Water

a reflection of land use

Options for counteracting land and water mismanagement

By M. Falkenmark, L. Andersson, R. Castensson, K. Sundblad in collaboration with C. Batchelor, J. Gardiner, C. Lyle, N. Peters, B. Pettersen, P. Quinn, J. Rockström, C. Yapijakis

Water, a reflection of land use

NATURVETENSKAPLIGA FORSKNINGSRÅDET

Water

a reflection of land use

Options for counteracting land and water mismanagement

By M. Falkenmark, L. Andersson, R. Castensson, K. Sundblad in collaboration with
C. Batchelor, J. Gardiner,
C. Lyle, N. Peters, B. Pettersen,
P. Quinn, J. Rockström, C. Yapijakis

NFR Naturvetenskapliga forskningsrådet
Swedish Natural Science Research Council

Unesco-IHP

isbn 91 546 0358 7
published by swedish natural science research council
p o box 7142, se-103 87 stockholm, sweden
tel +46 8 454 42 00, fax +46 8 454 42 50
e-mail: nfr@nfr.se
internet: www.nfr.se

graphic design: g. lulich grafisk form, uppsala, sweden
printed in sweden by elanders gotab ab, 1999
printed on chlorine free paper

Contents

About the authors and contributors

Lotta Andersson

Lotta Andersson is a physical geographer and hydrologist. She is a senior researcher at the Department of Water and Environmental Studies, Linköping University, where she studies streamflow generation linked to hydrochemical dynamics and influence of land use changes on water resources. She is also a lecturer in physical geograpy and geographical information systems at the Department of Geography at Linköping University, Sweden.

Charles Batchelor

Charles Batchelor is Head of the Agro-Hydrology Section at The Institute of Hydrology, Wallingford, United Kingdom. During the last twenty years, he has been involved in a wide range of research studies of irrigated and rainfed farming systems, water management, crop water use, integrated catchment management and the environmental impact of agricultural practices on water resources and water quality.

Reinhold Castensson

Reinhold Castensson is associate professor at the Department of Water and Environmental Studies, Linköping University, Sweden working with river basin development and management and regional water resources planning and landscape change. He is also senior lecturer in social and economic geography.

Malin Falkenmark

Malin Falkenmark is a professor of International Hydrology at the Swedish Natural Science Research Council, and chair of the Swedish Committee for the International Hydrological Programme. She is very active in various international bodies, including IUCN, the World Bank and the International Water Resources Association.

John Gardiner

John Gardiner is professor of sustainable management at Middlesex University, London; until 1995, he was technical Planning Manager with the National Rivers Authority. He has 23 years experience in all aspects of river corridor and catchment management, pioneering environmentally sensitive techniques, holistic project appraisal, catchment management planning and source control. He is active in research, consulting and lecturing in 5 continents, and in "greening" institutions such as the Institution of Civil Engineers, in the UK and abroad.

Clive Lyle

Clive Lyle is currently the Director of Natural Resources Policy for the Catchment Management and Sustainable Agriculture Division of the Victorian Department of Natural Resources and Environment, Australia. He is involved with policy making on land and water management at a senior governmental level. He was formerly the Director of Natural Resources Management with the Murray-Darling Basin Commission. He has extensive experience and interest in catchment planning linking land, water and vegetation management. He has been involved previously in preparing a number of community based, land and water management plans as well as research into soil, water and salinity management.

Norman Peters

Norman (Jake) Peters is a research hydrologist of the U.S. Geological Survey at the Georgia District Office of the Water Resources Division in Atlanta, Georgia. He also is President of the International Commission on Water Quality of the International Association of Hydrological Sciences (IAHS) and Associate

Editor of the international journal, Hydrological Processes. In addition to conducting research of small catchments for understanding hydrologic and biogeochemical processes, he is active in addressing global water quality issues through various IAHS Symposia and Workshops on water quality and collaboration in water-quality projects around the globe. Most recently, he is chairing a task group to develop a global water-quality program for the UN.

Berit Pettersen

Berit Pettersen is an Associate Professor on Environmental Engineering and Water Sciences at the Institute of Applied Chemistry, Technical University of Denmark. Main research topics have been: Utilisation of nutrients in waste waters by hydroculture and groundwater protection through bioremediation of oil polluted soil. Main field of interest is to create political awareness about the present global unbalance in the nitrogen cycle, causing a continuous increase of nitrate in the world waters, comparable to the continuous increase of carbon dioxide in the earth's atmosphere.

Paul Quinn

Paul Quinn has a degree in water resources and geology from Aston University and a Ph. D. in terrain analysis and hydrology from Lancaster University, UK. Since 1991, he has taught at Lancaster University and Stirling University and carried post doctoral research on modelling of the land surface for climate change models. Paul is now an environmental consultant with ADAS and specialises in hydrology and GIS with a particular interest in agricultural pollution. Modelling, scale and uncertainty remain at the hearts of his research interests.

Johan Rockström

Johan Rockström has a degree in agricultural sciences from the University of Agricultural Sciences, Uppsala Sweden. In 1993 he joined the Natural Resources Management group at the Department of System Ecology, Stockholm University, Sweden. He received his Ph.D. in 1997 in a study focused on soil and water research in dryland agriculture in the Sahel region in Africa (Niger) in collaboration with the French research institute ORSTOM (Institut Français de Recherche Scientifique pour le Développement en Coopération).

Karin Sundblad

Karin Sundblad is a Senior Lecturer in Environmental Science and Ecology at the Department of Biology, Linköping University, Sweden. She received her Ph. D. in 1988 in the field of constructed wetlands for wastewater nutrient recycling and has since then continued with research in that same area. Other interests and involvements are catchments studies of nutrient transformations and transport, and potentials for improving nutrient recycling between cities and surrounding countryside.

Constantine Yapijakis

Yapijakis teaches Environmental Engineering and is Director of Environmental Research at the Cooper Union for the Advancement of Science and Art, in Manhattan, New York. He has over 20 years of international experience, both academic and industrial, in all aspects of environmental engineering. He has taught in several major universities in the New York metropolitan area, and has been involved in all the major projects for New York City. These include drinking water treatment and regional resources, quality management, solid waste management, industrial waste pre-treatment, and toxic waste minimization programs.

Foreword

The water issue is set to become one of the major questions of the 21st century. Wise and far-sighted action is essential if human needs are to be met and if this most precious of resources is to become a potential source not of conflict but rather of agreements that can serve as a paradigm for peaceful international co-operation. This book, which originated from an invitation from UNESCO to the Swedish National Committee for the International Hydrological Programme aims to demystify the water cycle. Based on case studies provided from various National IHP Committees, the book illustrates many different ways in which man interferes with the water cycle and clarifies environmental problems which emerge.

The world's water problems arise not so much from a shortage of freshwater as from its uneven distribution, from ever-increasing demand and from practices detrimental to water quality. Water problems will grow worse unless urgent action is taken to address them at the national and international level: action firmly rooted in the idea of partnership with nature and sharing with all human communities. Our response to the water crisis should be based on a better understanding of the interconnection between water resources and human behaviour as well as enlightened policies at the national and international level. Education has a major part to play in promoting such an awareness.

Education for water awareness has a rich heritage on which to draw. Water connects us. It connects us by flowing across imposed boundaries, by linking diverse terraines and settlements. In religion, myth and legend, water is a universal symbol of wholeness and purification. It is the original element, a source of life, a metaphor for natural and mental process, the image of all that unites us in time and space. This civilizational inheritance is one that education can and must turn to account.

Already 20 years ago UNESCO drew attention to the fact that through the hydrological cycle an important part of the water used for economic purposes returns to rivers heavily polluted. Twenty years later the problems have worsened. The interdependence of water and civilization highlights the increasing and urgent need for close co-operation among all the stakeholders, extending from the local through the regional right up to the global level. One of the most important needs is for coordinated efforts to understand the processes occurring in the water cycle, to access surface and ground water resources, and to promote attitudes conducive to maintaining the quality and quantity of water resources for future generations.

Recognition of the importance of these objectives led to the launching of the International Hydrological Decade (IHD) in 1964, the first truly international scientific and educational effort ever made in hydrology. In 1974, UNESCO decided to set up the long-term International Hydrological Programme (IHP) with the aim of finding solutions to the specific problems of countries with different geographical and climatic conditions and at various levels of technological and economic development.

