Vision for Water and Nature

Freshwater ecosystem management and environmental security

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**Background paper to
Vision for Water and Nature Workshop,
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Preface

This paper is written as a contribution to the World Water Council's "Vision for Water, Life and the Environment in the Twenty-first Century" (the World Water Vision). It is one of three papers, commissioned by IUCN, linking freshwater ecosystem management and human security. The other two papers investigate the links between freshwater ecosystem management and social security, and economic security (Soussan *et al*., 1999; Swanson and Doble, 1999). The primary objective of this paper is to summarise current thinking on the associations between freshwater ecosystem management and environmental security. The purpose of the paper is to stimulate and provoke discussion at a workshop to be held in San Jose, Costa Rica in June 1999.

There are numerous different ideas incorporated in the concepts of ecosystem management and environmental security and this paper is far from comprehensive. However, it is not intended to be a definitive statement, but rather aims to highlight the principal areas of concern in this field and to emphasize the challenges that face communities around the world as the twenty-first century approaches.

Executive Summary

This paper has been produced to provoke discussion at a workshop to be held in San Jose, Costa Rica as part of the World Water Council's Vision for Water, Life and the Environment (Serageldin, 1999). It is not intended as a definitive statement but aims to highlight the links between the management of freshwater and environmental security. It is hoped that it will provide the basis for dialogue about what is believed by many to be one of the most pressing issues currently facing humanity.

As the 21st century approaches humankind is struggling with many complex problems related to management of freshwater ecosystems. Past mis-management of these ecosystems has resulted in widespread environmental degradation, destruction of ecosystem functions and loss of wildlife habitat. There is evidence that human-induced changes in freshwater ecosystems have brought about reductions in environmental security.

For the purpose of this paper, environmental security is defined as:

> *a means of achieving long-term social, economic and ethical security through: i) the sustainable utilisation of renewable resources and ecosystem functions; ii) protection from natural hazards; and iii) conservation of other species.*

The definition acknowledges the fundamental linkages between environmental security and management, economic development and the social well-being of people. This paper provides a review of technical issues related to freshwater ecosystem management and environmental security. Management strategies are considered within the context of a pressure-state-response model.

A number of issues associated with environmental security are presented and indices are used to show world-wide trends. However, it is recognised that statistics alone cannot adequately describe environmental security, and that there are limitations with all the indicators used. Not least, the complex nature of interactions between humans and the environment mean that it is presently impossible to derive quantitative links between indices of pressure, ecosystem state and environmental security. Nevertheless, the indices provide a crude way of assessing temporal and spatial variation in pressures on freshwater ecosystems and environmental security. The data demonstrate that world-wide there is:

- increasing human-induced pressure on natural freshwater ecosystems;
- increasing degradation of freshwater ecosystems in the sense that they are increasingly unable to provide the services which benefit humankind;
- greatest environmental security in countries which have most altered their freshwater ecosystems (i.e. developed countries).

Advocates propose ecosystem management as the modern and preferred way of managing natural systems. It is a management approach that aims to increase security through protection of the environment, maintenance of ecosystem functions, preservation of biodiversity and by ensuring sustainable development. There are numerous definitions of ecosystem management, but for the purposes of this paper it is defined as:

> *deliberate and conscious manipulation of ecosystem structure and/or function, or regulation of human uses of ecological systems, so as to retain defined and desired features and processes, and to meet human needs in an optimal and sustainable way.*

Although largely accepted at the highest political levels, strategies for the practical implementation of

ecosystem management are presently ill-defined.

Catchments provide the most appropriate physical entity on which to base freshwater ecosystem management. In this paper it is suggested that integrated catchment management (ICM) is the most practical strategy for implementing this. ICM is defined as:

> *The co-ordinated planning and management of the water resources of a river basin considering its interaction with land and other environmental resources for their equitable, efficient and sustainable use at a range of scales from local to catchment level.* (DFID, 1997)

Good management practices introduce feedback mechanisms that both mitigate and adapt to the impact of human interventions in freshwater ecosystems. A range of technical measures that hold promise for ICM include:

- demand management
- water recycling
- desalination
- water harvesting
- wastewater treatment
- watershed and groundwater resource protection
- habitat protection
- changes in the operation of dams and, in some instances, their decommissioning
- rehabilitation and restoration of freshwater ecosystems
- biotechnology

However, there remain considerable impediments to the practical application of ICM principles. These include lack of:

- understanding of linkages between land-use patterns, hydrological regime and biotic response
- data to support demand management programs
- effective monitoring
- practical methods to integrate environmental, social and economic aspects of freshwater ecosystems
- methods for incorporating science within the decision-making processes
- involvement of all stake-holders in decision-making

Environmental security priorities in the developed and developing world are very different. In developing countries, the emphasis must be on "elementary environmental care" mostly oriented to meeting basic water supply, housing and waste disposal needs. However, in the developed world the emphasis is on protecting the few remaining natural and semi-natural freshwater ecosystems, ameliorating the impact of existing development and restoring degraded ecosystems. Although the priorities are different, it is a key tenet of this paper that the basic doctrine proposed within the ICM concept applies to both developing and developed countries.

Increasing environmental security through ICM requires that:

- issues of environmental change and security are dealt with holistically
- ICM strategies satisfy both immediate and long-term needs
- research findings are used to provide an analytical perspective of problems, guide policy-making and inform assessments of management interventions

- resources are directed towards identifying vulnerable geographic regions and sectors of society and promoting adaptation and resilience in both
- the impediments listed above are overcome

This paper summarises three different future scenarios, developed, in draft form, by the Scenario Development Panel of the World Water Council . These provide very different visions of possible futures. In the “conventional water world” it is postulated that if economic growth, technological advances and demographic trends continue as at present, by 2025 the problems impacting on freshwater ecosystems will be the same as today, but increased in number and consequences. At the global scale, there will be a net reduction in environmental security, particularly in developing countries. Alternatively, in the “water crisis” scenario, it is postulated that if there is a slow-down in economic growth, less dissemination of new technologies and a failure to adopt water strategies, then there will be increased water scarcity and catastrophic reduction in environmental security in many regions. If the third scenario, a “sustainable water world”, is to be achieved, with an associated increase in environmental security, then significant changes must be made in the way that humankind manages and utilises freshwater ecosystems.

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1. Introduction

Giver and taker of life; essential element of all existence and untameable destroyer; spiritual expression of purity and contaminated purveyor of affliction; bringer of blessings and of tragedy; agent of social, economic and political discord. Water is all these things ....(Page, 1997).

As with all species, humankind is dependent on functioning ecosystems to survive; ecological processes keep the planet fit for life. All organisms impact on ecosystems, but only humans have the ability to significantly modify the environment to meet their own needs. It seems likely that as we approach the end of the twentieth-century humankind has altered, to a greater or lesser extent, nearly all natural systems on the planet. However, uniquely among the species on Earth, our cognitive abilities, enable us to make choices about how we utilise ecosystems and the extent to which we alter them. In this regard, key questions that need to be asked are:

X to what purpose do we modify natural systems ?;
X how should we plan the limits to which we modify natural systems ?;
X at what point do human-induced changes in a natural ecosystem become deleterious ?

The history of land-use in the developed world indicates that, in the most prosperous countries, the ecosystems that people most depend on are those whose function, composition and structure are far removed from natural systems. In most developing countries many people remain directly dependent on ecosystems that are in a much more natural state. In recent years concern about the modification of natural systems has been expressed for three reasons. First, it is not known if heavily modified systems are sustainable in the long-term. Second, the realisation that natural (i.e. less modified) ecosystems provide both economic and social benefits to society and that these benefits may be lost if an ecosystem is changed, has gained prominence. Third, it is felt by many that humankind has an ethical duty to protect nature from the impact of human activities.

In the light of these concerns, the ecosystem management approach has been cast as a new paradigm reforming the way that humans interact with nature. In broad terms ecosystem management seeks to restore and sustain the health, productivity, and biological diversity of ecosystems and the overall quality of life through a natural resource management approach that is fully integrated with social and economic goals (White House Interagency Ecosystem Management Task Force, 1995). Although there are numerous definitions of ecosystem management, for the purpose of this paper it is defined as:

deliberate and conscious manipulation of ecosystem structure and/or function, or regulation of human uses of ecological systems, so as to retain defined and desired features and processes, and to meet human needs in an optimal and sustainable way.

However, what this means in terms of practical application remains far from clear.

Water, vital for life, plays a complex and multifaceted role in both human activities and natural systems. Its availability varies both spatially and temporally and both too little (i.e. droughts) and too much (i.e. floods) have negative effects on human well being. In an attempt to control water resources humanity has manipulated freshwater ecosystems for thousands of years. For example, both the Sumerian and Egyptian civilisations, flourished in part because of food surpluses derived as a consequence of elementary water management strategies (Newson, 1992). Traditionally, water management has focussed on the direct provision of enough water for people to drink, grow their food and support industries.

Today, the world is struggling with complex problems related to freshwater management. Many areas of the world face water stress, millions of people die annually from water-related diseases, human-induced change of freshwater ecosystems continues apace and world-wide there are growing disputes over water. High population growth, increasing expectations and environmental degradation are increasing the severe strains on existing water resources. It is estimated that humans already appropriate more than half of all accessible surface water runoff and that this may increase to 70% by 2025 (Postel *et al.*, 1996). The use of water by humankind impinges on the volume, quality and seasonal rhythm of freshwater, so that the effective share available for the rest of nature declines.

Management of freshwater is required to balance conflicting demands. The primary goal of freshwater ecosystem management is to maximise the long-term economic and social benefits to be gained from freshwater whilst at the same time conserving ecosystem processes and biodiversity. Mis-management of freshwater ecosystems may result in environmental degradation, destruction of ecosystem functions and loss of wildlife habitat with a consequent loss in the benefits to humankind. There are instances where human interventions in freshwater ecosystems have induced, or at least contributed to, social disorder and violent conflict.

The publication of the Brundtland Report, Our Common Future (WCED, 1987) and Caring for the Earth (IUCN *et al.*, 1991) and the UN Conference on Environment and Development (UNCED) in 1992 mark a turning point in modern thinking and led to two interrelated concepts. The first is sustainable development, which has been defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". The second concept is that the lives of people and the environment are profoundly inter-linked. This has lead to an alternative definition of sustainable development, i.e. "improving the quality of human life while living within the carrying capacity of supporting ecosystems". Based upon principles developed at water conferences in Mar del Plata (UN, 1977) and in Dublin (WMO, 1992), Chapter 18 of Agenda 21 develops the concept of Integrated Water Resources Management (IWRM). This treats "water as an integral part of the ecosystem, a natural resource and a social and economic good, whose quantity and quality determine the nature of its utilisation" (UN, 1992). Central to an IWRM approach is the protection of surface water and groundwater resources, water quality and aquatic ecosystems and the management of land and water in an integrated way.

Hence, at the highest political levels, there is an increasing consensus on the need to manage water and water-related processes in a sustainable manner. However, at the local level, water is still often taken for granted and, in development, it remains the case that the value of ecosystems is rarely considered. A key problem for regional and local managers is how to allocate water between conflicting human demands and the requirements of the environment. It is often the case that the integrated effects of local management decisions are incompatible with the broader scale wishes of society and the agenda of high politics. There remain serious challenges to confront before there is widespread and credible application of the ecosystem management concept. As we approach the 21st century there are increasing constraints on human activities posed by the condition of freshwater ecosystems, the problems continue to escalate, and there is a growing feeling of an incipient world water crisis (Falkenmark and Lundqvist, 1998).

The increasing human pressures placed on freshwater ecosystems are a consequence of socio-economic states that ultimately arise from a number of global *drivers* of which population growth, urbanisation and economic globalisation are the most significant. Although these aspects are touched on briefly in this paper, they are not discussed in detail; this is the task of the other two papers in the series (Swanson and Doble, 1999; Soussan *et al*., 1999). This paper focuses on technical issues related to reconciling freshwater ecosystem maintenance and water resource management.

The primary objective of this paper is to present a summary of current thinking on the link between the management of freshwater ecosystems and environmental security. Environmental security can, in simple terms, be considered as a state of human well-being arising from a stable, protective and unthreatening physical environment. Discussed in detail in section 2, for the purpose of this paper it is defined as:

> *a means of achieving long-term social, economic and ethical security through: i) the sustainable utilisation of renewable resources and ecosystem functions; ii) protection from natural hazards and iii) conservation of other species*

Section 2 provides an overview of the key concepts related to freshwater ecosystems, summarises the benefits these systems provide for humankind, and outlines the principle of environmental security. Section 3 is a review of the human-induced pressures presently acting on freshwater ecosystems, the current state of these systems and the consequent implications for environmental security. As far as possible, numerical indices are used to summarise information about the complex inter-relationship between people and freshwater ecosystems. In section 4, three scenarios, conventional water world, water crisis and sustainable water world, are presented. These provide very different visions of possible futures. The implications for the state of freshwater ecosystems and consequent environmental security are considered in each case. Against this background, the concept of ecosystem management as a possible future strategy for resource management is presented in section 5. Various technical options for both mitigating and adapting to changes in freshwater ecosystems are discussed. A final statement, which draws together the key findings of this paper, is presented in section 6. In addition, a number of key issues, identified to provide the basis for discussion at the Costa Rica workshop, are offered.

2. Background

However much we learn to manipulate our environment, we cannot escape our dependency on biodiversity for food, medicines and materials or for the ecological services provided by healthy, diverse ecosystems
(Stephen Blackmore, Keeper of Botany, The Natural History Museum, London, 1996).

In this section, ecosystem concepts are discussed and the services provided by freshwater ecosystems to the benefit of human societies are summarised. A definition of environmental security is sought and the need for ecosystem management is addressed.

2.1 The global water cycle

Freshwater constitutes only about 2.5% of the total volume of water on Earth (Figure 1). Two-thirds of this freshwater is locked in glaciers and ice caps. Just 0.77% of all water (about 10, 665, 000 km^3) is held in aquifers, soil pores, wetlands, rivers, plants and the atmosphere and so circulates reasonably fast (Postel *et al.*, 1996). It is the renewable fast circulating freshwater which is of vital importance to humankind and to all other terrestrial flora and fauna. Precipitation over land is the overall freshwater available and is partitioned into green water (evaporating vertically) and blue water (flowing more or less horizontally) (Box 1).

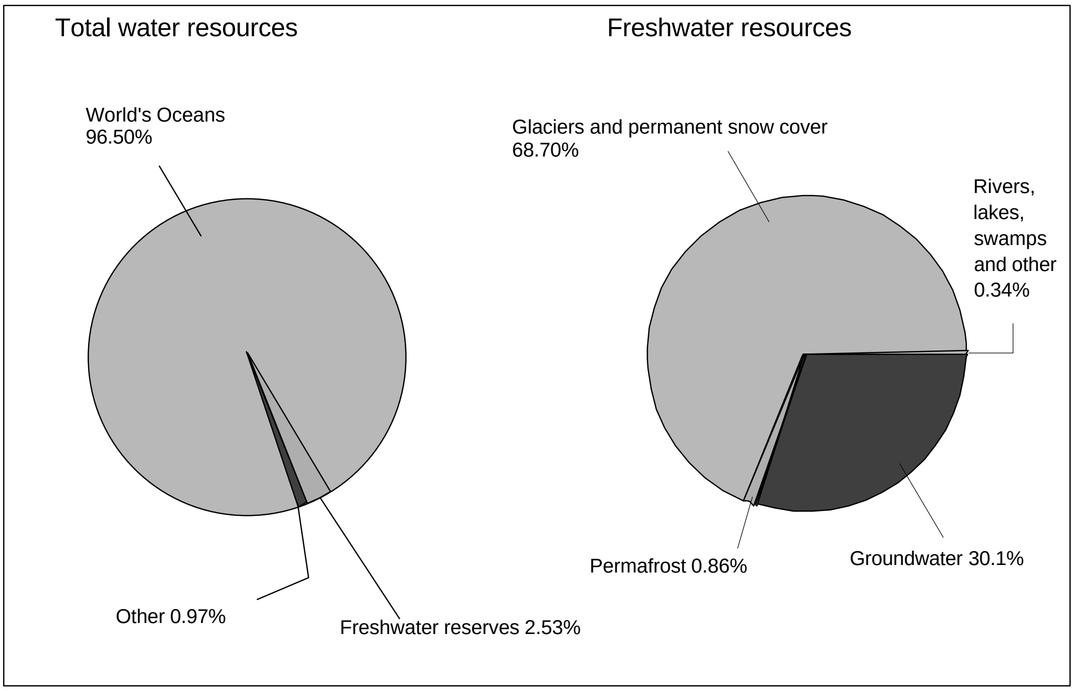
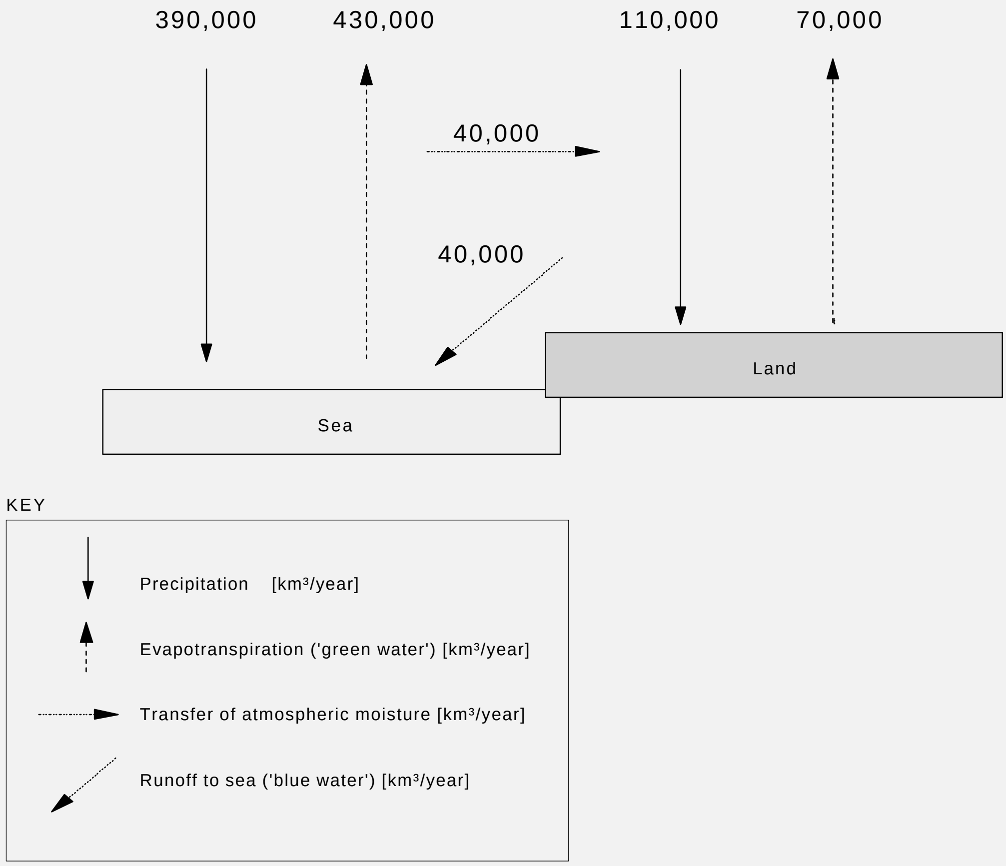


Figure 1: *Global total water and freshwater reserves*

Box 1: The Hydrological Cycle (after Postel *et al*., 1996)

Only freshwater flowing in the hydrological cycle is renewable. The terrestrial renewable freshwater supply ($RFWS_{land}$) equals precipitation on land (P_{land}), which then subdivides into two major segments: evapotranspiration (Et_{land}) (i.e. green water) and runoff to the sea (R) (i.e. blue water). Groundwater and surface water are often hydraulically connected and so soil infiltration and ground-water replenishment are included as part of this runoff component. Thus $RFWS_{land} = P_{land} = ET_{land} + R$.



A simplified depiction of the global hydrological cycle, adapted from Gleick, 1993)

Global water budgets are derived from interpolation of climatic, vegetation and soil information for different geographical zones. The methods are inherently imprecise; estimates of annual runoff range from 33,500 km^3 to 47,000 km^3. The value of 40,700 km^3, derived by L=Vovich *et al.* (1990) lies near the middle of this range.

2.2 Concepts used in freshwater ecosystems

It is important to note that the ecosystem concept was initially developed as a research paradigm. It was never intended to serve as the basis for resource management (Fitzsimmons, 1996). Ecosystems are not real entities on the landscape, but rather an arbitrary division of the landscape into elements to accommodate some human perception of interaction (e.g. between species or the flow of chemicals through space). Hence, ecosystems are real only in the sense that they refer to biota or processes identifiable on the ground. Ecosystems may be identified at multiple spatial scales by association of ecological factors, such as climate, geology, landform, soil, water, plants and animals (Jensen *et al*., 1996).

In this paper freshwater ecosystems are defined as linked landscape elements that affect the passage of blue water from the land to the sea and green water from the land to the atmosphere. As such nearly the whole of the terrestrial milieu can be considered as part of freshwater ecosystems. Freshwater ecosystems encompass all the environmental units associated with river catchments, not only the whole length of the river channel, but also lakes, ponds, meadows, floodplains, fens and swamps as well as the *upland* areas which drain into these. It can be difficult to define the boundaries of ecosystems and in the context of freshwater it is in many instances the river catchment that is the most easily identified management unit (section 5.1.2). A river catchment is defined as the unit of land from which water flows downhill to a specified point on a watercourse. It is determined by topographical features which include a surrounding boundary or perimeter known as a drainage divide or catchment boundary. However, it is important to note that the use of river catchments as a management unit has limitations. These include the fact that groundwater catchments are often very different to river catchments because the movement of groundwater is often determined by geological characteristics, rather than topography. Furthermore, river catchments do not include the coastal marine habitats, the ecology of which are often dependent on the inflow of freshwater (Box 2).

Freshwater ecosystems may be considered as structured, four-dimensional systems in which the spatial patterns of environmental variables and biological populations are determined by longitudinal, lateral, vertical and temporal gradients, linked by fluxes of water, energy and materials (Figure 2). Although on the global scale, blue water moves essentially horizontally, at smaller scales, vertical movement of water (i.e. into the ground) can be significant and groundwater must be considered a distinct, but very important, element of many freshwater ecosystems. Evaporation and freezing are important physical processes that play a key role in certain ecosystems. At the global scale, evaporation and condensation are the main forms of energy exchange between the land and the atmosphere and thus drive the energy balance and climate of the planet.

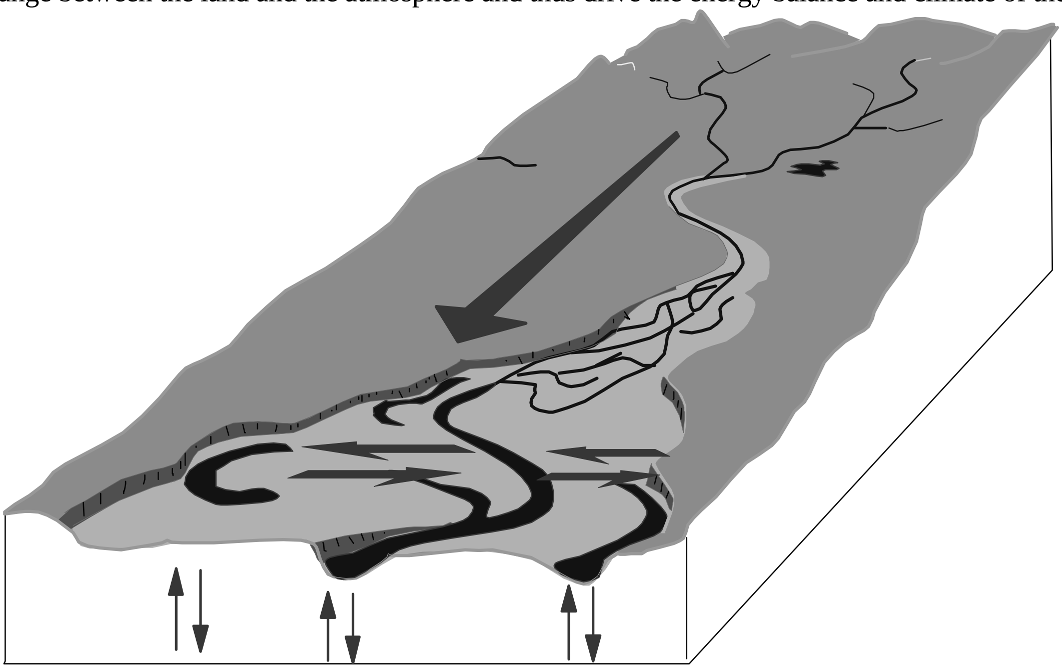


Figure 2: *Freshwater ecosystems: lateral, longitudinal and vertical fluxes of water, energy and material*

Box 2: The dependence of coastal marine ecosystems on freshwater ecosystems

Material and energy fluxes ensure that all ecosystems are linked in both space and time. Coastal ecosystems highlight the fact that all ecosystems are interdependent. Changes in terrestrial freshwater ecosystems can have a considerable impact on the state of marine and estuarine systems. For example, the Indus Delta , an area of some 600 000 ha on the borders of India and Pakistan is dependent on the outflow of freshwater and silt from the Indus River. In recent years the character of the delta has changed as it has been progressively deprived of 80% of its average annual freshwater and silt inflow as a consequence of upstream abstraction for irrigation, occurring hundreds of kilometres upstream (Pirot and Meynell, 1998).

