Working Paper

Freshwater Management: Problems and Challenges

László Somlyódy
David Yates
Olli Varis

WP-95-120
November 1995

IIASA
International Institute for Applied Systems Analysis □ A-2361 Laxenburg □ Austria
Telephone: +43 2236 807 □ Fax: +43 2236 71313 □ E-Mail: info@iiasa.ac.at

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ABSTRACT

Water (including increasing use relative to availability, and deteriorating quality) may be one of the most severe stresses on the exponentially growing human population in the next century. Problems are becoming increasingly complex and diverse and require more and more specific knowledge from both a technical and non-technical perspective. These complexities create the need to understand and comprehend the more detailed technical components as well as broader managerial and societal issues. These non-complementary elements will increasingly demand the efficient integration of various disciplines, sectors, countries, and societies. The major challenges addressed are whether we are capable of and prepared to realize the needed integration and whether we can resolve the large amounts of existing gaps and barriers. The paper analyzes major past and desired future trends in fresh water management. There is an attempt to draw from the three main socio-economic regions: the developed world, Central and Eastern Europe (including countries of the former USSR) and the developing world. A number of issues are selected with regards to integrated freshwater management:

- Identification, occurrence, and perception of various problems (e.g. eutrophication, acidification, global warming, salinization, groundwater contamination, eco-system degradation, land cover changes, vulnerability);
- Current integration of methodologies; their strengths and weaknesses;
- Large scale projects; dams, irrigation schemes and water transfers;
- Global urbanization;
- Wastewater treatment and pollution control types (considering also consumption emissions);
- Modeling and monitoring;
- Planning and environmental impact assessment;
- Legislation and institutions;
- Education and public awareness;
- Sustainable development and time preference;
- The role of science and engineering.

The past two decades showed tremendous developments in the management of water as seen from many different perspectives. In spite of these advancements there is still room for improvement. The focus of the present discussion lays mostly on the dissemination of lessons and questions which are crucial to likely future problems and desired improvements.

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Freshwater Management: Problems and Challenges

Lászlo. Somlyódy[1], David Yates[2] and Olli Varis[3]

International Institute for Applied Systems Analysis
A-2361 Laxenburg, Austria

1. INTRODUCTION

The control and use of water to meet a great number of human needs has been and continues to be a fundamental element of socio-economic development and human progress. The earliest of civilizations have understood the uniqueness of water within the biosphere and the multiple, beneficial roles of water; as a *sustainer* of life, an *enabler* for development, and as a *transporter* of wastes (Falkenmark 1992). Regretfully, however, this exploitation of water does not always satisfy intense human demands and is often harmful to the environment through the deterioration of water quality and the degradation of the surrounding aquatic ecosystem. From a global perspective, these issues were not of great concern until the current century. It might be argued that the present problems associated with water (primarily, but not exclusively, regional scarcity, poor quality, and mismanagement) were unforeseeable given the present state of the world — rapid population growth giving rise to accelerated exploitation of scarce resources. It is unlikely that anyone at the beginning of the 20th century was pondering the notion of an additional 5 billion people to the total world population within the next 100 years considering that the previous millennia had seen a maximum population of only slightly more than one billion (Lutz 1994). The world population is presently experiencing exponential growth, and may reach 12.6 billion by the end of the next century, with most of the increases occurring in developing countries (for example, see UN 1989 or Lutz 1994). Population pressure (with its direct and indirect consequences) is a key element of the water dilemma. It is likely that water will increasingly be in short supply in many locations, as the growing population presses for improved living standards, demanding for more water. Even where water is found in abundance, problems persist, as waste loads deteriorate water's quality and make it unfit for human use and consumption. Without proper management, control, and treatment of wastes, water quality problems will only increase.

One can simply read history books to gain an appreciation for the dependency of the earliest human civilizations on water (Kinnersley 1988, Pearce 1992). Control of the water cycle for socio-economic development has been a pressing task for engineers, planners, and

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[1] Also Budapest University of Technology, Department of Water and Wastewater Engineering, Budapest, Hungary.

[2] Permanent address: University of Colorado at Boulder, Boulder, CO, USA

[3] Permanent address: Helsinki University of Technology, Laboratory of Water Resources, Espoo, Finland. Contribution by Olli Varis was funded and supervised by UNU/WIDER under the special Finnish Project Fund, which is supported by the Ministry of Foreign Affairs of Finland.

developers throughout the ages. Where there has been water (or too much or too little for that matter), there has been an opportunity for exploitation, often using engineered means to achieve progress (dams, diversions, embankments, canals, channels, levees, storm-sewers, irrigation schemes, Cox 1987). Within the developed world, environmental impacts and water quality were only narrowly recognized during the early portion of the industrial era, as such slogans as "*dilution is the solution to pollution*" clearly reveal. Industrial development was the top priority driven by the ideology of exploitationism; integrated approaches that addressed conservation and preservation lagged. Regardless of the reasons for our current state, it is apparent that unchecked socio-economic development has placed a great strain on the natural ecosystems of the earth, as mankind has often chosen the exploitation of natural resources for economic progress and individual profit over the needs to protect the air, land, and water from which these resources were extracted.

There has always been a need to harness and control water for these beneficial uses as well as command the movement and allotment of water to protect from the disparities of inadequate (and sometimes quite harmful) spatial and temporal distributions. Other beneficial, but often conflicting uses have become increasingly important in light of the complexities of our modern society. A non-exhaustive list of these might include: irrigation, domestic and municipal demands, waste assimilation, flood control and storage, hydro-electric generation, navigation, industrial processing and cooling, recreation, drainage, conservation and preservation of natural eco-systems, sediment control, insect control, urban runoff control, etc. Competition among the various uses will only increase, as worldwide demand continues to grow within almost every sector.

As it will be presented, water resources issues are becoming more and more complex and diverse. Yet, there is not really a global or unified strategy on how to handle the variety of problems of different scales which may often appear jointly depending on the geographic location. The effective handling of the growing water related issues requires an increasing amount of specific knowledge and more efficient integration across various disciplines, users, industries, countries, cultures, and societies. These two requirements seem to be rather contradictory. Thus, the major challenge addressed here is whether we are truly capable of and prepared to realize the wished integration in both theory and practice.

The purpose of this report is to give a broad overview of some of the complex water issues that are facing our modern world both now and in the future, in order to serve as background material for contingency planning of IIASA's water related research activities. This is done by taking a brief look at the past, by examining the present, and by peering into the future with regards to the world's freshwater situation. Within a short summary such as this, it is obvious that many issues will not be given the coverage they deserve; and regretfully important topics of interest are likely to be overlooked. Yet, the goal is not detail but breadth. The first portion presents background material on current water quantity and quality issues, trying to put into focus their magnitude and scale. Section 2 highlights some of the major trends that have occurred in the past and reflects on possible future directions that freshwater management might take. Realizing the importance of point and non-point source contaminants on the use of water, Section 3 addresses the impact of control methodology and scale on pollution emissions. Increased demands from growing cities for water use and waste removal are perhaps one of the greatest problems facing today's water planners; this issue is addressed throughout the paper but receives special focus in Section 4. Other forthcoming problems such as intensified friction over large scale projects and the increasing number of international conflicts over shared freshwater resources are also covered in Section 4. Technology has played a large role in improving management strategies over the last twenty years; but a lack of data, both quantitatively and qualitatively, does not often support the use of advanced technology.

These issues need addressing and are pursued in Section 5. Improved management of water resources systems at all levels has recently received a great deal of attention. Ineffective legislation and institutional arrangements are one of the biggest barriers to the improvement of sound water management, addressed in Section 6. Section 7 touches upon the sustainability issue within the water resources field and points to the difficult need for improved awareness and education at all levels. With the approach of the 21st century and unprecedented growth of the human population, anthropogenic impacts at a global level are of critical importance. Scientific research must proceed in order to gain an understanding of these complex issues, but given the limited availability of financial resources, it is imperative that wise decisions be made with respect to future research initiatives. This is the final topic of this report.

2. TRENDS AND SCALES

With a rapidly changing world, a new set of problems and challenges has appeared that the water resources planners and managers are facing. A large global population is continuing to pressure the finite resource base of our planet. The recent development in the population growth rates, in per-capita incomes; and in infrastructure development (see, e.g., the annually published World Bank Atlas) clearly show a north-south division from a socio-economic perspective, with a greater portion of the wealthy, developed countries residing in the northern hemisphere and many of the poor, less developed countries situated in the southern hemisphere. These trends do not appear to be decreasing. In 1991 the richest one-fifth of the world accounted for 84.2% of the world GNP, while the share of the poorest one-fifth was only 1.4% (UNDP 1994). The North-South division continues to grow, which is an important and most regrettable globl megatrend.

As mentioned the approach, understanding, and appreciation of water are perhaps changing. In years past, water related projects often focused on immediate solutions to pressing needs and problems. If there were persistent water shortages, the solution was dams and reservoirs for storage. If there was abundant water and a need for energy, reservoirs were constructed or rivers altered for the generation of hydropower. If floods were a problem, levees and dikes were built to keep water out. Falkenmark (1992, 1993) states that past approaches asked "*How much do we need, and how do we get it*". This process primarily occurred in the developed world because adequate resources were available for large infrastructure development. In the developing world, past trends have been different. Often local problems are solved with local resources (Wildstrand 1978). Yet, where international funding agencies have been involved, large projects have flourished within the developing world (consider Pakistan, Egypt, India and others). Limited financial resources have restricted large scale infrastructure development within the developing world, which often leads to inadequate supplies and poor quality. Falkenmark points to a new trend, which asks "*How much do we need and how can we best use it*". Although idealistically nice, this perspective is going to be difficult to realize as there continue to be large scale needs. Hori (1994) mentions plans of Japanese funded super-scale water resources development in India, with a stated objective of alleviating the maldistrubition of water in order to improve the quality of life, so there is still a great deal of uncertainty as to future infrastructure development trends.

Another overlooked profoundly important development trend within the last 200 years has been the flush toilet. This convenient device was an innovation to reduce diseases and pests, but today we question whether 15-20 liters of water (per flush), primarily used as a transport mechanism, is too much? It significantly increases wastewater treatment costs (1 m^3/d capacity requires roughly 500-1000 USD capital cost for a medium sized plant) and also creates the need to extract more water from the natural environment. Or another question:

should we use a unified supply system in houses serving high quality water even though an order of magnitude decrease in water quality would be sufficient for most uses? Should we focus on better controlling the water cycle at the household level? Or another rarely addressed question: do we always need large collection systems forming the largest cost component of an urban water infrastructure? Would it be wise — depending on the actual situation — to consider also on site treatment, infiltration, and other non-conventional tools (and their mix with the traditional collection-treatment systems with a focus on impacts on groundwater; see Kindler 1992, Novotny and Olem 1994)? More generally, how and when should we change a good tradition which may lead to undesired future developments? Or differently stated (and a little exaggerated), how do we avoid the repeated and exclusive usage of methods we were "taught at the university" without asking why we acquired this approach in problem solving? How do we avoid using inappropriate technologies and find appropriate ones?

We know that the raising of the above issues seems naive for existing systems, but how would we develop the infrastructure of a new settlement or city today? How might we adapt development strategies in fast growing towns and forthcoming rehabilitation? Which policy should and could be followed in underdeveloped rural areas and developing countries? How we proceed in the future will greatly depend on the way we view our past approaches to problem solving. One thing is for certain, our future problems are not getting simpler and will require innovative approaches at all levels.

2.1 Vulnerability and the Developing World

The common notion or idea of water quantity is quite broad and the specification of use is difficult to define given the fact that water is not merely a used resource, but an integral part of human existence (*Homo sapiens* are themselves 60 to 80% water). However, it is important to understand that water is a limited valuable resource (freshwater resources form less than 1% of the total water on the Globe) essential to all forms of life. Figure 1 is a general account of the global freshwater situation and shows that stable river runoff (portion of freshwater that can be made available for human use) is approximately 25% of the water discharged by the rivers of the world. This Figure does not reveal more complex problems like spatial and temporal variability which make the problem more complicated and difficult.

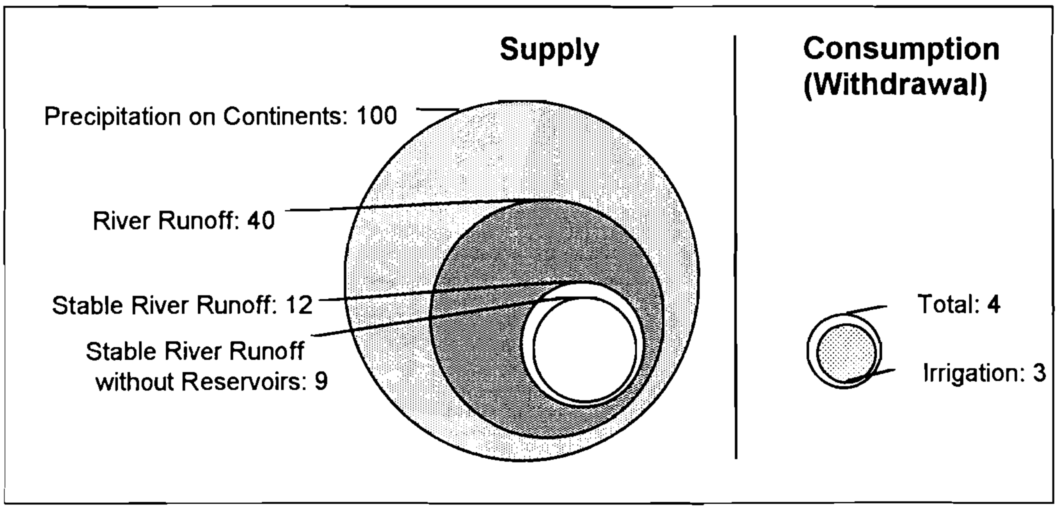

Figure 1. Global freshwater balance (data from Golubev 1993). Units are 1000 km^3 per year

Quite simply a growing population, searching for an improved quality of life, will require more freshwater to meet their increased needs. It is projected that by the year 2000, water withdrawals could increase by almost 60% over 1980 values (Shiklomanov 1993). This need is coming at a time when many are demanding that water remain within the natural ecosystem (Postel 1992, Pearce 1992). Unless extraordinary and inexpensive techniques are found to disinfect or desalinize water, there will be an increasing need to efficiently utilize and manage the limited freshwater supply.

Groundwater is one of the major freshwater sources, serving domestic and municipal supplies and irrigation. It comprises 85-95% of the water within the land masses (Wetzel 1992), making up a substantial portion of the supply in many places (in the former USSR, 60% of the towns are supplied exclusively with groundwater; Clarke 1991). The importance of groundwater as a reliable water source can only increase given forecasted future demands. In many locations demand is already outpacing supply, and groundwater aquifers are being overpumped. There are many examples that could be cited, but take Beijing, China. In the 1950's the water table was within 5 meters of the earth's surface in many locations, but today more than 40 000 wells draw from depths of more than 50 meters (Smil 1993). Another example is the Middle East region. Israel draws a major portion of its water from just two controversial aquifers which are now stretched to their limits and are experiencing pollution problems (Shuval 1992, Shamir 1994). Israel was overdrafting groundwater aquifers by 200 million m^3, but realized the non-sustainability of this practice and has struggled since 1991 to halt the practice of overpumping (Wolf 1993). Demand management might slow the rate of increased use, but are these long-term solutions?

Figure 2 is an estimate of the total global population currently experiencing different levels of vulnerability with respect to freshwater (Kulshreshtha 1993). The scarce vulnerability ranking is characterized by low availability (less than 1000 m^3 per capita per year) and high use (above 60% of availability). The four vulnerability classes (scarce, stressed, marginal, surplus) used to arrive at these results are based on a combination of per-capita availability and relative use (Figure 3). The portion of the global population currently experiencing a water scarce or stressed situation is relatively small (approximately 6% of the total), with most occurring in the Middle East. It should be mentioned that this analysis only includes water quantity based on national, aggregate values and it is likely that including quality information or disaggregating spatially and temporally could drastically change the results. Figure 2 also includes a 2025 forecast of global freshwater vulnerability, including current, mean value population projections. This scenario implies uniform demand increases as related to population growth, while availability remained unchanged. This 2025 by Kulshreshtha shows a ten times greater proportion of the population than today may be negatively affected by water "scarcity" by 2025.

The climate change issue introduces additional uncertainties into the vulnerability issue. It is important to realize, however, that significant uncertainties and poor understanding of climate change impacts on both water quantity and quality exist (with regards to water quality and climate change, a checklist study was performed by Varis and Somlyódy 1993). Under this climate change scenario, Kulshreshtha assumed humid climates would receive an additional 10% of available water, while all other regions would experience a 10% decrease. The same demand scenario was used as in the 2025 case, using the "average" population forecast. Under this scenario, the vulnerability position of two-thirds of the global population will become more vulnerable with respect to water. The analysis could be extended to include more detailed river basin data (e.g., such as given by Miller and Russel (1992), who had compiled runoff results from the GISS Global Circulation Models (GCM) for 33 of the large river basins of the world). Alarmingly, major portions of the global population shift from the central categories (marginal and stressed) to the scarce and surplus classes. It should be pointed out that the method and criteria chosen for vulnerability assessment can have a significant impact on the outcome of the results as pointed out by Kulshreshtha. This issue highlights the need to question the applicability of global assessments as issues of data, scale, methodology, etc. are critical and are waiting for answers.