Attaining the general objective presupposes advances in knowledge and their effective application in a number of fields. In particular, better understanding is required of the hydrological cycle as affected by human settlements and activities in terms of both quantity and quality under various climatic conditions. Today, IHP together with the Man and the Biosphere (MAB) programme, contribute to the scientific backbone of UNESCO's environmental activities.

Water is an integral part of our heritage. Each generation has only temporary rights over their water. When we talk about water and the environment, about a situation that may become irreversible, we see the need for a new water ethic. Now is the time for action based on a rigorous understanding of the water cycle. Only with such an understanding can today's unintended environmental impacts be transformed into an intentional landscape of ecological planning and management.

Federico Major
Director-General of the UNESCO

Preface

Although land/water links are known since a long time, conventional scientific and administrative structures have tended to keep the sectors apart. Considerable attention is currently paid to issues such as biodiversity protection, protection against droughts and desertification, sustainable management of tropical rainforests, and coastal zone management including protection of coastal waters from pollution. The joint characteristics of all these issues is the dominant role played by land/water interactions. Most of the water in the river has earlier passed land and carries the chemical memories from that journey. Much land use depends on access to safe water. And hydrological processes are deeply involved in the generation of ecological side effects of human interventions with the natural environment, like land clearing, urbanization, agriculture and forestry.

The need to close the gap between hydrology and ecology was given high priority in the preparations for UNCED in the International Council of Scientific Union in their analysis of the research needs to strengthen the understanding of the links between environment and development. Agenda 21 also stresses the need to take an integrated approach to land use and water resources. Such an integrated approach may however meet considerable difficulties both by a widespread dichotomy in the dominating perceptions of land and water, and by widespread reductionistic and simplistic water perceptions. Thus for a successful land use management, land/water linkages are essential to understand in both development planning and environmental protection and management.

The origin of this book is an invitation by UNESCO in 1989 to the Swedish National Committee for the International Hydrological Programme to consider the production of a textbook as a follow-up of an ecologist-hydrologist dialogue held that year in Vadstena, Sweden. An ecohydrological summer seminar in 1992 at Aspen Global Change Institute (Colorado, USA) further stressed the need for a publication that clarifies problems and opportunities in terms of how to manage in an ecologically more adequate way humanity's interaction with land and water.

The composition of the book was planned at an international author meeting at Friiberg's Manor in Sweden in October 1994. In preparation for that meeting a broad questionnaire had been sent out by the Swedish IHP Committee to its sister committees all around the world, inviting them to contribute concrete examples of land/water linkages as they had been experienced in different parts of the world. The fact that the response was remarkably high indicates the timeliness of this book: many countries have already severe problems due to land/water interactions but also in coping with them. A case study overview is presented as an annex to the book with a world map showing the global coverage.

The book has been written by a group of main authors, supported by a larger group of contributors, see List of Contents. After an introductory chapter explaining that the purpose of the book is helping politicians understand the fact that humanity is living at the mercy of the water cycle (Chapter 1), follows a chapter that presents regional challenges through examples from different hydroclimates (Chapter 2). Chapter 3 and 4 are complementary by describing the rules of the game, first the natural rules, then the societal rules. The former chapter explains how water and water-carried solutes move through the landscape, above and below the ground, and the main relations to wetness, soil, vegetation and human activities. The latter chapter has its focus on current policies, showing that they are inconsistent with natural rules, creating a wide range of problems. These problems are highlighted in Chapter 5 carrying the essential message that a land use decision is also a water decision. Here, the human influences in terms of landscape change and the side effects that they produce are examplified from different parts of the world: both activities influencing water flows and pathways, involving chemicals that are introduced into water pathways, disturbing land fertility, and typical social effects of such activities and effects.

After a chapter focusing on reversability and recovery issues (Chapter 6), we turn the interest to steps to be taken to better cope with the land/water interactions in the landscape (Chapter 7) with particular focus on not-undermining land and water management, on river basin action plans to implement those strategies, on the roles to be played by the main actors, i e politicians, and on the procedures to gain public acceptance. The final chapter (Chapter 8), after a short recapitulation, goes on to discuss how to incorporate new understanding for better decisions and what can be learnt from the few existing success stories.

The preparation of the book which is offered as a Swedish contribution to the fifth phase of International Hydrological Programme, theme 2, has been supported by a research grant from the Swedish Natural Science Research Council (NFR).

The authors are deeply indebted to Ms Iréne Johansson, Scientific Secretary, NFR for her function as a persistent Project Leader, to Ms Lina Berglöf, assistant, NFR for not only word processing but also for artistry, and to Professor Carl Widstrand, Carleton University, Ottawa, and his wife Rede Widstrand for linguistic editing. Without their respective inputs the book would never have materialized.

Stockholm 27 May 1997

Malin Falkenmark
Professor, Chair National IHP Committee
Swedish Natural Science Research Council

1 The purpose of this book

Helping politicians understand water

It is a fundamental principle that we are living at the mercy of the water cycle: it acts as the bloodstream of the biosphere. As human populations grow, their expectations grow as well. This translates into an increasing demand for livelihood opportunities and an increasing pollution of water resources. Thus, the need is urgent throughout the world for improved understanding of the ecohydrological linkages. This book has as its purpose to explain and demystify the water cycle, its integrity and key processes. It contributes towards understanding the complex issue of the interaction between humans and their environment which is the origin of the natural resources that support human society and prosperity. This understanding will enable better decision-making and more successful action to cope with the situation. The book will also give readers an opportunity to review and evaluate their own particular cases and to make informed decisions.

The purpose of this book can also be expressed under several main goals which are to:

- contribute to better future governance by educating the current and next generation of politicians and decision-makers as well as interested members of the general public;
- provide teachers with appropriate and useful information from which they will be able to further develop classroom materials and activities;
- create an awareness of fundamental regional differences in order to reduce the level of "temperate zone imperialism" on issues concerning the environment and development, and
- create awareness about the importance of education for changing attitudes on water issues.

Within that framework this book addresses three basic issues:

- interaction between human activities in the landscape (land-use) and the movement of water vertically and horizontally through that landscape;
- action needed to avoid the negative ecohydrological effects of such interactions (floods, pollution, desiccation, etc.);
- appropriate methods for environmental management to cope with such interactions.

Two types of land-use activities that have a fundamental impact on livelihood and thus on the issues outlined above will also be addressed:

- land-use dependent on drainage and flood protection, or, for example, dependent on limitations imposed by water on societal and biomass production. This type of land-use is called "water-dependent" land-use;
- land-use which has an impact on rainwater partitioning through soil and vegetation or impacts related to the function of water as a carrier of solutes and silt in the landscape. This type of land-use is called "water-impacting."

Living at the mercy of the water cycle: what does that mean?

Living at the mercy of the water cycle means that the water cycle is the central clockwork of the biosphere. It will go on as long as the sun shines and provides energy for the cycle. However, humans intervene in that cycle, both by the production of water-soluble waste products and by manipulation of vegetation and soils in what we here call the Total Earth System (Figure 1.1). Human activities easily create unintended side effects on both terrestrial and aquatic ecosystems; such activities may even lead to famine disasters.

Disturbances are generated by many different sectors of society, and they are often linked to or are part of economic developmental activities. This means that such effects – even when mainly spoken of as environmental effects – often produce problems from a development perspective since the environmental pre-conditions for human activities change continually. The present rapid population growth which, for reasons explained below, will not stop within the next several decades adds to the seriousness of these problems.

Massive landscape manipulation will be necessary to support a given population's needs for food, fodder, fibre, fuelwood and timber. Massive efforts are needed to take care of the wastes produced – including their disposal in the landscape. Thus, advice will be needed regarding where in the landscape different activities should preferably be concentrated, how landscape manipulation should be made, and when it should be carried out, i.e., what season would be the most appropriate.

Advice will be needed regarding where in the landscape different activities should preferably be concentrated, how landscape manipulation should be made, and when it should be carried out.