The construction of dams alters the flow regime of rivers which in turn modifies the input of freshwater, nutrients and silt into marine systems. This often results in increased salinity and reduced productivity in estuarine and adjacent marine areas with a consequent effect on associated fisheries. For example, in the Indus Delta the creeks and mangroves provide excellent nursery areas for young fish, especially shrimps. Shrimps are a major export commodity, making up 68% of the US$100 million which Pakistan earns from fishery exports. However, it is feared that shrimp and other commercial species will decline as the mangroves are lost as a consequence of human induced changes, both locally and upstream (Meynell and Qureshi, 1993).

Reduced sedimentation as a consequence of silt being trapped behind dams can result in coastal erosion. For example, parts of the coastline of the Nile delta are being eroded at a rate of 240 m a year. Although the delta was eroding prior to construction of the Aswan High Dam the higher rates of erosion observed in recent years are attributed by many to the reduction in sediment reaching the coast after closure of this dam (McCully, 1996). Similarly, erosion of parts of the Rufiji Delta, by up to 40 m per year, is attributed to the construction of dams (Horrill, 1993).

Freshwater ecosystems comprise features that may be classified as components, functions and attributes (Figure 3). The components of the system are the biotic and non-biotic features, which include soil and sediment, water, and aquatic organisms (i.e. microbes, macrophytes and micro-algae, riparian plants, invertebrates, fish, amphibians, reptiles, mammals and water birds). The interactions between the components comprise hydrological, biological, chemical and physical processes that result in ecosystem functions such as evaporation, respiration, photosynthesis, retention of water, nutrient transformation, productivity and habitat maintenance and development. The ecosystem itself possesses attributes, such as biodiversity, that derive from both the structure and functioning of the ecosystem. People obtain both direct and indirect benefits from all three facets of freshwater ecosystems (section 2.3).

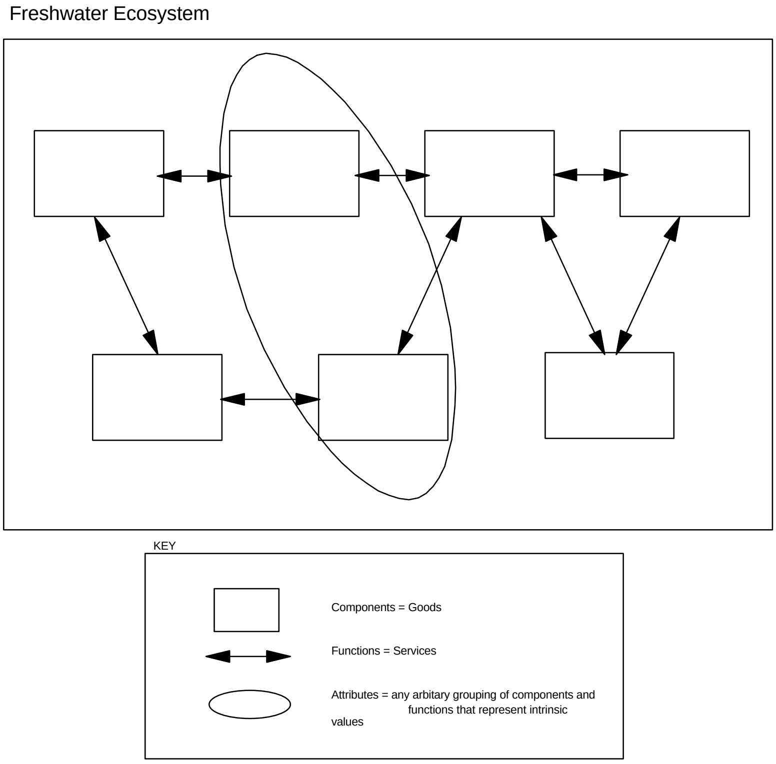


Figure 3: *General relationships in freshwater ecosystems*

The *integrity* of an ecosystem is a measure of its wholeness and its ability to continue to function in its natural way. The integrity of freshwater ecosystems is a function of ecological connectivity operating across a range of spatio-temporal scales (Ward and Stanford, 1995). In this context connectivity refers to the exchange pathways of water, resources and organisms between the different units or sub-systems that comprise a freshwater ecosystem (e.g. between a river channel, its floodplain and the underlying aquifer). Flow characteristics such as duration, frequency and timing of inundation; strength of surface-water and groundwater interactions; and retention times, influence both ecosystem functions and the distribution of biota.

Fluxes of material and energy vary constantly, so ecosystems are in a constant state of change. The *resilience* of a system is a measure of the magnitude or scale of disturbance that can be absorbed before the system changes irreversibly in structure as a consequence of change in the variables and processes that control system behaviour. In a system of low environmental resilience the natural processes are sensitive to change and easily altered so that a change of relatively small magnitude may have a big impact on the biota and the processes occurring in the ecosystem. In a more resilient system the same magnitude of change may have no, or only a minimal or short-term, impact on the biota and the functions of the ecosystem. In general, resilient systems tend to be those that are physically dynamic (e.g. low-order streams) in which there is greater buffering capacity and greater potential for natural recovery.

2.3 Human appropriation of freshwater

Humans appropriate water for domestic supply, agriculture and industry. This causes non-natural changes to the water-budget, hydrological connections and/or quality of the water in freshwater ecosystems. Not all water withdrawn is returned to rivers, lakes or other water courses or aquifers. The difference between the amount withdrawn and returned is called water consumption. Consumption includes water used by crops for transpiration or building plant tissue, water evaporated from land and reservoirs and that part of the water diverted for industrial or community use that evaporates or is consumed or incorporated into a finished product. Consumed water cannot be immediately re-used. Water returned to ecosystems may be polluted; warmer, cooler, richer in nutrients or heavy-metals etc.

In the past the effect of human activities on freshwater ecosystems was generally insignificant and of a local nature. In many cases, the natural systems had sufficient resilience to recover from the human-induced stresses placed on them. The situation has fundamentally changed during recent centuries; in many regions the effects of human activities are evident both in terms of water resource development, water use, and land-use change. In the past 50 years, increasing population, coupled with technological advances and intensive irrigation development have had an ever greater impact (both intentional and inadvertent) on freshwater ecosystems. Changes in water balance and water quality have resulted in environmental degradation, destruction of natural habitat and/or loss of ecological functions, with serious implications not only for the integrity of these systems but also for people's well-being.

Table 1 summarises how world-wide withdrawals and consumption have increased since 1900 for different water sectors. The irrigation sector is by far the biggest user of water, accounting for 61% of water withdrawal and 87% of water consumption. It is estimated that 30% of world food supplies are now reliant on artificial irrigation (Lanz, 1995). Industry is the second largest water withdrawal sector, followed by municipal use and the additional evaporation from reservoirs respectively. Total global withdrawal and consumption in 1995 are estimated to have been 3, 760 km^3 and 2, 275 km^3 respectively (Shiklomanov, 1997).

Table 1: *Water use by sector (km^3 y^{-1}) - first line is water withdrawal and second line is water consumption (after, Shiklomanov, 1997)*

Sector	1900	1940	1950	1960	1970	1980	1990	1995
Agriculture	525.0	891.0	1124.0	1541.0	1850.0	2191.0	2412.0	2503.0
	407.0	678.0	856.0	1183.0	1405.0	1698.0	1907.0	1952.0
Industry	37.9	127.0	182.0	334.0	548.0	683.0	681.0	715.0
	3.0	9.5	14.4	24.6	38.3	61.8	72.7	79.7
Municipal needs	16.0	36.8	52.6	82.7	130.0	208.0	321.0	354.0
	3.9	9.0	13.8	20.1	29.4	41.9	53.2	57.4
Reservoir evaporation	-	-	-	-	-	-	-	-
	0.3	3.7	6.5	22.7	65.9	119.0	164.0	188.0
Total (rounded)	579	1066	1365	1985	2574	3200	3580	3760
	415	705	894	1250	1539	1921	2196	2275

In addition to the provision of water, freshwater ecosystems provide a wide range of other benefits for people (Table 2). For example, freshwater ecosystems may perform natural hydrological functions that are of *service* to humankind. Examples include flood reduction, pollution absorption and groundwater recharge. In some instances services are fulfilled with no need for human intervention (i.e. largely regulation of quantity and quality of water) but in other cases such services may be augmented by human interventions. Freshwater ecosystems also generate *products* such as forest, wildlife, fisheries and grazing resources used by humans. Goods are products generated as components of the ecosystem. They can be either consumptive (e.g. fisheries, fodder) or non-consumptive (e.g. recreation, tourism). In addition, people also attain less direct benefits from the attributes of freshwater ecosystems. These include spiritual enrichment, cognitive development and aesthetic experience. Intrinsic values are those placed on the attributes of ecosystems by human society. For simplicity, in the remainder of this document the term ecosystem services is used to refer to both ecosystem goods and services.

Ecosystem services are of value to humans because they maintain and enhance people's well being. Changes in the quality or quantity of services either change the benefits associated with human activities or change the costs of those activities. Generally, it is attempts to maximise benefits through the exploitation of services that result in changes to freshwater ecosystems which, at times, decrease the total benefits provided (Box 3).

Although the economic value of many services can be determined relatively easily, that of many others is much more difficult to ascertain. This is partly because the contributions to human welfare by ecosystem services are often in the nature of public goods. They accrue directly to humans without passing through the money economy at all. In many cases people are not even aware of them. In other cases the benefits accrued are *indirect* and associated with qualitative human aspirations (e.g. aesthetic appeal) to which it is very difficult, and many would argue impossible, to attach a monetary value. However, economists are attempting to develop methods of true economic valuation. For example multi-criteria analysis is a method designed to take into account both quantitative and qualitative data, including non-monetary variables (Barbier *et al*., 1997).

Box 3: The value of freshwater ecosystems: the case of the Hadajia-Nguru wetlands, Nigeria

In northeast Nigeria, where the Hadejia and Jama=are rivers combine within the Komodugu-Yobe basin, an extensive floodplain of around 2000 km^2 used to be inundated annually. Since 1971, a series of dams have been constructed on the main tributaries and during recent droughts the area inundated has reduced, with only 300 km^2 flooded in 1984 (Hollis *et al*., 1993). The dams are used primarily to provide water for cereal irrigation and their construction was initiated partly by a ban on imported wheat which made irrigation profitable overnight. In 20 years the Nigerian Government spent US$ 3 billion on irrigation development, though by 1991 only 70, 000 ha had been farmed making an investment of US$ 43 000 per hectare (Adams, 1992).

The yields from intensive irrigation schemes are higher per hectare than from floodplain agriculture, although the high operational costs of the schemes reduce substantially the relative benefits. However, because water resources limit the economy, it is more appropriate to express the benefits of various development options in terms of water use. *Barbier et al* (1998) undertook an economic analysis of the Kano River project, a major irrigation scheme in the headwaters of the Kano River project. They showed that the net economic benefits of the floodplain (accruing from fisheries, firewood production and recession agriculture) were at least US$ 32 per 1000 m^3 of water (at 1989 exchange rates), whereas the returns from the crops grown on the Kano river project were only US$ 0.15 per 1000 m^3 and when the operational costs are included, this drops to US$ 0.0026 per 1000 m^3. Furthermore, this analysis did not take into account other benefits of flooding, such as groundwater recharge or flows downstream to Lake

Chad.

Table 2: *Benefits to people provided by freshwater ecosystems*

Services		Functions	Examples
Water supply	X	storage and retention of fresh water	52 million people draw upon the Mekong River, the longest in SE Asia, for their livelihoods (Hussain, 1993). In Norway, 55 000 people use Lake Mjøsa as their drinking water source (Tollan, 1992) The Edwards Aquifer in Texas, USA is the only source of drinking water for 1.5 million people (The Trust For Public Land, 1997).
Flow regulation	X	Flood attenuation – Temporary storage of precipitation and runoff	A flood prevention value of about $13,500 per hectare per year has been attributed to wetlands in the catchment of the Charles River in Massachusetts (Sather and Smith, 1984).
	X	Maintenance of baseflow through slow drainage of soils/groundwater.	In Motagua Valley, Honduras, US$ 1 million of crops produced on irrigated land depend on the dry season flow maintained by undisturbed montane cloud forest (Brown *et al*., 1996).
Waste assimilation	X	Nutrient and contaminant retention and breakdown	Work in the UK indicates that denitrification may remove between 21 kg ha^{-1} a^{-} and 44 kg ha^{-1} a^{-1} nitrate in some river marginal soils (Maltby *et al*., 1996).
	X	Heavy metal and agrochemical removal	In the USA discharges from some 300 mines are treated in artificial wetlands (McIntire *et al*., 1990). In Uganda much of the sewage from Kampala is filtered by the Nakivubu wetlands.
Gas regulation/Climate control	X	Regulation of atmospheric chemical composition	Peat deposits occupy just 3% of the worlds land area but store 16-24% of the globe=s soil carbon pool (Maltby, *et al*., 1992).
	X	Regulation of global temperature, precipitation and other biologically mediated climatic processes at global or local levels.	Freshwater ecosystems are important in the biogeochemical cycling of CO_2, CH_4, H_2S and N_2O (Armentano and Verhoeven, 1988). For example, 40% of methane input to the troposphere comes from wetlands and rice fields (Sahagian and Melack, 1996).
Goods		**Component**	**Examples**
Food production	X	Portion of gross primary production that can be extracted as food (e.g. fruit, nuts, game, fish)	Many species of edible fish breed exclusively on inundated floodplains. 100,000 tons per year are caught from the inner delta of the Niger alone (Barbier *et al*., 1997)

	X	Retention of soil moisture during dry periods (e.g. a water reserve utilised by small-scale farmers)	In Zimbabwe it is estimated that some 20,000 ha of seasonal wetlands, known as dambos, are utilised by communities of subsistence farmers (Whitlow, 1984).
Power Production	X	Difference in head along a river channel	Generators at Kafue Gorge hydropower station in Zambia have a capacity of 900 MW. The electricity produced (5800 Gwh per year) is used both within Zambia and sold to neighbouring countries.
Raw material production	X	Portion of gross primary production that can be extracted as raw materials (e.g. timber, fuelwood, grass)	In Matang Forest Reserve, Malaysia 40,000 ha of mangroves annually yield timber worth US$ 9 million (Ong, 1982)
Recreation	X	Provision of opportunities for recreational activities e.g. tourism, water sports, hunting	Nearly 1 million tourists visit the Florida Everglades National Park each year. Victoria Falls and the Okavango Delta are amongst the primary tourist attractions in Southern Africa. Visitors to Morrocy National Park in Venezuala are estimated to spend over US$ 7 million per year (Delgado, 1986)
Intrinsic value	**Attribute**		**Examples**
Genetic resource	X	Biodiversity	Kafue and Luena Flats, Zambia support an outstanding diversity of organisms including over 4500 species of plants, more than 400 species of birds and 120 species of fish (Howard, 1993).
Culture	X	Provision of opportunities for non-commercial use through aesthetic, artistic, educational, spiritual and/or scientific values placed on an ecosystem by human society.	To millions of Hindus the Ganges is a sacred and venerated river; Ganga Ma – Mother Ganges. The Kuomboka Ceremony among the Lozi people of the Barotse floodplain in western Zambia. The King. the Litunga and his people have two homes, one in the floodplain and the other on high ground. The Litunga and his people migrate out of the floodplain during periods of high water and back at low water.

2.4 Environmental security

Environmental security is an ambiguous term, which means different things to different people. However, essentially it is about improving human well being by making the most appropriate use of the planet's natural resources and functions. It is a key tenet of this paper that, within the context of freshwater ecosystems, this is best achieved by maximising the long-term benefits to be gained from all aspects of freshwater ecosystems.

Environmental security is an integral element of human security (Graegar, 1996). It is linked to both economic and social security and so may be conceptualised as a cornerstone of the tripartite system of global security (Figure 4). Reduction of environmental security reduces both economic and social security and, conversely, reduction in either social and economic security can result in reduction in environmental security. A decline in environmental security may initiate a downward spiral of poverty and environmental degradation. In extreme cases loss of environmental security, through environmental degradation or poor respect for environmentally-attuned resource management, may result in, or at least exacerbate, social conflict (Homer-Dixon, 1994).

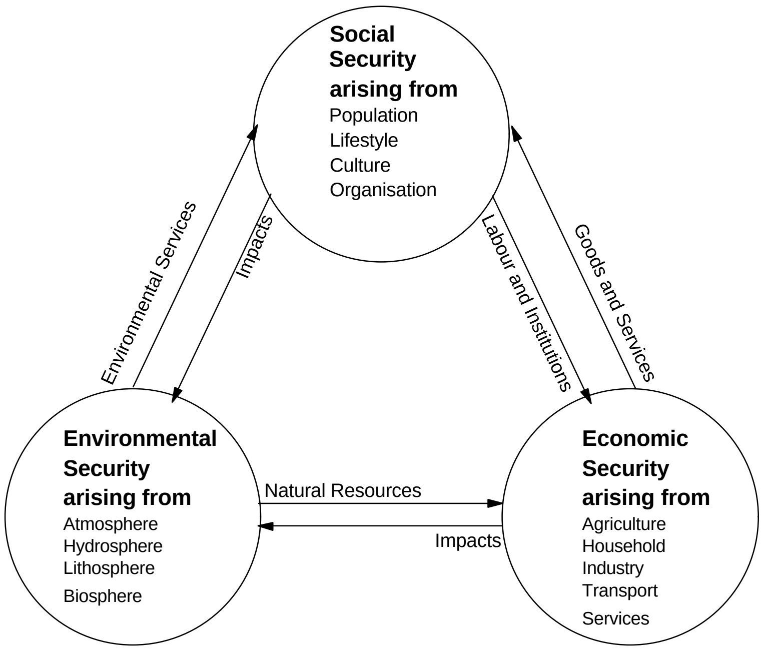


Figure 4: *Components of global security (adapted from Fig. 1 in Raskin et al., 1997).*

Different benefits accrue to people from natural and altered freshwater ecosystems (Figure 5). A wetland that is only slightly disturbed by human activities is a near natural system that, as discussed above, may provide services which contribute to the economic, social and environmental security of society. The benefits accrued to those people living close to the wetland maybe greater than those gained by people living further away.

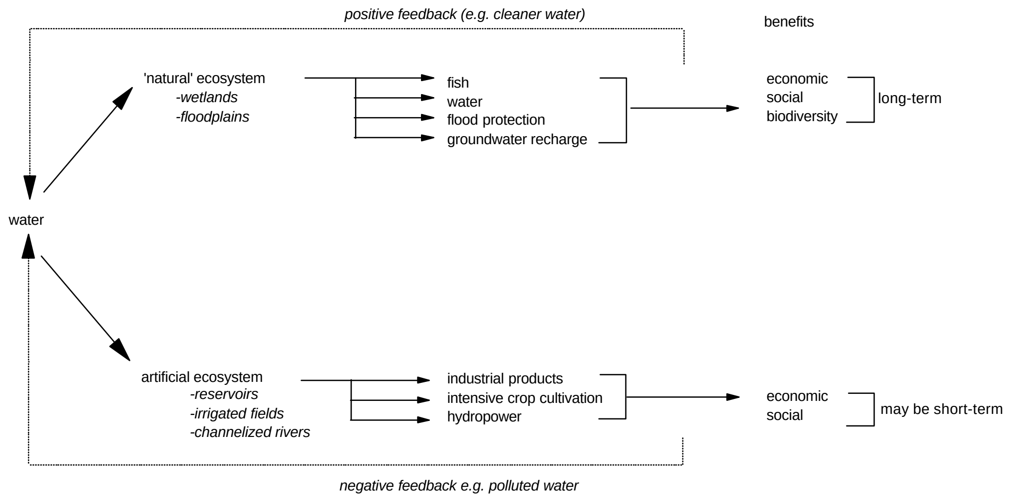


Figure 5: *Natural and non-natural ecosystem benefits*

A reservoir is an example of an altered or non-natural system, which provides economic, social and environmental security to those people in society who benefit by using the water it provides. However, in converting a natural system into a non-natural system, there is a trade-off between benefits gained and lost (Figure 6). This occurs because human-induced change in an ecosystem always has a derogatory effect on some natural functions, thereby undermining the services to some people. For example, dams disrupt the natural flow regime of rivers downstream. They often reduce flood peaks and hence the frequency, extent and duration of floodplain inundation which may in turn reduce opportunities for recession agriculture and so reduce the benefits accrued to people living in the vicinity of the floodplain (Box 3).

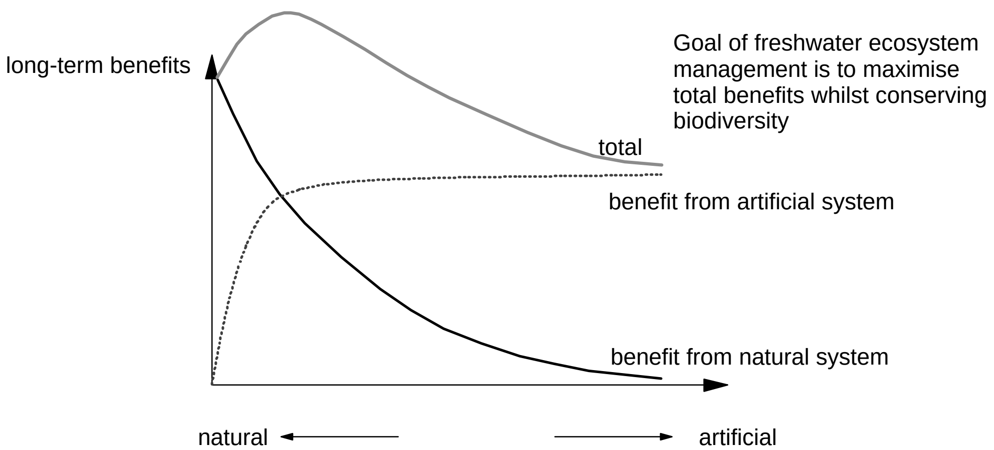


Figure 6: *Maximising benefits from freshwater ecosystems*

It is possible that benefits gained from a non-natural system are large in the short-term but decrease in the long-term. For example, the benefits provided by a reservoir while initially high will decrease over time if it fills with sediment and the amount of water available for human use decreases. Hence, long-term sustainability is a key consideration in the context of environmental security. It is believed by many people, that benefits gained from natural systems are sustainable over the long-term while those gained from very modified systems are not. However, evidence suggests that systems far from their natural state can be sustainable over the long-term if they are correctly managed. Thus for example, reservoirs may be sustainable if sediment flushing is introduced into their operation or catchments in which they are located are managed to reduce soil erosion and sediment transport into the reservoir. Furthermore, it may be possible to sustain downstream ecosystems by artificial flood releases (section 5.3.1).

In addition to changes in the balance of benefits to human society that occur when a natural system is altered by people, human induced change also impacts on the natural biota. For example, dams directly and indirectly influence a myriad of dynamic factors (i.e. not just flow regime but also sediment and chemical transport etc.) that affect habitat heterogeneity and successional trajectories and, ultimately, the ecological integrity of freshwater ecosystems. In a comparison of two floodplains of the Danube, one disconnected from the channel and the other with the connectivity largely in tact, Löffler (1990) documents much greater diversities of macrophytes (60 versus 20 species) and fishes (30 versus 4 species) on the unaltered site.