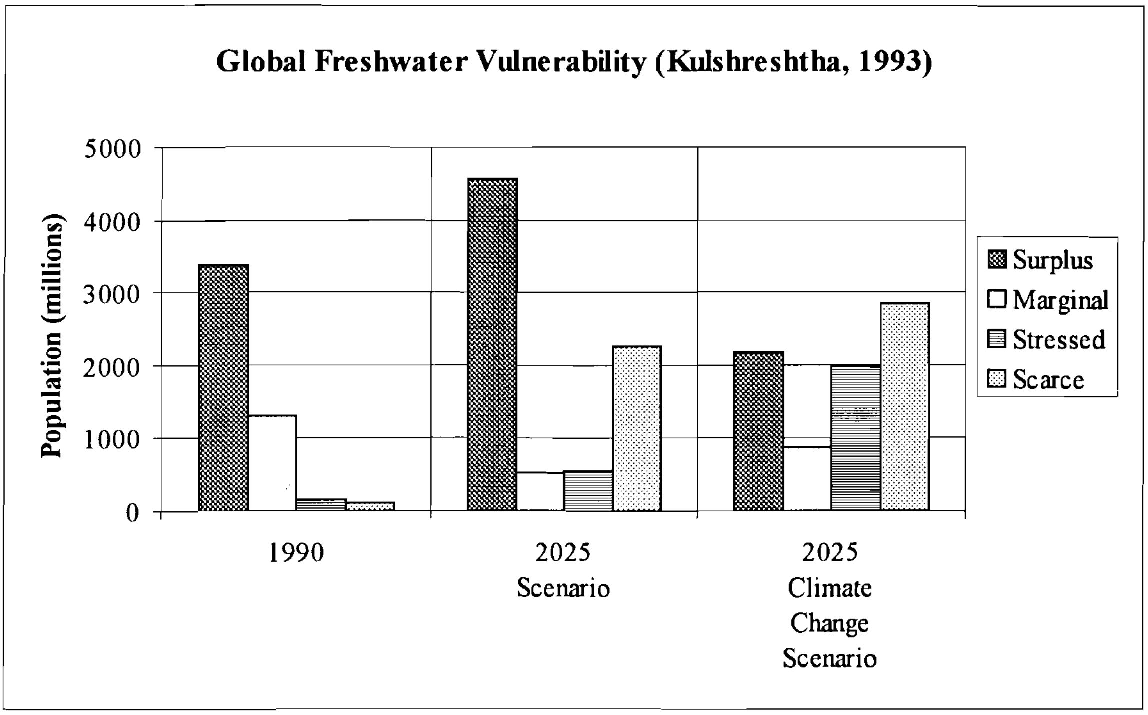

Figure 2. Vulnerability of the global population to water supply deficits using a use/availability approach (Kulshreshtha 1993).

Use / Availability ratio (%)

Supply per capita (m3)	<40	40-60	60-80	>80
<1,000	☆☆	☆☆☆	☆☆☆☆	☆☆☆☆
1,001-2,000	☆☆	☆☆☆	☆☆☆☆	☆☆☆☆
2,001-10,000	☆	☆☆	☆☆☆	☆☆☆☆
>10,000	☆	☆	☆☆	☆☆☆☆

☆ Water Surplus
☆☆ Marginally vulnerable
☆☆☆ Water stress
☆☆☆☆ Water scarcity

Figure 3. Use-availability criteria for vulnerability classification (Kulshreshtha 1993).

2.2 Water Quality

It is often accepted that water quality comprises all the properties of water besides its quantity; yet even quality can not be measured without reference to quantity. Contaminant concentrations are often expressed in terms of mass per unit volume, and only recently have mainstream water quality researchers widely accepted the use of mass balances and mass flows in conjunction with concentrations. This is evidenced by the fact that until the 1980's the dominating limnological textbooks (e.g., Hutchinson 1957, Wetzel 1983) contain practically no reference to mass flows or other quantitative terms.

The actual characterization of water quality is never unambiguous; dominating parameters depend on uses (such as domestic, industrial, agricultural, recreational and others), problems (hygiene, oxygen household, eutrophication, salinization, acidification, toxins, etc.), space and time, and the subjective judgment of the analyst which cannot be excluded. Water quality can refer to physical (such as temperature), to chemical (such as pH, dissolved gases, conductivity, nutrients, heavy metals), to biological (such as phytoplankton, hygienic indicators), and to ecological (such as trophic state interactions, food webs, biodiversity) characteristics of a water body. Water quality is also "body dependent", as rivers, lakes and groundwater aquifers experience different quality problems (Golubev 1993). Water quality management is a commonly used and somewhat vague expression referring to the (systematic) usage of a set of technical and non-technical measures and activities (and associated applied research, planning methodologies, etc.) to maintain or improve quality according to the requirements of its uses and to "protect" its ecosystem. It is worthy to note that while the desired quality of a particular use can be expressed by "concentrations", ecosystem "goals" are harder to quantify leading to an additional subjective element of management.

Figure 4 is a simplified illustration of the water quality related problems (Somlyódy 1995). It gives a broad idea of the approximate time when given problems were identified and research and management actions were launched extensively. It is striking to realize the huge gaps between the scientific identification of a potential problem, the first observed indicators, the perception by the professional community, public, and decision makers, and the development of response measures (for example, see Meybeck et al. 1989; Döös 1991).

For instance, the greenhouse gas issue, acidification, and eutrophication all were identified as likely future problems one hundred years ago or so. In spite of this, it took a long time to address and to tackle the above issues, although the basic knowledge was not missing. Reasons for this lag can be manifold. First, we can generalize the statement of the US National Research Council (1991) with regards to the application of scientific knowledge: "*science has followed rather than led the applications*". In fact, environmental and water quality management has been primarily driven by crises, accidents, and interest groups. Countermeasures and corrections are often made once the problem has occurred and are given a sense of immediacy (often referred to as remediation). "*Problems are accepted and treated, rather than prevented*", states Wetzel (1992).

In the formulation of Hukka et al. (1993) — when discussing urban water problems — the major constraint is that the focus lies most of the time on planning, implementation, and execution, but broader views such as "philosophy", "ideology", "politics", and "policies" are neglected. Secondly, management needs appear if the concern is serious (crisis was certainly not the case around the turn of the century for the above mentioned three issues). Thirdly, it is unclear even today how scientists can express their management views effectively (very few forums are available, and scientists may not be interested in devoting lots of time and effort to push through their message) such that they have an impact on applied research fields, engineering, development strategies and decision making alike.

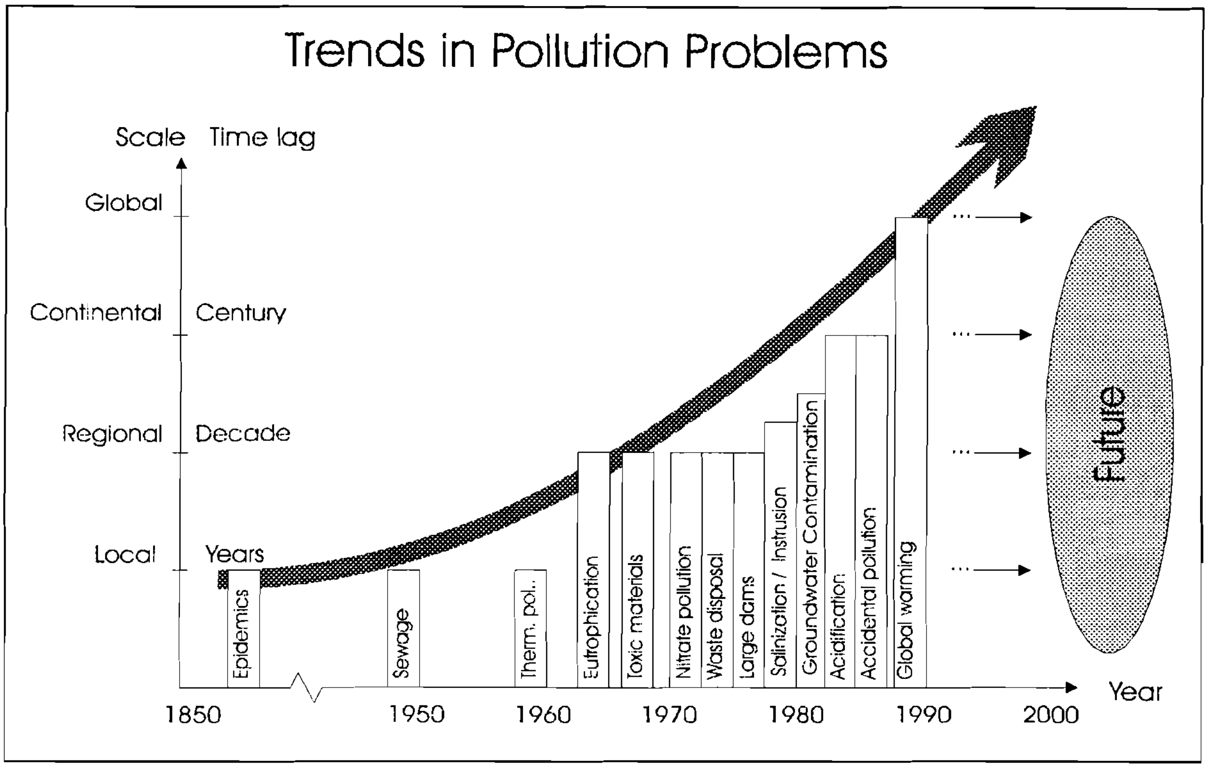

Figure 4. Trends in water quality related problems.

Figure 4 and Table 1 (taken with some modifications from Somlyódy 1995) illustrate some of the major changes in water quality issues as well as the ways in which we handle them. Many of the elements within this Table and Figure are well known and documented (e.g., see Meybeck et al. 1989, Meybeck and Helmer 1989, Wetzel 1992), thus it is not our intention to offer a comprehensive discussion, rather — as noted before — we will focus on a number of issues characterized by problems, shortcomings, trends, developments related to freshwater.

Some of the trends are observed today, and they are likely to be continued (changing scales, delayed and irreversible environmental responses, growing role of non-point source emissions, unforeseen interactions among different pollutants, media, "surprises," and so forth). In this sense, there may not be a sharp difference among past, present, and future (see Table 1). The changes of several other attributes cannot really be prognosticated, but at least the desired orientations can be identified (these are specifically marked in Table 1). Finally, many other features of future fresh water issues are unknown and uncertain as was the case in the past. Could we have fully foreseen the present state of fresh water management say twenty years ago? However, we can attempt to critically analyze historical developments and the primary reasons for "unexpected" changes, successes, and failures, and to disseminate experiences. These may help us to think more cautiously in the future than we did in the past.

Our ability to understand and solve water related problems has developed tremendously during recent decades — a fact which does not need any further discussions. However, open issues are abundant. We mention only a few examples. Dissolved oxygen problems — one of the most traditional issues — still offers a number of "puzzles" (for example, see Thomann 1987) due to the role of benthos, the non-linear impact of DO on nitrification, or the affect of photosynthesis and respiration. Eutrophication and the lack of anticipated responses to load reductions for a number of water bodies due to structural ecosystem changes and nutrient accumulation in the sediment calls for re-thinking and additional research. Our scientific understanding on combined effects is far from satisfactory. Can we, say, understand

Table 1. Trends in water quality management.

PAST	PRESENT FUTURE (expected/desired)
(1) General	
Local problems	Increasing scale
Fast response, reversibility	Delayed responses and irreversibility
Limited number of pollutants	Multiple, sophisticated interacting pollutants
Point sources	Diffuse sources
Single media (water)	Multi media (water, soil, air)
Static, deterministic, foreseeable	Dynamic, stochastic, uncertain
Regional independence	Importance of global interdependency
(2) Control Type	
"End of the pipe"	Source control, closing material cycles, land use management, concern on large scale projects*
Technical	Non-technical elements*
Discharge standard — rigid	Use attainability — flexible
(3) Infrastructure and Treatment Systems	
"Traditional technology"	Special treatment methods (biological-chemical treatment, high-tech processes, upgrading, appropriate technology, natural treatment, small-scale treatment). Emerging new traditions and technologies
Landfilling of solid wastes	Increased reuse and recycling*
Large scale control and exploitation	Regional and small scale development, management and conservation.
Massive, capital intensive urban infrastructure	Localized, small scale, creative infrastructure development*
(4) Monitoring	
Local measurements	Networks, remote sensing, continuous measurements
Conventional parameters	Special parameters (micropollutants, ecotoxicology, biomonitoring, etc.)
Monitoring of water	Integration of effluent and ambient monitoring and aquatic ecosystem monitoring
Poor data availability	Improved availability (data bases, digital maps, telecommunication), integrated information systems
Hands off "my" data policies	Open information flow
(5) Modeling	
Individual issues (processes, control, operations, planning, etc.)	Integration (model library, DSS, GIS, expert systems, etc.)
Limited, numerically based results	Scenario based and visual. Use of multi-media to explain complex ideas
Use by experts	Use in administration, meetings, etc.
(6) Planning and Project Evaluation	
Poor/narrow definition of objectives	Clear goals and objectives*
Short-term view	Long-term view*
Cost evaluation	EIA, risk and multiobjective evaluation, social and political impacts*
Little concern on failures and adjustment needs	The future is never certain: reliability, resiliency, robustness, and vulnerability*
Positive and negative impacts separately	Positive and negative impacts together

Table 1. Trends in water quality management (continued).

PAST PRESENT	FUTURE (expected/desired)
(7) Science and Engineering	
Science does not drive actions	"Science for action" and combination of broad, emerging scientific concepts with engineering*
	Improved planning*
Problem isolation and engineering solutions	Integration of quantity, quality, hydrology, economics, politics, social science and management*
Interdisciplinary gaps and barriers	
One correct paradigm — single discipline	Many paradigms known and accepted within and between disciplines*
(8) Legislation, Decision Making Institutions and Development	
General rules and rigidity	Specific rules and flexibility*
Fast implementation (a misbelief)	Process view*
Little enforcement	Improved Enforcement
Command and control	Polluter (and user) pays, and improved policy instruments
Confusing institutional settings	Clearer structures and responsibilities, less barriers and mismanagement*
Decisions by politicians and administration	Public awareness and participation, NGOs, and enhanced communication (scientists, planners, community, government, etc.)*
National policies	International policies*
	Sustainable development: how to proceed?

* Desired trends represent an attractive development course for water resources.

the fate of an organic micropollutant compound bound on the surface of an organic particle subject to decomposition in sediment while acidification and eutrophication cause chemical and other changes? With regards to quantity related issues one glaring example is the increasing number of conflicts among nations residing within shared river basins. As water continues to become more scarce, appropriate negotiation methods which seek an equitable solution will need to be developed. Another example comes from our past development approaches to water supply. We have developed a number of tools for operating reservoirs in what is commonly perceived as "optimal", but given the increased appreciation of the role of native ecosystems are there possible alternative scenarios which have yet to be analyzed?

Water quality problems are often directly related to regional human and economic activity. Around towns and cities *organic waste* is placed into surface waters which, among other problems, reduces the oxygen content of the water. Along with hygiene related problems, this type of water pollution was perhaps the first to be addressed and is often approached using traditional biological processes. Local problems associated with organic waste still persist on a worldwide basis, although being location dependent based upon the treatment facilities in place. Another water quality problem is *acidification* which has occurred at an alarming rate in many European countries. Industrial activity reduces the pH of rainfall which becomes stressful or even lethal to many aquatic species. For now, improvement can only be made through radical changes in industrial processes and emission control strategies. Industrial activity also produces harmful *toxic organic wastes* and *heavy metals* which can be discharged into a water body (GEMS/WATER 1991). A glaring example of this form of pollution occurred in the 1950's near Minamata city (the Minamata disaster). Mercury from a nearby industrial complex entered coast waters, was consumed by fish, and quickly entered the human population primarily through the food chain. Since the 1950's, more than 2200 cases of Minamata disease have been diagnosed and 750 of them have proven fatal (Sakamoto et al. 1991). Agricultural practices often produce large amounts of nutrient laced runoff from the developed land (primarily nitrogen and phosphorus). This nutrient rich water leads to the excessive growth of unwanted plant life (*eutrophication)* within the surrounding water bodies. Nitrogen fertilizers also contribute to *nitrate pollution* of surface and groundwater. Nitrates make drinking water unsafe and are expensive to remove; and even when measures are taken to reduce nitrate pollution, problems persists (see below). *Salinization* is the build up of salt concentrations in both the soil and water and is a problem primarily associated with irrigated agriculture. For example, Kishk (1986) estimated that approximately half of the irrigated lands of Egypt have experienced some degree of salinization. Volumes have been written on some of these more common water quality related problems and are given only for a broad overview.