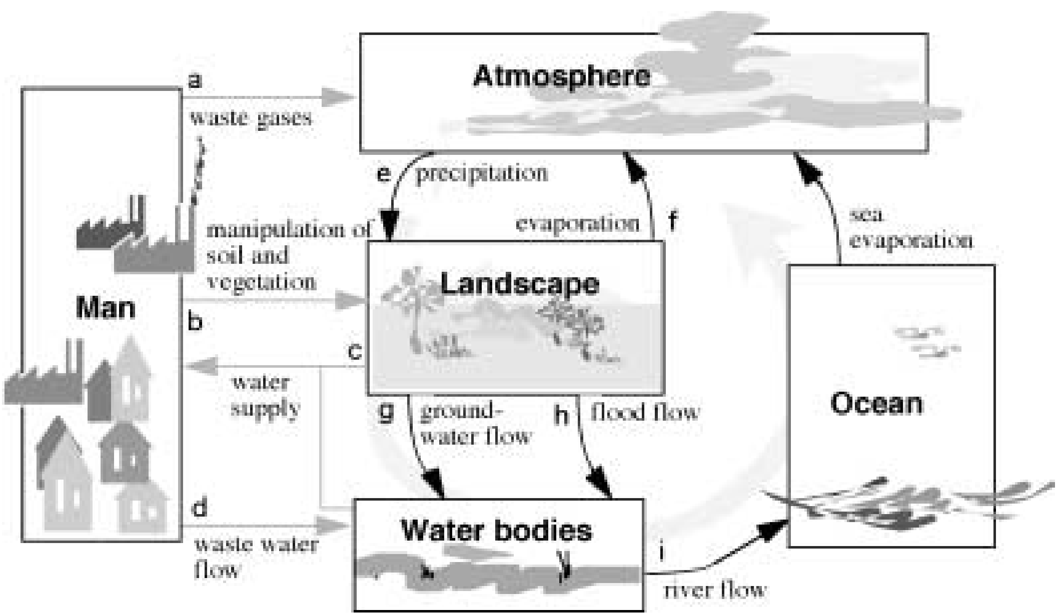


Figure 1.1.
The water perspective of the Total Earth System. The water cycle is the central clockwork of the atmosphere. Human interventions in the cycle are marked by grey arrows a, b, c, and d. The black arrows e, f, g, and h indicate water flows. Disturbances are caught in the water cycle and passed onward to terrestrial, aquatic and marine ecosystems.

Population growth

We know that the amount of water circulating around the globe and passing through inhabited landscapes is limited and finite. Knowing also that the world population will continue to grow, at least for the next hundred years, the question of how many people can ultimately be supported is highly pertinent (Figure 1.2).

In this discussion one has to distinguish between the unavoidable and the avoidable part of population growth. The former is related to the fact that mothers are already born and we can make conservative and realistic assessments of the number of children per woman in the next few decades. The latter is related to the increase in population that can be avoided by measures mainly in the areas of female education; family planning; availability of contraceptives; sterilisation services for males and females; and in improving maternal health (Figure 1.3).

People depend on water not only for household use, but also for use in industry to create foreign exchange income, and, above all, for producing the food needed for subsistence. Today, 90% of the increase of the world's population takes place in developing countries. A major part of this increase is located in tropical regions that also have widespread poverty. Water shortage is a daily reality here and a definite concern for development. Furthermore, due to the larger evaporative demand of the atmosphere (the "thirst" of the atmosphere) the amount of water consumed in the tropics to produce biomass is larger than in cooler climates. Here, where conditions for agriculture are the most precarious, food production has to increase the most in order to feed future populations.

Water can be put to use as it passes through inhabited landscapes. What can be expected is, of course, that the uses will be increasingly in

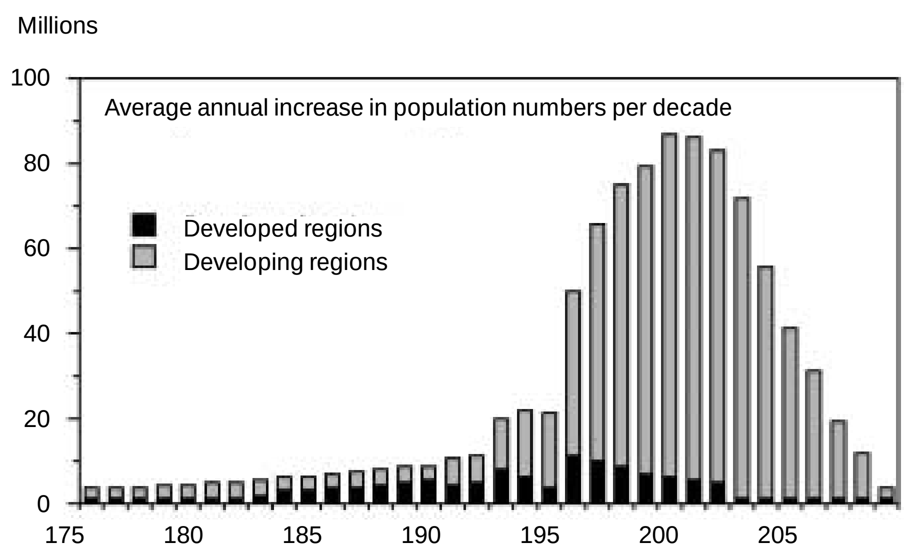


Figure 1. 2.
The world population is at present estimated to grow by 90 million people each year. The increase is largest in the developing countries. (Source: Population Reference Bureau, Washington DC.)

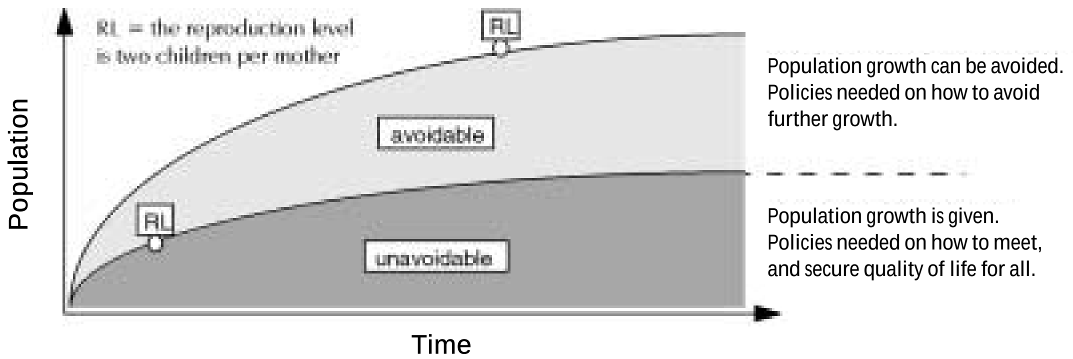


Figure 1.3.
A distinction between the unavoidable and avoidable part of population growth. The former is related to mothers already born and is a realistic assessment of the number of children per woman in the next few decades. In the figure, RL – the reproduction level – refers to the point of time when two children per mother are born.

conflict as populations grow and as the number of individuals who depend on each flow unit of water for survival, food, income, and quality of life increases. From Europe we originally inherited a simplistic and reductionistic approach to water resources management which we still use. This raises the following question: Is that approach at all adequate in this situation? Is the "business as usual" approach at all possible?

Water can be put to use as it passes through the inhabited landscapes...

River water arrives from land

In seeking answers to these questions it is essential to clearly understand land-water linkages, and how water movement through the landscape is linked to the quality of that water. We all know that rivers keep on accumulating runoff from land and that the amount of water arriving to the river as direct precipitation over the water surface is fairly limited. Since water is a unique solvent, it tends to dissolve everything soluble as it passes above and below the ground surface. It then carries the solubles along pathways towards the river. In this way pollutants from sources based on land are carried into the water system draining that land area.

Water, however, has also a large erosive capacity. This means that it carries along fine particles from easily erodable land into rivers. There, the soil particles are again deposited as silt when the water velocity decreases in lakes and coastal waters. In slow-flowing rivers, silt is also deposited in large quantities on the river bottom, which may increase the risk of flooding. As flood levees are built to protect the surrounding areas when the river level rises, the river finally may pass through the land high above agricultural lands, as can be seen in many places in China.

Not only water quality is influenced by human actions on land. When we clear natural vegetation or change land-use or land management, we also intervene in the partitioning of the incoming precipitation between different possible pathways. For example, vegetation uses water drawn from the root zone through the body of the plant and then sends it out in the atmosphere. This is called transpiration. Vegetation sends large flows of transpiring water back to the atmosphere, but when that vegetation is cleared more precipitation remains in the landscape. This precipitation may infiltrate into the ground and ultimately recharge groundwater formations or it may stay on the land surface producing erosive flash floods that are of no use for local populations. What happens depends on the composition of the soil. Where soil is vulnerable to crust formation when exposed to the atmosphere without protecting plant cover, groundwater recharge may decrease, and the runoff leaves as rapid flash floods.

