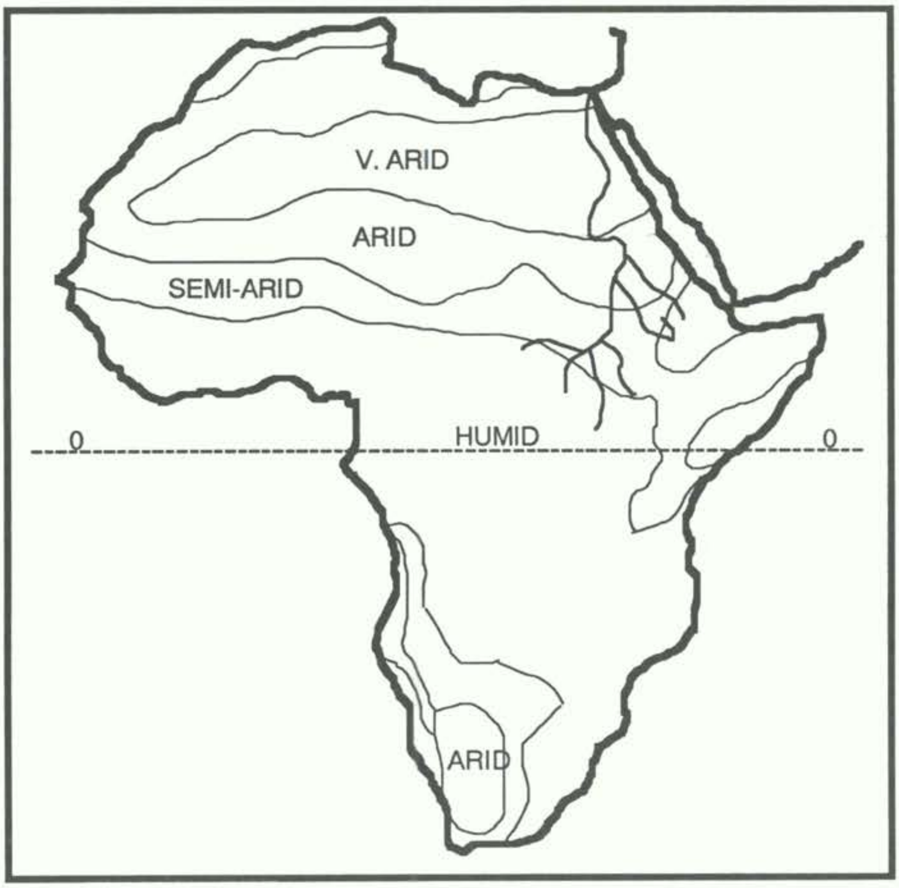

Figure 1. Africa - Arid and Semi Arid Zones

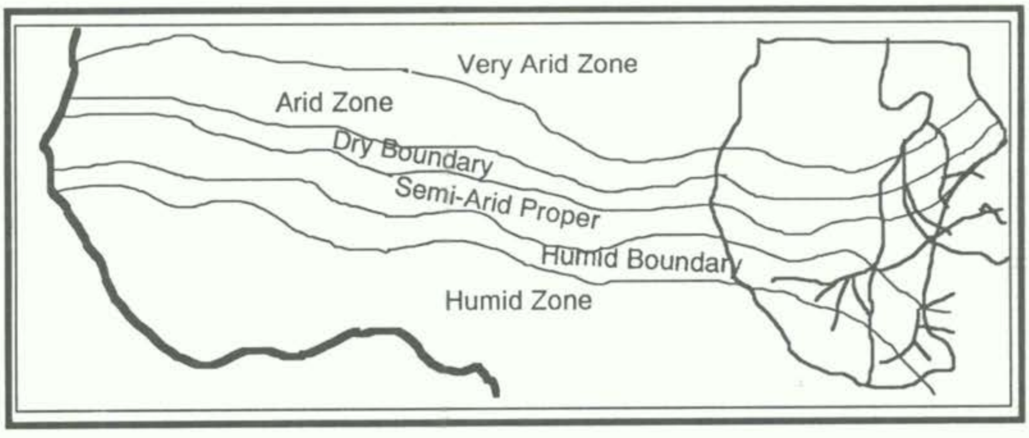

Figure 2. Arid & Semi-Arid Agro-climatic Zones

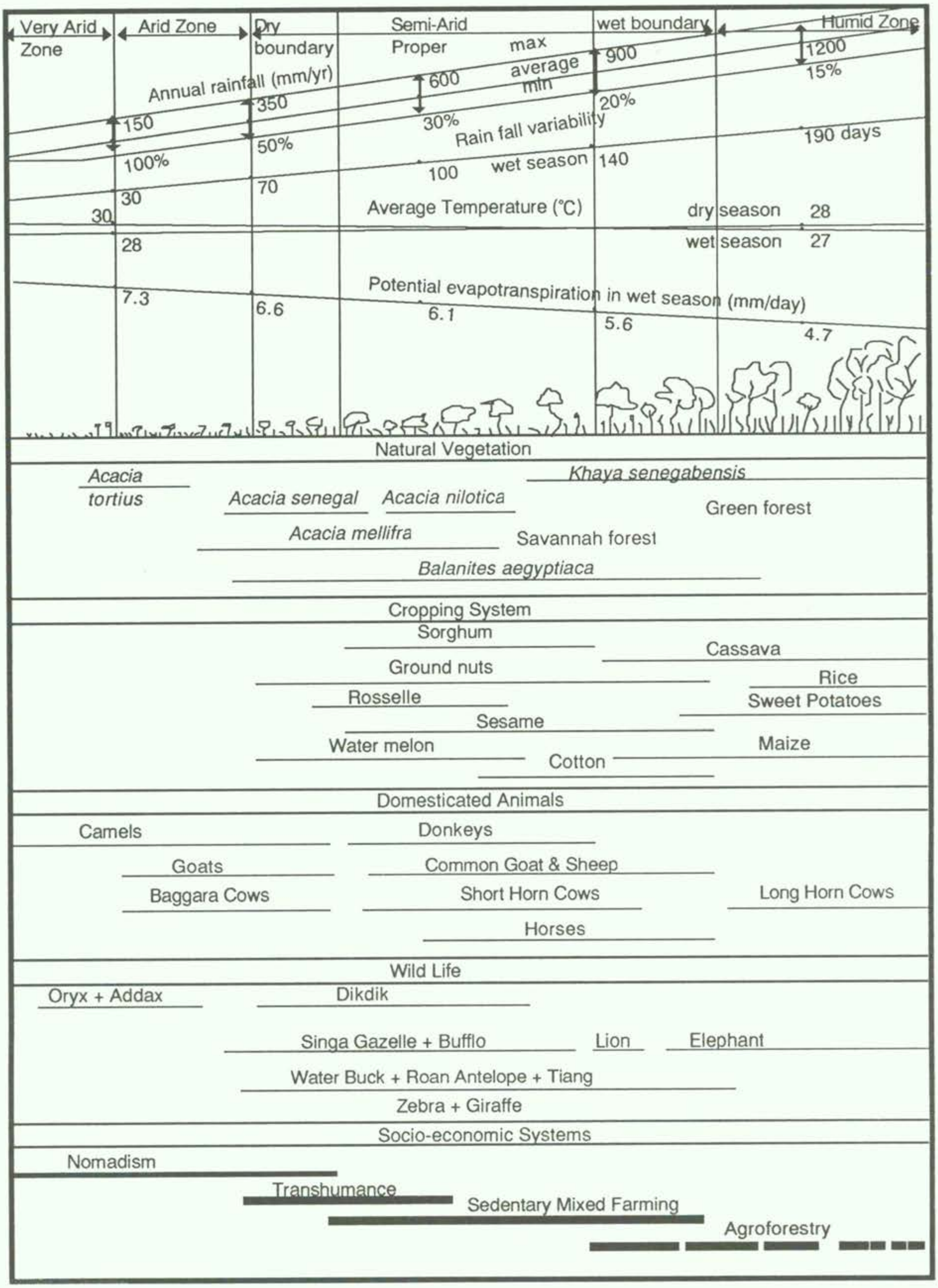

Figure 3. The Environmental Assemblage & Socio-economic Systems
Developed from Hekstre, G.P. (1985)

nomadic tribes including water supply and human and animal health centres.

The semi-arid area proper is the main area for crop production. The rainfall in this area range from 600-900 mm and its variability range from 30% to 50% and the wet season extend from 100-140 days. The crop diversification is high in this area and crop rotation is common and animal rearing is frequent. The crop rotation includes cereals + legumes or (cotton + cereals). The limitation to good yield is always caused by high variability of the onset and end of rains (Hecstra 1988). This area is characterized by sedentary and mixed farming settlements.