An alarming water pollution problem is the worldwide contamination of fragile groundwater resources. Groundwater has often proven to be a clean and reliable source, but is often threatened due to the careless disposal of organic and chemical wastes. This not only ruins water quality but also reduces the long-term filtering capacity of the soils through which it travels (Freeze and Cheery 1982, Nash 1993). Although the topic of intensive research during the last few decades, groundwater continues to be contaminated through both point and non-point pollution sources. As attention is drawn to groundwater contamination in the industrializing, CEE and developing countries (it is obvious that groundwater contamination exists in these regions), the astronomically high cost remediation schemes of the west are probably not transferable to these financially strapped regions (Simons 1994). But are there alternatives or will contaminated aquifers simply have to be abandoned in the future?

Another big groundwater problem is the vadose (unsaturated) zone, which traps contaminants in the soil matrix and reduces their flux to the groundwater below. Soil buffering capacities are high and toxins can be suspended within the soil for long periods of time without observing their effects. Biological, physical, and chemical processes act on contaminants within the unsaturated zone to create a continual source of contamination to the saturated water below (Elgersma 1991). One example is the rather toxic heavy metal, cadmium (Piotrowski and Coleman 1980). It is often found bound within the soil matrix of irrigated crop lands which have seen years of cadmium laced phosphate fertilizer application. Cadmium's leaching rate (downward movement to groundwater) is reduced at higher pH values, which is often the case in agricultural lands which use fertilizers with high pH values. If agricultural practices are halted and fertilizers are no longer applied, the pH within the upper soil layer will begin to decrease. This increases cadmium's leaching rate and groundwater contamination is inevitable. A positive environmental action within one system (reducing the impact of agriculture on the environment) becomes negative for another (groundwater contamination due to the heavy metal, cadmium). An expensive alternative to this dilemma is the artificial application of lime to maintain high pH values within the upper soil layers. The land remains inactive from an agricultural standpoint, and the cadmium remains bound in the upper soil matrix (Stigliani 1994), but what is the best alternative for protection of all components of the ecosystem in this case?

It could be argued that monitoring, data collection, and the effectiveness of institutions to carry out adaptive strategies are at the core of controlling water quality, but even with these elements in place problems persist. For example, when dangerously high heavy metal concentrations were detected in western European rivers like the Rhine, monitoring programs were already underway and strategies for improvement were undertaken. Often, measures to reduce heavy metal pollution such as cadmium, mercury and lead have met with success because the sources are primarily local, identifiable point discharges. Figure 5 shows the suspended concentrations of cadmium and mercury which reveal the drastic achievements in the reduction of these contaminants within the Rhine basin. However, adaptive strategies appear more difficult with respect to diffuse sources even when programs are in place. This is primarily driven by the fact that diffuse sources are regional in scale and it is difficult to find individual, identifiable causes (even though it is widely accepted that agriculture is the primary contributor). Figure 5 also shows a plot of nitrate concentrations in the Rhine river and it is quite apparent that strategies to reduce diffuse sources (often from agriculture and urban runoff) have not been as successful as those for point-source contaminants such as the two heavy metals.

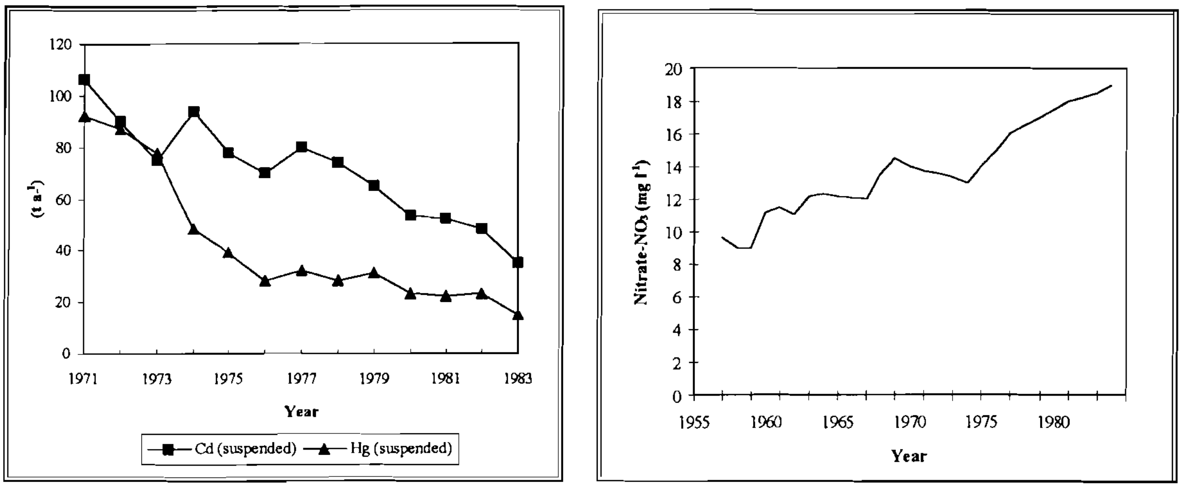

Figure 5. *Left*: Annual mean Cadmium (Cd) and Mercury (Hg) discharges to the Rhine between the German and Dutch borders. (after Malle 1985 in Meybeck and Helmer 1989). *Right*: Annual mean nitrate levels in the Rhine primarily from diffuse sources (Hock and Somlyódy 1990).

2.3 The roles of Different Scales

In the past, a general understanding of the main components of the hydrologic cycle was sufficient for the conventional infrastructure development and management schemes that were implemented. Gradually, however, this need is changing as the marginal value of freshwater gives an increased need to incorporate a more detailed understanding of ecological and hydrological cycles into engineering solutions. The importance of comprehending the hydrologic cycle in more details has been highlighted by the National Research Council (1991) who state that 'to safeguard life we must understand the anthropogenic influences on the water pathways and aqueous processes as they move through the earth system.' These cycles are in a constant state of dynamic equilibrium in all temporal and spatial scales.

At the microscopic scale — which has long been a topic of intensive scientific research by hydrologists, limnologists, meteorologists, botanists, and others — various phenomena have been studied at a growing level of detail. A high number of physical, chemical, biological and ecological processes and phenomena have attracted scientific interest, and a myriad of scientific information is available. But is this interest targeted to real-life water problems of practical importance? Could higher efficiency be achieved (we doubt that today's developments are towards decreasing efficiency)? How can this knowledge be incorporated in practical management schemes? Are there key processes that we do not understand, or are the systems and our society so complex that the parallel phenomenological scales are too messy too be coupled? Governing and dominating processes in different spatial and temporal scales need not be — and often are not — the same.

Water related problems are observed to occur at a range of different scales. Natural process still dominate most water bodies, but local, regional and global water quality problems are quite evident. At the local scale, problems related to infrastructure development with respect to both water supply and sanitation are common. Urban growth (see Section 4) is leading to widespread health problems which are often water related. According to WHO, for example, only 41% of the urban population in Latin America and the Caribbean has access to sewer systems and 90% of the collected wastewater returns to natural systems untreated (Nash 1993).

In the developed world, there is a gradual shift towards non-point source pollution control which must often be managed at a regional rather than a local scale. Agriculture is a primary contributor to many regional water quality problems. The growing number of chemical toxicants entering the environment (annually about 10,000 new organic compounds are synthesized, Wetzel 1992) form a vast problem: even detection capabilities are lacking (in spite of developments in analytical chemistry), and harmful effects are largely unexplored. Central and Eastern Europe are characterized by the co-existence of point and non-point source issues as well as traditional and toxic pollutants. Unlike arguments which suggest that problems in the developing world are similar to those in Europe 150 years ago, the low income countries face (or will soon) all the pollution problems of agricultural, industrial, and urbanization origins simultaneously. Frighteningly, the growth rate of those problems is much higher than it was in Europe (Drakakis-Smith 1987). Along with all of this is the increased competition for scarce resources within and surrounding growing urban areas. All this does not give a promising perspective.

There is an increasing need to understand water related problems on a global scale. The issues associated with the accumulation of greenhouse gases on the climate are still not well understood; and the likely impacts of the "greenhouse effect" on water quantity and quality are still very uncertain (as mentioned above). Future climate scenarios, which have been used for water resources analysis (Lettenmaier and Gan 1990, Kaczmarek and Krasuski 1991, Nash and Gleick 1993, Yates and Strzepek 1994), are often cast using the results from General Circulation Models (GCM's) or as a set of annual mean values (incremental increase in observed temperature and a percentage change in precipitation). It is widely recognized, however, that regional results from GCM's are highly uncertain, in fact Kundzewicz and Somlyódy (1993) point out that the spatial resolution of the current GCMs do not allow proper analysis of many of the most important hydrologic problems.

Also, few agree that the climate is likely to exhibit simple, annual mean deviations. Different types of possible, future scenarios need to be incorporated into the analysis with a more critical evaluation of all possible future scenarios and their likely uncertainties. This should include the highly uncertain, extreme events which have been largely ignored (Schneider 1994). In a planning sense it is unclear how we should proceed in light of the uncertain future climates throughout the world. The present approach is quite conservative and often seeks to minimize future regret, but is this really the correct approach if our analysis does not include the likelihood of extreme events? Should we be performing our planning analysis of future water resources systems based on annual mean changes or should we respect the water engineering tradition, where extreme design conditions play a major role (Varis and Somlyódy 1993)? What is the appropriate approach to addressing inter-annual variability with respect to climate change? These are questions which still need answers.

2.4 Integrated Freshwater Management

The integrated approach to water resources issues has not been the way in which the field has developed, as the many sub-systems were not adequately identified and/or coupled in the past. There has been a dis-integration of most components of the hydrologic cycle; air, land, and water were too often treated separately, creating a mental gap within the minds of those involved in the numerous water related professions. Integrated water planning, the use and control of water (quantity) combined with its protection and that of the surrounding environment (quality) were largely ignored. The last few decades have seen a desperate attempt to make up for the narrow-mindedness of the past and the fragmented approach to water (Falkenmark and Lindh 1976, Biswas 1976, Biswas 1983, Pantulu 1985, Kinnersley 1988, Pearce 1992, Postel 1992, Somlyódy 1995). We are realizing not only the responsibility of preserving the natural systems for future generations (*sustainability*) but also the economic and social benefits that can be derived from conservation and preservation.

The literature is full of attempts to make up for past, narrow approaches to water resources management, and rigorous efforts are being made to take an integrated approach (UN 1958, TNO 1979, Blackwelder et al. 1987, Ingram 1990, Falkenmark 1991, UN DTCD 1991, Hjorth 1992, Haimes 1992, Biswas and El Habr 1993, El Ashry 1993, Lundqvist et al. 1993, World Bank 1993, Huisman 1994, Somlyódy 1995). This has been called *integrated water resource management*, taking an *ecosystem approach* often at the *watershed level*. Even the term *integrated water resources management* is fairly controversial in nature because there are a number of different definitions and it draws from a number of professional fields like hydrology, biology, chemistry, ecology, engineering, economics, sociology, political science and other disciplines. Accordingly, the field is rather broad, and a range of professionals are dealing with water issues. Accordingly, there is not a unique profession which could have "ownership". These actors tend to focus on their area of interest or specialty, creating the tendency to concentrate on a specific issue, often at the expense of other issue which are likely to be of equal importance. Grau (1994) also points to the tendency of oversimplification, which is a likely response to the many complexities of an integrated approach and points to the infancy of integrated science.

Scientific techniques have been adapted and created in response to this new way of thinking about problems associated with water. Such concepts, approaches and techniques as a *holistic paradigm; integrated water resources management; water, land use, and human resource management; multi-criteria and multi-objective decision analysis; water resource planning; conjunctive use; ecological engineering and the ecosystem approach; and use attainability analysis* are some of the current catchwords. The often used notion of *river basin management* stresses that river basin is the natural scale of water resources management from both a quantity and quality perspective, although frequently forgotten in practice. “Integration" expresses the desire to look for the "totality" of the management problem, which immediately introduces a degree of subjectivity into the problem. Today there is a trend towards an eco-system approach which is considered some form of integration. Has this been adequately defined and is it being used in an operational sense? What are the differences, similarities, and links between a river-basin approach and an eco-system approach? Is there simply a mixture in the literature?

The question still remains: Can we truly define integration or will it remain a somewhat elusive term that is difficult to understand and effectuate? Difficulties arise in identifying which sub-systems are important and how they should be combined and linked, and which actors should be involved and what type of roles they should be given considering the many existing complexities and nuances. Examining the large number of conceptual models given the title *integrated water resources management*, these difficulties appear evident. Although these conceptual models tend to give a sense of the interrelatedness of different sub-systems, there doesn't appear to be a consensus on what elements are critical and what can be simplified. Often these models have a varying degree of complexity at all levels. The three Figures below highlight the problems with using conceptual models to define integration. A simple conceptual model of integrated management has been offered by Koudstaal et al. (1992, Figure 6) and another is given by Hufschmidt (1993, Figure 7). The more detailed integrated model by RIVM (Rotmans et al. 1994, Figure 8) comprises many disciplines, physical components and linkages. Is one of these models superior, are they useful in an operational sense, or are they just attractive pictures which give us a false sense of understanding?

The difficulties in dealing with integrated science is probably one reason why both the "Brundtland report" (WCED 1987) and the 1992 UNCED conference overlooked the water issue (see, e.g., Falkenmark 1988, Biswas 1992) which may become one of the most severe stresses on the human population in the next century. This oversight is apparently being addressed as the importance of water is gaining more international attention. This focus is evident and examples include the Mar del Plata Action Plan of the UN Water Conference in 1977 (UN 1977) which has been instrumental in steering international research programs into the most important water related issues. More recently, the International Conference on Water and the Environment (ICWE) held in Dublin, Ireland in 1992 outlined important issues of water as the world approaches the 21st century. Even the UN Conference on Environment and Development (UNCED) held in Rio de Janeiro in June of 1992 included a major water theme. There are a number of international research groups that are actively pursuing issues related to water resources from almost every angle. These organizations include the United Nations Educational, Scientific, and Cultural Organization (UNESCO), the United National Environment Programme (UNEP), the World Meteorological Organization, etc. (Kraemer 1994). Within each of them, there are projects and programs that focus on water related issues such as Man and the Biosphere Program (MAB), International Hydrological Program (IHP), the Operational Hydrological Programme (OHP), and the World Water Council (WWC) that is just in the process of finding its shape as an umbrella organization of professional organizations in the water field. They are trying to achieve cooperation at the international, national, state and local levels by developing a high degree of communication in hydrologic research, data collection and processing, and water resources assessment. This type of international interest can only help to address the challenges faced in developing integrated approaches to water related problems at every level. But an international water convention or treaty that would be strong enough is still far ahead, although there is some light to be seen.

As mentioned above, one of the latest buzzwords is the *ecosystem approach* to water and environmental management (Figure 9). A fundamental notion of this concept is that with proper management, both economic development and environmental protection can occur simultaneously. This is different from past development trends which seem to indicate that both can not occur together. There is a recognition that any physical development of a water resources system, whether it be for flood protection, water storage, waste assimilation, etc., will affect the surrounding environment in some manner. The primary objectives, then, are to minimize the detrimental effects of development while achieving the designated use of the water body and the preservation of the surrounding ecosystem. A shift from point source control to site specific water quality and habitat integrity combined with use designation and control is occurring more frequently within the water resources community — this idea might be considered the *ecosystem approach* (Novotny and Olem 1994).

Former management techniques to improving water quality often concentrated on chemical and toxic criteria. It is being recognized, however, that biological processes offer an excellent monitoring element of water quality, since biotic life cycles are good indicators of the state of the water environment (Volovik 1994). Past efforts at restoring water quality often focused on single processes, without an appreciation for the overall system. This was observed during the efforts to restore water bodies that had been polluted with biodegradable organics (BOD) through point source discharges to receiving waters (Novotny and Somlyódy 1995). Efforts to restore these water bodies often met with limited success because an overall understanding of the complex processes was either overlooked or not well understood.