Vegetation cover is, therefore, very important. For this reason it is often thought that forest plantations are helpful in securing more local water. A recent research study suggests, however, that this may be true mainly in cases where soil crusts may be broken up by new trees. In other cases, where the soil is already permeable, the fact that the plantations will consume large amounts water, may cause local springs to dry up and river runoff to decrease.

Deforestation "the European way" in the Amazonas is creating massive problems and is threatening to change the local climate.

A heritage from earlier generations

Our present approach to water and the handling of water is simplistic. As was stated, many of our ideas have been inherited from earlier generations, from a time when the population was small, human activities limited, and the waste produced was effectively evacuated by rivers without causing any disturbing pollution. For earlier generations, water was seen as a technical issue – a question of organising proper water supply for human societies and agricultural production. This, for example, was the approach taken in the American West. Population and human activities have now increased to a point where this simplistic view creates rapidly increasing problems.

Traditional approaches to land and forest management were also inherited from earlier generations in temperate zone countries. When European settlers in Australia cleared the land for cattle or started to grow irrigated crops, huge problems were created of groundwater rise; water logging; wasteful irrigation; and salinization. These problems are now large enough to consider the evacuation of certain areas where soils have become too saline. Deforestation "the European way" in the Amazonas is creating massive problems and is threatening to change the local climate.

In our approach to waste handling, we also continue the approach of our forebears. Today, pursuing industrialisation, we have been able to address some of the problems through using expensive waste water treatment plants. We are just starting to react to other problems, however, in particular those caused all over the industrialised world by dry waste deposits in the ground in waste dumps and landfills. Since the precipitation over many of these areas has now become acid – what is raining down over the deposits is no longer clean water, but dilute sulphuric and nitric acid – the effects of the deposits are increasingly adverse. This is the case in Central Europe, Scandinavia, and Northeast America.

A threatening water crisis

The international community now speaks about a looming water crisis. What are the warnings that we hear? The main problems of the present situation set out in the recent book Water in Crisis are as follows:

- A severe lack of knowledge about the water resources of the world, and only a limited understanding of how human activities are changing the particulars of the global water cycle;

- Harsh criticism, in cooler regions levied against current water management measures taken to supply society with water and energy. Arid regions, prone to drought and suffering from poverty, are genuinely dependent on realistic water management measures to support development. Their future depends on making better use of limited rainfall in order to secure the increases needed for agricultural production to feed a rapidly-growing population;
- Formidable challenges face governments in regard to water quality, since water quality degradation is threatening to become an unmanageable crisis. Industrialised countries have failed in their efforts to eliminate the pollution source since treatment of waste water is expensive;
- Regional water scarcity in the future will become a limiting factor for agricultural production; socio-economic planning will, therefore, have to be adapted to actual water constraints. Inevitably, we will have to develop policy tools capable of managing the shortage of common water resources between competing actors;
- Energy choices in dry climate regions are crucially influenced by water availability because water is required for almost every aspect of energy production and use: as a driving medium, as a cooling medium, and as an energy transfer medium.

Water is a much more complex resource than is presumed by the technical approach still taken to it all over the world. It has many parallel functions.

Getting out of the trap

The present predicament suggests that "business as usual" seems to be an extremely dangerous approach to take. Moreover, water is a much more complex resource than is presumed by the technical approach to it, which is still taken all over the world. A shift in thinking is required.

The many parallel functions of water make it necessary to keep at least five such functions in mind, and to create management models that pay adequate attention to all of them:

- *health function:* safe water is crucial for protecting the survival of a healthy population – this is the perspective of the sanitary engineers;
- *habitat function:* aquatic flora and fauna are critically dependent on the characteristics of the water in the water body in which they dwell – this is the perspective of ecologists;
- *two carrier functions:* of dissolved material, and of eroded material – this is the perspective of hydrochemists and geographers, respectively;
- *two production functions:* plant production in agriculture and forestry; plants and trees are feeding on water passing through the root zone back to the atmosphere. Socio-economic production in industry and urban societies is feeding on water passing through aquifers and rivers; The former is the perspective of agronomists and foresters, the latter of civil engineers;
- *religious and psychological function,* finally: water plays a crucial role in most religions: mosques are built around a spring, and visitors are supposed to clean themselves in the mosque well; Hindu temples have tanks for ablutions; in the Christian church, water is used in baptising and as holy water at the church entrance. Since ancient times fountains have been seen as desirable components of city architecture, creating a feeling of quality of life and well-being; and water bodies play a crucial role in recreation, both in and on the water. These are the perspectives of priests and city planners.

A breakthrough in ecological economics: possible benefits

The new discipline, ecological economics, represents efforts to translate ecological phenomena and processes into the language of the economist.

In recent years, a new interdisciplinary branch of knowledge and understanding has been developed by looking at the modern economy from a perspective of ecology. The new discipline, ecological economics, represents efforts to translate ecological phenomena and processes into the language of the economist. In order to close the gap between ecology and economy, ecosystems are seen as suppliers of certain functions and services. Effects of certain decisions on third parties, or externalities, represent a cost that has to be properly entered into the analysis before a decision is taken. Different ways have been proposed as to how these costs can be calculated. Differences in time scales between ecologists and economists, have caused lingering disagreements over the effects of human activities: ecologists tend to think in terms of the long-term effects of human activities, whereas economists tend to calculate short-term costs. Long-term costs tend to vanish when calculated at their current value.

Moreover, the links between wealth and environmental quality can be both positive and negative. Wealth is needed to be able to afford expensive, non-polluting technologies. However, wealthy countries have been the largest polluters – the negative link.

Politicians are the key players, regardless if we use eco-economic methods or other methods in the integrated management of land and water resources. In a modern society, a whole set of decisions must be taken by politicians on matters such as nature conservation, protection of biodiversity, wetland protection and management, to name only a few. These decisions urgently need the support of a better understanding of the physical, chemical and biological interactions between hydrological and ecological phenomena.

2 Regional challenges

Environmental problems and regional climate

The environmental pre-conditions of the globe create constraints; the inability of society to adapt activities to such constraints is causing a number of serious problems. The flow of water forms the link between various parts of the landscape. This flow ultimately depends on the amount of rainfall, evapotranspiration and other hydrological processes. Consequently, hydrological constraints will be very different in different climatic regions and the most urgent environmental problems are not the same in, for example, Alaska or Namibia. Some examples from the major regions of the world will be presented in this section to show how our inadequate understanding of ecohydrological linkages causes degradation of the natural resource base not only now but for future generations. A vital lesson for us is that problems can only be solved if they are perceived as important and if their causes are adequately identified.

Cold regions

When the canopy is removed from large areas of forest, strong winds and severe cold may prevent further growth of seedling.

The polar regions (E in Figure 2.1), has no months with average air temperature above +10° C, which means that no forest can grow here.

Also in the cold humid temperate regions, with at least one month with an average air temperature below -3° C, but at least one month with an average above +10°, (D in Figure 2.1), are biological and chemical processes very slow, but there are considerable differences between winter and summer. A large part of the annual streamflow generation takes place in connection to snowmelt in spring.

Large scale exploitation versus the vulnerability of cold regions

In Siberia, Canada and other cold regions of the world exploitation of natural resources such as oil, gas, minerals and forests destroys vulnerable ecosystems. There are numerous examples where exploiters have not recognised the vulnerability of the ecosystems. They have moved into regions where, for example, regrowth of forest after clear-cutting is restrained by climatic factors and where the productivity of the land is virtually reduced to a minimum.

Both plants and animals living under the increased climatic stress are more sensitive to additional stress factors such as pollutants. Cold and harsh climates reduce the rates of chemical and biological processes, such as decomposition of pollutants. Cold regions are thereby rendered particularly sensitive to pollution. Ecosystem recovery from pollution may take a very long time, much longer than in a subtropical climate. Large scale mining of minerals and oil, without due attention paid to controlling waste flows, is a very real threat both to the survival of vegetation, wildlife and human beings. Leakage from oil production in Siberia and the Exxon catastrophe on the Alaskan coast are only two examples of how land and water resources are being seriously polluted by exploitation activities.