Another aspect often associated with environmental security is what might be called the ethical security. This is the growing belief, of many people, that humans have a moral duty to protect wildlife. In the context of freshwater ecosystems this means provision of adequate water (both quantity and quality) to maintain indigenous flora and fauna. The idea that the natural environment has a right to water *per se* was taken up by the United Nations in 1982, when the governments of the UN made an ethical commitment to nature in the form of The World Charter for Nature. This expresses absolute support by governments of the principles of conserving biodiversity. It recognises that humankind is part of nature, that every form of life is unique and warrants respect *regardless of its worth* to human beings, and that lasting benefits from nature depend on the maintenance of essential ecological processes and life-support systems and upon the diversity of life forms (McNeely *et al*. 1990). In a sense this is environmental conservation in its purest form. Often termed deep ecology it promotes conservation of ecosystems as a public good independent of their utility as a resource.

Throughout the literature, environmental security is used as a broad concept encompassing all the issues discussed above. It can therefore be conceived as a broad paradigm that:

X recognises that the Earth=s ecosystems should be maintained and enhanced so that they yield the greatest sustainable benefit to present generations whilst maintaining the potential to meet the needs and aspirations of future generations
X recognises the need to protect humans from natural hazards
X recognises the environment as a legitimate user of water
X recognises that scarcity or inequitable distribution of natural resources (both in terms of quality and quantity) can often be the cause of conflicts in society

In any given set of circumstances the emphasis may be placed, by different people, on any one of the aspects listed above. Thus, the precise meaning varies depending on who is using it and in what context. In this paper, in an attempt to incorporate all the elements listed above, we use the following sweeping definition:

> *Environmental security is a means of achieving long-term social, economic and ethical security through: i) the sustainable utilisation of renewable resources and ecosystem functions; ii) protection from natural hazards and iii) conservation of other species.*

It acknowledges the fundamental linkages between environmental security and management, economic development and the social well being of people.

From the preceding discussion of environmental security, it is clear that there are complex inter-relationships between humans and the natural environment. Today, as discussed in section 3, various driving forces and human-induced pressures are increasing the competition for scarce water resources and causing a reduction in environmental security, across the entire spectrum of the term. Management is required to balance the different and competing demands placed on freshwater ecosystems. The need to balance human requirements for freshwater and freshwater ecosystem services against ecosystem capabilities and constraints is made more complicated by the additional need to take into account societal preferences about the manner in which ecosystems are utilised. There is no baseline state against which to determine the condition of a natural freshwater ecosystem so desired states must be determined by society.

3. Problem identification and analysis

Our numbers are burdensome.....the world can hardly supply us from its natural elements.....our wants grow more and more keen, our complaints more bitter, while nature fails in affording us her sustenance (Tertullian, Rome, 160-230AD)

Human induced pressures are causing changes in the state of freshwater ecosystems and leading to localised resource scarcity. However, the severity and consequences of these changes for humankind are still widely debated. There are two extreme positions. First, there are those, often biologists or ecologists, who claim that finite natural resources place strict limits on the growth of the human population and consumption; if these limits are exceeded, poverty, social breakdown and ecosystem degradation result. Second, there are those, mainly neoclassical economists, who argue that there need be few, if any, strict limits to human population, consumption or prosperity, because human ingenuity is such that resource substitution, the development of new resources, technological innovation and improved management will enable humans to surmount scarcity and improve their lot (Homer-Dixon, 1995).

A pre-requisite to resolving this debate is an understanding of the extent to which human interventions are altering ecosystems and their functions and quantification of how this impacts on environmental security. Against this background this chapter aims to:

- Describe the problem of unsustainable utilisation of freshwater ecosystems.
- Discuss the underlying causes of human degradation of these systems.
- Identify the principal anthropogenic pressures exerted on freshwater ecosystems.
- Review evidence of changes in the state of freshwater ecosystems and different aspects of environmental security related to freshwater ecosystems.

The issues are discussed as a series of themes. The interaction of humans with the environment is complex and, wherever possible, indices are used to provide summary or surrogate information. There are problems with all the indices used (as a consequence of data scarcity and/or definition of terminology), nevertheless they assist in making the complex phenomena discussed more perceptible.

3.1 The Problem: unsustainable utilisation of freshwater and environmental change

All natural ecosystems experience change as a consequence of natural phenomena. However, today, human interventions are causing unprecedented rates of change and the planets natural resources are being exploited in a manner that many argue is largely non-sustainable. Since the industrial revolution there has been a dramatic increase in population and resource use. The consequences of human exploitation of the environment are observable throughout the world in the form of decline in the quantity and/or quality of renewable resources which is occurring faster than natural processes renew them. At present, water pollution, falling water tables, soil erosion, destruction of ecosystem functions and loss of wildlife habitat are widespread. The direct threats to freshwater ecosystems result from physical, chemical or biological changes in the environment. Examples of physical changes include dam construction and changing the land-use within a catchment. Chemical changes include changing water salinity, increasing the organic loading, and/or increasing nutrient content or levels of toxic material in the water. Biological changes include over-exploitation of fish, changes arising from grazing and introduction of exotic species (Box 4).

The spectacular increase in the scale of global water withdrawals is illustrated in Table 3. Since 1900, total water extraction has increased by a factor of 6.5 as a result of both population increase (a factor of 3.4) and water use per capita (1.9). Although at first sight the estimated total freshwater withdrawal (i.e. 3, 760 km^3) which accounts for only about 9% of the total average annual runoff (40, 000 km^3), appears not to be a serious problem, the resource situation is actually a lot more critical than these figures indicate. There are three reasons for this:

- X a large proportion of the total runoff occurs in the form of floods and is presently largely inaccessible to humankind
- X humans do not just make withdrawals but also utilise water for a range of instream uses (e.g. navigation, recreation, waste assimilation etc.)
- X global averages mask large spatial and temporal variance of freshwater resource and requirement patterns. Episodic water scarcity occurs even where time averaged resources appear adequate.

Table 3: *Global trends in freshwater withdrawal* (after Shiklomanov, 1997)

	1900	**1950**	**1995**
World population (billion)	1.6	2.5	5.5
Water withdrawal per capita (m^3 y^{-1})	360	550	680
Water withdrawal total (km^3 y^{-1})	580	1,365	3,760

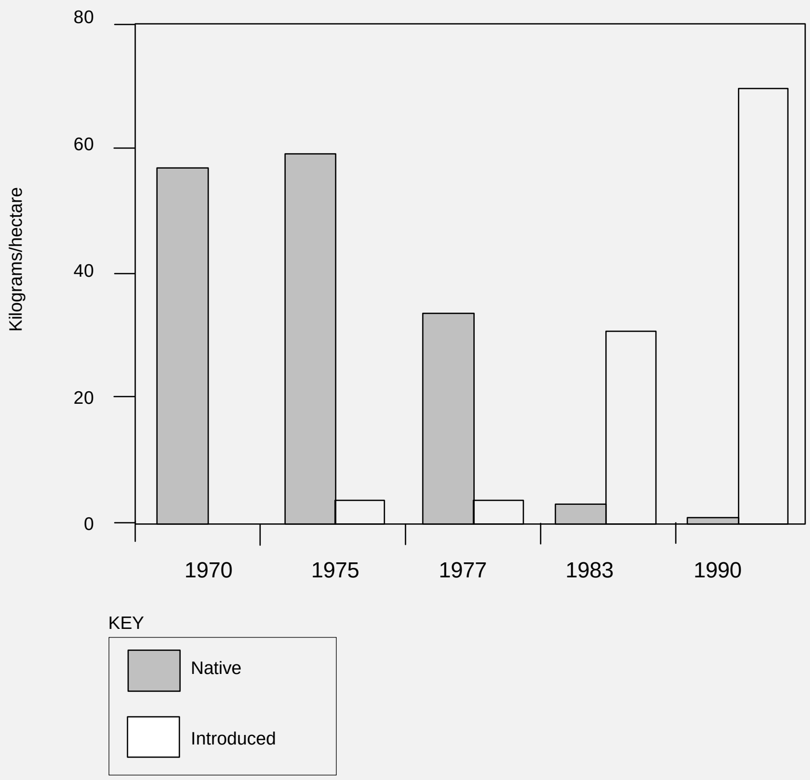
If allowance is made for the fact that not all water is presently available for human exploitation then it has been estimated that humans presently appropriate (i.e. withdrawals plus in-stream use) some 54% of the planets *accessible* blue water and some 26% of green water (Box 5). Increasing population, in conjunction with increased degradation of freshwater ecosystems, is making water increasingly scarce in relation to potential demand. There are increasing social tensions and conflicts due to growing water scarcities and higher wastewater discharges in many parts of the world.

Even where human utilisation does not consume freshwater, human activities may disrupt the dynamic hydrological regime of ecosystems and patterns of connectivity. For example, dams not only consume water through promotion of evaporation, but also disrupt the downstream river systems natural disturbance regime. Reduction of flood peaks reduces the frequency, extent and duration of floodplain inundation. Reduction of channel forming flows reduces channel migration. Truncated sediment transport typically results in channel degradation below the dam and a concomitant lowering of the watertable (Ward and Stanford, 1995). These changes, and others, directly and indirectly influence a myriad of dynamic factors that affect the ecological integrity of downstream freshwater ecosystems. These changes can have severe consequences for people who rely on the systems for their well being.

Box 4: Lake Victoria: Consequences of the introduction of Nile Perch (after Abramovitz, 1996)

The Great Lakes of East Africa are home to vast numbers of cichlid fish species. Because the largest lakes (Lake Malawi, Lake Tanganyika and Lake Victoria) are not connected to each other and lie in different catchments each ones fauna and ecology are distinct; 99% of the species found in each Lake are endemic.

Lake Victoria covering some 62,000 km^2 is the largest lake in Africa and the second largest lake in the world. Nile Perch were introduced into the Lake in 1954 to improve the local fishing industry. Nile Perch which may grow to 200 kg are predators which consume enormous quantities of small fish. Sine the perch was introduced, Lake Victoria has lost 200 taxa of endemic cichlids and the remaining 150 are listed as endangered. The exact reason for the relative success of the perch is uncertain, but the perch=s ability to alter its lifestyle and breeding strategy to suit prevailing conditions may play a significant role. In the late 1970s the lakes water began to undergo eutrophication (section 3.4.2). At the same time, the perch underwent a massive population explosion and quickly began displacing native fish. The results are apparent from fishery statistics. Kenya, for example, reported only 0.5% of its commercial catch as perch in 1976, but by 1983 the proportion reached 68%. While a small proportion of that increase may be attributed to larger fishing vessels and more fishermen scientific surveys also show the demise of the native fish and takeover by introduced fish species.



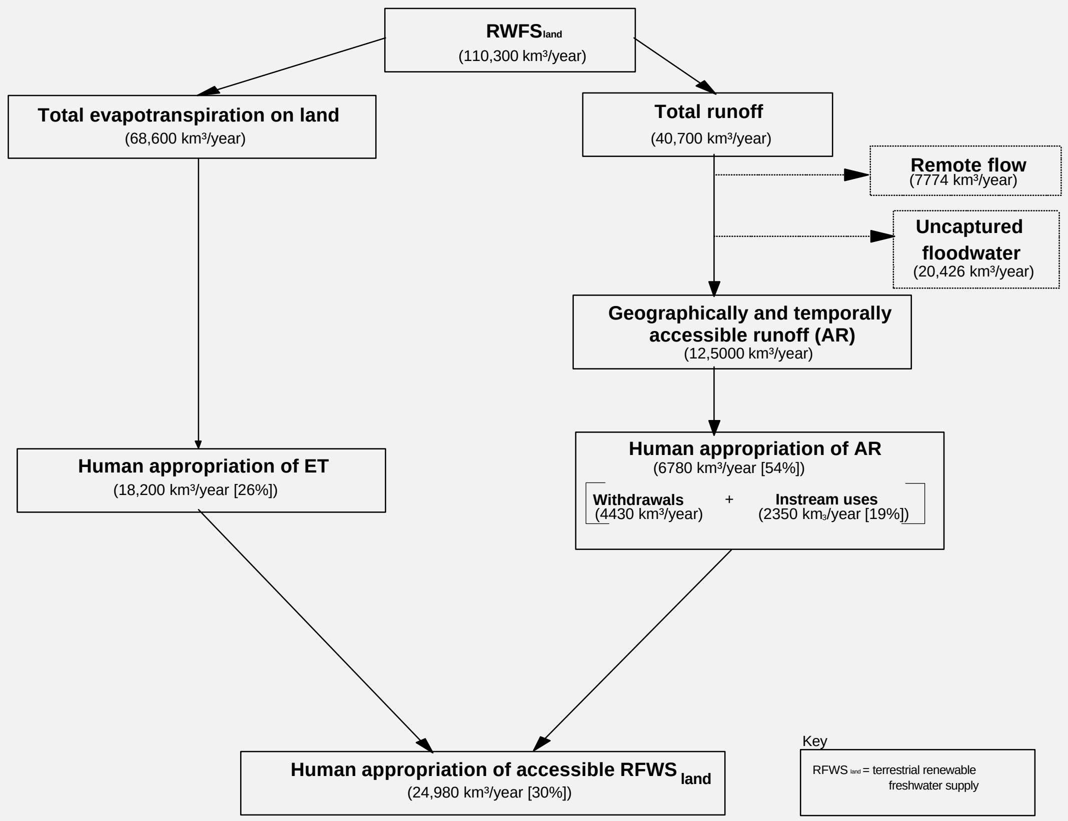
Impact of introduced species: the demise of native fishes of Lake Victoria (after, Abramovitz, 1996).

Box 5: Human appropriation of water (after Postel *et al*., 1996)

It is estimated that of the total runoff, 12 500 km^3 y^{-1} is at present geographically and temporally accessible to humans and of this, 2285 km^3 a^{-1}(i.e 18%) is consumed directly for human purposes and another 4495 km^3 y^{-1} is used for anthropogenic in-stream uses (e.g. maintenance of navigation paths, dilution of wastes, fisheries and recreational opportunities). Thus it is estimated that a total of 6780 km^3 y^{-1} or 54% of accessible blue water is appropriated for human use.

In addition it is estimated that cultivated land co-opts 18,200 km^3 y^{-1} (i.e. 26%) of the total green water (i.e. 69 600 km^3). This after subtracting the share provided by irrigation water (2000 km^3), to avoid double accounting. The remaining 74% of total terrestrial evapotranspiration must meet the water needs of all other land-based vegetation.

Thus human appropriation of water is estimated to be 24, 980 km^3y^{-1} (i.e. 30% of accessible $RFWS_{land}$ and 23% of total $RFWS_{land}$).



As discussed in section 2.4, when freshwater ecosystems are altered by people, although there may be short-term gains in environmental security, for some people, over the long-term there may be a net reduction in environmental security as a consequence of loss or decline in the quality of services provided by the ecosystem in its natural state (Box 6). Even where there is no immediate impact on the social and economic well-being of society, human induced change may have a deleterious impact on wildlife habitat causing the destruction of flora and fauna which cannot adapt to the altered environment. It should be remembered that the use and misuse of water in one location can have far flung effects, altering downstream resources, water quality and aquatic ecosystems (Box 7).

Box 6: Senegal River: an example of reduction in environmental security resulting from mis-management of water resources (after Homer-Dixon, 1994).

In the Senegal River Basin, past floodplain farming, herding and fishing was dependent on the river=s annual floods. However, in the 1970s concern about food shortages and drought led the governments of the region to seek financing for the Manantali Dam on a tributary, and the Diama barrage near the mouth of the river. These dams were designed to regulate the river=s flow with the multiple aims of producing hydropower, expanding agriculture and increasing river transport. However, the plan had unforeseen consequences. In anticipation of increased land values along the river, the Mauritanian elite, comprising mainly white moors, rewrote legislation governing land ownership; effectively preventing black Africans continuing traditional flood-based activities along the river. This resulted in ethnic violence in both Senegal and Mauritania. In Senegal, almost all the 17,000 shops owned by Moors were destroyed, and their owners were deported to Mauritania. In Mauritania some 70,000 black Mauritanians had property confiscated and were forcibly expelled to Senegal. Several hundred people were killed and the two countries almost went to war. Although diplomatic relations have now been restored, neither country has agreed to allow the expelled population to return or to compensate them for their losses.

Box 7: Aral Sea: an example of reduction in environmental security resulting from mis-management of water resources (after Zaletaev, 1995; Postel, 1996)

The Aral Sea is one of the planets greatest environmental disasters. Prior to 1960 an average of 55 billion cubic metres of water flowed into the Aral Sea, then the planets fourth largest lake, from the Amu Dar=ya and Syr Dar=ya. However, abstraction for cotton irrigation and the construction of flood storage reservoirs resulted in a decline in average annual inflow to 7 billion cubic metres between 1981 and 1990. This has resulted in a catastrophic regression in sea levels (16 m between 1962 and 1994) and a total decline in volume of three-quarters. Twenty of the 24 species of fish that used to be present in the sea have disappeared, and the fish catch that totalled 44,000 tons a year in the 1950s and supported 60,000 jobs has dropped to zero. There has been a drastic reduction in terrestrial biotic diversity on the floodplains of the Amu Dar=ya and Syr Dar=ya. Toxic dust-salt mixtures picked up from the dry seabed and deposited on surrounding farmland are harming and killing crops. The low river flows have concentrated salts and toxic chemicals making water supplies hazardous to drink and contributing to the high rate of many diseases in the area. The population of Munyak, a former fishing town, has dropped from 40,000 several decades ago to just 12,000 today. The 12 000 people who have left are ecological refugees; their environmental security has been eroded to such an extent that they have moved.

3.2 Underlying causes of decreases in environmental security (a conceptual model)

Given that the benefits that people accrue from freshwater ecosystems are now broadly understood, the question arises: why is it that management policies which result in a net decrease in environmental security continue to occur ? The reasons are complex and result from the interaction of environmental, social and economic issues. A detailed analysis is beyond the scope of this paper, but in summary, it arises mainly for three reasons:

X Insecurity in the socio-economic corners of the human security system outweigh the need to maintain environmental security. Long-term environmental security is sacrificed because of the need to maintain or re-establish security in the other corners of the tripartite system. Desperate people will often focus on immediate survival strategies and neglect the long-range value of ecological preservation. To care about the environment requires at least one square meal a day (R.Leakey, ex-Director of the Kenya Widlife Service - cited in Simonovic, 1996)).

X As a result of inappropriate and ill-informed decision-making. There is a tendency to focus on the benefits that alteration of ecosystems bring to certain people in society and not others. For example, catchments are often managed to maximise the benefits to be gained by the urban population while neglecting the rural populations. Furthermore, the focus is very often on short-term gain rather than long-term benefits.

X When environmental problems occur, existing management strategies are often focused on technical solutions that consider only certain parts of the total system. Such engineering solutions are implemented mostly as end-of-pipe measures (e.g. emission restrictions for the discharge of pollutants to receiving waters) to meet directly the experienced environmental problem (concerning water quantity or quality). Dynamics and interactions are investigated only in the small local system under consideration.

The relations between society and the environment are poorly understood. However, a simple conceptual model of the way social, economic and ecological subsystems interlink and interact is presented in Figure 7. This provides a framework in which to consider management strategies and the implications of management decisions for ecosystems. The model assumes that the current *state* of ecosystems are subject to *pressures* that are brought about as a consequence of global *driving forces*. The state of any ecosystem describes its condition and is dependent on the pressure and vulnerability of the system. Thus, pressures cause changes in the state of ecosystems. In turn the state of ecosystems at any given time *impact* on the social and economic well being of people and so affect environmental security. Impacts result in *responses* from society which in turn effect either the driving force or the pressures affecting a freshwater ecosystem. Thus societal responses introduce feedback into the system. By modifying human response it is possible to alter the impact on freshwater ecosystems. Ecosystem management strategies seek to identify mechanisms by which human interaction with the environment can be changed so as to enhance the long-term benefits not just of people but also of the other species reliant on the ecosystems (section 5).

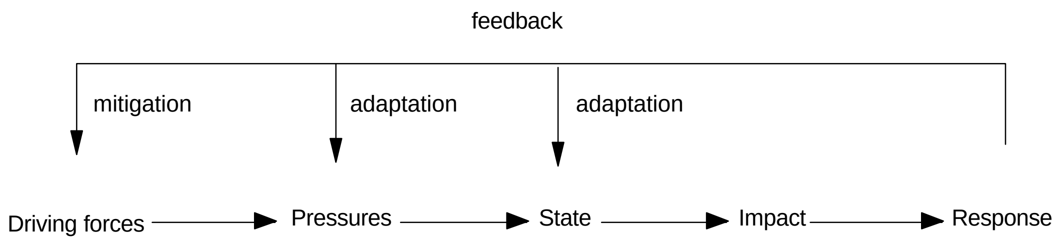


Figure 7: *Simple conceptual model of interaction within social-economic-environmental systems, highlighting the mitigation and adaptation feedback strategies of management*

Table 4 presents various aspects of freshwater ecosystem interactions into the classes defined within this conceptual model. It is a somewhat subjective division illustrating the complex nature of interactions and the difficulty of pigeonholing different aspects in the various classes of the model. For example, dam building can be viewed as either a pressure or a response; an example of the feedback in the system.

The driving forces are socio-economic and are discussed in detail in the other papers in this series (Swanson and Doble, 1999; Soussan *et al*., 1999). In the current paper we simply note that human population growth is the fundamental pressure underlying all others. At present the world population of 6 billion is estimated to be growing at just under 1.5 % y^{-1} (c.a. 80 million a year). Growth rates of some of the world=s most populous countries are hardly declining at all. India=s rate has levelled off at around 2.1% (17.9 million people), China=s at around 1.3% (14.8 million people) per year. The mid-range projection from the United Nations is that world population will grow to about 8.3 billion in 2025, 9.4 billion by 2050 and will probably stabilise towards the end of the 21st century at about 11 billion (Engleman and LeRoy, 1993).

Table 4: *Conceptual model for assessing causes and implications of change in freshwater ecosystems. The driving forces may cause any combination of pressures which in turn may induce any of the states, impacts and responses. More than one driving force/pressure may contribute to any particular state/impact/response.*

Examples of Driving Force	**Examples of Pressures**	**Examples of affected State**	**Examples of Impact**	**Examples of Responses**
XIncreasing population and mobility		XDegraded wetland habitat		XStricter birth control
	Xover-exploitation of natural resources		Xloss of ecosystem functions	
Xincreased expectation		Xdegraded headwater forests		Xdemand management
	Xincrease in irrigation		Xinequity in access to land and water resources	
Xglobalisation of world economies and continuing economic growth		Xdecreased quality of freshwater		Xincreasing expenditure on technical fixes
	Xdam construction		Xincreased social conflict	
Xindustrial development		Xdecreased bio-diversity		Xconferences/work shops
	Xincreased abstraction		Xincreased incidence of disease	
Xburning of fossil fuels		Xchanged rainfall		Xecosystem restoration
	Xincreased effluent discharge		Xincreased exposure to environmental hazards (e.g. floods)	
Xtechnological innovation				Ximmunization programmes
	Xeutrophication		Xincreased water scarcity	
				Xconstruction of flood defence walls
	Xclimate change			

3.3 Indicators of human-induced pressures on freshwater ecosystems

In this section the human-induced pressures placed on freshwater ecosystems are investigated. In many cases the pressures on freshwater ecosystems can only be ascertained indirectly. Data are sparse and problematic because descriptions and data collected vary from country to country. Hence, the themes and indices presented in this section are an illustrative rather than a definitive compilation.

3.3.1 Land-cover transformation

Worldwide human induced changes to land-cover represent perhaps the most significant direct threat to natural freshwater ecosystems. Changes in land cover cause changes in the energy and material fluxes that support freshwater ecosystems. It has been shown that conversion of forest cover to agriculture may alter the radiation balance of the surface, soil structure, evapotranspiration and runoff generation (e.g. Gash *et al.*, 1996). For example, results of simulations using a global circulation model in which Amazon tropical forest and savannah were replaced by pasture predicted a weakened hydrological cycle with less precipitation and evaporation and an increase in surface temperature as a consequence of changes in albedo and surface roughness (Lean and Warrilow, 1989). Rainfall was reduced by 26% for the year as a whole (Shukla *et al.*, 1990). However, the impact on an individual freshwater ecosystem depends on the specific nature of interventions, the scale of the land cover change and the interplay of site specific factors such as soil type, geology and slope with the local climate. It is therefore not possible to predict the consequences of specific land-use change for freshwater ecosystem integrity.