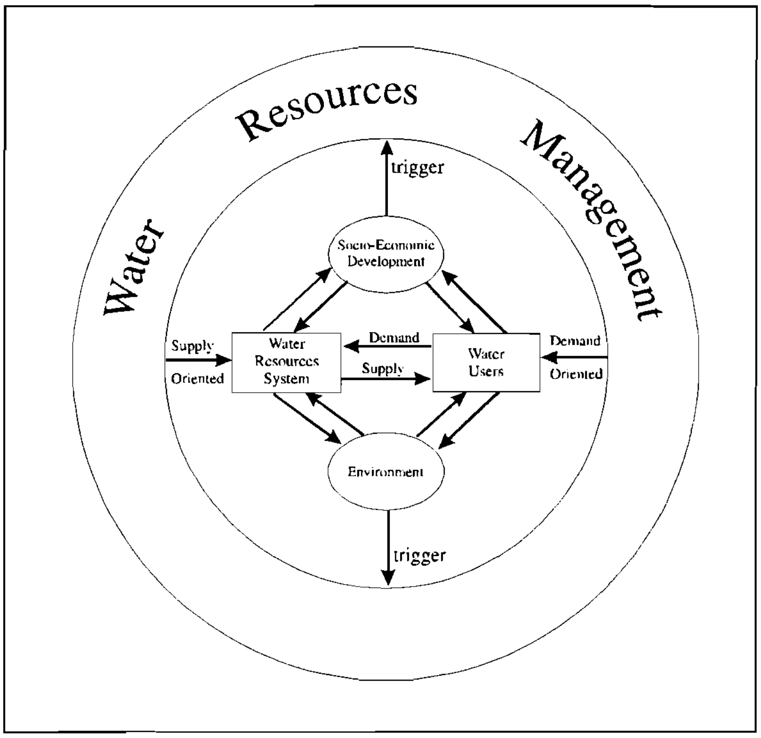

Figure 6. A conceptual model of integrated water management by Koudstaal et al. (1992).

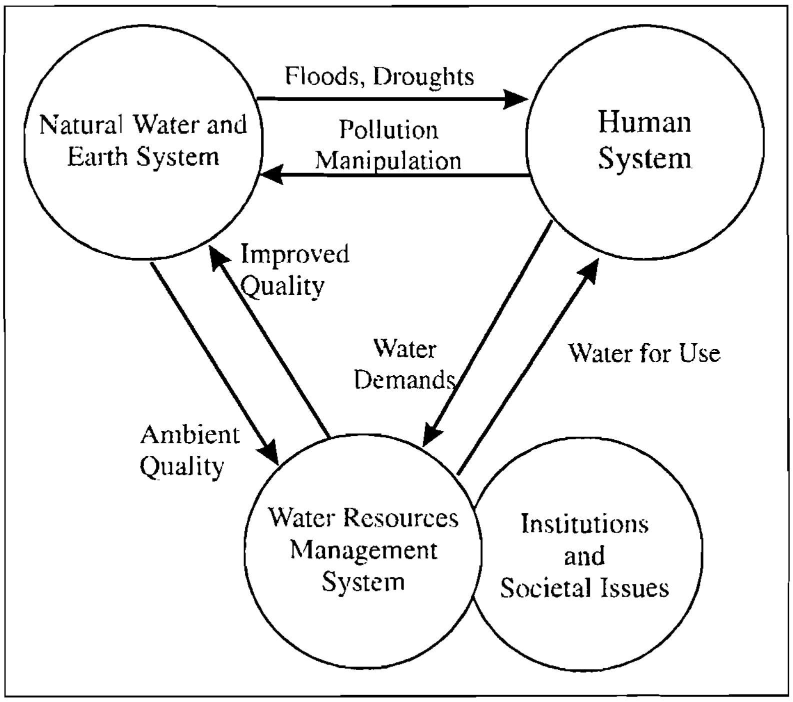

Figure 7. A conceptual model of integrated water resources management (Hufschmidt 1992).

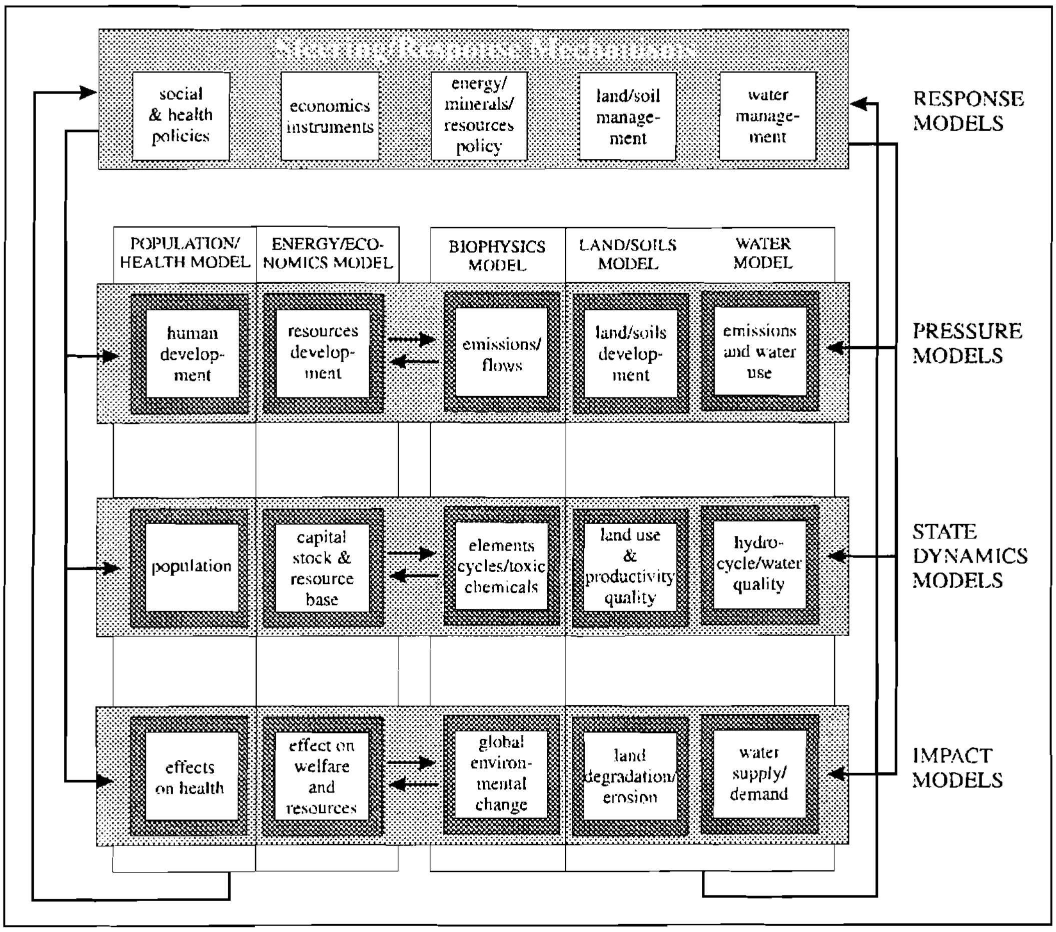

Figure 8. Integrated resources management from RIVM (adapted from Rotmans et al. 1994).

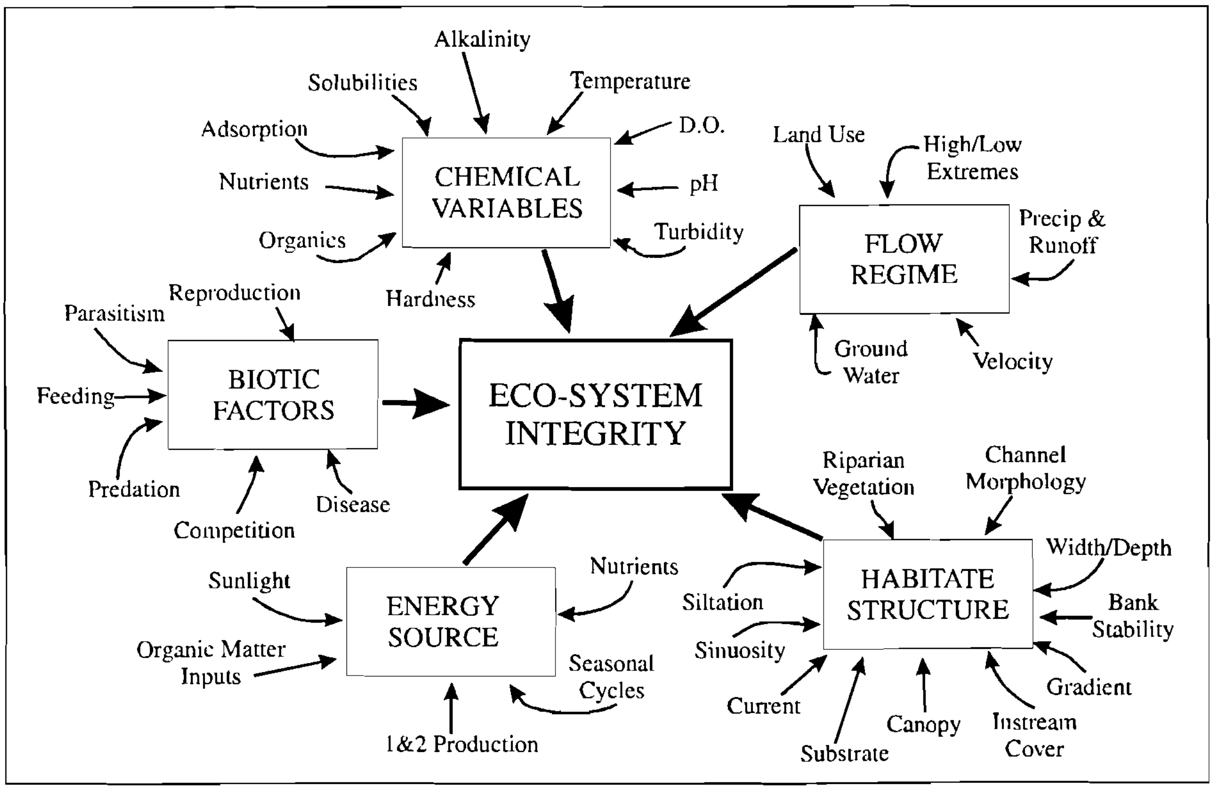

Figure 9. Elements of the aquatic ecosystem (Novotny and Olem 1994).

Although much attention has been given to water quality, it is readily appreciated that water is but a single component within a much larger and more sophisticated natural system. A strong tradition has been developing (over half a century) on biomonitoring including phytoplankton counts (eutrophication, fisheries) and hygienic indicator bacteria (hygiene). The interest in biomonitoring has grown rapidly during the last few decades, and a variety of approaches from microbiological tests to mussels and macroplants are available for water quality monitoring. The aquatic ecosystem, in some sense, is more of a philosophy by which all components of the surrounding water body are included in the analysis, by attempting to give value to all elements of the system, not just water itself. Using water and improving its quality are only part of the objective; the protection and enhancement of all biotic (living) and abiotic (nonliving) elements of the water body and its surroundings are also critical (Figure 9), clearly revealing the complexity of the issues with which we must deal with, as the ecosystem approach attempts to encompass all relevant components, (biological, chemical and hydrodynamical) by gaining an understanding of the different equilibrium states of these interacting systems. The different sub-systems are identified with the appreciation that any adaptation or disruption in one portion of the system will propagate through the other systems and will eventually reach a new desired or undesired equilibrium (Novotny and Olem 1994).

Questions still remain regarding this "holistic" approach to water resources because there are still important elements within the ecosystem model that we do not understand. Disappointingly, contemporary approaches to generic aquatic ecosystem models (mostly deterministic) do not work well; many have worked for decades on such models, but without much success (Park et al. 1974). Even if we could understand all the details, a natural ecosystem is so complex that a model is likely to mislead the analyst if automatically considered a proper tool a priori. For instance, a phytoplankton flora in a lake typically contains a few hundred monitored species. Even if we could understand the growth factor dynamics, zooplankton grazing intensities, respiration, migration, sedimentation, interaction with bacteria, etc., of each species, the model would be too complex to be practically useful. Instead, one has to have as much understanding as possible, but at a lower resolution and more case specific.

With climate change comes the need to understand large and small scale processes and their interaction at all levels (biological, physical and chemical). We still do not fully understand feedback processes which occur between biochemical processes and physical transport mechanisms in the soil (NRC 1991). Most of our understanding of regional distributions of biological species has been empirically derived through observation. Can we assume that these empirical models will hold under climate change or must we develop analytical models of these complex systems in order to understand potential change? These are just a few of the challenges that the ecosystem approach involves.

3. EMISSION CONTROL

3.1 Wastewater Treatment

Wastewater treatment has played a crucual role in water resources management. Biological and chemical treatment have a history of about a century. Biological processes have dominated wastewater treatment (except, e.g., in the Scandinavian countries), while chemical methods are in widespread use in water treatment (in combination with physical and other processes in both cases). The recognition of multiple pollutant problems and other issues (process optimization, improved design, etc.; see Hahn (1990), for details, successes, and pitfalls) led to the slow combination of the two methodologies. For instance, chemical addition is an obvious choice to remove phosphorus and heavy metals (for industrial pre-treatment and control at the source) and to increase the capacity of existing overloaded biological plants with primary clarifiers with low investment (which is an important issue today in the CEE region; see Somlyódy 1994). However, biological processes cannot be excluded if nitrification and denitrification are considered. In turn, there is also an increasing need in water treatment for combining the two different processes, whenever nitrate contamination is an issue.

The above, much desired combination often meets with difficulties. Professionals, manufacturers, and legislators sometimes believe in the exclusive application of a single method, and communication is far from being satisfactory. The arguments against chemicals are still the increased amount of sludge (despite of achievements of low dosage methods), and the societal fear of chemical use. Ironically, the application of biological denitrification at water plants is sometimes objected to because of possible public health implications.

Albeit wastewater treatment plays a critical role in water resources management, there is little communication between treatment engineers and those dealing with receiving waters. Design is often based on effluent standards, thus the analysis of basin wide water quality impacts (including emissions of different origins) and various control strategies (depending on water quality goals, financial conditions, and cost recovery these can be important considerations in the CEE region and in the developing countries) may remain fully excluded. The gap is further illustrated by the present state of modeling on these fields: although many achievements have been made in modeling carbon and nutrient removal by treatment plants (e.g. the IAWPRC activated sludge model; Henze et al. 1987) and cycling in rivers and lakes (see Thomann and Mueller 1987), there are hardly two such models which can use the same water quality variables (and fractionation) to be linked together (cf. Somlyódy et al. 1994).

We may continue the example with eutrophication and the 1970's. At that time, lake eutrophication was a widely recognized phenomenon, and successful restoration programs were also known (based on sewage phosphorus control). Still, there was little concern regarding the increasing use of fertilizers ("diffuse pollution" was identified later as an issue), the construction of drinking water reservoirs fed by rivers with high phosphorous concentrations (which then often led to "surprisingly" poor higher trophic states and related water treatment problems), eutrophication of rivers in downstream reaches or impounded stretches of increased residence times (many European rivers exhibit annual peak chlorophyll-a values close to or above 200 mg/m^3 which would characterize a hypertrophic state in lakes), or the continental nutrient enrichment problems of rivers and inland seas (for example, the Baltic or the Black Sea in Europe).

3.2 Source Control, Prevention and Material Cycles

In the western world, much progress has been made in monitoring and controlling point source emissions. As noted, the focus is shifting towards diffuse loads and control at the source. The realization of this thrust is not easy in practice and reasons are manifold. Traditional non-point source control (for example, in agriculture) requires rather different legislation and incentives than employed in the past. The focus should be on controlling activities and the application of materials of possible harmful impacts (e.g. by taxes), which calls for the integration of water quality management, land use management, and regional development. The issue is primarily institutional in nature (like for many other cases when prevention should be improved). Can we really achieve the desired integration?

Source control and the intention to close material cycles face many barriers even under relatively "well-defined" cases such as urban areas. The unbalanced water infrastructures in many urban areas (characterized by decreasing capacities of water supplies, collection networks, wastewater treatment, and sludge handling), unnecessarily high water consumption and wastewater treatment needs due to subsidies and unrealistic water prices (undervaluing), aged networks, and the lack of re-evaluating the application of seemingly successful traditional methods (see later) are some of the reasons leading to opened water and material cycles. For instance, a recent survey on municipal infrastructure in the CEE region (Poland, Czech Republic, Slovakia, Hungary, and Bulgaria, see Somlyódy 1994) showed that in an average 90% of the population is connected to public water supply. However, the ratio of connection to sewerage is not more than 70% (in some countries, only 50%), while biological treatment is less than 50% of the collected wastewater. Finally, only part of the sludge produced is adequately disposed (perhaps not more than 50%, but it is difficult to estimate). N and P cycles are nearly fully open. Many of these problems are likely to be institutional in nature and are discussed below.

Until now, we touched upon traditional diffuse pollution and "urban metabolism". These are relatively simple issues in comparison to "industrial metabolism". As Stigliani (1990) and Lohm (1992) point out, an efficient abatement of chemical pollutants requires accounting flows of manufactured chemicals through the economy and the society. Consumption related emissions including dissipation and disposal are additional components of industrial metabolism of increasing importance (for instance, for Cr in Sweden and Cd in the Rhine watershed). This depends on (among others) raw material import and consumption patterns broadening again significantly the scope of water quality and environmental management. This approach is contrary to the waste minimization approaches of the past and looks at material cycles from "cradle to grave"[4] (Lindfors 1992). Obviously with some industrial products this type of managerial procedure is simpler than with other products. Developing this type of approach within every sector will be challenging; but where consumer opinion is strong (often in developed countries), there is an increasing demand for companies to produce "green products" which minimize waste not only during production but also during consumption and disposal. A new approach to minimize the overall harmful environmental effects of manufactured products is the Product Life Cycle Assessment (PLCA) which attempts to address the environmental impacts of products from "cradle to grave" (Lindfors 1992). The recognition of the importance of industrial metabolism is an important issue, but the dilemma is — like with sustainability (see later) — whether or not we can take action and use it in an operational sense.