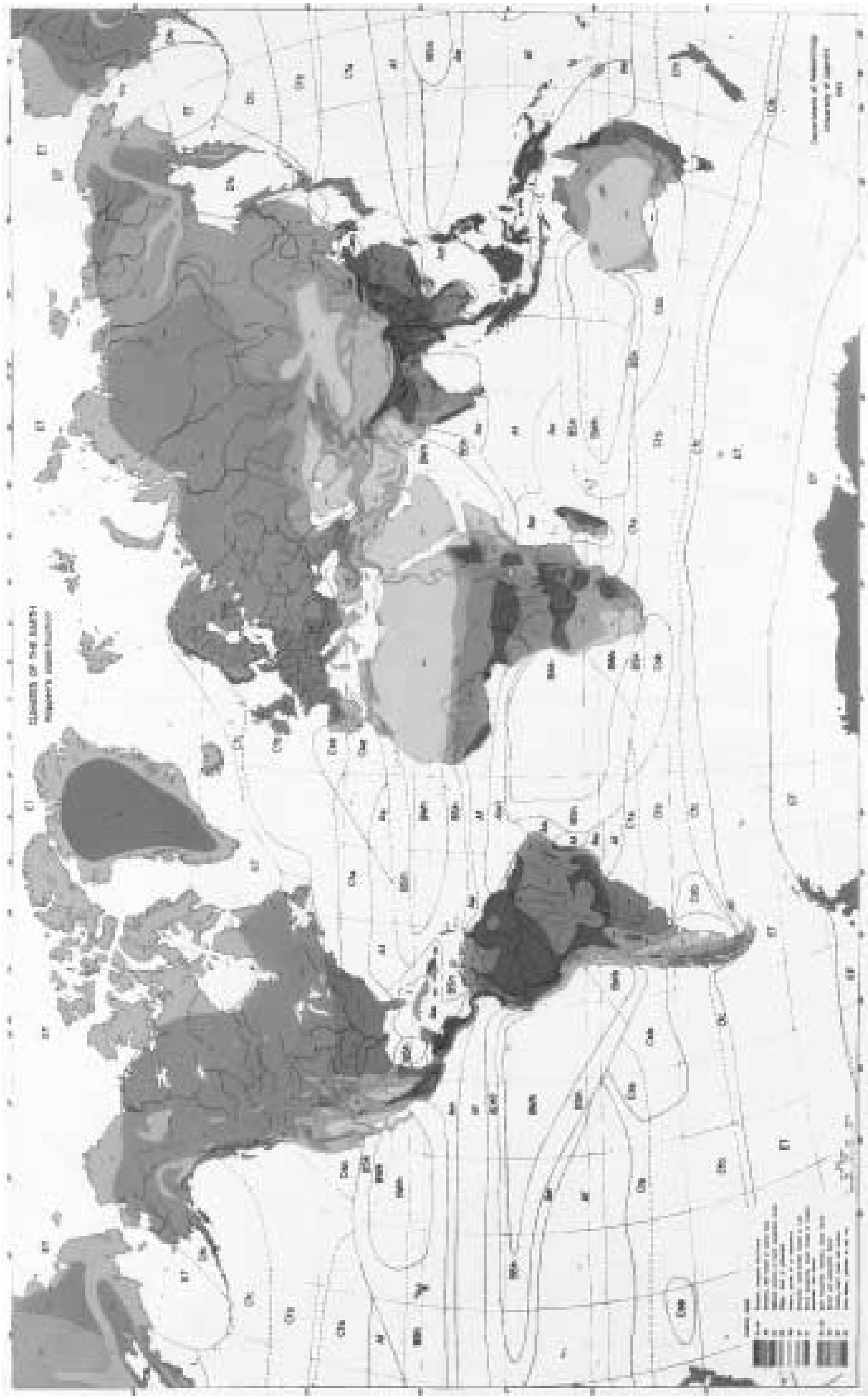


Figure 2.1. *Climate of the earth (After G.T. Trewartha 1968.)*

Temperate humid regions

Also temperate humid regions (C in Figure 2.1) have considerable differences between summer and winter temperatures. Chemical and biological processes are quicker than in the cold regions, since air temperatures are higher. The coldest month has an average air temperature between -3 and +18° C, and the warmest month above +10° C. There is usually streamflow generation all year around, although rather limited during summer when the soil is not saturated.

Pollution heritage transmitted to the future

In temperate humid regions water shortage is generally not a concern. Instead, pollution is the most acute problem. Pollution is caused both by today's emissions as well as by pollutants inherited from industrial and domestic activities in the past. The consequences of neglecting the risks of water pollution from metal waste deposited in soils are beginning to show up in, e.g., northern and north-western parts of the Czech Republic (Box 2.1).

Box 2.1 Water polluted from metal waste

In the post WW2 Czech Republic large industrial enterprises were established on a hardpan close to sources of high quality mineral water which had long been used for drinking and medical treatment. Due to numerous faults and fissures, the region has a very complicated hydrogeological regime. Deep groundwater is often mixed with the shallow water. Even though expected recharge areas are protected zones, the groundwater quality is affected by industrial activities far beyond the boundaries of those areas. Large amounts of heavy metals often remain stored in soils in the unsaturated zone. After periods of heavy rainfall or snowmelt those soil layers become saturated and, in these altered chemical conditions, metals dissolve into the groundwater and are washed away to downstream areas.

Present remedial action is complicated by difficulties in identifying the sources of the metals. Some can be traced only after searching through several decades of the factories' historical archives. In some cases the pollutants are located under the foundations of new factory buildings. Scarce economic resources and complicated legislation are other factors slowing the restoration process.

However, small domestic companies have recently been offering factories relatively low-cost assistance and, together with increasingly strict environmental regulations, companies are slowly beginning to invest in solutions to some of the environmental problems. The new legislation also requires that the "old load on the environment" is specified and reflected in the price of the enterprise when it is taken over by private companies.

The consequences of neglecting the risks of water pollution from metal waste deposited in soils are beginning to show up in various parts of the world.

A similar problem is caused by the leakage of heavy metals from numerous waste dumps in former mining areas. Large amounts of deposited tailings containing sulphide minerals are slowly oxidised and sulphuric acid, along with metals, are leached into ground and surface water. Such situations are frequent, and accentuate the problem of pollution of common resources by earlier generations. A question in such situations is whether the present landowner is responsible for measures to decrease the metal flow from the waste deposits, or whether it is a responsibility of the local or national government. In some cases, e.g., Bersbo, Sweden, the national authorities took the decision to implement one possible remediation method by covering the mine tailings with clay and soil which will considerably reduce the metal flow from the deposit. However, the high costs of this method probably prevents its use on many other sites (Box 2.2). Acid precipitation or "acid rain" further increases the solubility of metals. During the 20th century increasing emissions of acidifying substances into the atmosphere have caused extensive damage to many forest ecosystems. Acid deposition increases the mobility of metals in the soil. This decreases plant production on soils with low buffering capacity when important cations such as calcium, magnesium and potassium are leached away. Widespread damage of trees in South Sweden has recently been correlated with a considerable decrease of potassium in the trees. Joint international efforts have considerably reduced sulphur emissions in many countries, and similar conventions are in progress to reduce acid-producing nitrogen gases. Further reductions will, however, be required to eliminate these problems.

Nitrate pollution of drinking water resources constitutes a health hazard, particularly for children. This problem is rapidly increasing in regions that have permeable soils and slow groundwater movements and that are supporting very intensive agriculture. The concentration increases observed today originate from decades of intensive cultivation with high nitrogen inputs to soils. The increasing atmospheric deposition of nitrogenous compounds also contributes to the problem. However, improvements will be ob-

Box 2.2 Leaching of heavy-metals from waste dumps

In Bersbo, in southern Sweden, it was estimated that 5 – 10 % of the metals – ranging from 0.8 ton cadmium to 400 tons zinc – originally in the tailings (dating from the 14th century to 1900) have now reached the sediments in a downstream lake (Sandén and Carlsson 1990). However, the lake sediments have also functioned as a filter to considerably reduce the further spread of the metals to downstream areas.