In this report, two indicators are used to show broadly the pressure of land use change on freshwater ecosystems. These are a change in the proportion of agricultural land and the change in proportion of forest cover. Since, it will not support either forests or agriculture, the area of the Antarctic, was subtracted from the total land area of the planet when calculating the global indices.

Figures 8 and 9 present the trends in these two indices for different regions of the world for the period 1961 to 1991. The indices show that world-wide the proportion of the land surface given over to agriculture increased from 0.33 to 0.37 and there was a world-wide decline in forest cover from 0.33 to 0.32 between these dates. However, the data indicate that in developed countries there has been a decrease in the proportion of land used for agriculture and an increase in forest cover. This occurs particularly in Europe where the proportion of land used for agriculture decreased from 0.49 in 1961 to 0.45 in 1991 and over the same period forest cover increased from 0.29 to 0.32. This almost certainly reflects change in agricultural policy within Europe (e.g. set aside) and the increase in plantation forests (i.e. on-native species) in this region. In Europe primeval forest coverage continues to decline (DVL/OS, 1997). Hence, increases in forest cover and decreases in agricultural land do not in themselves necessarily indicate a decrease in the pressure on freshwater ecosystems.

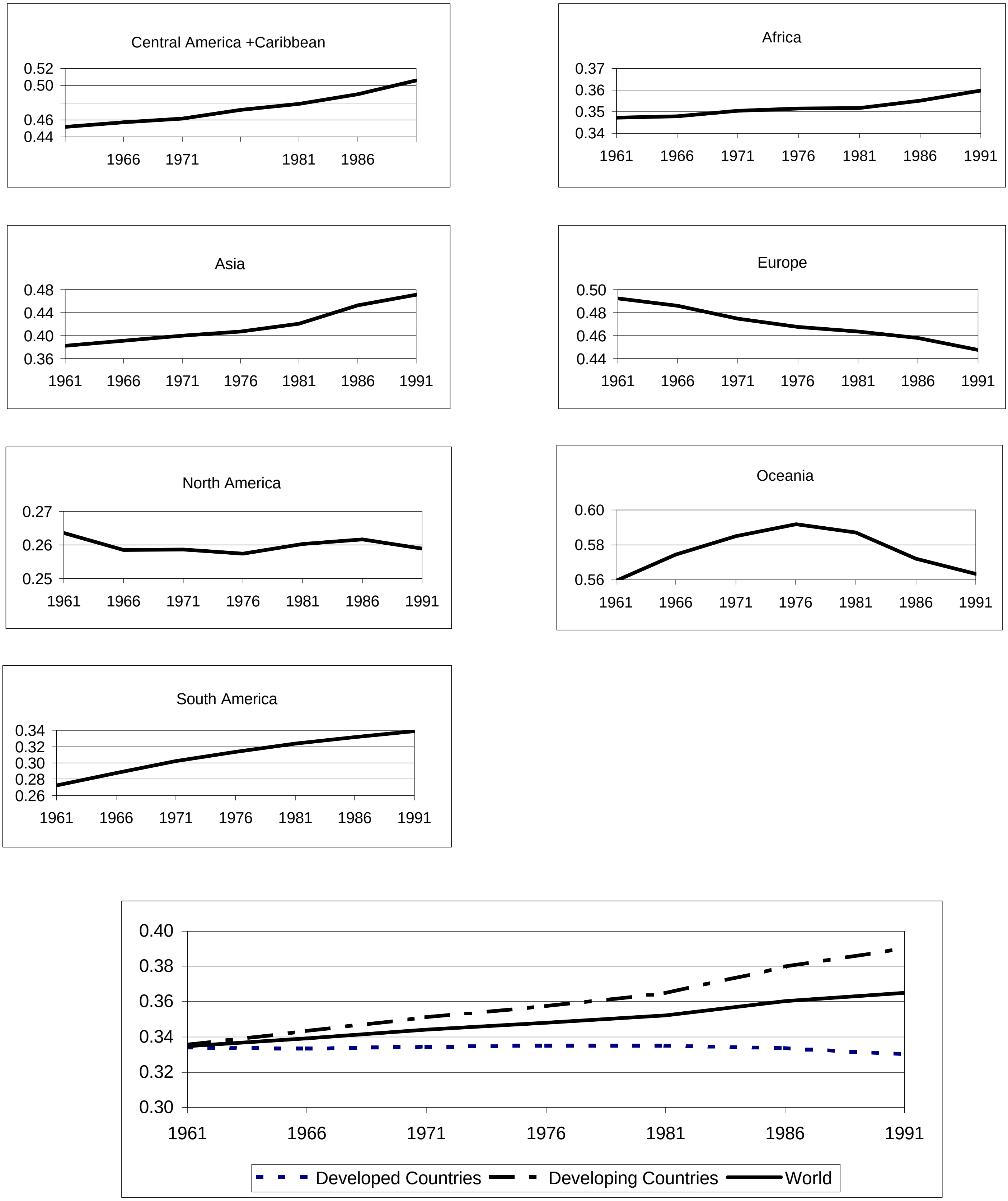


Figure 8: *Change in the proportion of agricultural land 1961-1991 a) by continent and b) in developed and developing countries* (data from FAO, Waicent database)

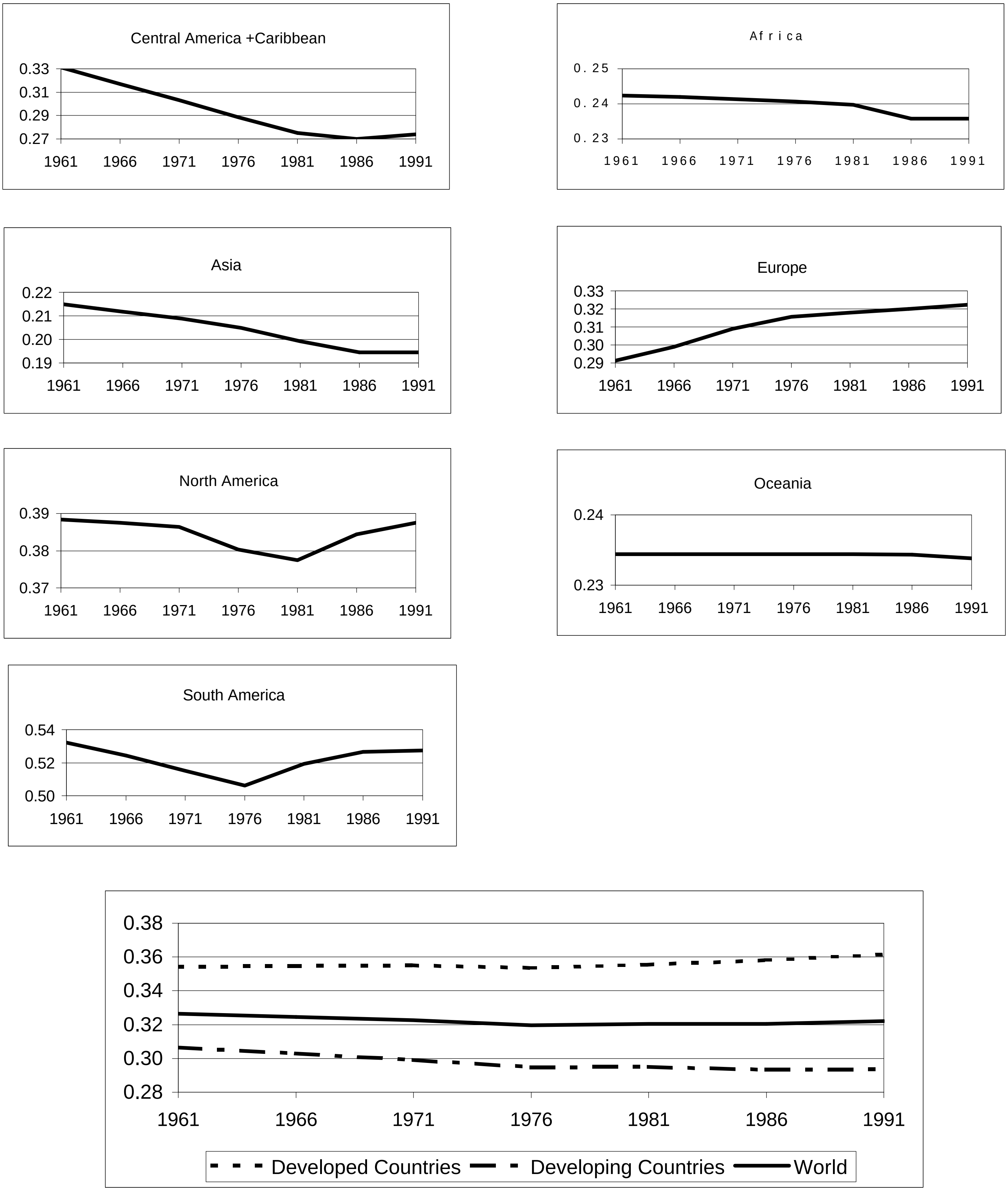


Figure 9: *Change in the proportion of forest cover (1961-1991) a) by continent and b) in developed and developing countries* (data from FAO, Waicent database)

3.3.2 Dam construction

Reservoirs store surplus wet season runoff for use in dry periods or when required for hydropower production. They are essential for the well being of millions of people throughout the world. It is estimated that world-wide there are presently some 40 000 large dams (i.e. >15 m high) and more than 800 000 smaller ones. More than 400,000 km^2 (0.3 % of the global land surface) has been inundated by reservoirs (McCully, 1996).

In addition to destroying wildlife habitat dam construction may be inappropriate and can have serious implications for environmental security (Box 6). Dams pose both long and short-term risks to environmental security. Perhaps, the greatest potential risk to downstream populations is that arising from catastrophic dam failure; usually caused by over-topping or erosion of foundations. The average world-wide risk of any dam failing in any given year is estimated to be of the order of 1 in 10,000 and it is thought there were “200 notable reservoir failures” between 1900 and 1980 (McCully, 1996). It is estimated that 12,000 people have been killed this century by dam-bursts outside China, excluding incidents caused by enemy action during war. The worst dam disaster occurred in Henan province in central China in 1975 when as many as 230, 000 people may have died when a large number of dams failed simultaneously. It is thought that 85 000 people died in the immediate flood wave and 145 000 in the epidemics and famine that followed (McCully, 1996). Table 5 lists the number of people killed in the world’s worst dam failures.

Table 5: *Dam disasters in which 1,000 or more people have been killed* (modified from, McCully, 1996)

Dam	Country	Height (m)	Year failed	Cause of failure*	People killed
Iruhaike	Japan	28	1868	OT	>1,000
South Fork (Johnstown)	USA	13	1889	OT	2,209
Tigra	India	24	1917	OT	>1,000
Oros	Brazil	54	1960	OT	ca. 1, 000
Panshet/Khadakwasla +	India	54/42	1961	SF, OT/OT	> 1,000
Vaiont	Italy	261	1963	OT	2,600
Banqiao, Shimantan, 60 others	China		1975	OT	≤230,000
Macchu II	India	26	1979	OT	> 2,000

+ The flood from the collapse of the first dam breached the second dam downstream
* OT = overtopping, SF = structural failure

There is also often a reduction in environmental security for those people that have to be resettled as consequence of dam construction. World wide many millions of people have been displaced. It has been reported that in India alone a total of 33 million people may have been displaced by the construction of large dams (Roy, 1999). The Sardar Sarovar dam, presently being constructed in India, will displace a further 200, 000 people. The land to which people are moved is often of inferior arable quality to that which they have to leave; if it was not, it would already be occupied. Furthermore, the displacement process often destroys communities and can lead to violence. Thus moving people to make way for dams can reduce not only environmental security, but also economic and social security. Table 6 presents examples of numbers of people displaced as a consequence of large hydro-power dam construction.

Dams also have negative environmental impacts. As discussed briefly in section 2.2 reservoirs drown the river upstream and disrupt the natural hydrological regime of downstream freshwater ecosystems. These changes can have severe implications for flora and fauna. For example, it is estimated that half the fish stocks endemic to the Pacific coast of the USA have been wiped out in the past century, often because of dam construction (Chaterjee, 1998).

Table 6: *Examples of numbers of people displaced as a consequence of the construction of large dams* (after, IUCN, 1997)

Project Name	Country	Megawatts	Area flooded (ha)	No. of people displaced	No. displaced/MW
Three Gorges	China	18, 200	110, 000	1, 300, 000	71
Itaipu	Brazil/Paraguay	12, 600	135, 000	59, 000	5
Guri Complex	Venezuela	10, 300	426, 000	1, 500	0
Tucurui	Brazil	7, 600	243, 000	30, 000	4
Grand Coulee	USA	6, 494	33, 306	10, 000	2
Churchill Falls	Canada	5, 225	665, 000	0	0
Tarbela	Pakistan	3, 478	24, 280	96, 000	28
Ertan	China	3, 300	10, 100	30, 000	9
Ilha Solteira	Brazil	3, 200	125, 700	6, 150	2
Yacyreta	Argentina/Paraguay	2, 700	172, 000	50, 000	19
Ataturk	Turkey	2, 400	81, 700	55, 000	23
Bakun	Malaysia	2, 400	70, 000	9, 000	4
Tehri	India	2, 400	4, 200	100, 000	42
Aswan High	Eygpt	2, 100	400, 000	100, 000	48
Cabora Bassa	Mozambique	2, 075	380, 000	250, 000	120
Ghazi Barotha	Pakistan	1, 450	2, 640	899	1
Sobradinho	Brazil	1, 050	415, 000	65, 000	62
Narmada Sagar	India	1, 000	90, 820	80, 500	81
Mangla	Pakistan	1, 000	25, 300	90, 000	90
Akosombo/Volta	Ghana	833	848, 200	80, 000	96
Kainji	Nigeria	760	126, 000	50, 000	66
Nam Theun 2	Laos	600	34, 000	4, 500	8
Pehuenche	Chile	500	400	10	0
Arun III	Nepal	402	43	775	2
Khao Laem	Thailand	300	38, 800	10, 800	36
Balbina	Brazil	250	236, 000	1, 000	4
Victoria	Sri Lanka	210	2, 270	45, 000	214
Nam Thuen-Hinboun	Laos	210	630	0	0
Nam Ngum	Laos	150	37, 000	3, 000	20
Pak Mun	Thailand	34	6, 000	4, 945	145
Kedung Ombo	Indonesia	29	4, 600	29, 000	1, 000
Kompiennnga	Burkina Faso	14	20, 000	1, 842	132

An indicator of the pressure of dams on freshwater ecosystem integrity, is the number of large dams per km^2 of land (Figure 10). Ideally the number per kilometre of river network would be used but data on the length of river networks is not available. Only large dams are considered because it is difficult to obtain the numbers of small dams in any particular region. The indicator is crude since, the overall effect of a dam on the integrity of an ecosystem is a function of not only its size relative to the flow of water in the river, but also the way in which it is operated and the specific conditions pertaining to the catchment in which it is built.

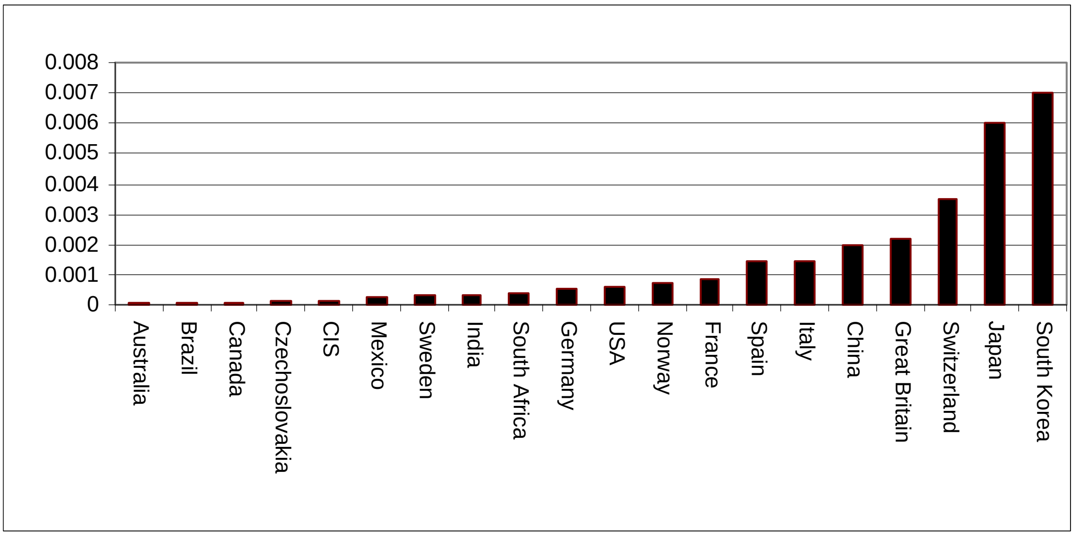


Figure 10: *Dam index (nos. of large dams/km^2) as an indicator of pressure on freshwater ecosystems*

Today, construction of large dams continues. Both China and India are pursuing ambitious hydropower development and projects are underway in Europe and South and North America. However, there is growing public opposition to large dams, primarily as a consequence of the negative environmental and social impacts. The rate of large dam building is slowing and in 1997 the US Government for the first time refused to relicense a hydroelectric dam (section 5.3.1). Many people predict the end of the large dam era in the near future (e.g. Lanz, 1995).

The World Commission on Dams is currently conducting an objective review of the overall costs and benefits of large dam projects. It has a mandate to assess the experience of existing, new and proposed large dam projects so as to improve (existing) practises, social and environmental conditions and to develop decision-making criteria, policy and regulatory frameworks for assessing alternatives for energy and water resources development. It also aims to develop and promote internationally acceptable standards for the planning, assessment, design, construction, operation and monitoring of large dam projects and, if the dams are built, to ensure that affected peoples are better off.

3.3.3 Urbanisation

Cities place pressure on freshwater ecosystems because the sustenance of the high concentration of people in one place requires large inputs of natural resources and tends to overload the sink capacity (e.g. for pollutants) of natural systems in the vicinity of a city. For example, Mexico City (population over 10 million) consumes 1 km^3 y^{-1} more water than can be provided by renewable sources in its abstraction area (DVL/OS, 1997) and Sana=a, Yemen (population over 1 million) is mining fossil aquifers to provided water for its population. In Zimbabwe, failure to properly treat the wastewater generated by the people and industry of Harare is placing the water quality of reservoirs and rivers in the vicinity of the city at risk. It is estimated that at least 600 million urban dwellers in Africa, Asia and Latin America live in housing that is so overcrowded and of such poor quality with such inadequate provision of for water, sanitation and drainage that their lives and health are continually at risk (United Nations Centre for Human Settlements, 1996).

The index used to illustrate the changing pressure of urbanisation on ecosystems is simply the proportion of population living in cities (Figure 11). Once again it is only a relatively crude indicator since it does not indicate the extent of investment in infrastructure (e.g. wastewater treatment plants) to protect the environment from the impact of higher urban population. Over the 35 years from 1961 to 1996 the world-wide proportion of the population living in the urban environment increased from 0.34 to 0.46. In 1995 321 cities had population in excess of 1 million and there were 15 mega-cities with population 10-20 million. The proportion of the population in cities is 0.73 and 0.38 in developed and developing countries respectively. However, the highest rates of urban growth are in developing countries (i.e. in Africa, South America and Asia) which are those least able, through lack of resources, to ameliorate the impact on the environment of greater urbanisation. It is estimated that by 2025, 56% of population will be urban and there will be more than 30 mega-cities (WMO, 1997). The increase in the world=s urban population has consequences for water planning and management around the globe.

3.3.4 Freshwater fisheries

The size of the annual freshwater fish catch provides a crude indicator of human exploitation of the natural resource function provided by freshwater ecosystems. Fish constitute a major source of animal protein throughout the world, especially in many tropical and subtropical countries. The change in freshwater fish catch between 1961 and 1996 is presented in Figure 12. This has been calculated from FAO statistics and is simply the total fish catch minus the marine fish catch.

The data show that between 1961 and 1996 there was a five-fold increase (from 8.7 x10^6 to 45.6 x10^6 metric tons) in the world-wide freshwater fish catch. The greatest growth has been in developing countries, particularly those in Asia, where over the same period there was nearly an 8-fold increase. Even allowing for the increase in farmed fish (estimated to have averaged 11.2 x 10^6 tons per annum between 1993 and 1995 (WRI *et al.*, 1998)) this still represents a very significant increase in the human exploitation of the natural fish resource. Although, the case for over-exploitation of the fish-stock is not as clear as for marine fish nevertheless it is considered that most freshwater fishes are being exploited at, or above, sustainable levels (Abramovitz, 1996).