The transitional humid boundary of the semi-arid zone is characterized by rainfall ranging from 900-1200 mm and a longer rainy seasons extending 140-190 days and the variability of rainfall range from 15% to 30%. Crop cultivation is limited by excess rainfall. The soils are suspectable to erosion unless the surface is protected by adequate cover before the heavy rains start. Despite these measures the soils are generally lost by erosion. The soil fertility in this zone is a limiting factor and therefore timely sowing is extremely essential in order to make use of the limited amount of nitrogen fixed by soil bacteria and leguminous plants in the first phase of the rainy season. Irrigation is sometimes common in this zone for production of tropical crops including rice, sugar-cane and cotton. Unless the irrigation water is well managed and adequate and efficient drainage system is provided, the soil will show signs off water logging and salinification.

3.WATER MANAGEMENT

Water is the main factor in shaping the environmental fabric of the arid and semi-arid zones and require very careful management techniques and supporting measures to sustain the integrity of this fragile system. As was explained earlier the system is witnessing serious symptoms of degradation. To meet the increasing food gap in the area dictated by increasing population rainfed agriculture have spread beyond its safe limits into the dry boundary in the north and the humid boundary in the south. In the former the high variability of the rainfall and its short duration could not support crop production and the result of this trespassing of the limits led apart from the high risk, to depletion of soil fertility as a result of lower rotation ratio to which the area was subjected. On the other hand this agricultural penetration and the associated settlement patterns brought by it have deprived the soil from its vegetative cover exposing it to wind erosion and the spread of desertification and serious tribal conflicts as a result of these exhaustive patterns of land use that has been brought about by these penetrations.

The agricultural penetration into the humid boundary of the semi-arid zone deprived the soil from its tree cover and hence its nutrients as shift agriculture become very frequent and the soils are subjected to erosion.

The drinking water supply question in the arid and semi-arid zones is an important factor in the stability of the environment. The nomadic population of the arid zones face great hard-ships to reconcile between water availability and grazing areas. Traditionally they utilize the water that remain in depressions along the grazing routes immediately after the rainy season and the sub-surface water in those depressions or wadi beds, or revert to shallow wells and man-made haffirs (ground dug tanks) in the semi-settlement areas in the dry boundary of the semi-arid zone as the dry season advance. Late in the dry season when the water and pasture are almost depleted, they trek with their herds deeper to the boundary of the humid zone.

The population of the proper semi-arid zone undertaking crop production used to depend on meagre traditional water supply system comprising rainwater harvesting in depressions or man-made haffirs and shallow wells. While the water supply at older times was a major constraint to agriculture production during harvest, but these people with that optimum size of their population were able to strike a balance with their fragile environment. It is to be admitted however that such realized balance was on account of an extremely low quality of life and lack of basic human needs and prevalence of rural poverty.

On the wake of the independence of many African nations attempts have been made to improve the water supply systems in the arid and semi-arid zones and the general well being of the rural population. But unfortunately such attempts as explained earlier have negative consequences and ultimately led to the conditions we are witnessing today.

4. ENVIRONMENTALLY SOUND MANAGEMENT OF WATER RESOURCE

Traditional water management and development approaches and technologies can no longer provide sustainable development within the arid and semi-arid zones south of the Sahara, nor realize the integrity of their fragile environment. Water management can no longer be undertaken in isolation of the components of the environment and must therefore be an integral part of the total environmental management package. This package of sound environmental management of water resources have the following basic elements.

i) Environmental assessment.
ii) Environmental management.
iii) Supporting measures.

4.1. Environmental assessment

An understanding of the characteristics of arid and semi-arid zones is a key element in the environmental assessment process in general and the water resources assessment in particular. The climate in arid and semi-arid zones is characterized by an abundance of solar energy, cloudless skies, high diurnal and seasonal temperature variations and annual and inter annual irregular rainfall with long dry seasons. The soils in these zones as a result of these climate conditions, are characterized by large variations in soil moisture, ground water storage and high infiltration rates. Dominant feature of these soils is their suspectability to erosion and degradation by wind, water and human activities. The vegetation in the arid and semi-arid zone by its extent from the boundary of the humid zone and the dry boundary of the desert proper vary from evergreen rain-forest the subtropical vegetation which finally grade into the Savannah the grass lands and the thorn bush of the semi-desert. These vegetation variations are directly related to the water availability.

This unique environmental fabric is interwoven with various patterns of socio-economic activities ranging from agro-forestry in the humid boundaries of the semi-arid zone, to settled agricultural communities and finally the nomadic and migratory socio-economic system. These human settlement styles are not well defined compartments but are characterized by seasonal penetrations up and down the zone in relation to the hydrologic regime of the area and the complex and acute land and water uses problems.

Therefore the water resources assessment process become essentially an integrated environmental assessment process in which the water resources systems play a dominant role.

4.2. The environmental management

The environmental management of the water resources follow from the environmental assessment function and essentially based on its findings. The management objectives should clearly be defined which mainly aim to realize the optimum water resources utilization for the well being of the arid and semi-arid societies in complete harmony with the environmental fabric of the area.

These include introduction of management techniques and technologies for conservation and rational use of the water resources systems in those zones compatible with the complex human, animal needs and with minimum harmful consequences on the fragile environmental system of the area. These set of management activities range from the whole zone level to project level and be essentially undertaken by and from the whole societies level of the zone to the individual level or the "end-user".

At the whole zone level the management activities include :

* Formulation of conservation and land and water use strategies and policies compatible with the environmental system of the zone to realize sustainable development.

* Devising land use practices, water shed management techniques, soil conservation measures and formulation of development patterns appropriate for the environmental conditions of arid and semi-arid zones.

In this respect concerted efforts will be required to create buffer zones at the humid and dry boundaries of the semi-arid zone by devising special land use practices and providing water supply and other basic services to limit the degradation that is taking place within the zones as a result of the uncontrolled penetration and destructive practices prevailing.

* Formulation of zonal and local programmes including guidelines and

standards for the management and control of agricultural and range land practices to combat desertification and coordinate efforts concerning land-use practices in relation to drought control and preparedness for prevention and mitigation of natural hazards.

* Development of water resources to meet the demands for water supply, irrigation and other basic needs compatible with the hydrologic regime of the zones.

* Development of monitoring and evaluation system for quantity and quality control of the water resources and control of supply and demand particularly from groundwater resources system to guard against depletion and deterioration of quality.

* Undertaking intensive human resources and manpower development programmes and encourage "end user" of water to participate in the planning construction and maintenance of their water systems.

At project level whether it is water supply, irrigation or rainfed project and pasture a full understanding of the zone environmental fabric in which the project is founded is an essential pre-requisite for the development and management of the project. The management activities at project level include inter alia.

***Water supply projects**

The drinking water supply systems prevailing in the arid and semi-arid zone have been in most of the cases planned and implemented in isolation from the consideration of the fragile environmental system of those zones. The result as explained early a complete collapse of the environmental balance in the form of tree felling, exhaustion of the vegetative cover and advance of the desert and soil erosion as a result of the population and animal pressures on the water supply points and the settlement centers that emerged around them.

The sound environmental water supply management and development at of drinking water supply system along traditional grazing and pasture routes to promote nomadism as an essential cycle in realizing the environmental integrity of the pasture lands and control the penetration and settlement of the nomadic population into the crop production areas in the semi-arid zone and abandonment of the nomadic style of life.

***Rainfed agriculture projects**

Rainfed agriculture is traditionally the dominant subsector of food production in the semi-arid zone south of the Sahara. With the persisting drought spells that have hit the area since the seventies and the increasing food gap, the rainfed agriculture have trespassed the dry and humid boundaries of the semiarid zone resulting in critical environmental consequences explained earlier.

The sound environmental water management activities in this respect could include formulation of agricultural techniques compatible with the soil conditions and the rainfall characteristics. In the dry boundary of the semi-arid zone where the wet days are rather short (70-100 days) adequate fallow system for maintaining soil fertility need to be adhered to, together with good land preparation practices to conserve soil moisture for production of limited short cycle crops safely without detrimental environmental consequences.

On the humid boundary of the semi-arid zones where the rainfall range between 900-1200 mm, the risk of flooding and soil erosion are the main constraints to crop production. The water management techniques could therefore aim to provide good drainage systems and adequate soil cover to combat soil erosion. Timely sowing before the on-set of the heavy rains is essential to establish good cover to reduce the risk of soil erosion and for maintaining the soil fertility.

In between these two boundaries lie the semi-arid crop production zone proper. The main limitation to realize good crop yields is the high variability of the onset and end of rain. This risk could be mitigated by formulation of a set of principles and guidelines for sound water management including improved forecasting systems, good land preparation techniques to improve soil moisture, timely sowing, providing drought resistance seeds and finally providing supplementary irrigation, through adequate irrigation storage infrastructure and conveyance systems. These measures are vital to sustain soil fertility and their potential production level to realize sustainable agriculture.

***Irrigated agriculture projects**

In the arid and semi-arid zone south of the Sahara, where there is adequate perennial water bodies (rivers and lakes) vast areas have come under irrigation (Egypt and Sudan). While these irrigated areas are contributing significantly in food and fibre production and social and economic well being, many negative environmental consequences have emerged. Apart from the health hazards associated with irrigated agriculture these consequences include water logging and salinization, loss of soil fertility, and waste-full irrigation water application. The prevailing irrigation efficiencies range from 50% to 60% which are extremely low. Therefore the environmental management should aim at raising the water use efficiency.