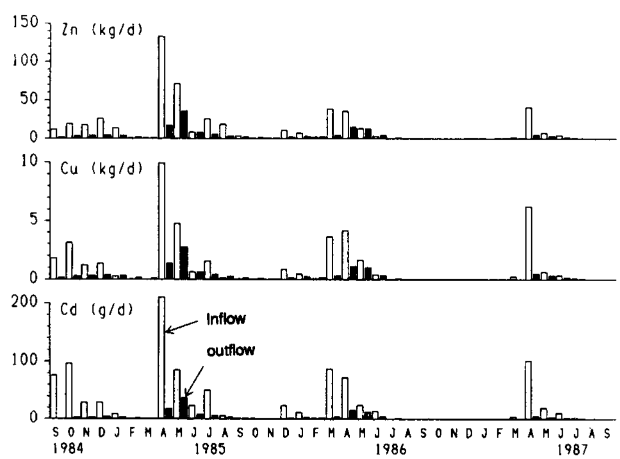


Figure 2.2.
Calculated influx and outflow of metals to Lake Risten, downstream from the Bersbo mining area (Sandén and Carlsson 1990).

Box 2.3 Nitrate in groundwater

In Denmark, the nitrate content in groundwater has increased steadily by a factor of almost 20 over the last 60 years (Pettersen 1994). In more and more places the nitrate content has risen above the WHO standard for drinking water. Nitrate in groundwater moves towards marine waters. In Kattegat, during the last 20 years, the nitrate content has increased by a factor of 5 which has led to increased algal production (Richardson and Ærtebjerg 1991). Moreover, some microalgae while in bloom, produce substances that are toxic to the sea fauna. A substantial amount of oxygen is consumed in the decomposition process of dead algae. The result is anaerobic seabeds and death of the bottom fauna – a vital food source for some fish species.

Nitrate pollution of drinking water is rapidly increasing in regions supporting very intensive agriculture on permeable soils that have slow groundwater movements. It constitutes a health hazard, particularly for children.

served over the coming decades as radical and co-ordinated changes in national agricultural policies related to, for example, fertiliser application, manure storage and cover crops are gradually agreed upon. Individual farmers also have a responsibility to undertake additional measures in particularly sensitive areas. Significant improvements may be achieved if western world decide to reduce overconsumption of animal protein (see Chapter 6).

In the drier parts of the humid temperate regions (Cw and Cs in Figure 2.1), cultivation of virgin grassland has had massive hydrological and ecological consequences. Wind erosion and soil salinization are severe problems in these areas. In some cases, the entire top soil layer has been eroded, destroying the base for further cultivation. Lack of wastewater treatment aggravates the seasonal water scarcity problems.

Tropical humid regions

In tropical humid regions (A in Figure 2.1), the monthly average air temperature is above +18° C all year around, and seasonal differences are rather limited. Potential evapotranspiration is less than the precipitation, i.e. there is no water deficit. Due to the high air-temperatures, and the constant availability to water, biological and chemical processes and transport of substances from the soil to groundwater and rivers is very quick.

Clearcutting: imitating the temperate forester

The effects of deforestation are a major concern in tropical humid regions. Deforestation is often followed by non-sustainable land-use. Productivity ultimately decreases due to soil compaction, erosion and to nutrient depletion. High floods follow with increased frequency causing severe damage to downstream areas. More important, extensive deforestation in this region poses a formidable threat not only to global biodiversity, but possibly also to regional and global climate. The forest canopy has a profound impact on local climate. When this canopy is removed over large areas, there is no protection for new trees and further growth of seedlings is prevented. Recent results indicate that large-scale deforestation of the rainforest would make the regional climate cooler due to lower evapotranspiration and reduced rainfall. The role of the forest as a sink for atmospheric carbon dioxide, bound as organic carbon in the tree biomass, may also have a significant impact on the climate.

Most clearing is done on large properties for cattle ranching and is motivated by land speculation...

The question of who is to blame for the deforestation has profound implications for programs to reduce forest loss. Poor "shifting cultivators" are often accused to be the main forest cutters, the argument being that "people clear land out of sheer necessity to grow more food". Whereas this may be true in some parts of the world, it is largely inappropriate for others. In Brazil, for example, a great deal of clearing is done on large properties for cattle ranching and sometimes motivated by land speculation. In such situations, measures aimed at changing cultivation practices among small farmers will not contain deforestation. In other areas, where demand for biomass for food and fuel is the driving force behind deforestation, shifting to various forms of agroforestry systems can be a viable strategy to avoid land degradation.

Box 2.4 Clearing rainforests impoverishes soils

In the Brazilian Amazon, 426,000 km^2 of the rainforest has already been cleared (Fearnside 1993). Almost all of this area has been converted to cattle pasture. After nearly a decade of use, the soil's nutrient store has been exhausted and the soil compacted. Non-productive land lies where rainforest once grew. The present extent of the cleared area has already surpassed the Brazil's financial limits and physical resources (such as phosphate) for maintaining permanent agriculture, ranching or silviculture. Thus, the motivation for further clearcutting, if land is to be cultivated in a sustainable manner can not be demand for new land. The foremost challenge is to develop sustainable landuse systems on the areas already cleared.

Box 2.5 Human interventions on land cause sand, salt and sulphate pollution in water

In Ukraine, the transformation of about 70 % of the virgin steppe into agricultural land has been followed by widespread erosion and increased sediment in the water courses (Manukalo 1995). In the areas where irrigation is practiced, soil salinisation, due to bad management of the irrigation schemes, is commonly encountered. Extensive drainage of catchments in the northern Ukraine has caused up to fivefold increases of ions such as sulphate and chloride in the river water, and, for this reason, has affected the use of water for households and industry. Increased high flood frequencies with ensuing severe economic losses have also been related to profound changes in the catchment hydrology.

Arid regions

In arid regions (B in Figure 2.1), the annual potential evapotranspiration exceeds the precipitation. Due to this, these regions can only feed rivers with water for limited parts of the year.

Water scarcity limits livelihood security

In many countries of the tropical dry region the population growth rate is among the highest in the world. Drylands constitute about 24% of the land area in developing countries.

These are the lands that will have to continue to fulfil most of the global requirements for food for expanding populations. Here, the challenge is how to secure livelihood for the unavoidable population growth in the next decades, as discussed in Chapter 1. The long-term goal of sustainable development in those regions is strongly linked to water availability, and in practice, to measures aimed at containing population growth and reducing poverty. Although the averaged statistics over large regions still indicate yearly increases in agricultural production, there is an alarming rate of decline in areal yields (tons/ha) of cereals. This is especially apparent in regions prone to water scarcity in sub-Saharan Africa.

Massive land degradation and water scarcity are directly linked to a rapid population growth. These are characteristic problems for many countries in the arid and semiarid tropics and subtropics. In order to keep pace with population growth, food production has to increase by no less than 3% annually.

There is an alarming decline in cereal yields for areas of Sub-Saharan regions prone to water scarcity.