3.3 Appropriate Technology

Are we really approaching water sanitation in the most optimal fashion with respect to our conflicting objectives? Are we stuck on the capital intensive approaches that were developed decades ago when the scale of clean up was much smaller? Niemczynowicz (1991) claims that the traditional approaches to waste water treatment must drastically change, but are radically novel, economically efficient and environmentally sound technologies waiting to be discovered? There are many instances in both the developed and developing world of inappropriate technology. In the developing world, this is often caused when donor countries incorporate high technology equipment within their aid programs with the self serving motive of promoting industry at home. However, also examples on developing low-cost solutions exist (e.g. Hansen and Therkelsen 1978, Eikum and Seabloom 1981, Schiller and Droste 1982, Winblad and Kilama 1985, Chan 1993, Ho and Matthew 1993). What is their applicability in megacities which will be the home of escalating number of urban poor?

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[4] "Cradle to grave" expresses the idea that industrial materials are monitored at the point of extraction from the earth (cradle) until their consumption and disposal (grave).

Technology transfer from the developed to the developing must be driven by the recipients needs and not donor self interest, and it must be implemented at the regional and local levels. Often institutional shortcomings at the national level lead to wasteful spending and unproductive and unsuccessful programs. Low technology research is frequently an under utilized and undervalued alternative whose cause is often social perception of inferior approaches and non-prestigious roles. Grau (1994) poses a direct question to the developed world with regards to its foreign aid to developing countries, "are we rich enough to buy cheap stuff?" Can we afford to give assistance where it is needed and not where it can be self serving? There are other issues related to technology and scale which are not only related to water quality but also to quantity; these are elaborated upon in the next Section.

4. EMERGING PROBLEMS

4.1 Large Scale Projects

The conventional wisdom of socio-economic development tends to ask: *how much do we need for development and how do we get it there?* With this style of thinking along with current growth and development trends, it is not too surprising to find enormous water development projects situated around our globe. Worldwide, water withdrawals have increased from 579 km^3 in 1900 to 3320 km^3 in 1980 and is projected to reach 5200 km^3 by the year 2000 (Shiklomanov 1993). Much of this new demand has been met through the construction of dams to store and transfer schemes to move water to the demand location (Figure 10).

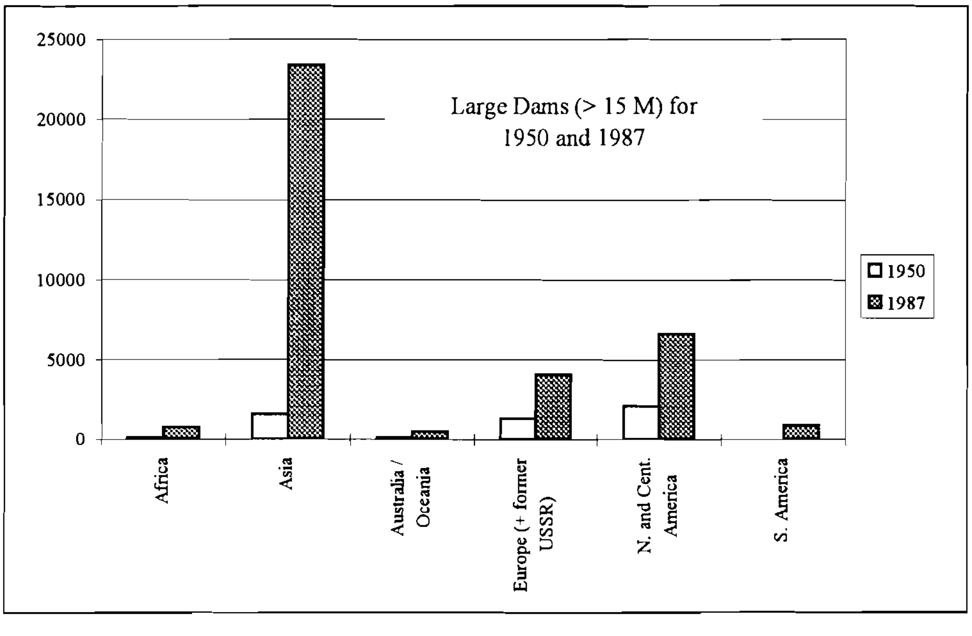

Figure 10. Number of Large Dams, over 15m, by continent (Veltrop 1993).

Comparing the total useful volume stored in reservoirs with stable river runoff, it is estimated that there has been a 25% increase in available supply due to this impoundment. Storage systems have lengthened the water renewal rate from 20 days to 100 days which has depressed the self purification capacity of rivers by reducing the entrapment of oxygen caused by turbulent flow. Large reservoirs also have a dramatic effect on the hydrology and ecology of the reservoir and the surrounding region.

In addition to meeting consumptive use demands, large reservoir projects have been created for the generation of hydro-electric energy and the protection against floods and droughts. These, often large scale water projects have been given a range of positive and negative publicity over the recent decades. Although often meant to serve a number of purposes, large water projects often do not measure up to their original objective. Reasons for this are as complex as the physical systems from which they were developed. As pointed out by Di Lascio et al. (1993) and Pearce (1992), within the developing world reservoir projects often cause detrimental ecological damage, displace native residents, do not bring improvement in living conditions of the local people, and the benefits are often sold at a fraction of their actual cost. Given the pressing needs and limited resources within developing regions, it is highly likely that these struggling communities will continue to look to large-scale infrastructure development of water resources in order to improve their living standards. (Di Lascio et al. 1993). This type of situation is difficult because there are no guarantees that development will bring improvement. The western development model can be quite deceiving with respect to returns in developing countries.

In the developed world large water projects were primarily built decades ago, long before public interest in environmental issues was of widespread importance. A question that naturally arises: given our present state of knowledge would these project be built today in the same manner as before? Early development schemes did not bring multi-criteria decision analysis to the planning room and flood plains were seldom considered as a positive resource. Trends have changed, and the development of Environmental Impact Assessments (see Section 5.3) are perhaps a response to past, narrow-minded approaches to water infrastructure development. Do we better understand the social, economic, and environmental benefits of natural ecosystems and flood-plains and do we fully appreciate how to develop, utilize and manage them in a sustainable manner?

But how can we assess past projects objectively? It is apparent that the often used and quite subjective benefit/cost ratio approach that is used to proclaim large projects as a success or failure is completely biased (Smith 1986, Abu Zeid 1990, Entz 1993). It is more likely that no definitive answer can be given regarding these massive engineered works because there are as many personal opinions as there are possible outcomes. More important is the fact that there are still a great number of large scale projects on the drawing board, whose appropriateness will have to be addressed in a responsible manner (Veltrop 1993). New environmental or ecological economic approaches are trying to give actual, economic value to natural ecosystems with the hope of finding performing a less subjective analysis, but is it possible to remove the element of subjectivity when we are comparing large socio-economic development projects with environmental conservation (Novotny and Somlyódy 1995, Smith 1995)?

What kind of technology and at what scale should future water resources development occur? One example of appropriate scale and suitable technology in the developing world might be the check dam (Biswas 1991). Check dams are generally small structures built across gullies or streams to store flood runoff in the upper portion of a basin. They can be constructed relatively quickly and without much capital investment and they not only help to control water flow, but also help to prevent sediment loss carried by flood waters, offering an alternative to large scale reservoirs in developing countries by keeping costs down and utilizing local resources. Check dams are seeing increased use in diverse areas like China, Nepal, India and Ethiopia and might prove to be an excellent alternative to large scale projects. As donor countries look to invest in large scale projects (Hori 1994), small scale solutions at the local level must play an increasingly important role as an attractive, alternative development strategy.

Can we continue along the path of "conventional wisdom" or must we develop unconventional methods? On a global scale, increasing demands for more resources make it difficult to move away from our traditional, capital intensive approaches. It appears, however, that we are beginning to see alternative methods. The World Bank, one of the largest funding agencies of large development schemes, is perhaps recognizing this new attitude (Serageldin 1994, 1995). They are giving increased attention to water resources management and are trying to de-emphasize costly infrastructure development (Olem and Duda 1994). But the multitude of interests and opinions will continue to make the issue of large scale water resources systems very difficult.

4.2 Transboundary Problems

Drainage basins and groundwater aquifers do not often follow political boundaries, in fact more often than not water resources are effectively shared between countries, sometimes with adequate and sometimes with inadequate cooperation. Some estimates put the number of shared river basins at more than 200, but as Biswas (1993) points out even this type of designation is highly subjective given the fact that there is still no agreed upon definition of an international watercourse or drainage basin. The issues related to international water bodies will demand an increasing amount of attention as demands grow, yet there appears to be a reluctance to realistically address this politically sensitive international issue. There are many barriers to overcome with regards to international water issues; such as physiographical differences, historical and cultural bias, political realities, and socio-economic variance (Biswas 1993). Currently, the region of the Middle East is perhaps experiencing some of the most interesting and difficult international water disputes. Many have addressed the related topics and issues (Shuval 1992, Shamir 1994). Each offers his or her prospective solution, but this is often from a personally biased perspective. Little is being done in many regions regarding actual resolution of related water conflicts, which is most likely due to the complexity of the issue and the desire to wish the problem away.

As of yet, there is no international legislation on how to establish equitable shares of water resource supply and there is even less international progress on establishing laws and rules for the protection of water quality within international basins (see Biswas 1993). Examples of international river basins exists on every continent of the globe and include basins like the Rhine and Danube in Europe, the Tigris-Euphrates and Jordan in the Middle East, the Colorado in North America, the Ganges in Asia, the Nile in Northern Africa, the Zambezi in Southern Africa, the Amazon in South America, along with a host of others. Some argue there is a need for international guidelines and the United Nations has responded by trying to develop implementable principles. In spite of these efforts, problems persist and negotiation procedures among interested nations still appear to be the primary mechanism for conflict resolution. Interested nations realize that a non-cooperative stance often leads to external economic pressures which translate into serious internal economic problems. Because there are few guidelines for states to use in order to manage shared water resources, disputes have primarily been solved under three conditions 1) states have good relations (US and Canada); 2) one state is clearly more powerful but wishes to end the conflict (US and Mexico); or 3) it is in the mutual interest of both to resolve the dispute (India and Pakistan), although in this case the amount of water supply was increased to both countries and the projects were funded by external sources (McCaffrey 1993). In all three cases there appears to be a dominating participant or interest; disappointingly however, these scenarios simply do not often exist.

International water bodies like the Black and Baltic Seas have been of growing interest, as anthropogenic waste loads have put a great deal of strain on their ecosystems. The Black Sea now has eight countries (Russia, Ukraine, Romania, Bulgaria, Turkey, Moldova, and Georgia) sharing her coastline. It wasn't until 1986 that all countries (excluding Moldova and Georgia which were formed thereafter) of the basin were involved in negotiations regarding environmental security of the water body. The six participating countries established a permanent Black Sea commission, with the power to guarantee effective implementation of the conventions' principles. It appears that where there was a high degree of mutual interest, effective negotiation took place (Pisarev 1993). The 'green movement' (political group within Europe focused on environmental issues) is also having a large impact on cooperation within the Black Sea and has called together countries which contribute waste loads from river basins which are physically connected to the Black Sea. Germany is an example, and has been an active participant in discussions since the headwaters of the Danube Basin, which drains to the Black Sea, start in Germany (Pisarev 1993).

Will present approaches used to solve international water problem be adequate to handle the looming water disputes or will international governing bodies like the United Nations play a crucial role in establishing principles and laws? There is a need for a predictive theory of cooperation and conflict resolution of transnational rivers, but given the reluctance of countries to sign basin water conventions it seems likely that these will only serve as ideological principles.

4.3 Urban Areas

There is a general prerequisite that an adequately functioning human society must have a satisfactory infrastructure that includes safe drinking water and sanitation. Yet as the 21st century approaches there is an exploding population of urban dwellers who are not able to access these types of services. This despite programs like the International Drinking Water Supply and Sanitation Decade (IDWSSD) of the 1980's. Urban population nearly doubled between 1970 and 1990 and in the next twenty years it may reach 3.7 billion (Niemczynowicz 1993), while rural population appears to have stabilized (UN 1989). The world's fastest growing and largest cities are located in the lowest income countries and are characterized by a low level of water infrastructure and wastewater treatment. The provision of water supply and sanitation would require strikingly high costs: on the order of 300 to 400 billion USD by 2000 (Niemczynowicz 1993). By 2025, the urban population of developing countries will almost equal the world's total population in 1975 (Kindler 1992). It is estimated that around 30% of this urban population could be living in cities of more than four million people. In Central and Eastern Europe (CEE), under the present political, social, and economic transition, high municipal emissions due to past non-sustainable infrastructure developments form one of the most serious problems and require heavy investments (Somlyódy 1994). In the developed world, the emerging need to rehabilitate aged infrastructure is a growing problem; whose seriousness is not yet recognized. All these statements stress that urban pollution management forms one of the biggest challenges of coming decades.

Problems persist, as urban populations and economic stagnation continue to grow, out pacing efforts to alleviate chronic water related problems. Rural populations continue to be pulled into massive cities despite often horrendous living conditions. The WMO estimates that 23% of the developing world living within urban areas was not "served with water", while 40% did not have access to "appropriate sanitation" (Gladwell and Sim 1993). Obviously in some places the situation is better, while in others it is much worse. Polluted waters within urban areas bring disease. Sewage transport systems are often inadequate, domestic and industrial solid wastes are simply thrown into streams, and sediment erosion from inadequate infrastructure development and upstream users often takes place. For example the Huangpu River which flows through Shanghai, China is treated as an open sewer and has been void of aquatic life since 1980 (Haughton and Hunter 1994). Can these deficiencies be narrowed or will world growth trends continue to outpace any development efforts?

Rapid urban growth within the arid, semi-arid and humid tropic regions is causing a rapid increase in the number of water related problems. Within the arid and semi-arid regions, a diminishing water supply per-capita will force the issue of sanitation and controlled wastewater handling and the need to increase the use of treated wastewater. More often within the world's tropical cities, the problem isn't too little water but too much too soon. Flood protection is often inadequate and protection against a deteriorating water quality is not any better. As these poorer regions are forced to deal with growing problems, the types of water treatment methods and water control structures will have to be addressed. These should be dependent upon the types of human settlements, the climatic zones, and the stages of development (Niemczynowicz 1993). To think that high cost technological approaches can always be applied is ludicrous and alternative technologies adjustable to local socio-economic conditions must be considered. For example, warmer climates offer favorable conditions for the exploitation of biological processes to treat wastewater. More natural processes are generally less expensive than the "high-tech" alternatives of the developed world. These might include photosynthetic oxygenation, biochemical flocculation of polyaromatic compounds and biofiltration by zooplankton or zoobenthos (Gladwell and Sim 1993).

Ways to make and maintain the urban water infrastructure are many. Along with the globally prevailing trends of deregulation and privatization, a.o., the World Bank's "New Agenda" (Serageldin 1994, 1995) is in favor of making water from a social good to an economic one. It has been shown in many cases (but far from all) that governments are unable to tackle the issue. Public awareness and community involvement, together with higher involvement of the private sector are believed to facilitate a more successful development than the "patronizing" public sector approach of the past. With better checks and balances, particularly in terms of enhanced cost-recovery, the water infrastructure should have better possibilities for capacity building, and therewith to meet the requirements, and to run without subsidies. Subsidies are often considered as being most beneficial to those with tap water supply, e.g., the rich and the middle class.

The responsibility issues, the fate of the secure, affordable water to the urban poor, the subsequent public health problems, the equity issue, among other things, have evoked wide concern (cf. Hukka et al. 1995). We share this concern. A serious trap in thinking may be the belief that the urban poor are willing to pay the real price for water. The creativity in digging own wells (with often very low quality), making holes to water pipes, and many other ways to get water without expenses has been great also thus far. Varis (1995) raised the following questions: 1) How the above scheme can be realized within the informal sector without strengthening the positions of those having the informal power (making the weak governments still weaker)? 2) How it will influence the public health and the urban poor in particular (less social function for water)? 3) How does this scheme handle with the sustainability issue (the nature does not charge for water, nor does it pay for it, although its needs were crucial, also for our survival)? These hardly are easy questions to answer, yet a skeptic might say that the result may not be too different from the public sector approach. After all, the importance and roles of externalities of the scheme are not discussed thoroughly.