4.3.The supporting measures

A number of supporting measures are essential to undertake sound environmental water development and management. These include inter alia :-

* Environmental legislation.
* Institutional system.
* Information system.
* Manpower Development.

i.The environmental legislation

Formulation of the legal framework for sound environmental water development and management is extremely important in the complex conditions in the arid and semi-arid zones. Such frame- work should not over look the traditional and tribal heritage in this respect for resolving acute water use and pasture conflicts and should essentially build over it to ensure its enforcement.

The legal framework for water management should also be an integral part of the land use law to give it a comprehensive dimension and insure integration of environmental consideration in the planning, development, construction, operation and rehabilitation of water projects for the utilization of the water resources for the well being of the zone societies and their diversified needs.

Proper machinery should be created for the implementation of the legislation.

ii.The institutional system

The existing water institutional systems that have been established over the decades suffers from a number of ills. These include professional biases particularly the engineering bias and narrow approach lacking the broad environmental outlook. They generally suffer from lack of coordination and their functions are overlapping and in many instances conflicting. Therefore the present institutional system will not be capable to undertake environmentally sound development and management of water resources. It will be futile to suggest dismantling of such deep rooted systems and it will take long time to damp the professional arrogance within them. It is to be admitted however that in recent years these institutions responded to a certain degree to the pressures from different circles to concern themselves with the environmental consequences that emerge from their engineering and technical endeavors in the development and management of water resources.

Pressure circles like technical assistance, funding and aid agencies from outside the countries could be a vehicle to such concepts and influence some restructuring of the institutional system.

Internal pressure circles in the form of voluntary environment protection committees which came into being in a number of developing countries are still in their infancy and ceremonial. They have no force to make pressure and in many instances they lack support of governments and communication with the public. The environment movement in developing countries (Particularly in Africa) is still very weak. The environment pressure still dominantly from foreign circles and reach the developing countries through the funding and aid agencies. Those bring highly sophisticated ideas and approaches not compatible with the institutional capacities nor the general conditions in many developing countries. Therefore the mobilization of indigenous environmental pressure groups are extremely vital for water resources management and development in the arid and semi-arid zones.

iii.Information system

In many developing countries the information system is extremely deficient. In between institutional systems information communication is lacking and hence coordination. Information which is vital for public awareness and hence their effective participation is very deficient.

For "environmental sound management and development of water resources" information as a support measure is extremely vital. It is therefore important to strengthen the information system to provide this basic services to target audiences to promote public awareness on the concepts of sustainable water development and enhance their effective participation in the different phases of management.

iv.Manpower Development

As explained under the institutional system, the water management in many developing countries is dominated by engineering biases and attitudes lacking the broad environmental outlook. To enhance the capability of those existing institutions, and enable them to undertake environmental sound management of water resources, intensive training and re-orientation of education is necessary. Education in the principles of conservation protection and development of the human resources need to be provided at different education levels and intensive training on the principles of sound management would be needed.

5.STRATEGY FRAMEWORK

In front of these fundamental environmental challenges in the arid and semi-arid zones south of the Sahara the formulation of new strategies become a vital issue to realize sustainable development and ensuring the integrity of the environment. Water related issues are fundamentally intertwined with most sectors in the economy and water cannot be seen as a sector of its own but essentially in the context of the total environmental fabric. It is therefore important that water strategies :-

* Should be truly multi-sectoral in character and integrated with the broader economy. The agriculture in the arid and semi-arid zones remain the primary sector for economic growth and major consumer of water and hence the pivotal role of water issues for sustainable agricultural development.

* The strategies will have to provide the necessary balance between the short-term and long-term perspectives. Measures will need to be found in terms of food supply and energy in the poverty stricken areas to combat the environmental degradation and destruction to the resource base. the long term needs of the increasing population need to be address taking into consideration, the natural resource base capabilities to support the increasing life support systems.

* Integrated soil/water management need to be taken as the pivotal issue in the new strategies to avoid water related land fertility degradation of soil and ensure sustainability of yields and production levels. Water use efficiency in scarce water areas becomes very crucial to meet the increasing population demands. The aim will be to do more with little and maximize productivity per unit of water.

* Finally the strategy should aim to restructure the institutional systems to undertake the task of environmentally sound management of water resources and enhance the scientific and technological capacities for renovation and adaptation of technologies to the conditions of the arid and semi-arid regions.

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WATER QUALITY MONITORING AND MANAGEMENT OF THE GANGA

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1. With rapid urbanization and industrialization in India, pollution loads released into the river channel at the points of industrial and urban centres have been fast increasing. The rivers which normally had clean waters throughout the year, have progressively started showing signs of deterioration in the quality of water. Foreseeing the adverse socio-economic impacts from such a trend, increasing attention is getting focused during the last three decades on the various issues associated with the monitoring and management of the water quality of the Indian rivers.

Water Quality Survey Network

2. Water quality survey network on the Indian Rivers was established initially by the Central Water Commission (CWC) in early 60s and then gradually expanded by CWC and other concerned agencies together to provide greater number of monitoring stations, to cover more streams and to report more parameters. By now, CWC alone has 272 number of water quality monitoring stations of different grades in the country as a whole. In addition, there are about 450 stations operated by other central and state agencies also.

3. In the Ganga basin alone, CWC carries out hydrological observations including water quality measurements at 122 stations on 57 different streams. At each one of these 122 stations, samples are collected for chemical and physico-chemical examinations. Samples of the ground water are also collected from near-by well for analysis. These samples are analyzed at one of the 9 water quality research laboratories established by CWC in the Ganga basin. In addition to the daily river discharge and suspended sediment load, 24 parameters as listed below are analyzed

1. Temperature	13. Iron
2. Velocity & Flow rate	14. Aluminium
3. Turbidity	15. Boron
4. Total dissolved solids	16. Carbonates
5. Specific Conductivity	17. Bi-carbonates
6. pH	18. Chlorides
7. Sodium	19. Sulfates
8. Potassium	20. Nitrites
9. Calcium	21. Fluorides
10.Magnesium	22. Dissolved Silica
11.DO	23. BOD
12.Gauge Level	24. Nitrates

Criteria for Selection of Network Stations

4. The following criteria have been used to locate key stations for water quality observations:

i) To have Stations associated with major urban and industrial centres.
ii) To locate Terminal stations on tributaries for distinguishing pollution contribution of tributaries/sub basin.
iii) To ensure at least one station each on major streams upstream of the confluence so as to obtain information on the background water quality.

Objective of Water Quality Monitoring

5. A systematic project for developing the data base regarding the quality of the waters of the river Ganga was initially taken up in 1978 and carried through over a period of seven year (78-85), resulting into a formal report under the title of Water Quality Studies - Ganga System - Status Report (1978-85) published by CWC in 1987.

The objectives of the study on the flow of pollution loads in the Ganga river were as under:

i) Compilation of the base line water quality data in various river reaches.
ii) Regular assessment of the quality of surface waters in different river reaches in terms of inorganic, organic and biological pollutants flowing from time to time and effects of industrial and domestic wastes on the water quality of the rivers at the receiving ends.
iii) Studies on the seasonal and temporal trends of variation in the chemistry of surface waters as compared to the base line datum level.
iv) Evolving mathematical models relating to the hydrological and water quality parameters for water quality simulation with pollution abatement and flow rate prediction.
v) Microbiological and bacteriological examination of river waters at critical points around densely populated areas.

The data from this work and the report on "Basin sub basin inventory of water pollution - The Ganga basin - Part II" published by Central Board for the Prevention and Control of Water Pollution in 1984, provided a proper insight into the behavior of Ganga in respect of quality of water and laid the foundation for the 'Ganga Action Plan' (GAP) launched in 1985. The observations on the quality of water have been continued thereafter in more elaborate manner and they provide valuable information about the impact of the clean up actions initiated under the said plan.

Water Testing Laboratories

6. A three tier system of quality testing laboratories have been set up by the Central Water Commission.

Level I laboratories are the simple field sediment measurement laboratories located at the hydrological stations. They are equipped with in situ monitoring instruments, different types of sampling devices, special glassware and stocks of essential chemicals. 17 such laboratories existed along the Ganga river in 1978-79.

Level II laboratories were originally set up at the divisional headquarters of the field hydrological organization and are equipped with refrigerators, BOD incubators, DO meters, spectrophotometers and other analytical appliances. They receive samples from the field gauging stations.

Level III water quality laboratory was developed at Varanasi (the main center of water quality analysis work in the Ganga basin) for undertaking analysis of trace and toxic elements, bacteriological and microbiological analysis and monitoring. The laboratory is well equipped with sophisticated analytical instruments like atomic absorption spectrophotometer, UV Visual Spectrophotometer, ultramicrobalance, DC Polarograph, Precision Carlzeiss microscopes with photographic attachments and other laboratory facilities like inoculating chambers, high speed centrifuge, colony counters, autoclaves, Magnetic stirrer & Deep freezer. This laboratory also supervises, compiles and analyses all the water quality data pertaining to the Ganga basin being collected by about ten additional well equipped laboratories of Level II Status.