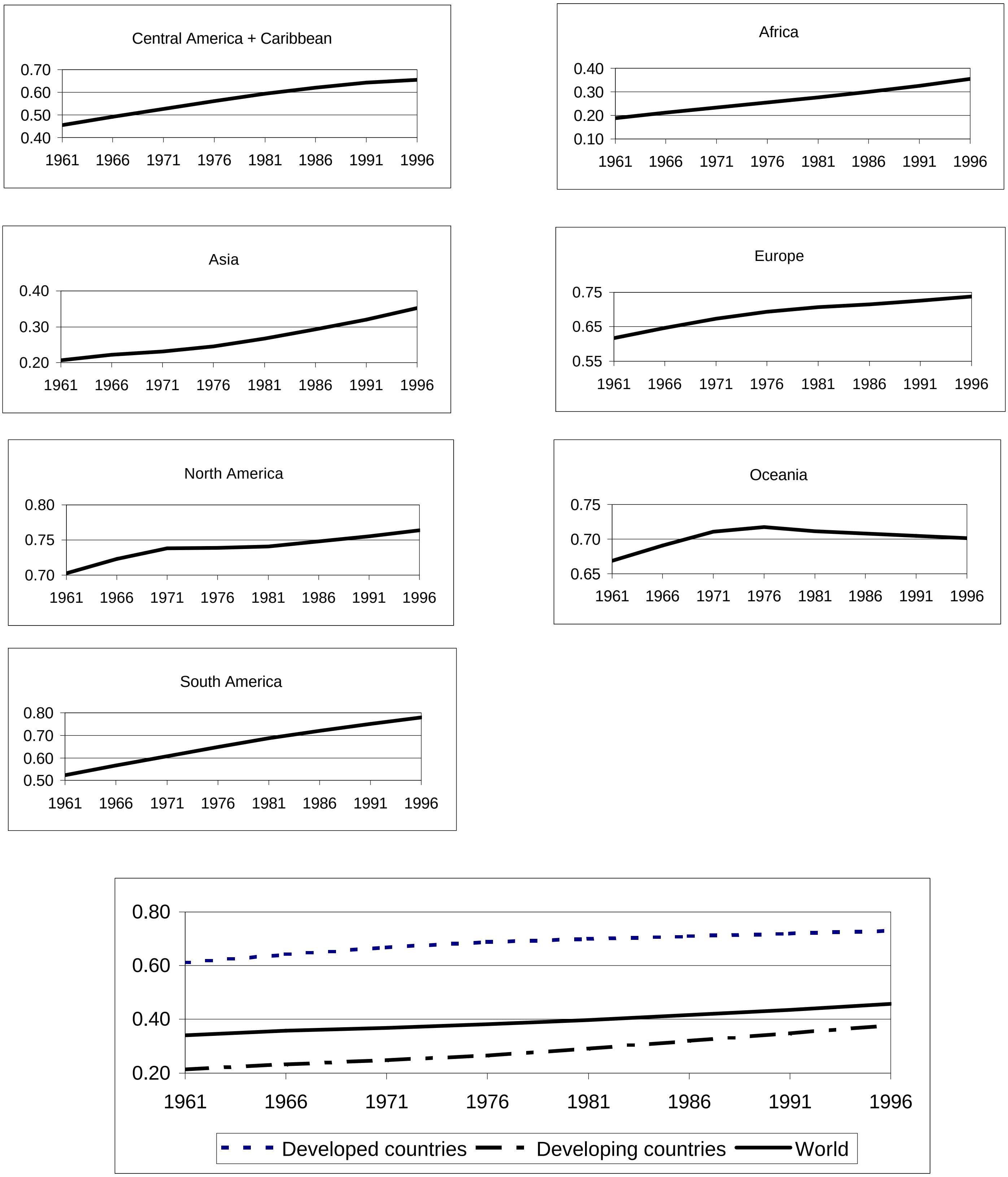


Figure 11: *Change in the proportion of urban population 1961-1996 a) by continent and b) in developed and developing countries* (data from FAO Waicent database*)*

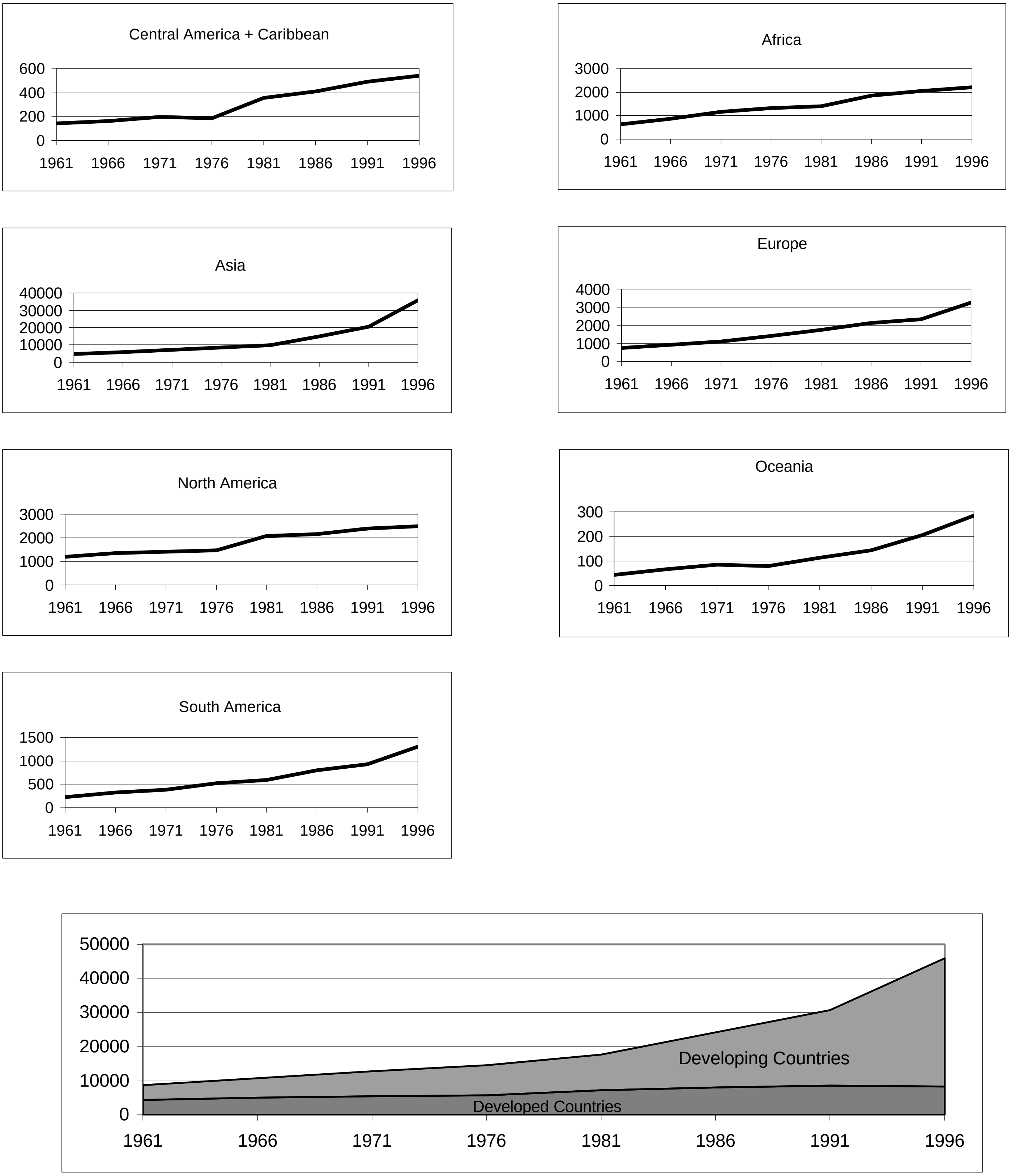


Figure 12: *Change in the freshwater fish catch (MT * 1000) from 1961-1996 a) by continent and b) in developed and developing countries* (data from FAO Waicent database)

3.3.5 Climate change

The Intergovernmental Panel on Climate Change (IPCC) concludes that since the late 19th century, human induced emissions of gases, such as carbon dioxide (CO_2) that trap heat in the atmosphere have contributed to an increase in global mean surface air temperatures of 0.3 to 0.6EC. Moreover, based on the IPCC=s mid-range scenario of future gas emissions and aerosols and their best estimate of climate sensitivity, a further increase of 2EC is expected by the year 2100.

There is little doubt that climate change will alter the globes hydrological cycle in a variety of ways, but there is at present little certainty about the form these changes will take. At the most general level IPCC (1996) predict that:

> *Warmer temperatures will lead to a more vigorous hydrological cycle; this translates into prospects for more severe droughts and/or floods in some places and less severe droughts and/or floods in other places. Several models indicate an increase in precipitation intensity, suggesting a possibility for more extreme rainfall events.*

However, many more impacts will occur. Changes in evapotranspiration, snowmelt, runoff and soil moisture will all affect freshwater ecosystem integrity both directly and indirectly as a result of human interventions designed to compensate for changes in water resources.

The hydrology of arid and semi arid areas is particularly sensitive to climate variations. Relatively small changes in temperature and/or rainfall can have significant effects on evapotranspiration and groundwater recharge. These changes will impact both the total annual flow in rivers and its distribution through the year. In a dry area of Tanzania model results indicate a dramatic 40% decrease in recharge caused by a 15% reduction in annual rainfall, which is further accentuated under degraded conditions to a 58% decrease (Sandström, 1998). Since dry season flow in rivers is maintained by groundwater recharge this has severe implications for freshwater ecosystem integrity in this and similar areas.

3.4 Indicators of the state of freshwater ecosystems

Human-induced pressures result in changes in freshwater ecosystems. In this section a range of themes and indicators of the changing state of freshwater ecosystems are presented. As with the previous section, the themes are illustrative rather than a complete compilation and once again the indicators must be treated with caution because there are problems with data collection and analysis.

3.4.1 Loss of wetlands

Wetlands, as defined by the Ramsar convention are:

> *areas of marsh, fen, peatland or water, whether natural, artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water, the depth of which at low tide does not exceed 6 m.*

This definition although encompassing saline-water systems also incorporates a wide-range of different freshwater ecosystems. Consequently, although there is not a direct one-to-one correspondence between the terms, loss of integrity or destruction of wetlands is an indicator of pressures on freshwater ecosystems. Furthermore, it should be noted that the integrity of estuarine, deltaic and coastal wetlands is also dependent on inputs of freshwater (Box.2). Loss of wetlands may arise either directly from conversion to agricultural, industrial or residential use or indirectly as a consequence of human-induced change elsewhere in the catchment in which the wetland is situated.

The amount of wetland lost is difficult to quantify for three reasons. First, the total area of wetland in the world is uncertain and different countries delineate different wetland types. Second, in many parts of the world the extent of wetland coverage in the past is unknown. Third, the definition of loss is subject to a wide range of different interpretations. However, despite these limitations, figures for loss of wetland provide a crude indication of pressure on freshwater ecosystems.

Table 7 presents figures for wetland loss in a number of countries and an estimate of the global loss since 1900. These average national loss figures hide much greater variation within regions. For example, in the USA it is estimated that Iowa has lost 99% of its original marshes, Louisiana 50% of its forested wetlands and Wisconsin 32% of its wetlands (Tiner, 1984).

Table 7: *Wetland loss* (various sources)

Country	Period	% loss of wetlands
Netherlands	1950-1985	55
France	1900-1993	67
Germany	1950-1985	57
Spain	1948-1990	60
Italy	1938-1994	66
Greece	1920-1991	63
USA	1970-1985	54
World	1900-to date	50

3.4.2 Water pollution

All natural waters contain a variety of contaminants arising from erosion, leaching and weathering processes. To this natural contamination is added that arising from human sources (i.e. pollution). Any freshwater ecosystem is capable of assimilating a certain amount of pollution without serious effects because of the dilution and biological self-purification mechanisms that are present. However, if additional pollution occurs the nature of the receiving water is altered and its suitability for various uses may be impaired (i.e. the system is degraded).

The type of water pollution that occurs is closely linked to water use and levels of socio-economic development (Figure 13). The industrialised countries have experienced a series of freshwater pollution problems involving domestic, industrial and agricultural wastes. Legislation and technology have been used to control each wave of pollution as it has occurred. Today, pollution from industrial wastes is beginning to be curbed, but issues arising from non-point source pollutants (i.e. acidification, organic micro pollutants, nitrates and groundwater contamination) are on the increase (Figure 13d). In the developing countries the rapid growth of urban population particularly in the South America and Asia (section 3.3.3) has outpaced the ability of governments to expand sewage and water infrastructure and domestic waste is a major problem. In some countries this remains the principal pollution problem. However, in rapidly industrialising countries all the problems faced by the developed countries are being experienced, but later and in more rapid succession than occurred in the developed countries (Figure 13c). Groundwater pollution as a consequence of urbanisation, industrial activity and from agriculture is increasingly a problem world-wide.

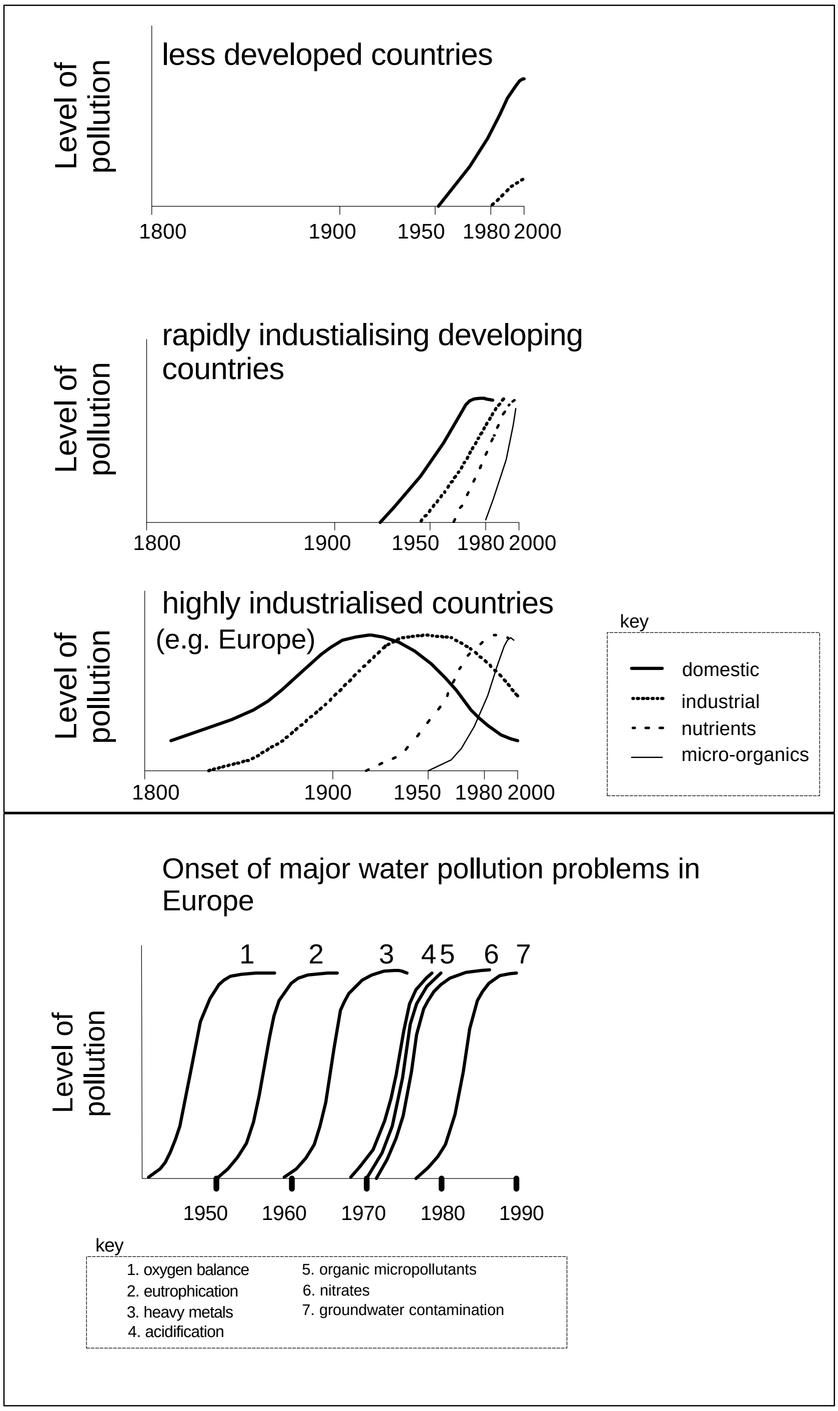


Figure 13: *Conceptual evolution of the development of water pollution in relation to socio economic development* (after, UNEP, 1991)

One manifestation of freshwater pollution is eutrophication. Eutrophication of freshwater ecosystems involves the deregulation of ecological processes in water and soil due to excessive supply of nutrients in the form of phosphates and nitrogen compounds. Eutrophication is evidenced for example in undesirably large quantities of algae in ponds, lakes or rivers. As a result of eutrophication plants species that thrive in low-nutrient environments are disappearing. In addition, the nitrate levels in groundwater are rising to such an extent that in a growing number of places the preparation of drinking water is under threat. In the United States for example, nitrate contamination is the nation=s most widespread groundwater pollution problem; in a national survey, 22% of wells in U.S. agricultural areas contained nitrate levels in excess of the federal limit (U.S. EPA, 1994). The main eutrophying agents are phosphates and nitrates derived primarily from a number of sources: fertiliser, manure, wastewater, sewage sludge, dredge spoil and solid waste.

World-wide total fertiliser application increased from 31, 182, 240 MT to 134, 324, 000 MT between 1961 and 1991. Eutrophication pressure is worst in Europe where large amounts of fertiliser have been applied to a relatively small total land area. Although Europe is the one part of the globe where fertiliser application rates have decreased significantly in recent years (a drop of 31 % between 1986 and 1991) the legacy of high fertiliser application is likely to remain for many decades to come. Asia has experienced the most rapid growth in possible eutrophication pressure as a consequence of fertiliser application; a 15 fold increase between 1961 and 1991. The gap in potential eutrophication between developed and developing countries has decreased significantly in recent years.

3.4.3 Freshwater biodiversity status and trends

The proportion of the world surface unaffected by man is now very small. Pollution and man-induced climate change are affecting all parts of the planet. However, there remains a large proportion of the globe that can still be considered natural habitat (i.e. has not experienced a form of land-use change). It is estimated that natural habitat comprises about 70% of the total land surface in 1990, but it is forecast that this will decrease to 60% by 2025 (DVL/OS, 1997).

Freshwater habitats are very rich in certain organisms; freshwater fish comprise 40% of all fishes and freshwater molluscs comprise 25% of all molluscs. As with much terrestrial and marine ecosystems, freshwater biodiversity tends to be greatest in tropical regions (Table 8). The richest habitats for freshwater include foothill streams, lowland rapids, as well as some peat swamps and ancient lakes.

The loss of freshwater biodiversity is poorly monitored except for some larger, commercial species. Available data suggest that between 20 and 35% of freshwater fish (the total number of species world-wide is estimated to be anywhere between 9,000 and 25,000) are vulnerable or endangered, mostly because of habitat alteration (Figure 14). Of seven freshwater dolphins one is vulnerable, two are endangered and one is critically, endangered. Of 23 species of crocodile, 10 are threatened. According to IUCN (1996) many of the worlds 4,522 known species of amphibian are threatened. The proportion of threatened species of fish and amphibians for a number of OECD countries are presented in Figure 15. It is probable that the fish statistics include salt water fish, although this is not made clear in the report from which these figures are taken (OECD, 1999).

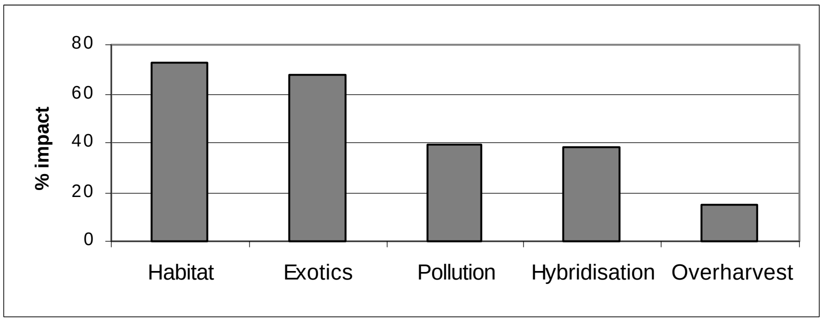


Figure 14: *Causes of and degree of impact on extinction in North American freshwater fishes. More*

than one factor may contribute to an extinction (after Sea and Wind, 1998*)*

Table 8: *Freshwater fish species: number per country and species per unit land area* (after World Bank, 1998)

Country	Number of species	Number of species/1000 km^2
Countries with most species:		
Brazil	3,000	0.36
Indonesia	1,300	0.72
China	1,010	0.11
Zaire	962	0.42
Peru	855	0.67
United States	779	0.09
India	748	0.25
Thailand	690	1.35
Tanzania	682	0.77
Malaysia	600	1.83
Countries with most species per km^2:		
Burundi	209	8.15
Malawi	361	3.84
Bangladesh	260	2.00
Malaysia	600	1.83
Sierra Leone	117	1.63
Lao P.D.R.	350	1.48
Cambodia	260	1.47
Vietnam	450	1.38
Thailand	690	1.35
Uganda	247	1.24

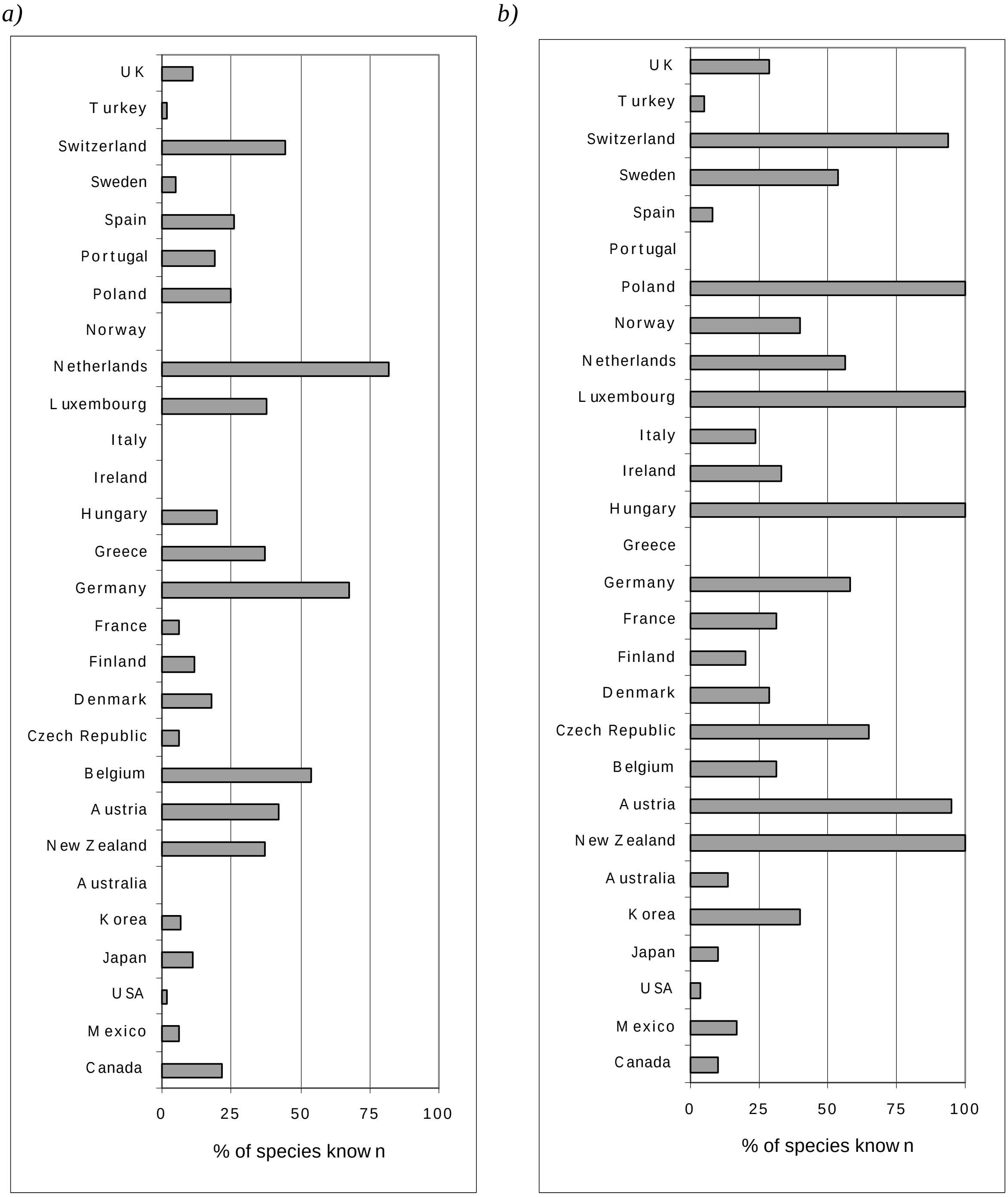


Figure 15: *Threatened species of a) fish and b) amphibians* (after OECD, 1999*)*

3.5 Indicators of environmental security

It is a key tenet of this report that pressures on freshwater ecosystems often translate to a reduction in environmental security. However, because of the spatial and temporal variation in the natural resource endowments provided by freshwater ecosystems it is difficult to establish theoretical values linking pressures and changes in security directly. In this section, the themes and indicators presented mark different attempts to quantify key elements of human-environmental security associated with freshwater ecosystems.

3.5.1 Water scarcity

There are a large number of measures of water sufficiency. A commonly used index is the use-to-resource ratio which is simply the ratio of water withdrawals to renewable water resources estimated at the country level (e.g. Raskin *et al.*, 1995). It is difficult to establish a link between the use-to-resource ratio to the levels of water efficiency, but a country which withdraws a large fraction of its renewable resources is likely to encounter water scarcity. For example, in Eygpt the use-to-resource ratio is 0.97 and clearly reflects the water stress in that country. In the USA the relatively low ratio of 0.19 suggests an overall water abundance, while masking water shortages in the arid western regions of the country. Table 9 presents use-to-resource ratio for those countries where it exceeds 0.25 the threshold often taken to indicate water stress. It is important to emphasise that in the analysis conducted to derive these ratios water use refers to withdrawals not water consumption. In situations where withdrawals are heavily for non-consumptive uses (e.g. power plant cooling) the use-to-resource ratio may exaggerate the pressure on water resources.

In an attempt to incorporate spatial and temporal variation into the discussion of water scarcity Meigh *et al.* (1998) have developed a number of indices and a computer model to determine water availability. The indices attempt to incorporate variation in supply and demand either within years or from year to year. The most complex index (I_{T4})is defined as the minimum over all months of:

$$I_{T4} = \frac{mr(90\%) + mgy - md}{mr(90\%) + mgy + md}$$

where: mr(90%) is 90% reliable monthly runoff
mgy is monthly groundwater yield
md is demand for that month

The index I_{T4} varies from -1 (negligible water available to meet demand) through zero (available water meets demand) to 1 (available water much greater than demand). The computer model makes allowance for return flows and so demands are consumption rather than just withdrawals. The model has been used to derive I_{T4} for cells in a 0.5 by 0.5 degree grid covering eastern and southern Africa. The grid size chosen is a compromise between that needed to represent spatial variation and the availability of the data required by the model.

It is important to note that in all analyses of water scarcity, the demand considered is usually direct human demand for water for use in industry, irrigation and domestic consumption. However, there is no reason why demand cannot include environmental requirements for water if this can be defined.