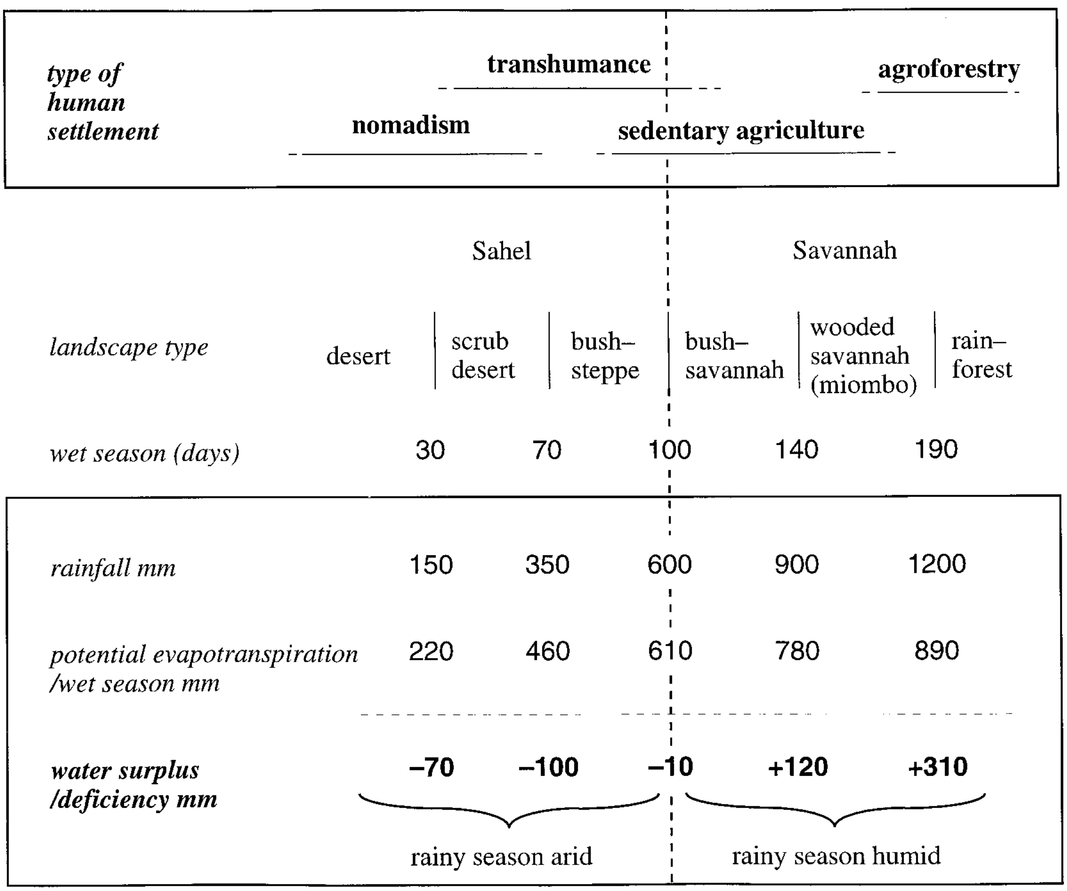


Figure 2.3.
The environmental preconditions for human settlement patterns in the Sub-Saharan zone in terms of rainfall, potential evapotranspiration and water surplus or deficiency. (Data from Mageed, Vadstena Seminar 1989.)

Productivity must increase three times faster than in the past since there are limited areas for extending cultivation. Water scarcity, a most important factor, limits achievement of this goal...

In Sub-Saharan Africa, food production has increased by merely 1.9% from 1970 to 1990, and half of this growth has actually been achieved by expansion of the cultivated area. Since there are limited areas for extending cultivation, productivity must rise by more than 3% a year — three times faster than in the past. Water scarcity is one of the most important limiting factors to achieving this goal. For instance, in the Sahel zone even the rainy season is arid in the sense that there is moisture deficiency in comparison with the potential evapotranspiration (Figure 2.3). In such areas, the available water only allows for fast growing annual crops cultivated during the short rainy season (e.g., pearl millet and sorghum) or perennial plants such as pasture grasses that can survive during dry periods. Traditionally, people have been coping with this, but the increasing population density forces people out onto marginal lands.

In Eastern and Southern Africa, cattle rearing over the last fifty years has caused severe degradation of the natural vegetation. In Botswana, drilling of boreholes has decreased the importance of water as a limiting factor for the number of cattle present in a certain area. Herds now exceed the long-term capacity. A large number of cows concentrated around the boreholes during dry seasons further accentuates overgrazing and soil erosion problems. Further, nitrate and microbial pollution of groundwater from the enormous increase of cattle herds is a growing problem that limits the suitability of groundwater for drinking water. Nitrate from latrines is also transported during rainy seasons, an observation that points to the need to adapt sanitary solutions to local soils and hydrological conditions.

Irrigation is commonly used to cope with water scarcity. In many areas "groundwater mining" for crop irrigation creates a non-sus-

Box 2.6 Extensive farming causes land degradation

Fearing another rainfall shortage after the droughts of 1973 and 1984-85, and to ensure some success under poor conditions, farmers in the Sahel increased their cultivated areas. Agriculture spread into zones characterised by accentuated water deficiency and high ecological vulnerability.

The resulting land degradation accelerated the water scarcity problem. In addition, pastoral land has been increasingly degraded. Factors considered responsible for this are land tenure conditions and a gradual transfer of livestock ownership from the pastoral population to absentee owners. (Bonfiglioli 1988).

Box 2.7 India's tank irrigation projects

In a part of Tamil Nadu in southern India, water is provided for 3-4 months during a 18-24 month period. This limited amount of water is shared in large irrigation projects to enable people to grow arable crops such as millet or oil seed. Rainfed tank irrigation projects are used to irrigate about 3 million hectares, but the projects suffer from bad land and water management that has lead to excess water at some places and to water scarcity in others. Extensive soil erosion in the catchment causes productivity losses and reduces tank capacities. Other problems have been observed including, in Coimbatore, sinking groundwater tables in areas under extensive groundwater irrigation (Sivanappan, 1995). However, technologies are available to integrate land and water management in a sound way and successful watershed development programmes have been initiated.

tainable farming system by rapidly decreasing the groundwater levels. The reverse situation, water logging and salinisation, is another commonly encountered problem. In the Murray-Darling basin of eastern Australia, which was previously mostly forested, about 50% of the trees in the basin have been cleared for agricultural land. In the past, recognition was not given to the importance of high evapotranspiration for maintaining the groundwater level. Severe salinity problems now occur on land where deep-rooted trees have been replaced by shallow rooted grasses (see Chapter 6). Irrigation contributes to the salinity problems in large areas of the world by elevating the water table to a level immediately below the soil surface. As soil salinity increases, plant growth is inhibited thereby enabling water and wind to erode much of the top soil. Degrading river water quality has caused severe problems for downstream users. The main reasons for these problems seem to be inadequate administrative and ownership structures for land and water management; such problems can be overcome.

The case of the Murray-Darling Basin is one example where a successful strategy for land and water integration has been implemented. There are also cases where small scale garden irrigation has been successfully integrated with traditional farming systems. Those and other viable strategies to cope with arid conditions will be further discussed in chapters 6 and 7.

Box 2.8 Problems in Australia's agricultural cradle

The Murray-Darling Basin, an area of about a million square kilometres, is Australia's most important agricultural region, accounting for e.g., 50% of the sheep flock, 50% of the crop land and 75% of the irrigated land. Extensive irrigation schemes, totalling over 1.1 million hectares, have been built in the lower basin. In the whole basin, about 4.5 million hectares of agricultural land is degraded each year due to salinisation (Walker and Lyle, 1994). In the lower basin, since the mid 60s, the salinity has caused an increasing concern about the deteriorating water quality in the lower Murray river. In the upper basin, water logging and salinisation cause production losses of about 40-50 million AUSD per year. Recently, however, a Natural Resources Management Strategy has been developed to protect water supplies and water quality. Because the majority of the land is privately owned, it was recognised, in developing the strategy, that a mechanism was required which involved the community in the management of the natural resource base. Land and water management can be successfully integrated as shown by this example, through the formation of regional organizations, a basin Commission and the introduction of legislation for catchment management (see also Chapters 6 and 7).

In the Murray-Darling Basin a successful strategy for land and water integration has been implemented.

Tomorrow's environmental problems are already here

Land and water: scarce resources

The global water cycle determines the volume of the potentially available freshwater resource. Only about 41,000 km^3/year recharge aquifers, rivers and oceans, and are thereby potentially usable by humans. 50% of this water flows, unused, as floodwater to the oceans, and about 12% of the rainfall falls in unexploited remote areas. A range of 9,000 – 14,000 km^3/year has been suggested as the practical upper limit for the world's available supply of renewable freshwater. We are presently withdrawing more than 4,000 km^3/year and this is projected to exceed 5,000 km^3 by the turn of the century.

Irrigated agriculture is by far the largest consumer of water, worldwide, withdrawing approximately 69% of the annual renewable water resource. In dry hydroclimatic zones of the world, the water withdrawals in irrigated agriculture even exceeds 80% of the yearly renewable water resource. The high consumption of water for food production in agriculture is unavoidable. Large volumes of water are necessary to cover crop demands for transpiration and the atmospheric water demands (evaporation). The water actually available for food production is closely linked to soil surface conditions, for example, crust formations which determine infiltration capacity, as well as the texture and structure of the soil profile. This in turn means that agricultural land management practices are closely related to water availability.

Land is a finite resource; yet in many regions of the world, population growth and demand for water and soil to provide food is increasing dramatically.