Sampling Sections

7. Sampling for determination of water quality parameters was carried out at each of the 17 stations at two sampling sections, one located at the upstream of the reach and the other at the downstream of the reach, receiving the waste water. The difference in the measurements at the two sections indicates the impact of the wastes admitted into the river flow in the river reach between the two sections.

Extent of Sampling

8.

i) One sample at each of the U/S and D/S sections was collected in pre-rinsed polythene bottle at 0.6 depth from the main flowing portion of the stream, using a point sampler, for detailed chemical examination, at a frequency of once in ten days.
ii) One additional sample each from the main flowing portion of the stream at U/S and D/S location was collected at 0.6 depth for estimating trace heavy metals on the first working day of every month.
iii) Three samples were collected at 1/3, 1/2 and 2/3 width of the river at U/S and D/S sections from a depth of 1 m below surface for in situ determination of pH, Specific Conductivity, Temperature, dissolved oxygen and color at a frequency of once in ten days.
iv) Requisite number of samples at 1/3, 1/2 and 2/3 of cross-sectional widths at U/S and D/S reaches were collected for the estimation of Bio-chemical Oxygen Demand at selected eleven stations (out of the total 42 stations) at a regular frequency of once in a week.
v) Intensive surveys for longitudinal dispersion of organic pollution ($^5BOD_{20}$

tests) below the outfalls of various waste water drains were carried out at 5 selected stations on the main Ganga river twice a year, once during the critical premonsoon months and again during the post monsoon period.

vi) Point velocities and depths of river at each sampling spot were simultaneously determined.

vii) Investigation on bacteriological, microbiological studies and identification of species diversity and richness index/intensity were carried out during the final stages of the project at selected stations, namely, Allahabad, Varanasi and Kanpur on Ganga and Delhi, Mathura and Agra on Yamuna.

New Biomonitoring programme is expected to commence from 1991.

Water Sampling

9. All the samplings were carried out generally keeping in view the standards laid down by the World Health Organization using prescribed devices specific to various parameters. Sampling devices like point samplers, Dissolved Oxygen Samplers, Plankton Samplers were deployed. Direct measuring instrument and probes were used at major stations for in situ measurement of DO, pH, Sp Conductivity and temperature. A large number of water quality parameters allow limited holding time for analysis. Since the level II Water Quality Research Laboratories are evenly distributed over the basin and along the main Ganga stem, it is possible to transfer the samples collected at various stations to the nearest level II laboratory within a span of 24-48 hours. Samples for BOD determination and biological samples are transported in ice boxes within 6 hrs. of collection. Special messengers are employed for transporting the samples to level II and level III laboratories following a rigid time schedule.

Time Series Data

10. For the station having a sampling frequency of once in a month, a time series for various parameters could be developed over the years of observations. Trend equations between time component X and Water Quality Parameter Y have been statistically computed in respect of different chemical parameters. The stream flow comprises 3 major components; namely surface run off, inter flow and base flow. The quality of water depends on the aggregate flow volume, flow velocities in the respective reach, sediment concentrations, temperature and associated DO levels, BOD loadings from waste effluents and activities of aquatic life. Interaction, between sediment and solution phase also results in absorption, ion-exchange, co-precipitation and chelation mechanisms. Some compounds are also released depending on pH value. Similarly plant nutrients, like nitrites, phosphates, potassium etc. also vary due to release and uptake by aquatic plants, weeds and micro-organisms. These processes lead to spatial and temporal variations in the quality parameters of river water.

Assimilation Capacity

11. Disposal of raw municipal waste waters is found to be the prime factor for water pollution of Ganga river. In the upper stretches of Ganga the turbulence and flow of water facilitates speedier aeration from atmosphere and the reaction scenes of the entire reductive and oxidative processes are carried down the stream to a substantial distance. But during lean flows in summer months, the reductive process is faster and predominant because of lower dilution of pollutants and slower rate of aeration from atmosphere at higher ambient temperatures. During high floods, the oxygen supply being abundant and coupled with a large dilution of pollutants by volumes of oxygen-rich water, the reductive process is soon over. The level of pollution and the affected stretches therefore vary considerably from season to season depending upon the hydrological and climatic factor.

12. In situ surveys of the kinetics of biochemical decay process and the associated rates of depletion of dissolved oxygen in the longitudinal stretches below the entry of effluents into the streams were carried out twice a year -- once each during the premonsoon and the post monsoon period providing DO and BOD profiles along the longitudinal reaches of Ganga at Kanpur, Allahabad, Varanasi, Patna and Hathidah. Experimentally determined values of critical DO deficits, critical distances and the critical travel times (time of passage) under varying stages of rivers and ambient conditions as revealed from these surveys have provided useful information for computing the aeration and deaeration constants of the reaction process and further evaluation of the self purification factor of the river.

13. From the observed data the deoxygenation rate constant K_1 was evaluated using the exponential relation:

$$K_1 = \frac{1}{\Delta t} \log \frac{L_A}{L_B}$$

where L_A and L_B are the ultimate first stage BOD value in mg/liter at U/S and D/S location on the longitudinal BOD profile and Δt is the travel time in days between the U/S and D/S locations. The reaeration rate constant, K_2 was worked out from Streeter Phelp's (1) model:

$$K_2 = K_1 \frac{\bar{L}}{\bar{D}} - \frac{\Delta D}{2.303 \Delta t \bar{D}}$$

where $\bar{L}$ is the average ultimate BOD of U/S and D/S locations, $\bar{D}$ is the average in situ DO deficit of the U/S & D/S location. ΔD is the difference of oxygen deficit between U/S and D/S locations. The values of K_1 and K_2 were corrected to the observed river water temperature by the relations:

$K_1(T^oC) = K_1(20^oC)\ 1.047^{(T-20)}$ and
$K_2(T^oC) = K_2(20^oC)\ 1.024^{(T-20)}$

The self purification capacity 'f' of the stream is the ratio of reaeration and deoxygenation constant:

$$f = \frac{K_2}{K_1}$$

The statistical values of 'f' were then utilized for predicting critical DO deficits by the Streeter Phelp's model:

$$\log D_C = \frac{1}{f} \log L_A - K_1 t_C$$

where D_C is the critical DO deficit at the sag point on the DO profile and t_C is the critical time of travel from the point of entry of waste waters to the DO sag point.

14. Average values of critical parameters, aeration and deaeration constants and self purification factors as derived from a number of longitudinal surveys for the five stations on Ganga during the period 1978 to 1985 are summarized in the table given below:

Table 1

Station	Distance from Hardwar km	Critical time of travel between U/S & D/S location	Critical DO deficit in mg/l D_C	Deoxy genation constant K_1 per day	Reaeration constant K_2 per day	Self purification factor 'f'
Kanpur	570	0.264	82.4*	4.73	34.91	7.38
Allahabad	820	0.105	8.93	3.67	48.20	13.13
Varanasi	1020	0.278	3.90	6.07	48.07	7.92
Patna	1330	0.278	2.78	1.40	1.92	1.37
Hathidah	1430	0.461	0.52	1.68	3.20	1.90

* D_C greater than saturation value of oxygen in water at ambient temperature

The critical parameters would vary from season to season. High ambient temperatures and lower discharges during summer months accelerate the carbonaceous decay process yielding high BOD values due to rapid amortization. Low velocities during summer months however result in an earlier occurrence of DO sag point. Additionally, the solubility of oxygen in water at the prevailing temperatures during summer months being lowered, the BOD and DO ratio of the stream becomes critical.

15. Lower temperature and relatively higher velocities prevailing during the post monsoon seasons carries the reaction scene to longer distances below the effluent outfalls. On account of slower reaction rates and higher solubility at the ambient temperatures, the dissolved oxygen sags are not as steep during the winter months as those obtained during summer season. Another important observation revealed by the average values of aeration and deaeration constants is their unusually high values in the case of Kanpur, Allahabad and Varanasi. Ratio of fresh water to waste water i.e. the dilution available at Kanpur, Allahabad and Varanasi during the non-monsoon period is unfavorable. Due to the combined storm water and sewage drains in the urban centres, solid fraction both

degradable and non-degradable is also extremely high.

16. Very high amortization rate in the river just below the outfall of drains as reflected by high K_1 values is largely due to the settling of solids to form sludge piles in the form of small delta on the river bed. The sludge deposits progressively grow into piles, the lower portion of which decays into benthal material. The extent of accumulation in the sludge pile depends upon the prevailing and preceding flow patterns in the river channel which control the solid deposition. It was seen that during low flows when the prevailing velocities in the deposit areas are not greater than 0.18 m/sec. the sludge pile generally attains equilibrium in a matter of 40 to 50 days.