Table 9: *Current water constraints according to use-to-resource index* (after Raskin *et al.*, 1995)

Country	Index *	Country	Index
Kuwait	very high	Spain	0.41
Libya	3.74	Jordan	0.41
United Arab Emirates	3.00	Madagascar	0.41
Saudi Arabia	1.64	Iran	0.39
Yemen	1.36	Morocco	0.36
Eygpt	0.97	Pakistan	0.33
Israel	0.86	Singapore	0.32
Belgium	0.72	Germany	0.31
Tunisia	0.53	Italy	0.30
Afghanistan	0.52	South Africa	0.29
Korea Rep	0.44	Poland	0.26
Iraq	0.43		

* Note use-to-resource index can exceed 1 when water use exceeds the renewable water supply. For example in Kuwait desalinated water is the primary source of freshwater for drinking and domestic purposes and in Libya the present rates of exploitation of groundwater exceed the rates of recharge.

3.5.2 Access to safe water and sanitation

In 1977, The United Nations Water conference declared that all people have the right of access to drinking water in quantities and quality equal to their basic needs. Two decades later, an estimated 1.1 billion people still do not have access to safe drinking water and 2.9 billion do not have access to adequate sanitation (UNICEF, 1996). In Cambodia only 7% of the population have access to safe drinking water. Improved water supply and sanitation services for those who lack them would do much to reduce the global burden of water-related diseases and so enhance environmental security.

Figure 16 shows how the proportion of the population that have access to safe drinking water and sanitation in developing countries changed between 1980 and 1994. It is important to note that the total number of people without access to safe drinking water fell from 1.8 to 1.1 billion, the total number of people without access to sanitation increased from 1.7 to 2.9 billion.

Limitations with the data include different definitions of access. For example, in Africa access to a pit latrine may be considered access to sanitation, but in many countries in S. America only access to a pipe sewage network is considered access to sanitation.

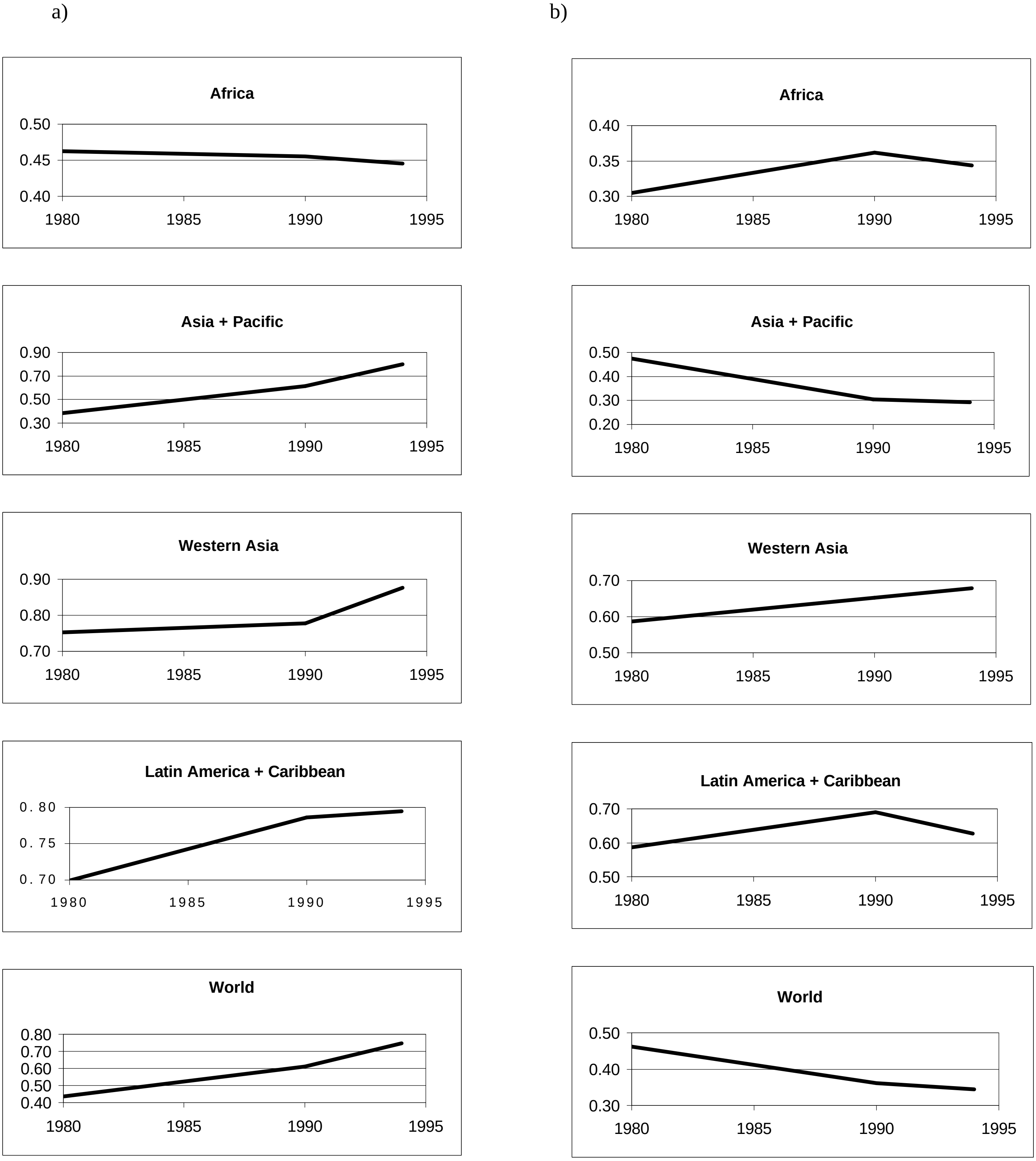


Figure 16*:* *Access (i.e. proportion of the population served) to a) safe drinking water and b) sanitation in developing countries 1980-1994* (data from Gleick, 1998)

3.5.3 Water related diseases

Interactions between human populations and freshwater ecosystems have consequences for health. Although data are incomplete and unreliable, the World Health Organisation estimate that there are of the order of 250 million cases of water-related diseases and roughly 5 to 10 million deaths annually (Table 10). Water-related diseases are of major concern in most of the developing world but have been largely eliminated from industrialised countries.

Drinking water contaminated with human or animal excreta is the main source of water-related disease. These include most of the enteric and diarrhoeal diseases caused by bacteria, parasites and viruses, such as cholera, giardia and rotaviruses. In the developed world dramatic improvements in public health were obtained in the1800s as a consequence of protecting and treating drinking water supplies. Figure 17 indicates that deaths from cholera now occur predominantly in Asia and Africa.

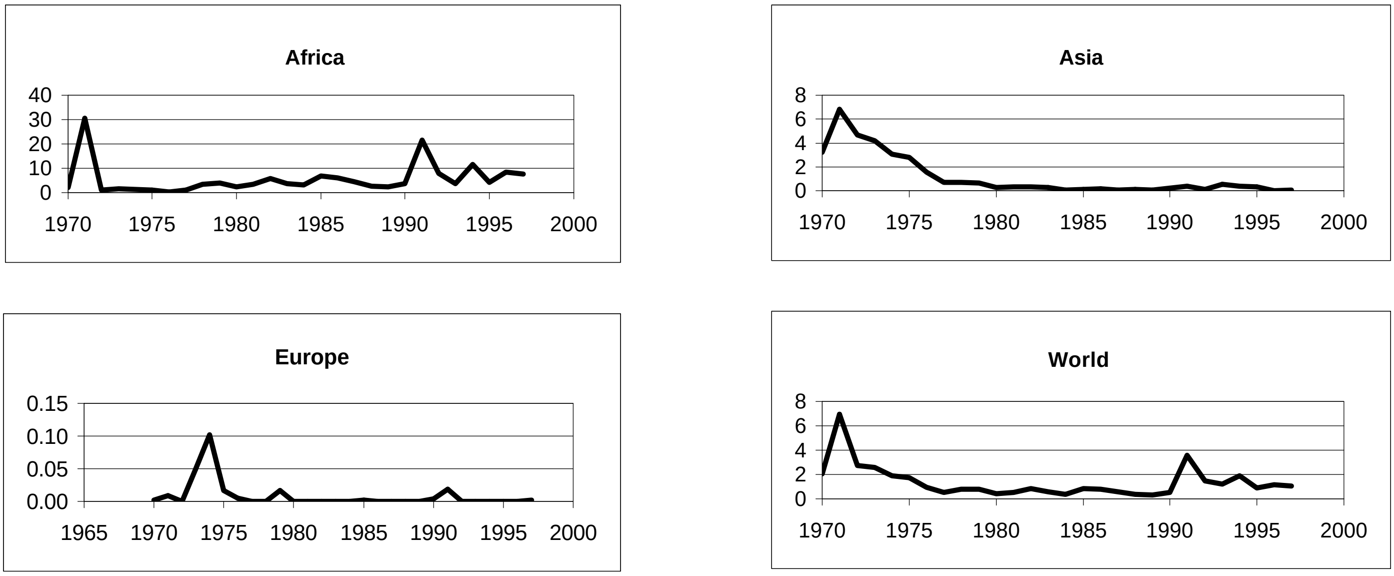


Figure 17: *Cholera index (nos. of deaths per million) as an indicator of environmental security* (data from Gleick, 1998)

Water-based diseases come from hosts that live in water or require water for their life-cycle. The two most widespread examples are schistosomiasis which results from contact with snails that serve as hosts and dracunculiasis (guinea worm) which results from ingesting contaminated host zooplankton.

Schistosomiasis currently infects 200 million people in 70 countries. World-wide prevalence of the disease has risen over the last five decades, due mostly to the expansion of irrigation systems in hot climates (WRI, *et al*, 1998). The slow moving water in irrigation channels, drainage ditches and at the edge of reservoirs provide ideal habitats for the host snails. Clear links to increases in schistosomiasis have been documented in irrigation projects such as the Mwea project in Kenya, where schistosomiasis accounts for 18% of all deaths (WRI *et al.*, 1998). Following construction of the Diama dam on the Senegal river, the prevalence rate of schistosomiasis rose from 2% to 72% (Bergkamp, *et al.*, 1998). In Ghana, schistosomiasis prevalence tripled in the late 1950s and early 1960s when a large number of agricultural impoundments were constructed (WRI, *et al.*, 1998).

Over the last decade the number of cases of dracunculiasis has dropped by 97% from an estimated 3.5 million cases in 1986 to about 150,000 cases world-wide in 1996 (Gleick, 1998) and it is hoped that the disease may be eradicated in about 5 years. The thrust of control strategies is to educate people about the origin of the disease and about the measures they and their communities can take to prevent it. It is relatively simple to filter water to remove the infected hosts and household members can be taught to prevent worms from entering sources of drinking water.

Table 10: *Estimates of morbidity and mortality of water-related diseases* (after Shiklomanov, 1997)

Disease	**Morbidity (episodes/year or as stated)**	**Mortality (deaths/year)**	**Relationship of disease to water supply and sanitation**
Diarrhoeal disease	1 000 000 000	3 300 000	Strongly related to unsanitary excreta disposal, poor personal and domestic hygiene, unsafe drinking water
Infection with intestinal helminths	1 500 000 000[1]	100 000	Strongly related to unsanitary excreta disposal, poor personal and domestic hygiene
Schistosomiasis	200 000 000[1]	200 000	Strongly related to unsanitary excreta disposal and absence of nearby sources of safe drinking water
Dracunculiasis	100 000[1,2]	-	Strongly related to unsafe drinking water
Trachoma	150 000 000[3]	-	Strongly related to lack of face washing, often due to absence of nearby sources of safe water
Malaria	400 000 000	1 500 000	Related to poor water management, water storage, operation of water points and drainage
Dengue Fever	1 750 000	20 000	Related to poor solid wastes management, water storage, operation of water points and drainage
Poliomyelitis	114 000	-	Related to unsanitary excreta disposal, poor personal and domestic hygiene, unsafe drinking water
Tryponosamiasis	275 000	130 000	Related to the absence of nearby sources of safe water
Bancroftian filariasis	72 800 000[1]	-	Related to poor water management, water storage, operation of water points and drainage
Onchocerciasis	17 700 000[1,4]	40 000[5]	Related to poor water management in large-scale projects

[1] People currently infected
[2] Excluding Sudan
[3] Case of the active disease. Approximately 5 900 000 cases of blindness or severe complications of Trachoma occur annually
[4] Includes an estimated 270 000 blind
[5] Mortality caused by blindness

Diseases associated with water related insect vectors include malaria, onchocerciasis, trypanosomiasis, dengue fever and yellow fever. Modification of freshwater ecosystems that create or remove conditions favourable to their hosts may increase or reduce the prevalence of these diseases. For example, the draining of wetlands made a significant contribution to the eradication of malaria in many developed countries. However, in Africa, deforestation favours malaria transmission by a species of mosquito which prefers to breed in the open rather than in dense forest. In the Usambara mountains in north-east Tanzania, forest clearing activities along the mountaintops are considered one cause for the introduction and spread of malaria (WRI, *et al.* 1998). At present three to four hundred million people carry the malaria parasite and malaria accounts for 20-30% of childhood deaths in developing countries.

It is impossible to quantify the additional toll of diseases related to irrigation, land conversion and other human-induced changes in freshwater ecosystems. The complex relationships between habitat modification, the functioning of ecosystems and the transmission of disease mean that it is difficult to predict how changes in freshwater ecosystems will affect disease rates, especially when the vulnerability of exposed populations varies so widely with income, access to health care and proper nutrition. Nevertheless, it is fair to say that on balance these changes contribute to the overall burden of water-related disease and so reduce environmental security.

3.5.4 Impact of Floods

Another aspect of environmental security related to freshwater ecosystems is exposure to too much water (i.e. floods). Floods play a dual role with regard to human welfare. Sometimes they provide environmental security through the maintenance of floodplain services (Box 3). However in other circumstances they reduce environmental security bringing death and destruction to communities. In this section their destructive role is discussed.

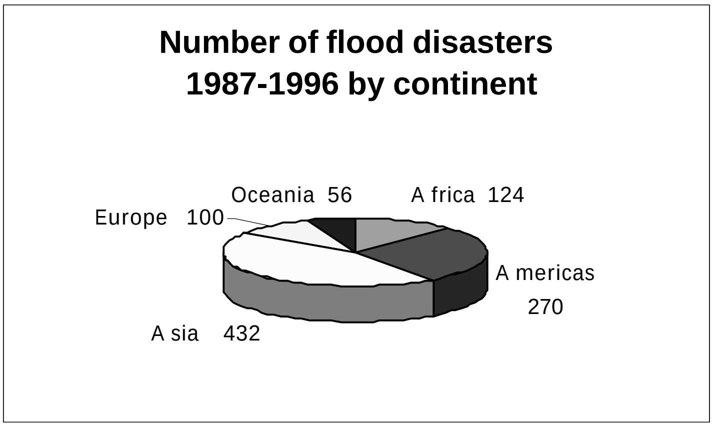
Floods are the most frequent and damaging of all types of natural disaster. Few countries are spared the effects of floods and between 1991 and 1995 it is estimated that floods caused more than US$200 billion in losses, almost half of all economic damage caused by disasters during the same time span. Each year floods are responsible for a quarter of deaths due to natural disasters and in 1996 alone 60 million people were affected by this natural hazard (Miller, 1997). In the worst natural disaster this century 3.5 million people lost their lives as a consequence of flooding in Hwang-Ho in China.

Asia is the continent that suffers the most from floods (Figure 18). It suffered 44% of all flood disasters and 93% of flood-caused deaths in the period 1987-1996. The high death toll is not only due to the dense population in the flood plains of the region, but also the difficulties that the developing countries in Asia face in mounting effective flood defences (Miller, 1997).

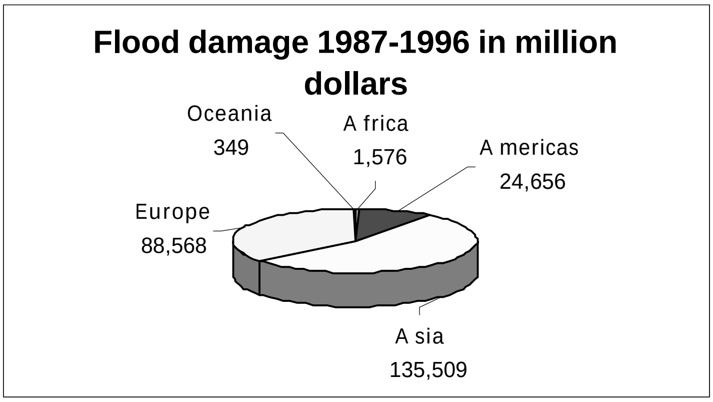
Flood magnitude and frequency may be altered by human-induced changes in freshwater ecosystems. For example, deforestation in the middle and upper reaches of the Yangtze River and its tributaries is widely attributed to have exacerbated the recent floods in China (The Economist, 1998). Although the exact nature of catchment response to deforestation is very site specific, removal of trees, particularly in the dry tropics tends to result in reduced rates of infiltration and percolation and hence increased runoff (Sandström, 1998). Societies have attempted to reduce the impact of flooding using both structural and non-structural flood control methods. Structural measures include the construction of dykes or levees to prevent water spreading across the floodplain and the construction of large flood control dams. Non-structural measures include soil and water conservation methods (e.g. reforestation and contour ploughing in fields) and floodplain zoning and general regulation of development on floodplains.

Flooding is a natural phenomenon that will inevitably occur from time to time. It is impossible to ascertain a direct relationship between human modification of catchments and freshwater ecosystems and the consequent impact of floods.

a)



b)



c)

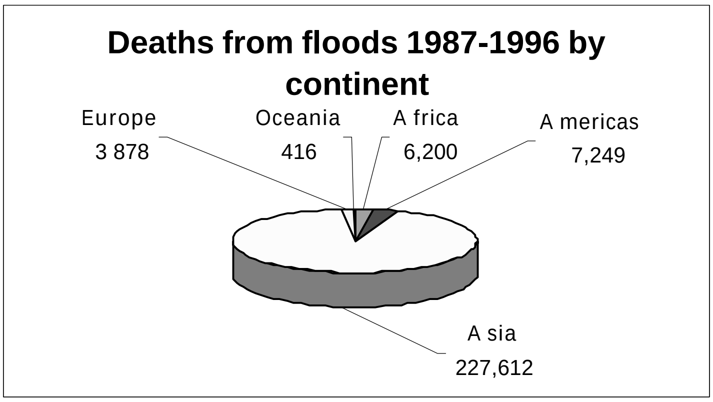


Figure 18: *Flood disasters: a) number of flood disasters 1987-1996 by continent*
b) flood damage 1987-1996
c) deaths from floods 1987-1996, by continent
(data from Miller, 1997)

3.6 Synthesis: links between pressures, environmental state and security

Although far from comprehensive the problems identified and discussed in this chapter are the currently most pressing issues in the context of freshwater ecosystems. Although there are problems with all the indices presented, they provide a crude way of assessing temporal and spatial variation in the human-induced pressures on freshwater ecosystems and the state of those ecosystems. As yet there is no method of integrating the indices to derive an index of either total pressure or current state. It is recognised that the synergistic effects of several different pressures will have a cumulative impact that is different to the simple sum of the individual pressures (Gosselink *et al.*, 1990). Furthermore, because of the complex nature of interactions between humans and the environment it is presently impossible to derive quantitative links between indices of pressure and ecosystem state and environmental security. Statistics alone cannot adequately describe the pressures on freshwater ecosystems, their state nor environmental security. Recognising these limitations the indices nevertheless provide useful information.

The indices show that, world-wide, there is a tendency for increasing human pressure on natural freshwater ecosystems. Conversion of land to agricultural use, deforestation, urbanisation, dam construction and freshwater fishing continue to impact on freshwater ecosystems everywhere. In the future it is likely that climate change will induce significant changes in the state of freshwater ecosystems. Many of the indices show that, to a large extent, the pressures are greatest in the developing countries which, not uncoincidentally, are where people presently have the lowest environmental security and populations are increasing most rapidly. In the developed world some pressures are decreasing (e.g. the rate of conversion to agricultural land and construction of large dams has slowed) but it is in the developed countries that natural freshwater ecosystems have already experienced the greatest alteration.

The indices show that world-wide natural freshwater ecosystems are becoming increasingly altered by human intervention. The loss of wetlands, water pollution and the changing status of biodiversity all indicate a decline in the “naturalness” of freshwater ecosystems. The water pollution indices highlight how the problems faced by freshwater ecosystems change as countries become increasingly industrialised; while some pressures maybe moderated new pressures arise. Nevertheless, in the developed world, there has been an overall improvement in the state of some freshwater ecosystems, in recent years, particularly with regard to water quality. To date this has been achieved primarily through engineering solutions and heavy investment in end-of-pipe technologies.

World-wide indicators of environmental security are mixed. At present the greatest levels of human security are in the developed world (i.e. in those countries which have the most altered freshwater ecosystems). In these countries, water related health risks have largely been overcome and in general terms societies are sufficiently prosperous to be able to choose between a range of options on how to manage freshwater ecosystems. In the developing world, for many people environmental security is greatly undermined by water scarcity, the continued lack of safe water and sanitation and the consequent prevalence of water related diseases.

4. Scenarios: assessment of long-range patterns and problems

Man…perfects, corrects and improves the works of lower nature. Therefore the power of man is similar to that of divine nature…. How wonderful is the cultivation of soil all over the Earth, how marvellous the construction of buildings and cities, how skillful the control of waterways (Medieval humanist, Ficino, cited in Sale, 1992)

4.1 The scenario approach

The future state of freshwater ecosystems on this planet is dependent to a large extent on the way humankind opts to manage them. Decisions related to the management of freshwater ecosystems should not be implemented on the basis of trial and error, but require a thorough review of the prospective effects. The long-term consequences and the total outcome on both the environment and society must be determined. However, the complexity of the interplay between human activities and freshwater ecosystems means the future of these systems is inherently unpredictable. Three types of indeterminacy can be identified:

X insufficient information on present conditions i.e. the state of systems and the forces governing their dynamics

X even if precise information were available, complex systems are known to exhibit chaotic behaviour - extreme sensitivity to initial conditions and branching behaviours at various thresholds which thwart prediction

X human freewill ensures that the future is unknowable.

While we cannot forecast the future accurately, we can use scenarios to present plausible futures; the scenarios are what if propositions. Applied to long range resources assessments scenarios draw upon both science (i.e. our understanding of historical patterns, current conditions and physical and social processes) and the imagination to conceive and evaluate a range of alternative pathways. In so doing, scenarios can illuminate the relationships within the total system and the relationship between human actions and the whole complex of interconnected outcomes. It is this added insight, leading to more informed and rational decision-making that is the primary objective of scenarios.

A water scenario has to include assumptions about many interacting elements: population and demographic patterns, life-styles and consumption patterns, economic scale and structure, technology and efficiency, policies and institutions. Three scenarios, developed, in draft form, by the World Water Council's Scenario Development Panel are presented. These scenarios, up to 2025, are:

Conventional water world: in which it is assumed that economic growth, technological advances and demographic trends continue as at present so that although the regional water resource pressure increase and environmental security is reduced in some regions, a global water crisis is averted .

Water crisis: in which it is assumed that there is less dissemination of new technologies, slower economic growth and a failure to adopt water strategies resulting in increased water scarcity and a catastrophic reduction in environmental security in many regions.

Sustainable water world: in which it is assumed that water-related objectives and targets are given higher priority than at present and are widely adopted resulting in increased environmental security world-wide.

In this paper the key elements of the scenarios are presented, with some additional information taken from other sources. The emphasis is on the technical issues relating to each scenario.

4.2 Conventional water world

The principal aspects of this scenario can be summarised as follows:

X Resource intensive consumption patterns of developed countries continue unchecked
X World-wide population levels continue to rise, particularly in developing countries
X Continued economic and social inequity between countries of the developed and developing world
X Developing countries continue to try and switch from agrarian to industrial society
X Populations are increasingly urbanised
X Progressive globalisation of culture and commerce
X Gradual convergence of developing and industrial economies
X Climate change

4.2.1 Consequences for freshwater ecosystems and environmental security

Changes in land-use increasingly affect water resources, particularly as a result of deforestation in moist tropical areas and grazing that has increased in arid areas. In developed countries problems with toxic (micro-organic) pollutants and new strains of water-borne viruses in surface and groundwater become increasingly problematic. In the developing countries problems of access to safe drinking water and adequate sanitation continue to pose the most significant risk to environmental security.