The challenges facing the urban centers of the developed world are not trivial either. The rapidly growing populations within these areas will increasingly demand environmental protection and sustainable approaches to development. However, few agree what this really looks like from a practical perspective in light of the many conflicting objectives. Niemczynowicz (1993) points to two possible scenarios. The first is a continuation of traditional, capital intensive approaches that that are centrally controlled and data and technology intensive, with the aim of controlling diffuse sources using innovative technologies. The second scenario uses an ecological approach by building small scale biological units close to the wastewater source which take advantage of zero pollution discharge and maximum recycling of waste streams. Niemczynowicz points out that neither approach is likely to be purely implemented but believes that the second approach is less vulnerable and more "sustainable" to society. However, an open question is how realistic small scale solutions are in ever growing megacities of the third world? The mass flows should somehow be controlled and closed, but are there any realistic means to do it?

One example of this approach might be found in Tokyo, Japan. Tokyo responded to the mercury poisoning disaster of the 1950's (Minamata) and has gone from no waste water treatment to almost full coverage within in 40 years. City planners have used recycled waste water to irrigate parks and sports complexes which are fed by water that has been sand filtered. Sludge is being converted for fertilizer use, road construction, brick material, even to grave stones and gems. Although the Japanese example is capital intensive, the innovative approaches are reducing waste and are increasing the awareness of conservation and preservation (Hannerberg 1994)

What does the future hold for these fast growing urban centers with respect to water resources development and protection? The situation does not look promising, as there will continue to be a pressing need to implement cost effective strategies for water and environmental protection. We must reduce the negative environmental impacts of the growing population by reducing per capita waste and by developing innovative techniques for infrastructure development, waste water treatment, environmental protection and solid waste management.

5. TOOLS

5.1 Monitoring

There is also a schism between data collectors and analysts (as stated by the US National Research Council 1991, for hydrology): "*the pioneers of hydrology*" (and our profession) "*were active observers and measures, yet now, designing and executing data collection programs (as distinct from field experiments with a specific research objective) are too often viewed as mundane or routine*" which leads to an "erosion" of such programs. The analysis adds, "*modeling and data collection are not independent processes. Ideally, each drives and directs the other. Better models illuminate the type and quantity of data that are required to test hypotheses. Better data, in turn, permit the development of better and more complete models and new hypotheses. We must reemphasize the value and importance of observational and experimental skills.*" Also, we should be honestly and critically evaluating the "hands off" approach to data gathering which has been possible through advances in technology. This is now occurring all over the world, but an area of special concern is the developing countries which often do not have the institutional infrastructure in place to use this technology effectively. High-tech instruments aboard aircraft and satellites and the advances in the digital computer have given us an unprecedented ability to gain a wealth of new information, but is this technology being used wisely? International aid programs are busy installing high technology equipment within many developing countries, yet the impact of these monitoring programs on the present environmental problems as well as the long-term sustainability of these projects is in question. Often these high-tech programs tend to divert the attention of the real problem which is a lack of interest in data gathering, poor institutional arrangements which discourages cooperation and integration, as well as complex societal issues which are not understood, or simply overlooked.

There is a growing awareness of the need for monitoring and data gathering on the global level. The Global Environmental Monitoring System (GEMS/WATER 1991, Figure 11) has been actively pursuing its goals of providing water quality assessments to governments, the scientific community and the public, on the quality of the world's freshwater relative to human and aquatic ecosystem health, and global environmental concerns. The World Meteorological Organization (WMO) has also been active in establishing monitoring programs, particularly throughout Africa (Kraemer 1994). But will these international programs attempting to gain global coverage be effective? Only time will tell.

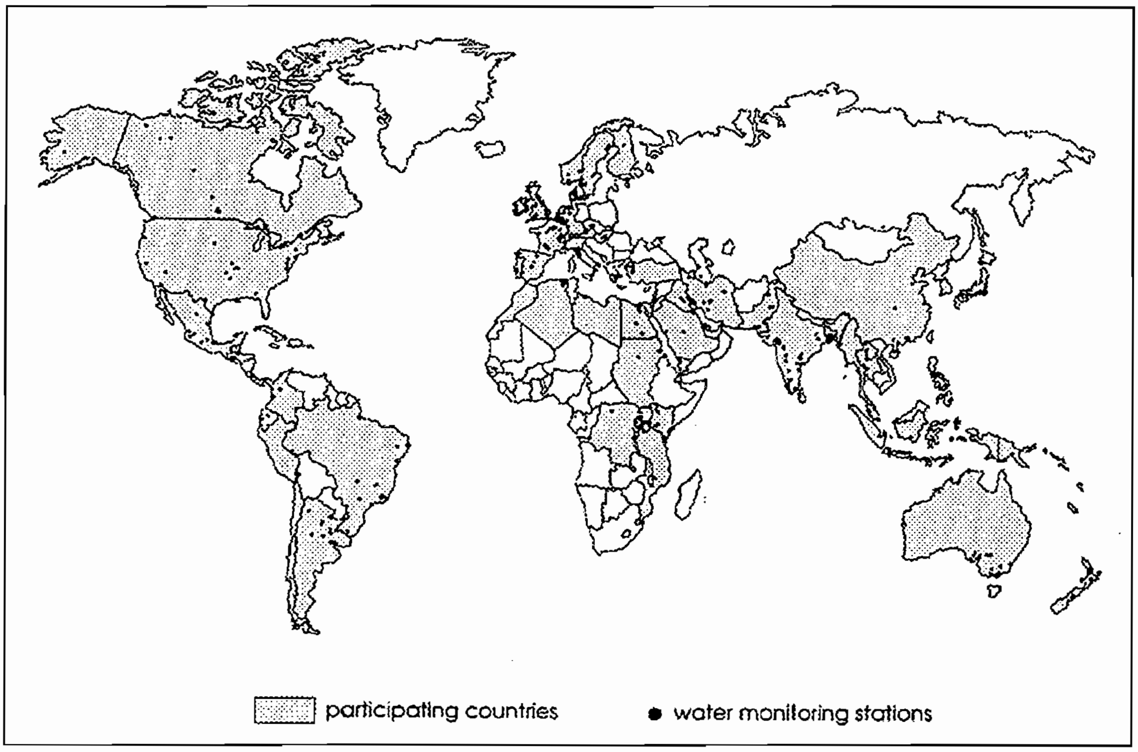

Figure 11. Country wide water quality monitoring around the world (GEMS/WATER 1991).

Country wide water quality monitoring is a common practice all over the world. The major objectives (frequently non-specified) are the description of *the state of the water environment* and the causes of changes, trend detection, estimation of annual (or monthly) average loads, and the derivation of certain statistical parameters for water quality classification, and so on. But are these monitoring systems well and economically designed? Are the obtained data utilized satisfactorily? For instance, is the error of estimating averages and percentile values if the sampling frequency is fixed (often on the basis of intuition) analyzed? Is it recognized that trend detection is often an impossible task (or the probability of the estimate is unacceptably low) if the likely trend is small, the variance is high, or the time series is strongly autocorrelated (Somlyódy et. al. 1986)? Why are we monitoring rarely simultaneously emissions and ambient quality? Too often there are discontinuities between monitoring of treatment plants or industrial processes (which are more and more being monitored and controlled on-line) and monitoring of their discharges and the ambient quality by authorities. All these are disappointing questions calling for future improvements.

5.2 Modeling

Developments in information and computer technology, electronic communication, remote sensing, instrumentation, control, and modeling have already had a significant impact on our profession (comprising research, operation, planning, EIA, decision making, etc.). Combining databases (including on-line monitoring and areal information), models, and interfaces, i.e. the development of decision support systems (see e.g. Fedra and Loucks 1985, Henderson-Sellers 1991, Fedra 1993, Patry and Takács 1994), offers earlier unthinkable opportunities of integration, analyses, and the consideration of complex water and environmental problems. Visual and multi-media tools are becoming more and more useful in transferring technical knowledge to decision and policy makers as well as the public. The global sharing of data-bases is becoming more common all around the world and is a likely key component in improving integration. The "information age" is allowing integrated research to take place around the globe, eliminating the need to bring researchers together for a long period of time. Groups can meet for short planning meetings and then head back to their respective institute, with updates to the project occurring via the "electronic airwaves". This technology is quite helpful in brining together different experts and disciplines in order to focus on a particular problem.

These trends in utilizing electronic technology are likely to continue, but there are still a number of alarming symptoms. First, it appears that the development of computer technology far exceeds the present opportunities of data collection and experiments. Second, modeling approaches developed years ago are often used in fancy packaging — there may not be enough focus on developing new ideas and methodologies. Groundwater modeling is a good example. Many of the traditional approaches to modeling the processes do not work well due to problems of scale, the complexities of three phase flow (air, soil and water), the heterogeneous nature of the soil matrix at all scales, and our lack of complete understanding of complex microscale processes which are necessary for the development of mesoscale predictive models. Third, with increasing sophistication, the quality assurance becomes more and more important, and the knowledge of the analyst remains a crucial factor (for instance, the usage of "standard," rather sophisticated models without understanding equations, parameters and inputs cannot lead to anything other than failure). Fourth, the communication gap between "modelers" and "non-modelers" is not diminishing to an extent we would like to see it, which clearly raises educational issues.

5.3 EIA: Approaches, Shortcomings, and Needs

Water resources planning and EIA processes are unavoidable when considering problems and projects which could potentially have widespread impacts within many sectors. The related literature is vast, even for developing countries (for example, see UNEP 1988; Ebisemiju 1993). Well-known schemes identify subsequent steps of the procedure such as the specification of goals, objectives and constraints, definition of alternatives, screening, evaluation of impacts (economic, environmental, social, cultural, political etc.), selection and decision making, implementation, monitoring, and modification, if desired. Biswas (1994) argues that current EIA practices focus on negative impacts which are then contrasted to economically measured benefits. There is a need to make economic, EIA and social objectives more clear since there are positive and negative aspects within every component. Lee and Walsh

(1992) point out the problem of lag time between EIA appraisals, and the need of strategic assessments at a policy, plan and programme (PPP) level. The lags tend to skew the EIA evaluation, which is often biased towards negative environmental impacts. Biswas (1994) points to three problems with regards to present EIA approaches: 1) macro linkages between EIA and socio-economics is are not clear; 2) project level EIA has developed strongly, but policy and programme levels have not; 3) we have concentrated too much on *what is not* sustainable as opposed to *what is* in our EIA approaches.

There are a number of success stories in planning and EIA (which was first introduced in 1969 in the US). On the contrary, there are cases where problems stem from the lack of applying the above methodologies. Obvious examples come from the pre-EIA era (for instance the High Aswan Dam) as well as from the developing world and the CEE region where the related institutional framework is still weak. For instance, in the developing world, less than 10% of the countries have an established (for about ten years) EIA framework and the performance is rather disappointing. As stated by Ebisemiju (1993), the gap between the intent and performance is attributed to legislative, administrative, institutional, and procedural reasons much more than to technical ones. Frequently, the assessment is made at a postscript stage only for a single "alternative" already decided upon. The practice was rather similar in the earlier socialist countries.

Some of the pitfalls come from incorrect definition of goals and objectives (like the mistaken estimation of future demands), the overlooking of some of the impacts (several dam projects exhibit this undesirable feature), and the lack of the integration of the assessment into the entire project cycle. The EIA guidelines, checklists, matrices, etc., are very useful, but a too strict application of them can lead to overlooking the most critical consequences. The guidelines do not pay attention to the assessment methodology to be used (Varis 1996). The monitoring after implementation and adjustment possibilities are often missing, or more importantly, correction needs are rarely admitted. To have an earlier decision altered — even if there have been significant changes in our knowledge and changes in the actual conditions of the system — is one of the most difficult achievements.

Certainly, there are also a number of evaluation difficulties even in relatively simple cases. It suffices to refer to projects where, on the economic side, costs play the decisive role: the availability or lack of the starting investment costs and the assumption on the interest rate automatically makes the task multi-objective in character. Traditional economic approaches often fail, as benefits are obtained over a long time horizon and are often discounted using ordinary rates (6%). The issue becomes much softer as soon as we incorporate benefits in terms of water uses and protecting aquatic life (not including social, aesthetic, and other implications). While perhaps the first one can still be defined, the second one is non-quantifiable, and it really depends on public awareness, public interest and a willingness to pay. We can systematically organize the pros and cons, but the final decision will largely depend on subjective arguments of participants involved in the procedure.

Many of the infrastructure investments are particularly difficult to evaluate. These issues are very political in nature, and decisions strongly depend on the priorities of politicians in power. To attract tourists, investors, cheap loans, to create new enterprises, to stabilize the economy and the society, and so forth, are arguments frequently used.

Projects often raise serious conflicts (of rather differing nature) which are hard to evaluate. Dams and man-made reservoirs are recognized as a source of emerging conflicts between the economy and the environment, between different branches of water management (see, e.g., Kundzewicz 1993), and possibly between different countries (such as the Slovakian-Hungarian dispute on the Gabcikovo-Nagymaros barrage scheme on the Danube). At present, the views on such projects are rather extreme: what we need is a forum to discuss positive and negative experiences collected to set a future agenda on how to proceed.

Water and environmental scientists/engineers face the dilemma of solving problems of tomorrow today. Risk and uncertainty are logically receiving an increasing amount of attention. New concepts and notions have been introduced such as robustness, reliability, resilience, and vulnerability (see Hashimoto et al. 1982) to characterize the value of today's decisions on an uncertain future. Although real life applications are scarce, hopefully related methodological innovations will lead to improved planning and assessment in the future.

6. LEGISLATION AND INSTITUTIONS

6.1 Institutional Shortcomings

Too often science has had little impact on policies. Even more alarmingly, applied sciences and engineering are not significantly better off in enhancing the prevention of likely problems. These facts can often be associated with confusing and weak institutional arrangements. Water demand management has a long tradition, and advanced planning methods are available; yet, supply, demand, and the waste generation side are usually handled independently in planning, operation, and management. There often are a number of professionals involved at all levels, so often at the root of the problem is an array of ineffective institutions that fail to handle the multi-discipline nature of the problem. Evidently, in an efficient institution, the whole is much greater than the sum of the parts. This is not always the case in many locations of the world. Some of these issue are rooted deep within the framework of the culture and society and are problems which are difficult to identify much less solve.

How do international funding institutions figure in the future development of effective management strategies in developing countries? There is a push to develop management techniques around the globe, but these will require the establishment of properly functioning institutions to carry out their prescribed mandates. This is an important issue which needs to be addressed because there will be a continual need for financial and technical assistance to help eliminate chronic water problems in developing countries (Dewan 1993). As mentioned above, donor countries and their respective institutions must check their self-serving motives or this supposed good-will might come back to “haunt” them.

Examples of institutional inefficiency are frequently found throughout the developing world. One glaring example is found in countries with large irrigation networks, where there is often a ministry of irrigation (supply) whose primary responsibility is the operation and maintenance of the irrigation network throughout the irrigated area, and a ministry of agriculture (demand) whose key role is issues related to agricultural management. Often there are inter-agency rivalries and power struggles among these two groups and an integrated approach to managing the overall system is seldom realized (Bottrall 1978).

In many locations, competing and conflicting institutional arrangements often serve only to hamper the problem solving process. Conflicting objectives and limited resources often force different institutions (which should be cooperating in view of their linked problems) to battle over objectives, power, and money. In light of this, a clear definition of each institutions’ role and institutional links in solving water related problems is essential.

6.2 Role of Engineering, Science, Politics, and Society

Those involved in water resources development and protection are sometimes accused of narrowly considering defined sub-problems which lead to inadequate water protection, storage, and transport systems as well as failures in achieving water quality and environmental protection. Too often the approach is to find solutions to the smaller sub-problems, however these solutions may not be equivalent with that of the entire issue. This and similar statements raise a number of questions. Can we avoid having individual "actors" like developers, planners, and engineers? What is the scale and scope of a problem engineering can tackle? What is the proper level of governmental control over new water development projects which are initiated by the private sector? Whose responsibility is it to decompose problems into tractable pieces? The answer to the last question is systems analysts, planners, or generalists.

But where are they acting? Although we have no answer, we argue that legislation and institutions should be developed such that they self-evidently appear in the picture. However, it is rarely the case, and for this reason, poor legislative and institutional settings often lead to mismanagement. As water quality and quantity have generally developed upon independent paths, there are often a number of institutions even within a single river basin that have some responsibility in managing the water resources system. Will the notion of a single, integrated institutional agency really work in achieving development improvements, or has the "central planning" approach been proven unsuccessful. In some developed countries, basin wide agencies appear to be successful in managing large systems, with one example being the Tennessee Valley Authority (TVA) in the United States. This agency greatly influences water related issues by controlling more than 20 dams over 100,000 km^2 area, but its role in influencing development has greatly diminished in the last few decades because of more powerful economic sectors within the region (Knop 1979). Are agencies such as the TVA a good model to go by in the development of water related institutions in other parts of the world?