Cross Sectional Variations

17. From a study of the spatial variation of BOD values carried out at Kanpur, Allahabad, Varanasi, Hathidah and Patna; it was seen that the present sampling practices are not adequate to reflect the true picture of the water quality both lateral and vertical. It was therefore found necessary to prescribe revised and improved standards for collection of water samples as indicated in **Table 2** below. Considering the experimental data collected by the Central Water Commission on the spatial variation of water quality parameters in natural rivers, a procedure was evolved for Water Quality Monitoring. The revised procedure was subsequently endorsed by an Expert Committee headed by Dr. M.A. Chitale, Secretary, Ministry of Water Resources, which was constituted in connection with the Ganga Action Plan. The Report of the Committee was accepted by the Monitoring Committee of GAP in their 12th meeting held on 21.11.1989. These have been adopted since January 1991 for all the stations operated in the Ganga basin and also serve as a model for the work on the other rivers in the country. Based on this experience, there is a case for laying down international standards in this respect, so that information on the status of water quality from different rivers in the world can be properly compared.

Table 2

New Standards for the Pollution Monitoring Programme

Items	Practices adopted upto December 1990	New standards adopted since January 1991
1. Location	U/S and D/S of the potential source of pollution	U/S and D/S of the potential source of pollution i.e. town/industry. In addition two more cross sections may be selected D/S of the pollution source to monitor the cross sectional dispersal
2. Normal Sampling		
(i) Position Along Section		
a) Trace Heavy Metals and Chemical examination	One sample from mid-stream of the river at each section	At least at three places, 1/3, 1/2 and 2/3 width of the river at each section
b) pH, conductivity, temperature, DO, BOD, color, etc	From three places i.e. 1/3, 1/2 and 2/3 width of the river at each section	No Change
(ii) Position of sampling point along the vertical	At 0.6 depth from water surface	No Change
(iii) Frequency	Once in ten days	No Change

Items	Practices adopted upto December 1990	New standards adopted since January 1991
3. Special Sampling		
(i) Longitudinal survey for DO, BOD and chemicals and other pollutants	Twice a year, once before the monsoon season from U/S point to the D/S point till the dissolved oxygen gets fully recovered. Samples are taken at a distance of not more than 1 km.	Thrice in a year, once before the monsson season, once after monsoon and once during the low flow period. Longitudinal surveys should be conducted during any apparent heterogeneous distribution of pollution loads in the rivers. The samples will be taken along the river at a distance not exceeding 1 km.
(ii) Detailed sampling at each cross section due to heterogeneous distribution of pollution loads in the cross-section	Detailed surveys for DO, BOD, are done occasionally	Full cross sectional sampling should be done, at least three times in a year before the beginning of every season. In addition, in case of apparent heterogeneous distribution of pollution loads, full cross-sectional sampling should also be adopted. The sampling position should be as under:

Width of the river vertical	No. of verticals along the width of the river	No. of points in each verticals
<20 m	3	surface, 0.3, 0.6 & 0.9 depth
20 m to 200 m	4-8	-do-
200 m to 500 m	8-12	-do-
>500 m	15-20	-do-

Items	Practices adopted upto December 1990	New standards adopted since January 1991
4. Velocity and silt measurement	Measured regularly everyday according to Indian Standards	Flow characteristics like velocity, depth, discharges and sediment should be accurately measured in different segments every day according to IS:4890-1968 and S:1192: 1981.
5. Method of sampling & equipment needed	Samples collected by bottle samplers with the help of boat/motor launch	Normally point integrating samplers will be used. However the samples are to be collected at more than one point in a vertical, depth integrating samplers may be used. This will reduce the number of samplers in each vertical to one only. There should be a proper set up at site with regular motor boat/ launches for operation and collection of samplers and other equipments as per Annex II.
6. Biological parameters	Biological parameters, like Zoo- Plankton and Phytoplankton are analyzed at selected stations.	Biological parameters like Zoo Plankton and phytoplankton should be analyzed at all points regularly along with other parameters.

Water Quality and Quantity Correlations

18. A general equation of the form $Y = AQ^a$ has been satisfactorily tried to correlate the quality and the quantity of river water. In the above equation 'Y' is the load (tones/day) of the particular water quality parameter, Q is the river discharge (cumec) and 'A' and 'a' are constants representing the characteristics of the river stretch. Constant 'A' represents the input of pollutant mass received in the river in the immediate upstream reaches which is still in the process of assimilation in the water body; while the exponent 'a' represents the chemical load in equilibrium state flowing as a part of background water quality. These are found to be specific to a reach for a stable spell of river regime. Their values, however, are subject to change with the improvement or deterioration in the water quality.

Ganga Action Plan (GAP)

19. In view of the disturbing trends of pollution scenario along the Ganga river, Government of India embarked on an ambitious programme in the year 1985 to clean up the river. This is known as the 'Ganga Action Plan' (GAP). The objective of the Ganga Action Plan is to restore the water quality of the river so that it is fit to sustain its various uses, through an integrated approach to river management. Under the Ganga Action Plan, many new technologies like Biorope contactors, upflow anaerobic digester, application of sewage for horticulture etc. are also being developed for sewage treatment and resources utilization. Water quality at 27 stations (7 at confluence) along the river Ganga is being monitored by the Central and Stale Pollution Control agencies together. Of these, as many as 15 stations are maintained by the CWC. The Action Plan was initially estimated to cost about Rs. 3 billion.

Water Quality Monitoring by Pollution Control Boards

20. An Expert Group formed to render advise on identification of relevant parameters for data base framework for water quality management under monitoring committee of Central Ganga Authority (CGA) recommended monitoring of 41 parameters at 27 locations in the basin with a frequency of sampling once a month. This is in addition to sampling already being done by various Central/State Government agencies. This monitoring programme is known as MACRO LEVEL MONITORING PROGRAMME. However, Central Pollution Control Board, New Delhi was entrusted with the task of monitoring 27 parameters out of 41 identified, viz., physico-chemical, bacteriological and mineralogical parameters while analysis of remaining parameters i.e. heavy metal and pesticides etc., have been entrusted to ITRC of Government of India, Lucknow.

In addition, the Group recommended that around the 4 major cities viz., Rishikesh, Haridwar - 12 locations, Kanpur - 10 locations, Allahabad - 10 locations, and Varanasi - 11 locations, i.e., total 43 locations, where heavy pollution exists, the physico-chemical, bacteriological and mineralogical parameters (19 parameters among 41 parameters) should be monitored at higher frequency of thrice a month. Accordingly, at these 43 locations in the vicinity of above 4 cities close monitoring was done under MICRO LEVEL MONITORING PROGRAMME through Uttar Pradesh Pollution Control Board, from April 1986 to April 1990.

21. The Ganga Action Plan in its first phase provides for water quality monitoring and management of the main stem of river Ganga only. It was seen that there are five major centres of pollution along the man stem of river Ganga namely, Kanpur, Allahabad, Varanasi, Patna and Hoogly. Waste water management measures for the first four cities were covered by the schemes undertaken under the Ganga Action Plan in 1985. By now, considerable progress has been achieved in the interception and diversion of the municipal effluents.

The Kumbh Mela

22. While work for 27 class I cities on the banks of the Ganga was in progress from 1985 onwards under the plan, it was felt essential that a major part of the work at Allahabad should be completed before the 'Kumbh Mela' of 1989 (a national pilgrimage held once in 12 years) with millions of devotees coming for a dip into the holy river. The schemes for Allahabad were, therefore, assessed and sanctioned on priority making it possible to complete the targeted schemes before the event of the Kumbh Mela in 1989. The result was that even though as many as 10 million devotees thronged to Allahabad on 14th, 25th and 28th January 1989; the water quality continued to remain above the prescribed standards for bathing. However coliform and BOD level increased along the bank.

23. At Allahabad, priority has been given to rectify the present sewage system so that the domestic waste and untreated sewage is diverted from flowing into the river and instead routed through treatment plants. It is to be converted into a valuable energy source, and used for fish ponds, aquaculture and agriculture. The action plan for Allahabad commenced about the middle of 1986. 18 schemes for sewage-interception and diversion were sanctioned at an estimated cost of Rs. 218 million, out of which 14 have already been completed by October 1991. The main pumping station for the city, [Gaughat Pumping Station], has been commissioned at a cost of Rs. 31.28 million. This has caused 90 MLD liters of untreated sewage daily to be diverted to the two Sewage farms instead of being allowed to escape into the River Yamuna above the confluence. Other Pumping Stations were also completed. The intermediate Pumping Stations were renovated to meet the new requirements. The Chacher Nalla, which accounted for 27% of the total flow of waste water was successfully tapped and diverted to the main pumping station. A total of 13 local nallas have been tapped, thereby stopping 1.6 MLD of untreated sewage from polluting the river. Extensive renovation of the sewer network has also been achieved.

24. Low Cost Sanitation: Since the sewage network is not extensive in the city, a low cost sanitation programme at a cost of Rs. 77 million was jointly financed by the Ganga Project Directorate, Ministry of Social Welfare, and UP Government under which 194 community toilets and 27,800 pour flush latrines were constructed. 6,000 poor households were provided with low-cost toilets. A total of 30,000 people are estimated to have been benefited by the facility.