The integrity and resilience of freshwater ecosystems continues to be degraded as a consequence of encroaching human settlement and pollution. Nonetheless, water-related diseases are kept at the same percentage levels that exist at present through some improved sanitation and water management. The death toll of curable water-related diseases such as diarrhoea, particularly among children, remains high. There have been no major widespread and dramatic epidemics of cholera or typhoid, but the chronic impact of low water quality remains a major health problem in developing countries.

The conversion of wetlands into arable land and residential areas has slowed, but not halted, except in some developed countries where the public outcry over the last remaining wetlands has led to costly actions to protect and even recreate small areas. In developing countries water-based tourism remains economically important in some areas, but others have over-exploited their resources and seen their tourism revenues decline.

There has been an increase of water use by agriculture because of an expansion of irrigated land. It is estimated that 60% of all food will be produced by irrigation in 2025 (Lanz, 1995). Water use efficiency has increased, because of increased application of more efficient irrigation systems as well as the development of less water demanding crops. However, these gains only partly offset the increases in water withdrawals for irrigated lands. A slight shift from irrigated to rain-fed agriculture has occurred because the increase in yield of rain-fed agriculture grows faster than that of irrigated crops. This reduces the rate of water use for agriculture because irrigated lands, while accounting for an important fraction of agricultural production, represent a relatively small amount of total agricultural land in terms of area.

By 2025, world-wide water withdrawals reach 5187 $km^3\ y^{-1}$ and of this 2879 $km^3\ y^{-1}$ are consumed. Groundwater levels in many renewable aquifers gradually fall because withdrawal exceeds recharge. Increased technological efficiencies and improved management prevent dramatic water crises. However, continued water degradation and increased costs of new water supplies make the global situation less resilient and more vulnerable to crises.

Humankind takes for direct use an even greater share of the limited renewable fresh water than today. This water can only be obtained at an increasing financial and ecological price. This results in increased stress on water resources, human health and ecosystems. The problems impacting on freshwater ecosystems are the same as today, but increased in number and consequences at the global scale. There are continued socio-economic problems due to persistence of poverty, failure to achieve global equity and increase in conflict over scarce water resources. Thus there is a net reduction in environmental security, particularly in developing countries.

4.3 Water Crisis

Until 2015 this scenario follows a similar pattern to that of the conventional scenario (section 4.2) except that overall global economic growth is slower and capital flows away from some parts of the developing world. After 2015 this results in a significantly worse water situation. The principal aspects of the scenario are as follows:

X Income inequality between the rich and poor countries increases and both relative and absolute levels of poverty rise
X Economic globalisation has expanded the economy but various types of trade conflicts have reduced the overall rate of growth
X Global co-operation is undermined by the scarcity of water
X Many technological developments are applied in some parts of the world, but not others, thereby increasing inequities
X Global food production and trading systems are becoming vulnerable to disruption
X International and national equity have decreased significantly with related social tension and pressures for migration
X Water withdrawals have continued to grow without the efficiencies expected from improved water resources management, resulting in acute water stress in many countries
X Little progress has been made to solving current critical water problems, other than locally at a small scale
X The resilience of natural and social systems is eroded to such an extent that climate change causes large scale ecological collapse

4.3.1 Consequences for freshwater ecosystems and environmental security

Despite their diversity, the events unfolding in this scenario have one thing in common; they all contribute to the general erosion of resilience in both human societies and the natural and ecological realms. The result is environmental degradation leading to critical resource scarcity and human catastrophes that in turn effect global economic processes, creating a downward spiral of reducing global security.

Water scarcity combined with the need for irrigation and economic development, particularly in Africa, India and China resulted in exceedance of the ecological thresholds required to protect ecosystems. This generates widespread degradation of freshwater ecosystems. With ecological resilience lost in those areas, some of the effects have global implications. Episodes of large scale ecological collapse, involving conversion of forests to agricultural land to dustbowls or wastelands, eutrophication of inland freshwater bodies, collapses of freshwater fisheries and increased catastrophic floods triggered by loss of ecological regulation at the catchment level occur frequently.

Water resource systems do not collapse globally, but major catchments and socio-economic regions are affected. International conflicts over shared water resources occur with increasing frequency. Water use efficiency decreases as investment and maintenance decline. The price of water increases. Increasingly developed countries and corporate alliances look towards water-surplus areas such as the Congo and Amazon basins to grow their food and spare their water reserves for industrial and domestic use. However, this has devastating consequences for the ecosystems of these areas. Environmental security is severely compromised, world-wide.

4.4 Sustainable water world

The principal aspects of this scenario can be summarised as follows:

X The rate of growth in the human population is decreasing and it is forecast that it will stabilise e.g. at 10 billion) by 2070
X An international consensus is achieved on the principles that should govern utilisation of natural resources
X Methods of resource evaluation have been developed and introduced - water is correctly valued and benefits provided by ecosystems understood as a consequence of research
X Basic human needs for water have been identified. Significant advances have been made in providing access to water for drinking, sanitation and food preparation throughout the developing world
X Domestic water use in the developed world is more efficient and equitable as a consequence of technological advances and re-use of wastewater for non-potable uses.
X Solar desalination is widespread
X National and international actions to protect ecosystems have been established. These include comprehensive minimum environmental water commitments and international agreements on species protection and management. All international aid and development projects include explicit ecosystem protection and management components. Basic ecosystem water needs are identified.
X Water-related conflicts resolved through negotiations. Formal agreements/treaties are signed for all the worlds major river systems, including shared responsibility for environmental and ecological protection
X Increased irrigation efficiency is obtained through adoption of modern technology (e.g. sprinklers, drip irrigation, sensor and computer technology).
X Climate change cannot be prevented but management policies are flexible and adaptable enough to cope with changes that are occurring

4.4.1 Consequences for freshwater ecosystems and environmental security

As a consequence of social, economic and technological changes, water withdrawals are stabilised at a sustainable level. Technological innovation increasingly concentrates on biosystems, harnessing the potential of ecosystems to produce resources necessary for life at low energy intensity and high material efficiency.

Ecosystem restoration and rehabilitation becomes a leading sector of the economy. As a result environmental quality improves. While not all ecosystems can be recuperated, many new, sustainable and productive ecosystems evolve. Freshwater ecosystems are managed in a sustainable manner and to the benefit of humankind as well as other flora and fauna. Environmental security is significantly increased.

4.5 Synthesis: future water security

The foundation of the three scenarios described is the Conventional Water World, which has as its basis current trends and practices. The driving forces of the Conventional Water World then diverge at some point to produce either the Water Crisis or the Sustainable Water World.

Human intervention affects the state of freshwater ecosystems, and the services provided to human society, through the feedback mechanisms illustrated in Figure 7. Over the long-term these may be either negative (i.e. increased degradation of ecosystems so that there is a net reduction in benefits) or positive (i.e. reduced degradation and a net increase in benefits), depending on the nature of the intervention.

As discussed in section 3.2, the underlying reasons why the Conventional Water World results in a net decrease in environmental security, are primarily a consequence of: i) socio-economic insecurity outweighing the need to maintain environmental security; ii) ill-informed decision making and iii) an inappropriate emphasis on technological solutions. If a Sustainable Water World is to be achieved, significant changes must be made in the way that humankind manages and utilises freshwater ecosystems. Many people argue, that if drastic decreases in environmental security are to be avoided, changes must be implemented soon (e.g. Falkenmark and Lundqvist, 1998).

The interaction of humankind with freshwater ecosystems is complex. Successful management must incorporate all social, economic and environmental elements in an integrated approach aimed at attaining specific goals. These goals should be targeted at increasing environmental security by building resilience in both social and environmental systems so that future change (e.g. arising from climate change) does not have detrimental impacts on either ecological integrity or human security. Consequently management strategies must be holistic in nature and adaptable. It is important to note that requirements for improving environmental security vary from place to place; there are no simple recipe–book solutions.

To a large extent social and economic interventions influence the global driving forces to a much greater extent than technical interventions. Nevertheless, at the catchment scale, technical intervention in conjunction with appropriate social and economic strategies can significantly alter the impact of human interventions on ecosystem integrity and hence environmental security. It is beyond the scope of this paper to describe the social and economic interventions in detail, but these are discussed in the other two papers in this series (Swanson and Doble, 1999; Soussan *et al*., 1999). In the following section, technical approaches and technological options that may be incorporated in the future management of freshwater ecosystems and that will assist in approaching a sustainable water world are discussed.

5. Future Strategies

The need for integrated, basinwide, water resource management is considered a prime security objective for the prospects of …… regional co-operation (SIDA, 1995)

Freshwater ecosystems are changed as a consequence of land conversion, agriculture, pollution, major engineering schemes and urban development. As discussed above, these changes may alter ecosystems to the extent that benefits accrued to society from the natural functions and attributes of an ecosystem are lost. As such human-induced changes can represent threats to environmental security. In this context a degraded ecosystem is one which has lost some or all of its direct or indirect value to human society

Although there remains much debate about the best approach to reduce the impact of human intervention on freshwater ecosystems there is growing recognition, at the highest political level, that wide ranging and integrated strategies are required to resolve complex problems (section 1). In this section the role of ecosystem management as a conceptual framework on which to base future management of freshwater ecosystems is discussed. We argue that although it provides a useful water "ethic" ecosystem management is poorly defined and so does not provide a rational basis for environmental and natural resource policies. The concept of integrated catchment management (ICM) is conceived as a practical framework for implementing ecosystem management because catchments provide an appropriate physical context in which to apply resource planning.

Mitigation and adaptation strategies are conceived as components of ICM that seek to alleviate the negative impacts of human intervention in freshwater ecosystems on environmental security. For the purpose of this paper these strategies are defined as follows:

- Mitigation strategies are strategies that are intended to significantly reduce or eliminate defined threats or sources of degradation. In terms of the conceptual model described in section 3.1 approaches which successfully mitigate human-induced change in freshwater ecosystems are those which break the link between the driving forces and the resulting pressure on the ecosystem. This can be achieved either by dealing with the driving force directly (e.g. reduction in population growth by stricter birth control) or by altering the anthropogenic response to the driving force (e.g. reduction in per capita water consumption through demand management).

- Adaptation strategies are strategies that seek to regain ecological services that have been lost as a consequence of human-induced change in an ecosystem. In terms of the conceptual model of environmental security described in section 3.1, strategies which alleviate the impacts of changes to freshwater ecosystems, are conceptualised as those which break the link between pressures on the ecosystem and its state or, alternatively, break the link between the state of the ecosystem and the consequent impact on environmental security. In terms of Figure 6 this can be visualised as moving back towards the benefit peak from a position on the recession limb of the total benefits curve.

Within this paper the emphasis is on technical aspects of mitigation and adaptation within the context of ICM. Although social-economic interventions are mentioned these are dealt with in more detail in the other two papers of this series (Swanson and Doble, 1999; Soussan *et al*., 1999). It is important to recognise that the separation between mitigation and adaptation is somewhat arbitrary because, within the context of ICM, many technical interventions can be classified as either, or indeed both, depending on the specific circumstances in which they are applied.

5.1 Concepts

5.1.1 Ecosystem management

Ecosystem management is proposed by advocates as the modern and preferred way of managing natural systems. It is offered as a management approach that will protect the environment, maintain ecosystem functions, preserve biodiversity and ensure sustainable development (e.g. Norton, 1992). The basic idea is that resource and landscape management is tailored to landscape conditions, processes and potential so that desired features and processes of ecosystems are maintained and human needs are met in an optimal and sustainable way (Pirot and Meynell, 1998). This involves defining, on the basis of sound scientific evidence, the intrinsic capabilities and limitations of ecosystems to support, over the long-term, a particular suite of human activities.

Others (e.g. Fitzsimmons, 1996) see the concept of ecosystem management as flawed because, despite the widespread acceptance of the general ideals, the concept remains full of ambiguity and at present there is no operational framework for integrating technical analysis into land use and natural resource decision making. However, although these criticisms are valid, it remains the case that something like ecosystem management is needed to address the environmental and social problems arising from the exploitation-focused, and single resource approach to management that has generally been applied in the past. There is a critical need to decide the role of science in policy-making and resource management.

It is beyond the scope of this document to analyse in detail the many issues raised by the concept of ecosystem management and discussed interminably in recent scientific literature. However, Table 11 summarises seven key principles of ecosystem management and comments on each in relation to the management of freshwater ecosystems. Here, we simply note the following:

X It is self-evident that water-dependent ecosystems rely on water for their existence and functions and so provision of water is needed for their services to the environment and people.

X Land and water resources are linked so it is essential that they are managed in an integrated manner.

X Although there are limitations, nevertheless, catchments provide the most obvious physical entity on which to base management of natural resources, particularly freshwater (section 5.1.2).

X Heavily modified ecosystems can be sustainable over the long-term, in that the transformed systems can continue to be productive indefinitely, providing that appropriate management systems are established.

X Ecosystem management should seek to maximise the benefits to human society to be obtained from both the natural and non-natural services provided by any particular ecosystem (Figure 6).

X To be successful management practices must be based on knowledge of ecosystems and an understanding of social mechanisms. There is a need to develop methods that link the two directly.

X Local and traditional knowledge can be of immense value as a basis for designing and implementing management plans.

X Management should promote resilience within freshwater ecosystems on a long-term basis and should be adaptable so that future changes in societal preference can be accommodated (Berkes *et al.*, 1998). This has to be achieved by adoption of a variety of physical, social and economic policies and techniques, all aimed at minimising the adverse consequences of development.

X Water allocation needs to be based on participation and joint decisions of all stakeholders.

X At present the developed world=s preference is seemingly paradoxical: wanting the benefits and affluence obtained through extreme modification of ecosystems but at the same time placing high value on the non-consumptive elements of ecosystems such as pristineness.

Table 11: *Core principles in the management of ecosystems* (adapted from Lackey, 1998)

Core principles underpinning ecosystem management	In the context of freshwater ecosystem management
Ecosystem management reflects a stage in the continuing evolution of social values and priorities; it is neither a beginning nor an end	Ecosystem management requires the definition of a goal and the design of a strategy to implement a mix of decisions to reach the goal. However, since society=s values and priorities constantly change in ways that are not foreseeable it is essential to develop strategies that are flexible and adaptable.
Ecosystem management is place-based and the boundaries of the place must be clearly and formally defined	Watersheds are the obvious geomorphologic units on which to base management decisions related to freshwater. They can provide an analytical framework for gathering and interpreting environmental information at appropriate scales. However, it must be remembered that decisions to maximise the benefits in managing a 1000 ha catchment nested within a much larger watershed may well be very different than decisions for the same smaller catchment that were designed to maximise benefits over the entire catchment. Protection of ecosystem services downstream may involve constraints on upstream water-use and land-management.
Ecosystem management should maintain ecosystems in the appropriate condition to achieve desired social benefits	There is no baseline state against which to determine the condition of natural freshwater ecosystems. The debate is really over determining desired state; something that must be defined by society not scientists.
Ecosystem management should take advantage of the ability of ecosystems to respond to a variety of stressors, natural and man-made, but all ecosystems have a limited ability to accommodate stressors and maintain a desired state	The key to successful freshwater ecosystem management is to balance ecosystem robustness (i.e. the ability to respond to stress) against human-induced alterations to the ecosystem so that the ecosystem is not altered beyond its ability to provide those benefits.
Ecosystem management may or may not result in emphasis on biological diversity	Like any other attribute of freshwater ecosystems the value of biological diversity to society must be based on society=s preferences. In many instances ecosystem functions can be maintained with reduced numbers of species. Hence, as a characteristic of ecosystems, biological diversity may operate as an ecological constraint on utilisation, not as a benefit, in the short-term but maybe a societal preference in the long-term.
The term sustainability, if used at all in ecosystem management should be clearly defined – specifically, the time frame of concern, the benefits and costs of concern, and the relative priority of the benefits and costs	In management of freshwater ecosystems the following questions must be answered: - what is to be sustained (e.g. water, functions, attributes) ? - over what time frame is sustainability to be measured ? - what is the scale of sustainability (e.g. a small catchment, a region or a country) ?
Scientific information is important for effective ecosystem management, but is only one element in a decision-making process that is fundamentally one of public and private choice	Scientific understanding is essential for ecosystem management. However, such information often makes decision-making harder rather than easier. In deciding on how best to utilise ecosystems it is necessary to appraise social and economic concerns within an overall context of seeking to increase total human security.

5.1.2 Integrated Catchment Management

The concept of Integrated Catchment Management (ICM) recognises that successful natural resource management requires a holistic approach that integrates both land and water-use as well as technical and non-technical human interventions. The key tenet of the approach is that water catchments represent the most appropriate physical entity on which to base water management policy. The term is often used interchangeably with similar terms including integrated water resources management, integrated watershed management and total catchment management. It can be defined as:

> *The co-ordinated planning and management of the water resources of a river basin considering its interaction with land and other environmental resources for their equitable, efficient and sustainable use at a range of scales from local to catchment level.* (DFID, 1997).

ICM programmes comprise an overall strategy that clearly defines the management objectives, a range of delivery mechanisms that enable these objectives to be achieved and a monitoring schedule that evaluates the programme performance. Mechanisms and policies are established that enable long-term support to programmes of environmental recovery (Box 8).

The objective of ICM can be summarised as increasing environmental security through the following:

- In the short term, to prevent further environmental degradation and, in the longer term, restore degraded resources.
- Promote sustainable agricultural, forestry, fisheries, industrial and urban development
- Ensure appropriate resource use planning and management
- Ensure a long-term viable economic future for basin dependants
- Safeguard self-maintaining populations of native species
- Preserve cultural heritage
- Maintain the tourism potential and develop linkages between tourism and conservation

ICM strategies recognise that:

- Decisions need to be formulated in the context of a broad strategy that takes the long-term view, incorporates assumptions about the actions and reactions of all participants in water management, and fully considers the ecosystems and socio-economic structures that exist in an entire river basin.
- Solutions need to focus on underlying causes not merely their symptoms.
- Issues must be approached in an integrated way
- In general, development of sound resource management and collective responsibility for resources will take place at the sub-regional or village level
- There is potential for multiple reuse of water within catchments and that some water that is lost at the household or field level may be reused.
- Protection of ecosystem services downstream in rivers may involve constraints on upstream water-use both in terms of quantity and quality

Box 8: The Murray Darling Basin Initiative: the Worlds largest catchment management programme

The Murray Darling catchment covers more than one million square kilometres, one sixth of Australia and includes 24 major rivers. Salinity is a natural feature of the catchment. The problem is that changes in land use and water use have intensified this aspect of the catchment resulting in conflict with human and environmental needs. Removal of natural vegetation has altered the water balance of the land so that watertables have been rising, leading over time to salinisation of the soil. Saline inflows in turn impact on river water quality with salinity endangering important aquatic and riparian ecosystems as well as threatening domestic water supplies for the city of Adelaide and much of South Australia.

In recognition of this, and other problems in the catchment, the Murray Darling Basin (MDB) Initiative was established in 1987. The Natural Resources Management Strategy that deals with the management of the riverine environment, management of irrigated and dryland regions and basin-wide issues, underpins the MDB Initiative. The riverine environment sub-programme covers three broad areas: improvements to water quality; river flows with respect to balancing human and environmental needs and nature conservation. A salinity and drainage strategy has been for irrigated regions. Through this strategy:

- Improved land management techniques are being introduced to minimise the amount of irrigation water being added to the watertable. Through the use of new crops and more efficient irrigation technology this will encourage the use of land within its sustainable capacity.

- Engineering works are being constructed to intercept highly saline groundwater and pump it to suitable disposal sites before it flows into the main river system

- New operating rules have been introduced to reduce evaporation losses from reservoirs.

In addition the MDB Initiative recognises the role of wetlands in enhancing river water quality and the Floodplain Wetland Management Strategy has been developed. This aims to maintain and where possible enhance the floodplain wetland ecosystems. Constructed wetlands are being specifically designed to reduce nutrient loads from farm runoff, sewage treatment and industrial plants and urban runoff.

Throughout Australia, ICM and the Landcare system have encouraged farmers and other rural industries to work together with government and rural communities to solve a wide range of rural problems (Campbell, 1994a). The Landcare system combines elements of community and environmental education, action research and participatory planning. More than 2000 voluntary Landcare community groups are currently working to develop more sustainable systems of land and water use supported by a national 10-year funding program.

To be successful ICM requires basic understanding about biological, physical, chemical and socio-economic systems and how they interact within a catchment. There is therefore a need for inputs from a wide range of different professions. Much can be learnt about the success and failure of different management interventions from previous experience. By collating and analysing this experience it is possible to synthesise current "best practise" in the form of guidelines. For example, in the UK a framework has been drawn up to support the sustainable management of groundwater source abstractions. This provides a practical basis for strategic water resource planning (Acreman and Adams, 1998). Similarly, the Economic and Social Commission for Asia and the Pacific have developed guidelines for land-use planning and practices in watershed management and disaster reduction (UN, 1997). As noted in section 3.3.2, the World Commission on Dams, established in 1997, is presently assessing the experience with existing, new and proposed large dam projects in order to evaluate the development effectiveness of large dams. The development of such guidelines can highlight where absence of data or lack of knowledge requires further environmental monitoring or research respectively.

In recent years a range of technical tools have been developed to assist with ICM (Table 12). As noted above, key aspects of ICM are both to mitigate against change but also to adapt to inevitable change in freshwater ecosystems. These elements of ICM are discussed in the next two sections.

Table 12: *Tools for use in Integrated Catchment Management*

Tool	Description
Integrated water resource simulation models (IWRSM)	Computer models that enable water resource issues to be investigated in an integrated manner. Include modules for simulating all aspects of the hydrology and water resource utilisation of a basin, including water quantity, water quality, hydro-ecology. Ability to model sub-catchments at a variety of scales spatially and temporally.
Geographical Information Systems (GIS)	Organised collections of software and geographic data (temporal and spatial) designed to efficiently capture, store, update, manipulate, analyse and display all forms of geographic data.
Habitat models	Computer models that predict the change in habitat availability for key target species given changes in river flow, channel morphology, water quality and substrate. Can be used to assist in setting river flow objectives
Decision Support Systems (DSS)	Similar to IWRSM, DSS allow decision-makers to combine personal judgement with computer output in a user-machine interface. Combine quantitative models and database elements for problem solving and it is claimed provide a comprehensive framework to balance water allocation between competing demands (Simonovic, 1996)

5.2 Responses to mitigate threats to freshwater ecosystems and environmental security

Two broad types of mitigation strategy are recognised. Remedial actions are those which try to prevent degradation at the end of the line (e.g. by removal of pollutants at a treatment plant). Preventative actions are those which attempt to remove the cause of the problem (e.g. reduce the amount of chemicals used by farmers). Technology has a role to play in both approaches. It can help to increase the efficiency of use of resources; delivering equivalent or improved services while substantially reducing environmental burdens.

5.2.1 Mitigation measures that impact on water quantity

Although renewable, it is now recognised that freshwater is a finite resource. Heavy water consumption frequently leads to environmentally disruptive decreases in the level of water in many freshwater ecosystems (Box 7). Only if human demands for direct utilisation of water can be restricted or alternative water resources can be found will more water become available for those freshwater ecosystems presently being degraded as a consequence of human abstraction.

Demand Management

Demand management refers to actions for affecting the ways in which water is used. Demand management seeks to improve the efficiency of the direct use of water by people. It is increasingly coming on the agenda in regions where concerns have arisen over water sufficiency, allocation, high costs of expanding supplies and environmental preservation.

World-wide, irrigated agriculture is by far the greatest direct consumer of water (section 2.3). It is also the least efficient. Traditional surface irrigation generally achieves 40% efficiency. Modern technology can improve efficiency by improving the timing of delivery of water and by cutting the amount of water applied. Automated methods that measure soil water directly and so ensure water is applied only when crops are stressed are now available. Sprinkler irrigation can be 70 to 80% efficient and drip irrigation can reach over 90% efficiency (Wolff and Stein, 1998). These methods are expensive and require significant maintenance. Consequently they are inappropriate for many regions in developing countries. However, for subsistence agriculture, simple methods based on subsurface or pitcher irrigation have been developed (Batchelor, 1996).

Water supply and sanitation systems in many urban areas are characterised by high leakage and low efficiencies. A great deal of water is not returned directly (treated or untreated) to the source from which it was withdrawn. In some communities water these losses can reach 40-60%. In contrast in modern cities with centralised water pipeline systems and relatively new sewage systems consumption does not usually exceed 5-10% (Shiklomanov, 1997). These figures demonstrate that actions to improve operational efficiency and reduce leaks could make a significant impact on water demand in urban areas.