The difficulty of water quality management starts with the fact that impacts and benefits are frequently hard to identify (see e.g. Thomann 1972), and thus "efficiency" analyses are often considered of low value (unlike air quality management). The consequence in the developed world is that legislation is based mostly on three assumptions: (1) to set generalized effluent standards (relying upon the "best available technology") such that ambient quality will be good "all the time", (2) economic conditions are sufficient to realize such a safe policy, and (3) the principle of "equity" leading to uniform emission reduction (which may be significantly more expensive than a regional least-cost policy).

6.3 Developed, CEE, Industrializing, and Developing Countries

The three above assumptions have led to a number of successful applications. However, e.g., in the US, the number of water bodies not meeting water quality goals is appreciable after completing point source control programs. The dominant reasons are diffuse pollution and the failure to consider all emissions and ambient quality impacts jointly (separated by effluent criteria). The ongoing revision of the Clean Water Act of 1972 looks for a more "holistic" approach focusing strongly on river basins (which was not the case before), watershed wide planning and management, non-point sources and economic implications (Novotny and Olem 1994). Governments and consumers of the developed world will continue to demand environmentally friendly production systems and life cycle analyses, environmental tags, and auditing systems which will require effective legislation and institutional settings.

Within the CEE region economic recovery appears more critical to leaders in this region than does environmental protection. Simons (1994) asks, "*should anti-pollution devices, fines and taxes be further postponed in order to protect factories and jobs or will this bring more health and cleanup costs in the future?*" Even with legislation in place, there is little enforcement because inspectors are not well trained or motivated and fines are low. There is little desire to comply.

The situation is similar within rapidly industrializing nations such as Indonesia, Thailand, Mexico, and China where economic growth continues to dominate effective environmental policy. Helmer (1987 in Golubev 1993) claims that only 10 of the 60 rapidly industrializing countries have established effective laws, regulations and enforcement infrastructures to cope with the pollution problems.

The future is by all means towards integrated land use-water management policies. But how can we realize it, given the huge amount of existing institutional shortcomings, mismanagement, and administrative barriers (e.g., see Moss 1992, Falkenmark 1992)? "The administrative infrastructure basically mirrors the scientific divisions," according to Falkenmark (1992), but perhaps the isolation is even stronger. Regional water and environmental authorities have very little controlling role on economic activities (agriculture, industry, tourism, housing development, etc.) in a given region and where both exist are often in conflict. Various interest groups and lobbies often play a powerful role in the associated issues. How can we integrate water management under fragmented conditions when different ministries all have their own role (health, quality, pollution from various sectors, quantity, etc.)?

Management of water quantity and quality confronts many more obstacles in the developing world than in industrialized countries (see Hamza 1992). Missing or inadequately developed legislation, institutions, standards, economic instruments, monitoring, enforcement, unclear institutional responsibilities, and the overall lack of financing form perhaps the most significant barriers. There is often a very low level of administrational control and powerful informal economic sectors often dominate within developing countries (particularly within cities). The development of appropriate standards, economic instruments, technology, and financing schemes are absent. These are perhaps adequate arguments for the return to related ideas of water management, which are rarely utilized in the industrialized world, and to re-think how to proceed (Thomann 1972). A similar statement applies to most of the earlier socialist countries; for although knowledge exists, financial constraints will remain a significant problem in coming decades (see Somlyódy 1994).

On a global level, financial problems will continue to be a key barrier to improving water related problems. If one considers global per-capita incomes (or GDP per capita) and translates these into spending on environmentally related issues (such as water), the prospects for rapid change do not look promising. In developing countries, the share of the GNP given to environmental issues no greater than 3% (IAWPRC 1991), being often far smaller. So for a developed country with an annual per capita GDP of 15 000 USD, environmental spending would amount to 115 USD per capita. Within a poorer developing country, with a GDP per-capita of 200 between 400 USD, the corresponding per-capita environmental spending would be no greater than 3 USD. Typically, the political will and power to invest in environmental concerns decreases with decreasing per-capita GDP. Such disparities have an increasing trend. In 1991, the richest one-fifth of the world accounted for 84.2% of the world GNP, while the share of the poorest one-fifth was only 1.4% (UNDP 1994). Obviously, the comparative use of GDP per-capita is subjective, but hints to a realistic level of environmental investment that can be made within different countries.

With increasing water scarcity and pollution problems at a growing scale, international, transboundary issues become increasingly important, making the entire setting more complex. Upstream extraction of water from rivers, combined with waste discharge into streams with smaller flows are likely to be seen more frequently. The Rio Grande river flowing from the Southwestern corner of the United States into Mexico is one such example. Conflicts over flow volume and salinity concentrations date back to the 19th century and continue today (McCaffrey 1993). As pointed out by Biswas (1992), information available on such problems is outdated, and we cannot identify the real magnitude of the issue. At the same time, the power of international agencies is gradually eroding and in many cases the same applies to national governments. International organizations are shying away from the resolution of specific problems because they are viewed too politically sensitive. Strong leadership is missing. "*What perhaps is needed is an International Law of the Hydrologic and Biogeochemical cycles*" mentions Moss (1992) when discussing issues of global environmental change (which could be formulated even broader). But can it ever be realized? Concurrently, there appears to be a continued global-economic restructuring process which has liberalized trade, has reduced the public sector, and has increased the private and informal sectors[5]. Power is shifting to the international economic system with its transboundary capital flows and multinational companies. The share of private capital flows to developing countries has dramatically increased during the last few years. Whereas the net flow of official development finance to developing countries has dropped from 70 billion USD in 1988 to 67 billion in 1992, the net private flow has doubled from 45 billion to 91 billion within the same period (OECD 1993). The poorest economies which often have the highest debt-GNP ratio are the least attractive recipients for foreign investments.

This is forcing us to move away from command and control and towards economic instruments and incentives and public awareness of environmental issues. But how can these be understood on a global level?

7. SUSTAINABILITY AND WATER AWARENESS

Agenda 21 of the Earth Summit '92 in Rio de Janeiro (UNCED 1992) postulates the concern and urgent need to plan and implement environmentally sustainable development strategies. Evidently, in addition to the environment, the sustainability criteria should also incorporate the exploitation of natural resources, development of human reources (health and education) and development of an efficient macroeconomy. Trends in development and environmental problems, notions of prevention, source control, consumption emission, closing of material cycles, cross-sectorial and other, improved integration, etc., self-evidently lead to needs which are expressed by sustainability. At least two questions emerge. Is it more than one of the many buzzwords which we cannot really define? Can we use it operationally?

The best-known and probably most widely used definition (the number of definitions seems to grow exponentially) of sustainable development was given by the WCED as "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" (see Peet 1992). Peet adds correctly, "*this definition is so general . . . there is a real danger that sustainability as a goal will lose its credibility.*" And later, he writes, "*the Brundtland definition may be better than nothing for as long as there is nothing better*". Referring to de Vries, he states, "*Sustainability is not something to be defined, but to be declared. It is an ethical guiding principle.*"

We tend to agree that sustainability is *an ethical guiding principle* which is hard to make operational (certainly, this principle may influence the definition of goals and objectives of a particular project, with an indirect impact on planning). We suppose that sustainability will have a broader impact than earlier principles (like *environmentally sound management*), owing to the increased recognition, aggressiveness and publicity of environmental issues by the public and the political sector (at least in the industrialized world) when compared with past ideas. Still, about a decade ago, the prevailing attitude was that technical progress will solve the problems we create. It is becoming more apparent, however, that technical progress

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[5] Here, the informal sector represents the economic sector primarily found within major urban centers of developing countries that often run without official knowledge from the established government.

has actually been the cause of many of our current problems. There appears to be a shift in thinking towards more cautious behavior coupled with less optimistic attitudes.

Still, the question "*can we give a concrete definition to sustainability and how should we use it?*" remains open. For instance, the related action program of the European Community (CEC 1992) summarizes rather general guidelines. The purpose is to provide "*a framework for a new approach to the environment and to economic and social activity and development, and requires positive will at all levels of the political and corporate spectrums, and the involvement of all members of the public active as citizens and consumers in order to make it work*".

There is the hope for a new *guiding principle* with regards to not only water resources but also to sound socio-economic development. This doctrine might have been well summarized by Falkenmark (1991) as a three point, common sense set of principles: to protect the potability of freshwater/edibility of food/productivity of land; to protect the bio-diversity of the eco-system; and to halt the overexploitation of our limited resources. We think that improved education from kindergarten onwards and improved integrated planning are one set of crucial pre-requisites to realize slowly the new *guiding principle*, but achievement of these noteworthy and ideological principles is difficult. Along with education there is the perhaps more important, crucial need for stable economies and stable societies.

How can we achieve this for most of the population? The current state of the world's freshwater is being described with such strong words as: Crisis, Urgent, Dangerous, Scarce, and Vulnerable (Postel 1992, Falkenmark 1991, Kulshreshtha 1993, Gleick 1993), yet projecting this awareness to the general public is difficult and barriers to developing an overall water awareness are enormous. Misuse and pollution of water have been an accepted habit in many regions and societies, and changing individual and societal behavior is difficult. A summary of the five primary barriers to water awareness as outlined by Castensson et al. (1990) include: *Action barriers*: multiple uses and users with different values; *communication barriers*: different frames of reference (research, application, public); *decision-making barriers*: national, regional, local actors and interests; *structural barriers*: institutional conflicts and legal shortcomings; and *individual barriers*: limited understanding of problem and lack of interest or concern. These are obviously formidable barriers to overcome in developing a new *water awareness*, but if the situation is as urgent as some speculate, then overcoming these obstacles in order to meet our objectives is crucial.

The pressing need for global scale institutions to tackle the water issue has been recognized many times, and frustration has become prevailing in many people's minds. However, a new wave of initiatives are just under way, and there is a justification for some positive attitudes, we feel. We are waiting with particular enthusiam the evolution of the World Water Concil, the Global Water Partnership, and the Global Freshwater Treaty. Perhaps such initiatives help in bringing a global water leadership at least slightly closer to reality.

8. CONCLUSIONS

The historical development of water resources management has shown a shift in focus from quantity to quality issues. The increasing role of non-point sources, toxic contamination, large scale, multiple pollutant and multiple media problems, the recognition of consumption emissions and global changes as a whole have created the need for yet another shift in the profession as it appears that quantity and quality can no longer be handled independently. A much stronger integration of hydrology (the water cycle), the biogeochemical cycle, water resources management, land use management, and water quality management is required. In a broader sense, integration should also comprise environmental management, technology, development, and society. With increasing complexity and growing scale of concern, the analyses must be more integrated and interdisciplinary.

The existing, tremendous gaps and barriers should somehow be overcome. Gaps between existing and used knowledge, lack of future vision supported by science, gaps between different disciplines and professions, barriers in legislation, institutions, and decision making, lack of communication (among an increasing number of different specialists, between specialists and the society, between researchers and decision makers, etc.), gaps between experts dealing with same problems in different temporal and spatial scales are just a few examples.

Water management cannot be performed, and our profession cannot exist without scientists and engineers. Their activity is driven by questions and answers, respectively. They should remain within their own fields preserving, improving, and nurturing their strengths, but be more able to work with individuals with different background than their own. More *science for action* is probably needed, and a stronger focus on how complex problems can be split into tractable pieces to be handled by engineers and professionals, i.e., improved analysis and planning. The slogan *think globally, act locally* expresses well the dilemma we face. Whether we can handle it, remains to be seen.

A particular challenge is due to the enhancement of the future evolution of fresh water management towards the desired trends. To a large extent, such trends can be influenced or even controlled by the water professionals. Yet, much development in societies, institutions, legislation, economic and political conditions, education, and other necessary prerequisites is also required in most countries of the world, particularly but not solely in the Third World. In those countries, the bottlenecks are presently typically in social priority setting, institutional shortcomings, and economic affordability. Technical solutions may exist, yet the professional community should address increasingly the paradigm *high science for low technology*. This is mandatory in order to make improvements on freshwater sector that would touch the majority of the mankind.

With increasing exploitation pressure to which water resources invariably are subjected to, the rapid evolution of watersheds to be increasingly artificial and less natural appears evident. Therefore, the sustainability concern, despite its problematic operational comprehension, grows in importance. Ecological consideration of water resources and protection of nature should gain more priority. Ecosystem management, closing of material cycles, ecological engineering, demand management are among issues that are acute today but they still will be rapidly emerging in importance.

Among global changes affecting freshwater resources, the expansion of human population should deserve high concern. Not only the absolute number of people is growing, but the excessive urbanization changes water use patterns drastically. The growing aspirations to water use and agricultural products along with climatic changes will accelerate the pressure on freshwater.

According to the title of this paper, we focused on problems and challenges that freshwater management is facing at present and in close future. Therefore, we created more questions than answers. We are sure that not even all most crucial questions, not to talk about answers, have been touched in this report. The work on both questions and answers must go on. The problems and challenges we are confronted to are huge enough. We should try to find solutions that in essence solve more problems than they create.

REFERENCES

Abu Zeid, M. 1990. Envrironmental impacts of the High Aswan Dam: a case study. In: Thanh, N. and Biswas, A. (Eds.), Environmentally Sound Water Management. Oxford University Press.

Biswas, A.K. 1976. Systems Approach to Water Management. McGraw-Hill, New York.

Biswas, A. 1983. Major water problems facing the world. Water Resources Development 1: 1-14.

Biswas, A. 1991. Water resources in the 21st Century. Water International 16: 142-144.

Biswas, A. 1992. Sustainable Water Development: A Global Perspective. Water International 17: 68-80.

Biswas, A. 1993. Management of international waters: problems and perspective. Water Resources Development. 9(2).

Biswas, A. 1994. Sustainable water resources development. Water Resources development 10: 109-116.

Biswas, A.K. and El-Habr, H.N. 1993. Environment and water resources management: the need for a holistic approach. Water Resources Development 9: 117-125.

Blackwelder, B., Harding, B. and Colbron, T. 1987. Alternatives to traditional water development in the United States. Ambio 16: 32-37.

Botrall, A. 1978. The managment and operation of irrigation schemes in less developed countries. In: Wildstrand, C. (Ed.), The Social and Ecological Effects of Water Development in Developing Countries. Pergamon Press, New York.

Castensson, R., Falkenmark, M. and Gustafsson, J. 1990. Water Awareness in Planning and Decision-Making. Swedish Council for Planning and Coordinated Research. UNESCO. Stockholm, Sweden.

Chan, G.L. 1993. Aquaculture, ecological engineering: lessons from China. Ambio 22: 491-494.

Clarke, R. 1991. Water: The International Crisis. Earthscan, London.

Commission of the European Communities (CEC) 1992. Action Plan. Vol. II.

Cox, W.E. (Ed.) 1987. The Role of Water in Socio-Economic Development. No. 46. UNESCO, Paris.

Dewan, R. 1993. Role of nationalized banks in financing water resources development in India. In: Biswas, A., Jellali, M., and Stout, G. (Eds.), Water For Sustainable Development in the 21st Century. Oxford University Press.

Di Lascio, M., Bentancurt, J., and Araujo Neto, M. 1993. Hydropower for Sustainable Development of the Amazon Region. In: Biswas, A., Jellali, M., and Stout, G. (Eds.), Water For Sustainable Development in the 21st Century. Oxford University Press.

Drakakis-Smith, D. 1987. The Third World City. Routledge, London.

Döös, B. 1991. Towards sustainability. RR-91-16, IIASA, Laxenburg, Austria.

Ebisemiju, F. 1993. Environmental Impact Assessment: making it work in developing countries. J. Environmental Management 38: 247-273

Eikum, A.S. and Seabloom, R.W. (Eds.) 1981. Alternative Wastewater Treatment. Reidel, Dordrecht.

El Ashry, M. 1993. Policies for water resources management in arid and semi-arid regions. In: Biswas, A., Jellali, M. and Stout, G. (Eds.), Water for Sustainable Development in the 21st Century. Oxford University Press.

Elgersma, F., Anderberg, S. and Stigliani, W. 1991. Aqueus emission factors for the industrial discharges of Cadmium in the Rhine. WP-91-05, IIASA, Laxenburg, Austria.

Entz, B. 1993. Natural History of Lake Nasser-Nubia with special reference to Environmental and Economic Questions. Draft. Balaton Limnological Research Institute. Hungarian Academy of Science.

Falkenmark, M. 1988. Sustainable development as seen from the water perspective. In: Perspectives of sustainable Development: 71-84.

Falkenmark, M. 1991. Regional Environmental Management: The Role of Man-Water-Land Interactions. The World Bank. Environmental Dept., Policy and Research Division, The World Bank, Washington D.C.

Falkenmark, M. 1992. Possibilities for sustainable development: adapting to the possible future. In: van Dam, J.C. and Wessel, J. (Eds.): Transboundary River Basin Management and Sustainable Development. Proceedings, Vol. 1: 211-233.

Falkenmark, M. 1993. Urgent need for a water perspective. In: Biswas, A., Jellali, M. and Stout, G. (Eds.), Water for Sustainable Development in the 21st Century. Oxford University Press.