25. Under the Environment Protection Act and Water Act the industries exceeding prescribed limits of pollution load are required to set up Effluent Treatment Plant (ETP) or face closure. Out of 68 such gross pollutant units along the main stem of Ganga, 43 have set up ETPS and 10 units have been closed down. Forty nine research projects were taken up by 14 universities along the river Ganga on the physico-chemical and hydro-biological profile of the river Ganga. Their findings are being published as a book titled 'Ganga - A Scientific Study'. Water quality monitoring carried out by CWC and the Pollution Control Board together has revealed that water quality has improved over the years at most of the stations. With reference to the dominant parameters of evaluating water quality namely, DO, BOD and coliform bacteria.

Public awareness Programmes

26. Films on ecology of Ganga, resource recovery from waste, and hygienic use were prepared and telecast on the national network. School children were involved in programmes like painting competition, debates, competitions of songs, dramas, essay writing on themes associated with Ganga's water quality. They were also extended an opportunity to participate in river quality monitoring through simple kits specially designed for them. Youth have been involved in programmes like cleaning of Ghats, (paved access on river banks) through voluntary labor and for taking out processions for canvassing the goals of the Ganga Action Plan. Non Government Organizations (NGO) participated in educating and motivating people to use electric cremator and the community toilets and to desist from unhygienic bank side river uses.

Water Quality Status Prevailing

27. The present picture of water quality status in Ganga river system as revealed from the data collected by the Central Water Commission clearly indicates three distinct zones.

(i) The upper reaches consisting the main river Ganga upto Narora and the Ramganga sub-basin where the deterioration in the water quality is found to be within tolerable limits i.e. BOD < 3 mg/l and DO > 5 mg/l.
(ii) The middle reach extending from Kanpur to Buxar on the main Ganga and including the most seriously affected Yamuna sub-basin especially between Delhi and Etawah. This middle zone is marked by dense urbanization, excessive growth of industry and intensive agriculture practices. A large number of municipal towns depend for their water supplies and waste disposals on the rivers.
(iii) The segment of the basin below Buxar including the Ghagra, the Sone, the Gandak, the Kosi, the Mahananda and other sub-basins. Higher mean run-offs due to increased contributions from tributaries helps to maintain lower concentrations of pollutionary loads in the lower segment of Ganga basin.

In the worst affected reach of Ganga, i.e. between Kanpur and Bewar, BOD concentrations which were observed as high as 93.29 mg/liter in December, 1982 have now come down to 51.70 mg/liter in December, 1990.

Water Quality Trends

28. The impact of the measures undertaken at these places on the health of the river has also been evaluated. Although the waste water management programmes influence all the water quality parameters to some extent, it was seen that only 4 parameters really contribute to the 'Index of water quality' viz., DO, BOD, Chloride and specific conductivity. Hence these have been considered together for evolving a single index number for each station.

29. When the monthly mean values of five selected parameters viz., temperature, DO, BOD, Chloride and specific conductivity were graphically presented for a period of 10 years, for the five station at Kanpur, Allahabad, Varanasi, Patna and Hathidah, it was seen that Ganga water quality is critical only at Kanpur, Allahabad and Varanasi. At Patna and Hathidah the river has sufficient flow to keep the pollution concentration within the permissible limits. It was therefore not considered necessary to go into the details of management of flows and the treatment measures at these two places.

Lessons of the Ganga Action Plan

30. In addition to the clean up of main river, wherever underground sewers have been added, they have reduced the unhygienic conditions and foul smells. The incident of water borne diseases has also been reduced in those localities. But the work on Resource Recovery and Revenue Generation from sewage treatment plants has not progressed upto the expectation. Much headway could not be made on the other aspects like use of sewage in pisciculture, forestry and agriculture. There is also a need for upgrading the manpower required for the operation and maintenance stages.

Electric Cremator constructed under the programme are not yet fully utilized mainly due to people's reluctance and beliefs to contrary. Many people still continue to throw the dead bodies into the river channel on the basis of their religious belief, that those offered to the river can reach to the 'heaven'. Social educational programmes will have to form an integral part of any further work.

Requirement of minimum flows in the Ganga upto Varanasi

31. An inter-disciplinary group was set up in January 1989 by the Ministry of Water Resources at the instance of Central Ganga Authority for studying the requirement of minimum flows in the river Ganga upto Varanasi under the chairmanship of Chairman, Central Water Commission. The Committee recommended retention of at least 10 cumec of flow round the year all along the length of the river for maintaining the water front for bathing and other purposes. The present availability of water in Ganga at Kanpur is about 50 cumec at 90% dependability. A similar working group was set up for studying the requirement of minimum flows in the Yamuna river also which in May 1989 recommended the adoption of 10 cumec of minimum flow for the entire length of Yamuna considering river bed characteristics and the population settled on the river bank.

Further Actions

32. An inter-ministerial group has now been set up under the Chairmanship of Chairman, CWC to consider the measures for ensuring the desired minimum flow in the Ganga in its critical reaches such as at Kanpur. This group is assigned the task of:

(i) formulating proposals for ensuring a minimum flow in the river Ganga throughout the year keeping in view the various committed and priority requirements such as those relating to drinking water supply to towns and cities;
(ii) reviewing the annual flows in the Ganga river in its different reaches upto Varanasi and suggest suitable adjustments in the operational plan for ensuring (i) above;
(iii) suggesting measures for augmenting the surface water flows and improving the river front adjoining the major cities along the river Ganga upto Varanasi; and
(iv) monitoring the waste assimilation capacity of the rivers in reaches covered by industrial belts and suggest appropriate remedial measures for ensuring the prescribed quality of the river flow in the Ganga upto Varanasi.

A standing committee has also been set up with Project Director, Ganga Project Directorate (GPD) as one of its members for interaction with the Ministries of Agriculture and Health for controlling the hazardous pesticide residues in river Ganga. Separately, Industrial Toxicological Research Centre at Lucknow is carrying out heavy metals and pesticides analysis at these stations from 1986. Indian Agricultural Research Institute (IARI) with Uttar Pradesh animal husbandry dept. at Rishikesh is studying the fodder crop growth by using algae - rich Oxidation pond effluent, Indian Drugs Pharmaceuticals Ltd. (IDPL) effluent and well water. Bio-monitoring of river Ganga has been taken up by Bhagalpur university for the Bihar stretch - i.e. the D/S reaches of the river. Automatic water quality monitors are installed at Kanpur for continuous measuring and recording for improved water quality parameters and 8 more are to be installed by March 1992. These monitors measure pH, Temperature, Turbidity, D O and Conductivity. It is proposed to prevent carcass dumping and illegal fishing by installing river police at critical points along river Ganga.

Extension of work to Yamuna

33. Encouraged by the results of the Ganga action Plan it is now proposed to undertake similar measures for monitoring and management of Yamuna, a major tributary of the Ganga river. Central Water Commission already has 18 monitoring stations on the Yamuna River and its main tributaries and 13 monitoring stations on the sub-tributaries of the Yamuna River. Thus, the Yamuna Sub-basin has a total of 31 water quality monitoring stations 18 are on the main stem of which 11 stations are special study stations and the remaining 7 routine observation stations. A Committee under the Chairmanship of the Minister (WR) which went into the requirements of the low flows to be maintained in Ganga and Yamuna upto their confluence at Allahabad has already decided that a minimum flow of 10 m^3 per second should be maintained in these rivers to provide a proper river front along the length of these rivers upto their confluence. The abstractions and other uses in the basins/sub-basins are to be regulated in such a manner as to ensure this minimum quantity even during the driest parts of the year. Exercises for achieving this objective by systematically regulating the uses and the abstractions as and where necessary have been taken up. Setting up of a Monitoring Committee under the chairmanship of Chairman (CWC) is under consideration to monitor minimum flow in River Yamuna.

34. The proposal of cleaning of the river Yamuna has been posed for assistance to the Overseas Economic Cooperation Fund (OECF), Japan under bilateral funding. The project is estimated to cost Rs. 5.0 billion. A National River Action Plan (NRAP) is also under formulation to cover other major rivers of the country.

Ground Water Impact

35. The inter river aquifer interaction is very important in the context of the management of the river. In the Ganga basin as well as in the Yamuna basin the ground water pumping for agriculture has increased immensely in the last three decades resulting into lesser quantity of regenerated flows reaching in the river channels and thereby reducing the natural dilution affected in the channel flow. Studies have so far focused on the quality of the surface water. But the inter-linkage with the quality and the quantity being received from the aquifer remains to be studied. In the future water management strategies, this aspect is expected to receive greater attention.

Conclusion

36. Monitoring of the quality of a river, particularly a large one like Ganga, with a considerable variation in the flow through the year (extreme high flows in monsoon and very low flows in summer) presents many problems for systematic and scientific water sampling because of the year to year hydrological variations. The measurements are also required to be carried over a long period before any worthwhile conclusions for river management can emerge. In the case of Ganga the initial actions and the monitoring phase is over in the 80's. Now the management phase for the river has commenced. Different interests' groups involved in the use of water and release of effluents into the river are required to be coordinated. This is a very complex technocratic work that can be performed only through an integrated approach adopted by the variety of agencies involved and hence the need for high level management committees as have been appointed by the Government of the purpose. The 90's will be the decade for establishing such proper management procedures so that 'clean' Ganga is definitely ensured during the 21st century.