An idea closely associated with efficiency of water use is the notion of efficiency of allocation. This is the idea that water should be allocated to those sectors from which the greatest economic returns are obtained. This is strictly an economic evaluation and is discussed in more detail in the paper on economic security (Swanson and Doble, 1999).

Water recycling

Recycling refers to the capture and reuse of water prior to ejecting wastewater to ground or surface water receptors. Hence, recycling reduces water withdrawal requirements for a given set of final uses. For example, end-use water requirements for an industrial process may be met totally by withdrawals in a once-through processes, or by lower levels of withdrawals in combination with internal recycling which captures and reuses waste water. Similar considerations apply in the capture and reuse of water in municipal and irrigation systems.

Domestic wastewater has been used in irrigation for over a century in some countries, including Germany. Prudent management can considerably reduce health risks. At present some 5000 km^2 0.2 % of the world=s irrigated farmland is watered using wastewater. Although it is probable that this figure will increase in future, it is unlikely that it will increase above 1% of the total irrigated surface area (Wolff and Stein, 1998).

Not all industrial and domestic processes require water to be of potable standard. For example, there is no reason why water used for toilet flushing needs to be of the same quality as drinking water. The use of recycled grey water (i.e. wastewater that is not sewage) for non-potable uses is becoming increasingly common. For example, in California there are about 380 schemes and a state ordinance requires that all large new buildings include dual plumbing (Surendran and Wheatley, 1998). The re-use of sewage is also being investigated. In a new housing development in Sydney tertiary-treated and disinfected sewage effluent has been connected to toilets and external taps (Mills and Asano, 1996).

Desalination

The production of new freshwater by desalinating sea water has attracted much attention in recent years. In Kuwait desalination (six desalination plants with maximum capacity of 950 000 m^3d^{-1}) is the primary source of freshwater for drinking and domestic purposes. The quantity of desalinated water produced in Kuwait in

1993 was 231 million m^3 (Green Cross, International, 1998). In Morocco a 10 MW nuclear power station is being built to provide electricity for a desalination plant that will provide water for 70,000 people (George, 1999).

However, at present only 0.1 % of human water-use is supplied by desalination. This is because it is energy-intensive and hence expensive. The theoretical minimum energy requirement to remove salt from water is 2.8 million joules per cubic metre, but even the best desalination plants now operating use 30 times this amount (Postel *et al*., 1996). Nevertheless, in recent years technological advances have caused a significant decline in the costs of desalination. For new plants the cost is about US$ 1 m^{-3}. In California, new plants have become operational to desalinate brackish water at a cost of US$ 0.5 m^{-3}. It is anticipated that improved technologies in future (e.g. improved exploitation of solar energy) could reduce the costs to the extent that desalination becomes a relatively small component of the overall cost of urban water supply and sanitation. However, it is unlikely that desalinated water will be used extensively for irrigation in the near future.

Water harvesting

Water harvesting is the direct capture of rainfall or collection of surface runoff to use as drinking water and to water crops and livestock. In some circumstances traditional methods of harvesting water may present opportunities for relieving water shortages in arid areas. Techniques include:

Xthe capture of rainfall draining from the roofs of buildings;
Xtanks to capture surface runoff;
Xlow earth embankments built across drainage channels to divert runoff onto fields;
Xbunds constructed on fields to promote the infiltration of surface runoff.

Such practices generally do enhance the efficiency with which precipitation is used. However, whether water harvesting measures improve the efficiency of water use in a catchment area as a whole depends on local conditions. For example, too much water retention in the upper part of a catchment can reduce the water yield lower in the catchment creating the risk of water shortages for users downstream (Hollis, 1986).

5.2.2 Mitigation measures that impact on water quality

Human induced changes in the quality of freshwater can have very large impact on environmental security. For example, disposal of industrial wastewater and untreated sewage in the Indian city of Ludhiana has contaminated wells with chromium and cyanide and so jeopardised future development of groundwater, the only source of drinking water for the city (Singh, 1998). Contamination of water can also have very serious consequences for freshwater biota. There are various mitigation measures that improve water quality.

Wastewater treatment

Treatment of wastewater is an end-of-pipe solution to the problem of contaminated water. As mentioned in section 3.5.3 dramatic increases in environmental security were obtained in the developed world in the 1800s through the introduction of treatment of industrial and municipal effluent. New technologies, such as ultra-violet treatment, have been developed to improve the quality of effluents discharged to freshwater ecosystems.

In recent years the use of wetlands to passively treat polluted discharges has been widely proposed, and in places attempted. In the USA 300 man-made wetlands treat polluted mine discharges and the approach is becoming increasingly used in Europe. In the UK eight systems have been installed. These wetlands are designed to mimic the waste assimilation and self-purification functions of natural wetlands. Such wetlands are ideal in situations where chemical treatment of diffuse source pollutants is very expensive. Presently the wetlands are designed for function rather than form, but it is hoped that in future it will be possible to integrate them as far as possible into the natural ecological systems of catchments (Younger *et al*., 1998).

Watershed and groundwater resource protection

Production of potable water depends on three things: watershed protection, filtration and disinfection. In the past watershed protection, which attempts to keep pathogens and pollutants from entering the water, rather than killing or removing those that do, has received scant attention. Instead as new threats emerged, engineering solutions were introduced. New technologies - such as airstripping to remove volatile organic pollutants from groundwater, activated carbon filtration and ozone disinfection - were devised. However such treatments are very expensive and watershed protection is proposed as non-engineering alternative in some cases (Box 9).

The principle is that potentially polluting activities are prohibited or restricted in water source areas. In Europe and the USA the source protection zones may be complex and relatively large. They are often divided into two or three sub-zones and the most severe restrictions applied only close to the source. Strips of vegetation along streams and around reservoirs are also important buffers in both urban and rural settings. These buffer zones demonstrably lessen the amount of pollution entering the water system. Similarly, protection around individual wells may be used to protect water abstraction points.

In developing countries community water supplies in rural areas are rarely treated but sloping concrete aprons around wellheads to prevent spilled water leaking back into the well and the prohibition of animals from the area immediately around a water source can significantly reduce the risk of pollution. A circular protection zone of 50-100 m in radius can be introduced to reduce the risk of pathogenic contamination. Within this zone pit latrines, septic tanks and other potential sources of contamination are not allowed.

Box 9: Watershed protection in New York (source: The Trust for Public Land, 1997)

New York City has set aside US$250 - 300 million for land acquisition as part of an integrated strategy to protect water supplies from pollution. The intention is to purchase some 80 000 acres of the land, more if necessary, in order to protect water sources. Watershed regulations are also being expanded to address things like the construction of roads and parking lots - impervious surfaces – close to reservoirs and watercourses; storm-water runoff; the unprotected storage of highway salt; and rigorous standards for sewage handling. Special attention is being given to septic systems of which there are 130,000 in New York's watershed. Many of these will be closed and strict standards set for the construction of new ones. Homes and businesses will be connected to newly constructed, city subsidised tertiary treatment plants. Total investment in the strategy is US$1.5 billion. However, by protecting the water sources that supply New York from pollution, the city is able to avoid constructing a water filtration plant that would cost US$ 6 - 8 billion and would incur annual operating costs of $300 million.

5.2.3 Habitat Protection

As demonstrated in section 5.2.2 protected areas can play a central role in developing strategies of water management. People can benefit directly from the protection of downstream areas as well as catchment headwaters. For instance, the protection of downstream ecosystems may conserve critical fisheries, floodplain forests or pasture. Moreover, the idea of protecting natural ecosystems for no other reason than that they exist is becoming an increasingly popular societal preference in developed countries. Studies have shown that people in these countries are willing to pay simply to know that such places exist, even if they will never visit them and they gain no direct benefits from them (Barbier *et al.*, 1997). This suggests that once a certain level of social and economic security is attained people seek ethical security through the protection of near pristine environments.

Frissell and Bayles (1996) propose the establishment of watershed reserves. They argue that these reserves should constitute a network of the best-remaining examples of relatively unaltered ecosystems and aquatic communities. In extensively altered landscapes they suggest that these would need to be supplemented or replaced by the least-disrupted ecosystems that retain much of their ecological value and hold good promise for relatively rapid and cost efficient restoration. Such a reserve network would ideally encompass a regionally representative range of terrestrial and aquatic ecosystem types and natural successional conditions, and incorporate areas that have especially high ecological integrity or natural diversity, high incidence of rare or seriously declining aquatic and riparian species and assemblages, and relatively unimpaired natural-historical catchment-wide biophysical processes and disturbance regimes". They propose that the network would provide a fall-back position against uncertainties about the success of future management manipulations of ecosystems that are bound to have unanticipated and unforeseeable consequences. The reserves would serve this purpose in four ways. First, they would ensure that the same mistakes would not be made everywhere. Second, they would provide necessary and appropriately-scaled scientific controls against which the ecosystem management strategies might be assessed. Third, if selected as described above, they would represent the areas where the greatest share of biotic resources can be protected with limited resources. Finally, they would provide the best possible living models for the development of truly restorative ecosystem management on severely altered parts of the landscape.

5.3 Responses to adapt to changes in freshwater ecosystems and environmental security

ICM is supposed to be flexible and adaptive management approach. The need for development is recognised and so adaptation strategies are a key element of ICM. The principle of "no net loss" is one that may in future become increasingly called upon when assessing development strategies. The principle stipulates the need for compensation for loss of ecosystems through measures to create, restore or improve a similar nearby area if a freshwater ecosystem is degraded or destroyed as a consequence of development. It is often a costly option and at present is only applicable to certain forms of freshwater ecosystem.

In this section the restoration of ecological services in altered systems and the idea of utilising biotechnology to adapt to changes in freshwater ecosystems are discussed.

5.3.1 Restoration of ecological services

Altering operation and decommissioning dams

Reservoirs, if properly managed, meet one of the key requirements for environmental security, namely long-term sustainability. The water can be used only once and it is then necessary to wait for the next season's rainfall before refilling, thus it cannot be over exploited. However, as discussed in section 3.3.2 dams do have negative environmental consequences. They drown the river upstream of the dam and they replace the natural cycle of floods and low flows with a more constant flow related to downstream supply requirements and electricity demand. These changes, in addition to destroying wildlife habitat can have serious implications for the environmental security of people living in the catchment.

However, setting aside some reservoir volume to mimic critical environmental flows can in part reduce the negative aspects of dams. For example, it is now common practise to stipulate minimum compensation flows in rivers in order to maintain dry season baseflows and the idea of releasing artificial flood flows (sometimes termed freshets) to inundate floodplains at critical times of year is becoming more widely promoted (Acreman, 1996). For example, on the Kafue River, control rules for the operation of the Itezhi-tezhi dam stipulate that a minimum flow of $25m^3s^{-1}$ must be maintained all year and a release of 300 m^3s^{-1} must released for 4 week period in March each year in order to flood the ecologically important Kafue Flats.

It is also possible for management strategies to be introduced to compensate for the truncation of sediment transport. For example, on the upper Rhine, gravel is added to the channel to compensate for reduced sediment transport arising as a consequence of upstream impoundments. This intention is to reduce bed degradation and maintain groundwater levels (Dister *et al.*, 1990 - cited in Ward and Stanford, 1995). To be successful the preservation of freshwater ecosystems must be given high priority within whatever management strategy is adopted or else when water is scarce, dam operators will tend to use the water in ways which do not protect the downstream ecosystems.

An alternative to operation of dams to preserve downstream ecological functions, and one which is increasingly being considered in the USA and Europe, is the decommissioning of dams. In 1997 the US federal government refused to relicense an existing dam for the first time ever. The reasons given were that the benefits to be obtained by removal outweighed those that accrued from continued presence of the structure (Box 10). It is important to note that decommissioning dams can itself cause environmental problems. For instance the washing of sediments previously stored behind the dam into the river may cover fish spawning areas, damage river habitats (particularly that of species that are happier in still water) and change the shape of the river. These problems may be compounded by the fact that the sediments are often toxic.

Box 10: Decommissioning of the Edwards dam, USA

When in 1997 the Federal Energy Regulatory Commission (FERC) in the USA ordered the removal of the Edwards dam (built in 1870) it cited compelling environmental considerations. The Commission said its actions were based on the following key considerations:

- power produced at the dam can easily be replaced by existing resources in the region
- removal will provide 9 species of fish with continuous access to 15 miles of spawning habitat
- removal will provide 4 species of fish that do not use fishways, with access to their entire historic range within the Kennebec river
- wetland habitats, recreational boating and fishing will benefit
- there will be no major environmental or social drawbacks

Rehabilitation and restoration of freshwater ecosystems

Restoration refers to the process by which freshwater ecosystems are returned to what is regarded as a more natural or less disturbed state. It aims at the full or partial replacement of structural or functional characteristics that have been extinguished or diminished and the substitution of alter native qualities or characteristics than the ones originally present with the proviso that they have more social, economic or ecological value than existed in the disturbed state (Cairns, 1988). A distinction can be made between restoration, which is any activity that aims to return a system to the condition it was prior to the disturbance (regardless of whether this was pristine), and rehabilitation, defined as any activity which aims to convert a degraded system to a stable alternative use which is designed to meet a particular management objective (Frid and Clark, 1999). Restoration is usually regarded as having a well defined end point (i.e. the status of the system before it was degraded). However, it is very rarely possible to return ecosystems to their original condition.

A key goal for science is to establish the appropriate mechanisms and the level of support required to restore freshwater ecosystems to a desired natural or artificial state. Progress is being made in developing relationships between hydrological change and habitat for biological indicators (Petts, 1996). These will enable evaluation of the ecological effects of change. However, although models exist (e.g. PHABSIM) they are at present imprecise and remain largely qualitative in nature. Furthermore, even when quantitative data are available the decisions on the acceptability of a particular ecosystem state depend largely on value judgements. A major challenge of restoration of freshwater ecosystems is the need to integrate scientific knowledge with those economic and social pressures that have a direct impact on the system.

Schemes for restoring or rehabilitating freshwater ecosystems will be most successful if consideration is given to the following (adapted from Wade *et al*., 1998):

- clear goals and objectives must be identified at the outset
- schemes are adaptive and flexible
- maintenance costs in the long-term are kept to a minimum
- the scheme is suitable for existing climate and hydrological regime
- the scheme can cope, indeed is designed for extreme events as well as average conditions
- all stakeholders are included in the design process
- it is recognised that schemes will not become functional instantaneously
- schemes are designed for function and not form
- schemes are not over-engineered, but are as natural as possible

There is a need for monitoring to determine if restoration projects are effective. Three types of monitoring have been identified as appropriate (Kershner, 1997): implementation, effectiveness and validation. Implementation monitoring identifies whether the restoration measures are functioning as intended. Effectiveness monitoring determines if the restoration is meeting the objectives identified at the outset of the scheme. Validation monitoring is primarily a research activity, used to gather information on the basic assumptions needed to develop objectives.

5.3.2 Biotechnology

Advances in biotechnology may lead to the introduction of drought, salt and pest resistant crops thereby increasing crop yields and allowing expansion of potentially arable land. It is likely that within the next 5 to 7 years, the functions of most of the genes that are in plants will be known. With this knowledge it is surmised that it may be possible to develop transgenic plants that are more tolerant to drought and salinity stress (Panel on Biotechnology of the Water Commission on Water, 1999). In 1996, there were 7 million acres of transgenic crops in the world. There were 31 million acres in 1997 and over 75 million acres were planted in 1998. If this trend continues rain-fed agriculture may provide the most effective way to expand food production on a global scale with a consequent decrease in projected irrigation withdrawals.

Although biotechnology options have potential there remain two significant problems. First, despite numerous studies conducted there is still only limited knowledge of the physiological, biochemical and genetic determinants of stress in plants and a great deal more understanding is required before DNA modification can be used to manipulate water and salinity stress resistance. Second, recent events in Europe suggest that biotechnology is treated with suspicion and it may be that genetically modified organisms are unacceptable to some societies.

5.4 Synthesis: impediments to future strategies

In the past improvement in environmental security in the developed world has been dependent to a large extent on the application of technology. Existing and new technologies will have a role to play in increasing environmental security in the future. However, it is now widely recognised that whilst freshwater management has traditionally been governed by "supply side planning" or utilisation of engineering solutions to manage the resource to meet levels of projected, and often unregulated demand, such an approach is not sustainable in the long-term. ICM, a new approach based on the ethic of ecosystem management, is now being widely promoted.

The environmental security indicators presented in section 3.5 indicate that priorities in the developed and developing world are very different. In developing countries the emphasis must be on elementary environmental care mostly oriented to meeting the basic water supply, housing and waste disposal needs. In the developed world the emphasis must be on protecting the few remaining near-pristine freshwater ecosystems, ameliorating the impact of existing development and introducing management strategies to restore degraded ecosystems. Although the priorities are different, the basic doctrine proposed within the concept of ICM applies to both developed and developing countries.

There are at present considerable technical difficulties to the practical application of ICM principles. These can be summarised as follows:

- Successful ICM schemes are dependent on understanding the cause and effect linkages between land-use patterns, hydrological regime and biotic response. To a large extent these relationships are not understood. There is a need for increased research to develop quantitative useable relationships between these three components of freshwater ecosystems.

- There is a great deal of potential for societies to improve the efficiency of direct use of water. However, the interest in demand-side management is new and the required database for analysing water use patterns in detail in order to formulate sound demand management programs are in many places sparse.

- Monitoring programs are important in ICM because management strategies must be adaptable. However, such "effectiveness" monitoring is time consuming and costly. Many current monitoring programs are inadequate, for a variety of reasons, and do not provide information that is useful for ICM.

- Successful ICM strategies must integrate environmental, social and economic factors. However, there are very few practical methods for directly linking these different aspects of freshwater ecosystems.
- Good scientific analyses often make decision making more difficult because it highlights critical uncertainties arising from the complexities of ecology and the history of human interventions. Consequently, it is not clear how science should be incorporated within the decision-making process.

Overcoming these impediments is essential if ICM is to provide a basis for freshwater ecosystem management and the enhancement of environmental security in the next century.

6. Final Statement

Freshwater ecosystems are inherently complex, comprising many interdependent components. History has shown that human activities undertaken without full consideration of the social, environmental and economic implications can, and do, have adverse repercussions. Management practices that respond to a single water use, a single population segment, or a single sector have caused inadvertent disruption to ecological functions and resulted in a net loss of environmental security. Comprehensive management strategies that recognise the interdependencies existing within freshwater ecosystems are required in order to maximise benefits accrued to society and so increase environmental security.

Ecosystem management represents an ill-defined basis for resource management. To be technically credible the term must be defined in much narrower policy and scientific terms. Nevertheless, it does provide a valid water ethic on which freshwater management can be founded. As we approach the 21st century, the main challenge is to put the general principles of ecosystem management into practice. It is suggested that the multi-objective goals relating to society, economics and the environment can be integrated within catchment management strategies, but many problems remain in deriving practical approaches to doing this.

It is clear from the analysis presented in this document that environmental security issues are multiple and complex. Environmental degradation and resource depletion creates or exacerbates human insecurity. Currently, the environmental security problems in developing countries are very different to those of the developed world. In developing countries the future emphasis must be on elementary environmental care mostly oriented to meeting the basic water supply, housing and waste disposal needs. Appropriate technical solutions exist and have a crucial role to play in increasing security in these countries. In the developed world, high levels of social and economic security have been obtained through application of complex technologies and considerable alteration of natural ecosystems. These societies are now sufficiently prosperous that they can contemplate a large range of possible options on the way they manage freshwater ecosystems. In these countries societies are placing greater value on the indirect benefits of near-natural freshwater ecosystems, to the extent that costly rehabilitation schemes and the establishment of reserves, that provide no direct benefits are being increasingly implemented.

In both developing and developed countries successful management of freshwater ecosystems requires an integrated approach drawing upon the expertise of multi-disciplinary teams. Much can be learnt from local resource management based on traditional practise. Although there are limitations, nevertheless river catchments provide the most logical, easily identifiable hydro-geomorphologic unit on which to base management strategies. ICM has been developed to provide a framework for action. Management strategies must be adaptable and flexible to meet constantly changing environmental conditions and human demands. As this paper has illustrated, ingenious solutions are often required to solve complex problems. Scientific and socio-economic monitoring is essential to further understanding of cause and effect relationships both within the natural environment and in human interactions with the natural environment.

In summary, increasing environmental security requires that:

- Issues of environmental change and security are dealt with holistically. Management strategies must be conceived, designed and implemented with a clear appreciation of the interconnectedness of poverty, environmental change and security.
- Management strategies satisfy both immediate and long-term needs.
- Research findings are used to provide an analytical perspective of problems, guide policy-making and inform assessments of management interventions.
- Resources are directed towards identifying vulnerable geographical regions and sectors of society and promoting adaptation and resilience in both.
- The impediments to ICM summarised in section 5.4 are overcome.

Issues for discussion at the workshop

The objective of the San Jose workshop is to develop practical strategies that move towards the vision provided in the sustainable water world scenario. Box 11 lists a number of issues that might be discussed at the workshop:

Box 11: Issues for discussion

- X Biodiversity is sometimes a benefit and sometimes a constraint on human development. How do we assess when it is acceptable to sacrifice biodiversity and when should it be retained? Is this simply a question of societal preference ?
- X Should environmental security (i.e. protection of the environment for human benefit) and ethical security (i.e. a moral duty to protect the environment from human interference) be treated as separate issues ? The distinction between the two has perhaps been blurred by conservationists but surely they are quite separate.
- X Is it the case that at present, planning for ecosystem management remains largely focussed on defining how and where traditional resource extraction activities and environmental disruption can be continued without irreversible damage to water quality, biodiversity and other ecosystem values ? As such is it simply a search for the last free lunch ? Is something more required ?
- X Is it the case that attempts to meet multiple conflicting and changing needs simply result in continual compromise and gradual degradation of natural ecosystems ?
- X Is it true that all very artificial freshwater ecosystems are non-sustainable over the long-term, despite our best management efforts ?
- X Is it necessary to do more than integrate water and land-use ? Should the idea of water management as a legitimate land-use (i.e. as in the case of New York ?) be more widely promoted?
- X What are the tools necessary to effectively implement freshwater ecosystem management so as to maintain and/or enhance environmental security ?
- X Recognising that it is impossible to know everything about the structure and functioning of an ecosystem, is it possible to define what we must know in order to effectively manage them to maintain and/or enhance environmental security ?

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Glossary

Aquifer: Porous rock containing water

Catchment: Used synonomously with watershed, river basin or drainage area. It is the unit of land from which water flows downhill to a specified point on a watercourse. It is determined by topographical features which include a surrounding boundary or perimeter known as a drainage divide or catchment boundary.

Connectedness: A general term for the cohesiveness of a system. Systems with strong interaction are relatively highly connected, as are systems with a large number of the parts interconnected.

Connectivity: A measure of the degree of connectedness of a system

Degraded ecosystem: An ecosystem that has lost some or all of its direct or indirect value to human society.

Ecosystem: A discrete entity that consists of living and non-living parts, interacting to form a stable unit.

Ecosystem management: deliberate and conscious manipulation of ecosystem structure and/or function, or regulation of human uses of ecological systems, so as to retain defined and desired features and processes, and to meet human needs in an optimal and sustainable way.

Environmental Security: A means of achieving long-term social, economic and ethical security through: i) the sustainable utilisation of renewable resources and ecosystem functions; ii) protection from natural hazards and iii) conservation of other species.

Integrated Catchment Management (ICM): The co-ordinated planning and management of the water resources of a river basin considering its interaction with land and other environmental resources for their equitable, efficient and sustainable use at a range of scales from local to catchment level.

Integrity: The continuity of a complex and the totality of its locations within some order.

Robustness: The property of remaining unchanged even under the influence of new forces, new data or new perspectives of observation.

Resilience: A measure of the magnitude or scale of disturbance that can be absorbed before a system changes in structure by the change of variables or processes that control system behaviour. Resilience in this context is a measure of robustness and buffering capacity of the system to changing conditions.

Rehabilitation: The conversion of a degraded ecosystem to a stable alternative use, designed to meet a particular management objective.

Restoration: The conversion of an ecosystem to the condition it was in prior to anthropogenic disturbance.