Falkenmark, M. and Lindh, G. 1976. How can we cope with the water resources situation by the year 2015?. Ambio 3-4.

Fedra, K. 1993. Expert systems in water resources simulation and optimization. In: macro, J.B. et al. (Eds.), Stochastic Hydrology and its Use in Water Resources Systems Simulation and Optimization: 397-412.

Fedra, K. and Loucks, D.P. 1985. Interactive computer technology for planning and policy making. Water Resources Research 21: 114-122.

Freeze, R. and Cherry, J. 1979. Groundwater. Prentice-Hall, New York.

GEMS/WATER 1991. Water Quality. Earthwatch, WHO/UNEP.

Gladwell, J. and Sim, L. 1993. Tropical Cities: Managing Their Waste. IHP Humid Tropics Prgramme Series No. 4. UNESCO, Paris.

Gleick, P. (Ed.) 1992. Water and Conflict. Oxford University Press, New York.

Golubev, G. 1993. Sustainable water development: implications for the future. Water Resources Development. 9: 127-154.

Grau, P. 1994. Comments on integrated water quality management. Water Quality International '94, IAWQ, Budapest, Hungary.

Hahn, H. 1990. Quo vadis chemical treatment?. In: Hahn, H. and Klute, R. (Eds.), Chemical Water and Wastewater Treatment. Springer-Verlag, Berlin.

Haimes, Y.Y. 1992. Sustainable development: a holistic approach to natural resources management. Water International 17: 187-192.

Hamza, A. 1992. Water quality monitoring in the developing world: chalelnges and prospects. In: Proceedings of the Stockholm Water Symposium: A Holistic Approach to Water Quality Management. Stockholm.

Hanneberg, 1994. Tokyo's wastewater-fed parks. Tomorrow. Worldwatch Institute, Washington DC.

Hansen, J.A. and Therkelsen, H. 1978. Alternative sanitary waste removal systems for low-income urban areas in developing countries. Polyteknisk Forlag, Viborg.

Hashimoto, T., Loucks, D.P. and Stedinger, J. 1982. Reliability, resiliency and vulnerability criteria for water resource system performance evaluation. Water Resources Research 18: 14-20

Haughton, G. and Hunter, C. 1994. Sustainable Cities. Jessica Kingsley, London.

Henderson-Sellers, B. 1991. Decision support systems for stored water quality: I The environmental decision support system. Environment International 17: 595-599.

Henze, M., Grady, jr. C.P.L., Gujer, W., Marais, G. and Matsuo, T. 1987. Activated Sludge Model No. 1. IAWPRC Task Group on Mathematical Modelling for Design and Operation of Biological Wastewater Treatment. IAWPRC, London.

Hjorth, P. 1992. Some Principles for Sustainable Management of Natural Resources. In: James, W. and Niemczynowicz, J. (Eds.), Water, Development and the Environment. Lewis Publishers, Chelsea, Mich.

Ho, G. and Matthew, K. (Eds.) 1993. Appropriate waste management technologies. Pergamon, Oxford.

Hock, B. and Somlyódy, L. 1990. Freshwater Resources and Water Quality. In: Hinrichsen, D. and Enyedi, G. (Eds.), State of the Hungarian Environment. Hungarian Academy of Science.

Hori, H. 1994. Macro-engineering: super-scale water resources development. In: Biswas, A., Jellali, M. and Stout, G. (Eds.), Water for Sustainable Development in the 21st Century: 94-101. Oxford University Press.

Hufschmidt, M. 1993. Water Policies for Sustainable Development. In: Biswas, A., Jellali, M., and Stout, G. (Eds.), Water For Sustainable Development in the 21st Century. Oxford University Press.

Huisman, P. 1994. From One-Side Promotion of Individual Interests to Integrated Water Management in the Rhine Basin. In: Living with Water. IAWQ/EWPCA/NVA.

Hukka, J., Katko, T., Seppälä, O. and Viitasaari, M. 1995. Holistic strategy for development co-operation in urban water supply and sanitation. In: Proceedings of the Stockholm Water Symposium: A Holistic Approach to Water Quality Management: 131-143. Stockholm.

Hukka, J., Katko, T., Pietilä, P. and Viitasaari, M. 1995. Urban infrastructure — The case of urban water supply and sanitation. UNU/WIDER Conference on Human Settlements in the Changing Global Political and Economic Processes 25-27 August, 1995, Helsinki, Finland.

Hutchinson, G. 1957. A Treatise on Limnology. Wiley, New York.

IAWPRC 1991. The contribution of IAWPRC to the COWAR report. Water In Our Common Future.

Ingram, H. 1990. Public involvement in water resources decisionmaking in a climate of uncertainty. In: Managing Water Resources in the West under Conditions of Climate Uncertainty. National Academic Press.

Kaczmarek, Z. and Krasuski, D. 1991. Sensitivity of water balance to climate change and variability. IIASA WP-91-047 IIASA, Laxenburg, Austria.

Kindler, J. 1992. Water quality impacts of urban expansion in developing countries. In: James, W. and Niemczynowicz, J. (Eds): Water, Development and the Environment: 96-105. Lewis Publishers, Chelsea, Mich.

Kinnersley, D. 1988. Troubled Water. Shipman, London.

Kishk, M. A. 1986. Land Degrdation in the Nile Valley. Ambio 15: 228-230.

Knop, H. 1979. The Tennesse Valley Authority: A Field Study. RR-79-02. IIASA, Laxenburg, Austria.

Koudstaal, R., Rijsberman, F. and Savenije, H. 1992. Water and Sustainable Development. In: International Conference on Water and the Environment: Development Issues for the 21st Century. WMO, Geneva, Switzerland.

Kraemer, D. 1994. Water Related Activities of WMO and the Follow-up to UNCED. World Meterological Organization, Geneve, Switzerland.

Kulshreshtha, S. 1993. World Water Resources and Regional Vulnerability: Impacts of Future Changes. RR-93-10. IIASA, Laxenburg, Austria.

Kundczewicz, Z. 1993. Conflicts between environmental and water resources issues. ECO Newsletter: Environmental Conflicts 1(3): 4-7.

Kundczewicz, Z. and Somlyódy, L. 1993. Climatic change impacts on water resources - a systems view. WP-93-30, IIASA, Laxenburg, Austria.

Lee, N. and Walsh, F. 1992. Strategic environmental assessment: an overview. Project Appraisal 7: 126-136.

Lettenmaier, D. and Gan, T. 1990. Hydrologic Sensitivities of the Sacramento-San Joaquin River Basin, California, to Global Warming. Water Resources Research. 26(1): 29-86.

Lindfors, L.G. 1992. Environmentally adapted industrial production. In: Proceedings of the Stockholm Water Symposium: A Holistic Approach to Water Quality Management. Stockholm.

Lohm, U. 1992. Predicting harmful fluxes through analysis of industrial metabolism. In: Proceedings of the Stockholm Water Symposium: A Holistic Approach to Water Quality Management. Stockholm.

Lundqvist, J., Datye, K. and Falkenmark, M. 1993. Biomass strategy for watershed development. In: Biswas, A., Jellali, M. and Stout, G. (Eds.), Water for Sustainable Development in the 21st Century. Oxford University Press.

Lutz, W. 1994. The Future of World Population. Population Bulletin 49(1).

Malle, K. 1985. Metalgehalt und Schwebstoffgehalt im Rhein. Wasser Abwasser Forsch. 18: 207-209.

McCaffrey, S. 1993. Water, politics and international law. In: Gleick, P. (Ed.), Water In Crisis: A Guide to the Worlds Freshwater Resources. Oxford University Press, New York.

Meybeck, M., Chapman, D. and Helmer, R. 1989. GEMS: Global Freshwater Quality, A First Assessment. WHO and UNEP. Blackwell.

Meybeck, M. and Helmer, R. 1989. The quality of rivers: From pristine stage to global pollution. Palaeography, Palaeoclimatology, Palaeoecology (Global and Planetary Change Section) 75: 283-309.

Miller, J., and Russell, G. 1991. The impacts of global warming on river runoff. J. Geophys. Res. 97: 2757-2764.

Moss, B. 1992. Uses, abuses and management of lakes and rivers. Hydrobiologia 243/244: 31-45.

Nash, L. 1993. Water Quality and Health. In: Gleick, P. (Eds.), Water in Crisis: 40-51. Oxford University Press, New York.

Nash, L. and Gleick, P. 1993. The Colorado River Basin and Climate Change: The Sensitivity of Streamflow and Water Supply to Variations in Temperature and Precipitation. USEPA. EPA230-R-93-009.

National Research Council (NRC) 1991. Opportunities in the Hydrologic Sciences. National Academy Press, Washington D.C.

Niemczynowicz, J. 1991. Environmental impacts of urban areas - the need for paradigm change. Water International 16: 83-95.

Niemczynowicz, J. 1993. New aspects of sewerage and water technology. Ambio 22: 449-455.

Novotny, V. and Olem, H. 1994. Water Quality: Prevention, Identification, and Management of Diffuse Pollution. Van Nostrand Reinhold, New York.

Novotny, V. and Somlyódy, L. 1995. Water quality management: Western experiences and challenges for Central and Eastern European countries. In: Novotny, V. and Somlyódy, L. (Eds.), Remediation and Management of Degraded River Basins with emphasis on

Central and Eastern Europe. NATO ASI Series 2: Environment Vol. 3. Springer-Verlag, Berlin.

OECD 1993. Development Co-operation. OECD, Paris.

Olem, H. and Duda, A. 1994. International watercourses: The World Bank looks toward a more comprehsive approach to management. In: Living with Water. IAWQ/EWPCA/NVA.

Pantulu, V.R. 1985. Ecosystem Modeling of a River Basin. In: Strategies for River Basin Management. Reidel, New York.

Park, R. et al. 1974. A generalized model for simulating lake ecosystems. Simulation 23: 33-50.

Patry, G. and Takács, I. 1994. GPS-X: a wastewater treatment plant simulator. Presented at 1. MATHMOD Conference, Vienna, Austria.

Pearce, F. 1992. The Dammed. The Bodley Head, London.

Peet, J. 1992. Energy and the Ecological Economics of Sustainability. Island Press, Washington D.C.

Piotrowski, J. and Coleman, D. 1980. Environmental Hazards of Heavy Metals: Summary Evaluation of Lead, Cadmium and Mercury. UNEP/GEMS No. 20, London.

Pisarev, V. 1993. Turkey, Bulgaria, Romania, and the Soviet Union: The Black Sea. In: Faure, G. and Rubin, J. (Eds.), Culture and Negotiation. Sage Publications.

Postel, S. 1992. Last Oasis. The Worldwatch Environemntal Alert Series. W.W. Norton.

Rotmans, et al. 1994. Global change and sustainable development: a modelling perspective for the next decade. Globo Series Report 4, RIVM Report 461502004. Delft, The Netherlands.

Sakamoto, M., Nakano, A., Kinjo, Y., Higashi, H. and Futatsuka, M. 1991. Present mercury levels in red blood cells of nearby inhabitants about 30 years after the outbreak of Minamata disease. Ecotoxicology and Environmental Safety 22: 58-66.

Schiller, E.J. and Droste, R.L. (Eds.) 1982. Water Supply and Sanitation in Developing Countries. Ann Arbor Science, Ann Arbor, Michigan.

Schneider, S. 1994. Climate Change Seminar, IIASA, Laxenburg, Austria.

Serageldin, I. 1994. Water Supply, Sanitation, and Environmental Sustainability, the Financing Challenge. The World Bank, Washington DC.

Serageldin, I. 1995. Toward Sustainable Management of Water Resources. The World Bank, Washington DC.

Shamir, U. 1994. Water Resources Management in Israel and the Middle East. April 1994, Technicon Conference, Vienna University of Technology, Austria.

Shiklomanov, I. 1993. World Fresh Water Resources. In: Gleick, P. (Eds.), Water In Crisis: A Guide to the Worlds Freshwater Resources. Oxford University Press, New York.

Shuval, H. 1992. Approaches to resolving the water conflicts between Israel and her neighbors - a regional water-for- peace plan. Water International 17: 133-143.

Simons, M. 1994. In the New Eastern Europe, Old Pollution Problems Worsen. International Hearald Tribune, Nov. 4, 1994.

Smil, V. 1993. Chinas Environmental Crisis. M.E. Sharpe, New York.

Smith, M.G. 1995. The state of the art in economic instruments and institutions for water quality management. In: Novotny, V. and Somlyódy, L. (Eds.), Remediation and Management of Degraded River Basins with emphasis on Central and Eastern Europe. NATO ASI Series 2: Environment Vol. 3. Springer-Verlag, Berlin.

Smith, S.E. 1986. General impacts of the Aswan High Dam. J. Water Resources Planning and Management 112: 551-562.

Somlyódy, L. 1994. Quo vadis water quality management in Central and Eastern Europe? Water Sci. Tech. 30(5): 1-14.

Somlyódy, L. 1995. Water quality management: can we improve integration to face future problems? Water Sci. Tech. 31(8): 249-259.

Somlyódy, L., Pintér, J., Koncsos, L., Hanáczek, I. and Juhász, I. 1986. Estimating averages and detecting trends in water quality data. IAHS Pubication 157: 61-69.

Somlyódy, L., Kularathna, M. and Masliev, I. 1994. Development of least-cost water quality control policies for the Nitra river basin in Slovakia. Water Sci. Tech. 30(5): 69-78.

Stigliani, W. 1990. Chemical emissions from processing and use of materials: the need for an integrated emissions accounting system. Ecological Economics 2: 325-341.

Stigliani, W. 1994. Industrial Metabolism. Seminar, IIASA, Laxenburg, Austria.

Thomann, R. 1972. Systems Analysis and Water Quality Mangement. McGraw-Hill, New York.

Thomann, R. 1987. Systems analysis and water quality mangement - a 25 year retrospect. In: beck, M.B. (Ed.) Systems Analysis and Water Quality Mangement: 1-14. Pergamon Press/IAWPRC, London.

Thomann, R. and Mueller, J. 1987. Principles of Surface Water Quality Modelling and Control. Harper and Row, London.

TNO 1979. The Relation Between Water Quantity and Quality In Studies of Surface Waters. Committee for Hydrological Research. Central Orgnization for Applied Scientific Research in the Netherlands.

United Nations (UN) 1958. Integrated River Basin Development. Department of Economic and Social Affairs. New York.

United Nations (UN) 1977. Mar del Plata Action Plan. United National Water Conference, Argentina.

United Nations (UN) 1989. Prospects of World Urbanization 1988. Department of International Economic and Social Affairs. Population Studies 112, UN, New York.

United Nations Conference on the Environment and Development (UNCED) 1992. Agenda 21: Programme of Action for Sustainable Development. Rio de Janeiro, Brazil.

United Nations Development Program (UNDP) 1994. Human Development Report. UNDP, New York.

UN DTCD 1991. Integrated Water Resources Planning. United Nations, New York.

United Nations Environmental Program (UNEP) 1988. Assessment of multiple objective water resources projects: approaches for developing countries. TCD/SEM 88/3, INT/84/R36.

United States National Research Council (US NRC) 1991. Opportunities in the Hydrologic Sciences. National Academy Press, Washington D.C.

Varis, O. 1995. Development of Urban Infrastructure — The Expanding Puzzle UNU/WIDER Conference on Human Settlements in the Changing Global Political and Economic Processes 25-27 August, 1995, Helsinki, Finland.

Varis, O. 1996. Water quality models: typologies for Environmental Impact assessment. Draft. Helsinki University of Technology, Espoo, Finland.

Varis, O. and Somlyódy, L. 1993. Potential impacts of climatic change on lake and reservoir water quality. WP-93-25, IIASA, Laxenburg, Austria.

Veltrop, J.A. 1993 Importance of dams for water supply and hydropower. In: Biswas, A., Jellali, M. and Stout, G. (Eds.): Water for Sustainable Development in the 21st Century. Oxford University Press.

Volovik, S. 1994. Ecological and Fishery Water Management Aspects Related to the Don River Restoration Problem. In: Living with Water. IAWQ/EWPCA/NVA.

WCED 1987. Our Common Future: Report of the World Commission on Environment and Development. Oxford University Press, Oxford.

Wetzel, R.G. 1983. Limnology. 2nd Edition, Saunders, Philadelphia, PA.

Wetzel, R.G. 1992. Clean water: a fading resource. Hydrobiologia 243/244: 21-30.

Wildstrand, C. 1978. The Social and Ecological Effects of Water Development in Developing Countries. Pergamon Press, New York.

Winblad, U. and Kilama, W. 1985. Sanitation Without Water. Macmillan, Hong Kong.

Wolf, A. 1994. The Jordan watershed: past attempts at co-operation and lessons for the future. Water International 18: 5-17.

World Bank 1993. Water Resources Management. A World Bank Policy Paper. The World Bank, Washington D.C.

Yates, D. and Strzepek, K. 1994. Comparison of models for climate change assessment of river basin runoff. IIASA WP-94-46, IIASA, Laxenburg, Austria.