Annexure I

SALIENT FEATURES OF GANGA BASIN

S.No.	Feature	Unit	Total	Upto Allahabad
1.	Length of Ganga (along Hoogly/ Bhagirathi)	km	2525	1050
2.	Catchment Area	Thousand sq.km		
	a) Total		1087	462
	b) Within India		861	-
3.	Population (1991 Census)	Million		356.32
4.	Culturable Command Area (CCA)	Million ha.		57.96
5.	No. of persons per ha. of CCA	Number		6
	Ganga Main Stem			
6.	Length (Upto confluence of Gomati)	km		1295
7.	Culturable Area	Million ha.		4.26
8.	Precipitation (Normal)			
			Annual	Monsoon
	a) Total Ganga Basin	mm	1065	952
	b) Yamuna Sub-basin (excluding Chambal)	mm	749	678

Annexure II

SALIENT FEATURES OF YAMUNA SUB-BASIN (Excluding Chambal)

S.No.	Feature	Unit	Quantity	
1.	Length	km	1400	
2.	Catchment Area	Thousand sq.km	227	
3.	Estimated Population (1991 Census)	Million	74.53	
4.	Culturable Command Area (CCA)	Million ha.	16.98	
5.	No. of persons per ha. of CCA	Number	4	
6.	Precipitation			
			Annual	Monsoon
	a) Total Ganga Basin	mm	1065	952
	b) Yamuna Sub-basin	mm	749	678
	c) Chambal Sub-basin	mm	826	780

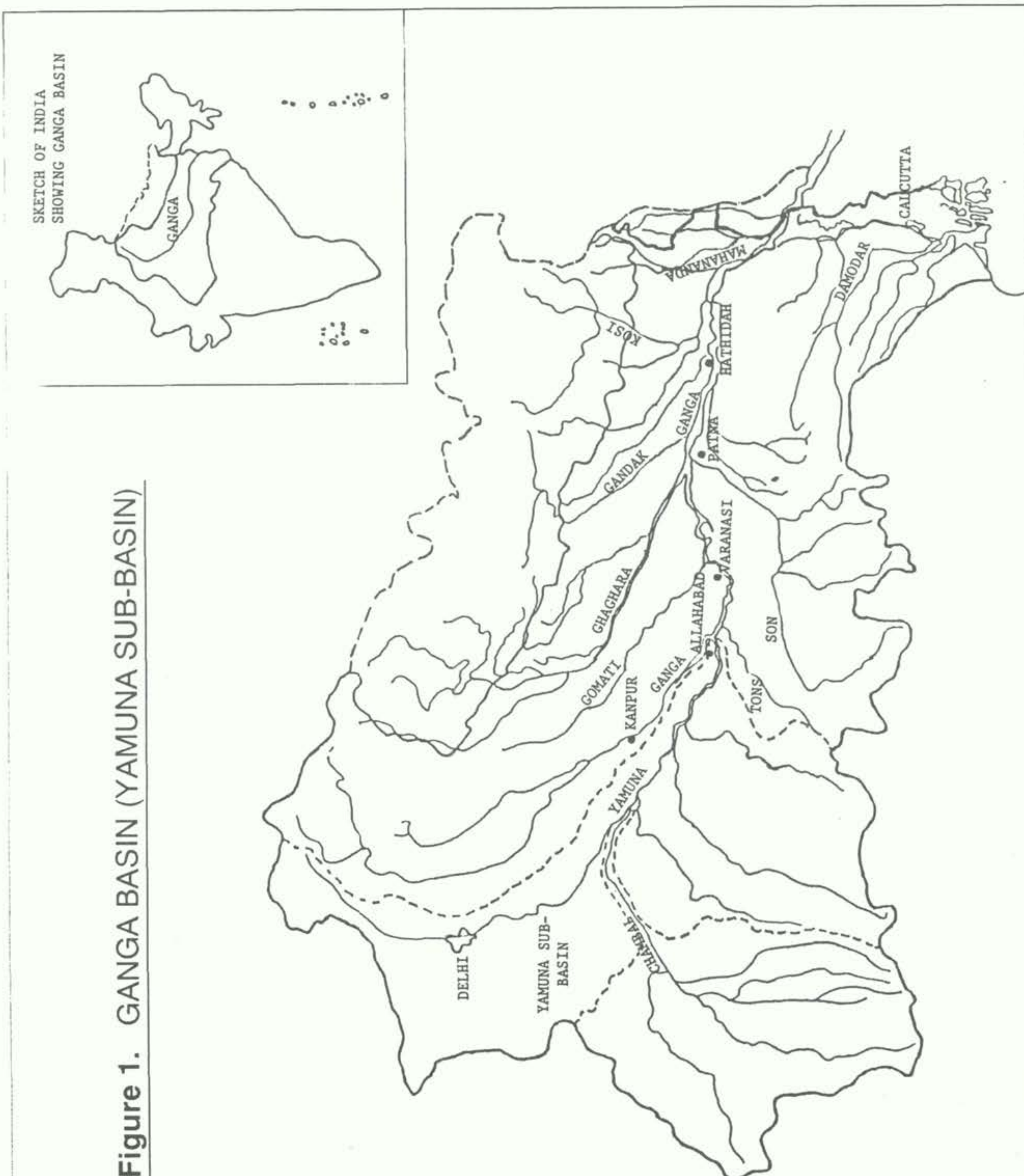

Figure 1. GANGA BASIN (YAMUNA SUB-BASIN)

CONCEPT AND APPROACHES FOR INTEGRATED WATER RESOURCES MANAGEMENT

By

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Water is a limited renewable resource and the projected global water demand is likely to exceed the potential global supply for a long time to come. The importance of water resources will increase each year as agriculture, industry and other users impose ever greater demands for water. By the year 2000 we might need between two to three times as much water as in 1980. Only through careful management, and development, is there a possibility of satisfying future demands.

Economic development is an imperative for mankind. To meet growing demands of ever increasing population of the world it is impossible without development, and development goes on. However, there are so many examples of consequences of "development at any cost": eroded and salinized soils, polluted waters, deteriorated and destroyed forests, increased incidents of environment-related diseases and so on. It seems that no country will escape these problems, developed and developing ones alike.

This kind of development will undermine our resource base for further progress. Therefore, the only road to mankind is to pursue the way of sustainable development.

United Nations Environment Programme was, since long time ago, advocating sustainable development.

In 1987, it got a strong reinforcement of its position after the recommendations of the World Commission on Environment and Development (WCED) which were published in a report "Our Common Future". These were largely incorporated into the Environmental Perspective to the Year 2000 and Beyond approved by the Governing Council of UNEP.

For the time being, there is no acceptable definition of sustainable development. The explanation provided in the WCED report tells that it is "...... to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs".

And further: "... sustainable development is not a fixed state of harmony, but rather a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are made consistent with future as well as present needs".

All this is very relevant to the sustainable management of water resources.

Traditionally, water management pursued a resource-oriented approach. That means that ever more resources were exploited without corresponding regard to conservation of water, environmental protection or other considerations. Usually, when the demand had exceeded the amount of water resources during periods of low water, dams were built to regulate water supply in terms of time. If in spite of regulation, the demand had been more than the supply, projects were made to exploit water resources from outside.

In the process of water development, one-purpose projects were being substituted by multi-purpose water projects.

Usually, the resource-oriented approach is accompanied by a number of problems such as mounting side effects (deterioration of the environment, change of income and social structure of the population, etc.). Even if the design of water project goes along with assessment of the side effects, evaluation of the project efficiency often is incorrect because either environmental impact assessment is not properly done, or mitigation measures at-e not implemented. Factors included in the cost-benefit analysis are selected voluntarily. For instance, one country used a methodology of CBA for water reservoirs where on the cost side the only expensive factor was the cost of transfer of settlements to be inundated while losses of very valuable agricultural land were not accounted for.

Another issue is that of beneficiaries: there are voices that while the benefits of hydroenergy power plants, in particular in Africa, come to some part of cities' population, the losers are farmers who are either displaced by water reservoirs or whose production cycle is disrupted because of the changed hydrological regime.

One must, however, make it very clear that despite criticisms associated with negative effects briefly mentioned above there are a lot of benefits stemming from a properly-designed, built and exploited water project. Clear example of it is the Aswan High Dam on the Nile River. Perhaps, more attention was given to the negative effects of the Dam than to obviously positive effects. There is continuous low water period for the last years, and without the Lake Nasser formed by the Aswan Dam the irrigation in Egypt would have enormous problems. A share of energy supply in Egypt coming from Aswan is also very considerable.

Resources-oriented approach of water management is being changed as the scarcity of the resource grows. More attention is paid to the demand side: attempts are made to increase efficiency of water use; prices of water are introduced or increased, etc. These processes lead further to the mechanisms which match supply with demand. When there is a real need to address the demand side of the water management and to match the supply with the demand, the economy in the basin is already quite complex and well developed. Different sectors of the economy then have different water demand patterns; they exert a strong influence on water resource (both quantitatively and qualitatively); natural resources are used in competitive ways and in many cases can be substituted by one another. Actions exercised by one sector of economy in one corner of a basin may bring quite a number of implications in a lower part of the same basin. The quantity of the resource may not be sufficient already and the quality may be quite far from the desired one.Further development of the basin may be impeded. In other words, the development may become nonsustainable. The way out of it is to begin to exercise environmentally sound water management over the whole basin.

However, to address this point we have to consider different functions the natural waters have:

Obviously, the first function is that water is a very important resource. We have discussed some problems associated with this function above.

Another function is the role water plays in ecosystems, both natural, modified and man-made. It is a factor unifying ecosystems because exchange of matters and energy within ecosystems goes, to a great extent, through the water cycle there. Any changes of ecosystem lead to changes of quantity and quality parameters of water component of the system. The reverse statement is also true. Hence, the role of water in ecosystems can be compared with that of blood in a body. This role although accepted by science, often is not considered in a process of management of territories.

Yet another function of water is that it is a carrier of matters in global biogeochemical cycles. Naturally, the second and the third functions are interrelated: the water as component of ecosystems could be considered as a local branch of the global cycle. Global biogeochemical cycles are considerably and involuntarily modified by man's activities.

These functions of water put it in the center of practically every territorial system in such a way that neither economic development of a territory nor water management of it are possible without due regard to each other. One comes to the need of basin-wide management where the links between various parts and components of a basin as a system are taken into account.

In many cases, it is impossible to find the best strategy for basin-wide sustainable environmental management. Rather, optimal strategy or strategies could be designed. Trade-off is a key word there: one gives up something in order to gain something else. A few examples below may help understand the complexity of the problems and possible (not the best) solutions.

When natural ecosystems are converted into agricultural land, the rate of soil erosion increases by roughly 10 times for grasslands and at least by 100 times for formerly forested areas. Productivity of land goes down as erosion removes fertile topsoil while increased amount of sediments in river downstream silts irrigation canals and water reservoirs. Frequency and magnitude of floods may also increase. It is a typical case everywhere, in particular in mountainous areas of developing countries. In designing sustainable development strategies for such basins one has to take into account these (and many other) interrelations. The strategy could possibly concentrate on soils protection. That would remedy problems mentioned above but would bring such problems as land availability for growing population, need for investment into soil conservation which does not provide short-term return, etc.

Lake Balaton is the largest lake in Central Europe. Warm climate, beautiful landscape and clean water attract about one million tourists at a time during summer months. Economic development in the basin leads to increased eutrophication of the lake threatening, therefore, tourist industry. The solution is based on understanding of the basin/lake system. The key factor is availability of phosphorous in the lake and the strategy is to limit phosphorus input by a number of actions such as: reconstruction of a small lake which formerly existed at the mouth of the main tributary, River Zola, which would accumulate sediments usually enriched with phosphorus preventing them to come into the main lake; improved treatment of sewage waters; more efficient and environmentally sound use of fertilizers. However, this strategy cannot provide for the full solution of the problem because a major source of phosphorus which is bottom sediments in a very shallow lake is not managed as it is too costly.

Soviet Central Asia is specifically oriented towards irrigated agriculture while having limited water resources. By now almost all available water is used for irrigation. It led to a number of implication, among them: Aral Sea which receives waters from that closed basin has shrunk very considerably; massive development of irrigation causes not less massive transport of salts accumulated in the soils with water. It leads to increased salinity of water in the downstream parts of rivers, in groundwater and in newly formed lakes which collect water seeping from the fields. The problems are many and the strategies could be different. In considering only one problem, the control of the level of Aral Sea, one has to face a very hard trade-off between reduction of water used by irrigation and the increase of level of the Aral Sea.

The need for a comprehensive basin-wide approach to water management as a part of strategy for sustainable development is on the agenda of today. In view of this, UNEP launched in 1986 a programme for Environmentally Sound Management of Inland Waters (EMINWA). This programme pursues the objective to assist governments to integrate environmental considerations into the management of inland water resources at the level of entire water systems.

The most important aim of the EMINWA programme is to introduce this comprehensive approach to planning and management of freshwater resources on a basin-wide scale thus promoting sustainable development of the whole of the inland water system. The main aims of the programme are:

a) To assist Governments to develop, approve and implement environmentally sound water management programmes for inland water system and to use this approach for demonstration purposes elsewhere;

b) To train experts and establish training networks in developing countries to implement environmentally sound water management programmes, including drinking water supply and sanitation programmes;

c) To prepare a manual of principles of and guidelines for the environmentally sound management of inland systems;

d) To make regular world-wide assessments of the state of the environment for inland water systems; and

e) To inform the mass media on the achievements and activities of the programme and to increase the public awareness for environmentally sound water development.

Of the above, the first priority is to help countries sharing common river/lake/aquifer basins to develop their water resources in a sustainable manner and use them without conflict. This part of the programme has much in common with UNEP's Regional Seas Programme, which has succeeded in developing action plans for eleven regional seas areas, including some where the participating nations were actually in conflict.

Although each basin should be approach differently, three phases are envisaged for each regional programme. The first phase starts by organization of the working group of experts, who are nominated by the relevant ministries of the basin countries. A diagnostic study on the present status of environmental problems and water management in the basin is to be developed by these experts, to assess the conditions of the basin. The objectives of the diagnostic study are:

a) To define specific environmental problems and their impacts for the time being and for the foreseeable future, and to help the basin governments to formulate programmes for the incorporation of environmental concerns into the management of water resources; and

b) To strengthen the awareness of the various governmental institutions involved in socio-economic development activities on their potential impacts within the basin. To encourage possible donor countries for their contribution to the implementation of the projects.

Second, the diagnostic study will be used for the preparation of the action plan based on the findings in the basin. The objectives of the action plan are to overcome the problems identified and to promote environmentally sound management of the whole basin as part of the strategy. for sustainable development.

For implementation of the action plan, some legal and institutional arrangements need to be made. Typically, this should include a convention or an agreement expressing the willingness of the governments to co-operate in the implementation of the action plan and the modalities of its implementation.

Finally, the action plan will be put into effect through a series of projects financed either by the basin countries, United Nations Organizations, regional organizations or donor countries.

The EMINWA programme plans to deal with river and lake basins as well as with groundwater aquifers, with the priority given to international water systems.

The first experience has been gained in addressing the international system of the Zambezi River. It drains an area of about 1,300,000 Km^2. The length of the river is about 3,000 Km; the mean annual flow at its mouth is 106 Km^3. About 20 million people live within the river basin, which includes eight countries: Angola, Botswana, Malawi, Mozambique, Namibia, Tanzania, Zambia and Zimbabwe.

There are currently no major conflicts in the utilization of the river system. This makes it highly desirable to start water resources management of the river system in a coordinated manner by participation of basin countries to avoid possible future conflicts.

After three meetings in two years, the draft action plan for the Zambezi basin was developed by the Working Group of Experts. The agreement on the Action plan for the Environmentally Sound Management of the Common Zambezi River System was adopted by five basin countries at the Conference of Plenipotentiaries on the Environmental Management of the Common Zambezi River System held in

Harare in May 1987. The Zambezi Action Plan is being implemented as a programme of the Southern African Development Coordination Conference (SADDC).

The second experience was the preparation of a Master Plan for the Development and Environmentally Sound Management of the Natural Resources of the Conventional Lake Chad Basin Area. This Plan was finalized in August 1991.

At the same time other continents are explored in attempts to identify international and national river/lake basins and aquifers to develop similar action plans and agreements upon request from the governments. Orinoco River Basin, Aral Sea Basin and Lake Titicaca could be mentioned among them.

Development of manuals and guidelines is another major component of the EMINWA programme. Expected outputs of the programme in this field are as follows:

i) Methodological Guidelines for Integrated Environmental Evaluation of Water Resources Development;
ii) Code of Conduct on the Prevention and Management of Accidental Pollution of Transboundary Inland Waters;
iii) Guidelines on Lakes Management;
iv) Decision Support System for Management of Large International Rivers.

Development of human resources by means of education and training is considered as essential requirement for successful implementation of the EMINWA programme. Following three major components are included in this field:

a) Development of the standard training materials (text books, curricula and syllabi) on environmentally sound management of water resources;

b) Organization of training courses, seminars and workshops;

c) Establishment of the specialized training network of institutes.

In the implementation of all these concepts UNEP is working with UN Organizations like UNDP, UNDTCD, FAO etc; Regional Organizations like Lake Chad Basin Commission (LCBC); SADDC; Organization of American States; OAU etc; and National Organizations.

In conclusion, one could say that environmentally sound, comprehensive, basin-wide water resources planning and management is the only correct contribution of the water sector into the strategy for sustainable development.