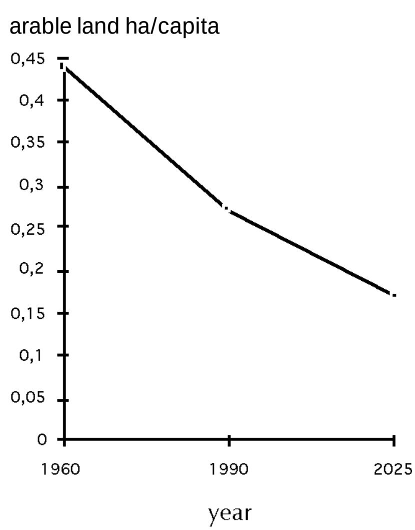


Figure 2.4.
The global per capita availability of arable land has diminished rapidly, dropping from 0.44 ha/capita in 1960 to 0.27 ha in 1990, with a projected 0.17 ha/capita by the year 2025. (Engelman and LeRoy 1995).

The problem of managing land and water is further aggravated by the fact that land is also a finite resource at the same time as population growth and demand for water and soil to provide food are increasing dramatically in many regions of the world.

As already indicated ninety percent of population growth occurs in developing countries where there is little or no more land to put into cultivation. Projections to achieve a 3% increase in food production over the next decades rely on 30% cultivation of new land, and up to 17% on intensification of cropping patterns. This includes continuous cultivation (less fallow) and intercropping. The question is if this land actually is available. Can it be managed in a sustainable way to avoid soil degradation and fertility depletion?

The production of biomass is not only a question of covering human needs for food; biomass also constitutes a source of fodder, fibre, construction wood, and fuelwood. In rural regions in Sub-Saharan Africa, fuelwood contributes about 90-95% to energy needs. The landscapes are poor in biomass with above ground primary production attaining only 100-2,000 kg/ha. There is, therefore, in many dry rural landscapes throughout the developing world, a very real and ever present "biomass conflict" between different users.

Urban areas: growing environmental problems

Almost half of the world's population lives in urban areas and expansion of large cities continues at an accelerating rate. From 1970 to 1990, the urban population increased by 86%, and 67% of this increase occurred in less developed regions. The largest and the fastest growing cities are situated in regions with the lowest GNP, and with the lowest economic resources to manage the formidable infrastructure and environmental problems that are intimately linked to urbanisation. (see Figure 2.5). In the less-developed regions, measured as GNP per capita, the world's fastest

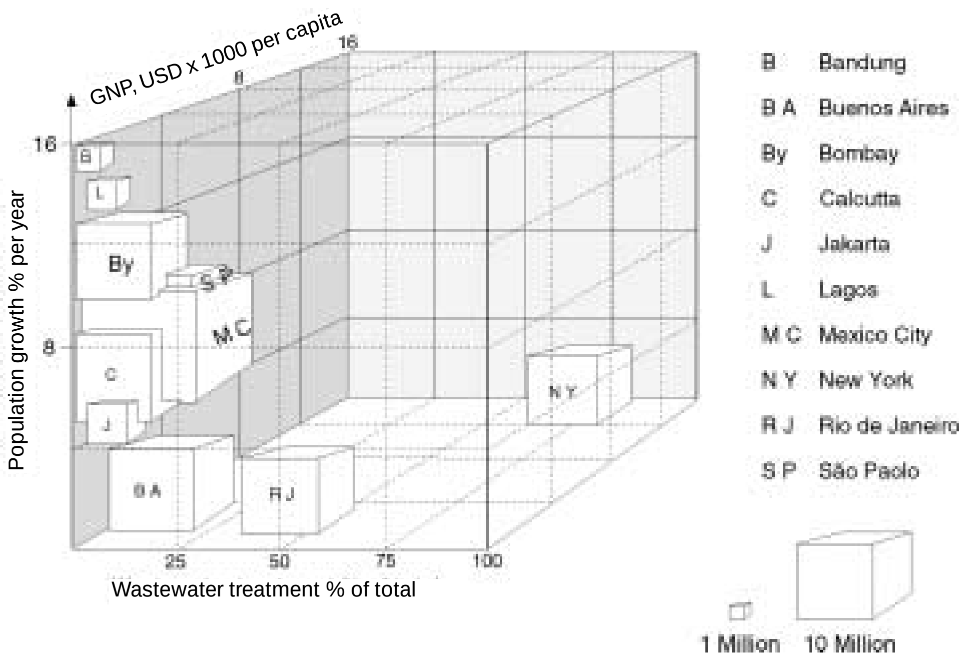


Figure 2.5.
Relation between population increase rate, GNP per capita and wastewater treatment capacity in some large cities in the world.
(After Niemczynowicz 1992.)

growing cities are situated, e.g. Lagos, Mexico City, Jakarta. Those are also the cities with the lowest percentage of the population served by wastewater treatment.

Not only is urbanisation a problem of resource supply, e.g., water, food and energy; a major part of global pollution is probably generated in urban areas. In most of the cities in less developed countries, waste and wastewater are discharged into the environment at an accelerating rate without regard to recirculation and treatment. The result is often degradation of the quality of water resources for downstream users. A serious threat is coastal pollution since most of all large cities are situated by the sea. In many areas, both biodiversity and fish production have been strongly reduced as a result of urban pollution, particularly in tropical and subtropical regions.

Box 2.9 Indonesia's megacities

In the city of Jakarta, the water supply and disposal systems were once designed for half a million people. In 1985, the city had a population of 7.7 million and a projected growth to 17 million by the year 2000. The city currently suffers continuous water shortage and less than a quarter of the population have direct access to water supply systems. Over-exploitation of groundwater increases saltwater intrusion in the aquifers and further accentuates the water supply problems. The water level in what was previously an artesian aquifer is now generally below sea level; locally it is down to 30 m below. Saltwater intrusion has practically ruined this as a source of drinking water (Lindh and Niemczynowicz, 1989).

Water dissolves metal ions from products in the technosphere and transfers them to land, water and living organisms.

Using is polluting

The long-term problems with toxic metals such as cadmium, lead and mercury are strongly related to their indestructible nature and their continued mining and use in the technosphere. This use moves the metals from a slow geological cycling to a faster cycling in the biosphere. Snowmelt and rain water dissolves metal ions from the products in the technosphere and transfers them to the land, water and living organisms, where concentrations may increase by several orders of magnitude. However, the total metal emissions from production processes and from products in use in a river basin or a country are usually very low in comparison with the total amounts supplied to the area. For Sweden, estimated emissions of chromium and lead correspond to only 4 and 9%, respectively, of total amounts (Figure 2. 6).

A similar problem is the accumulation of some other toxic compounds such as PCB and other halogenated organic chemicals, which are highly resistant to decomposition in the environment. Furthermore, we are only beginning to guess the effects of the widespread use of oestrogen-mimicking compounds.

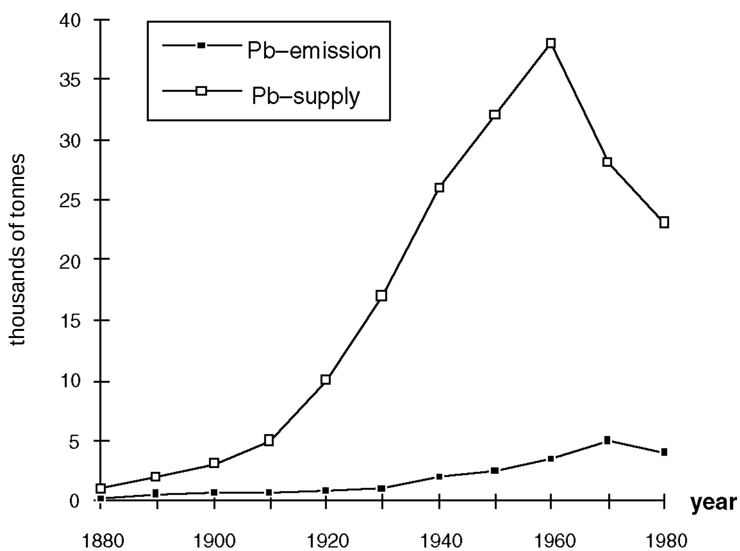


Figure 2.6. *Total calculated emissions compared with total supply of lead in Sweden. (After Bergbäck 1992.)*

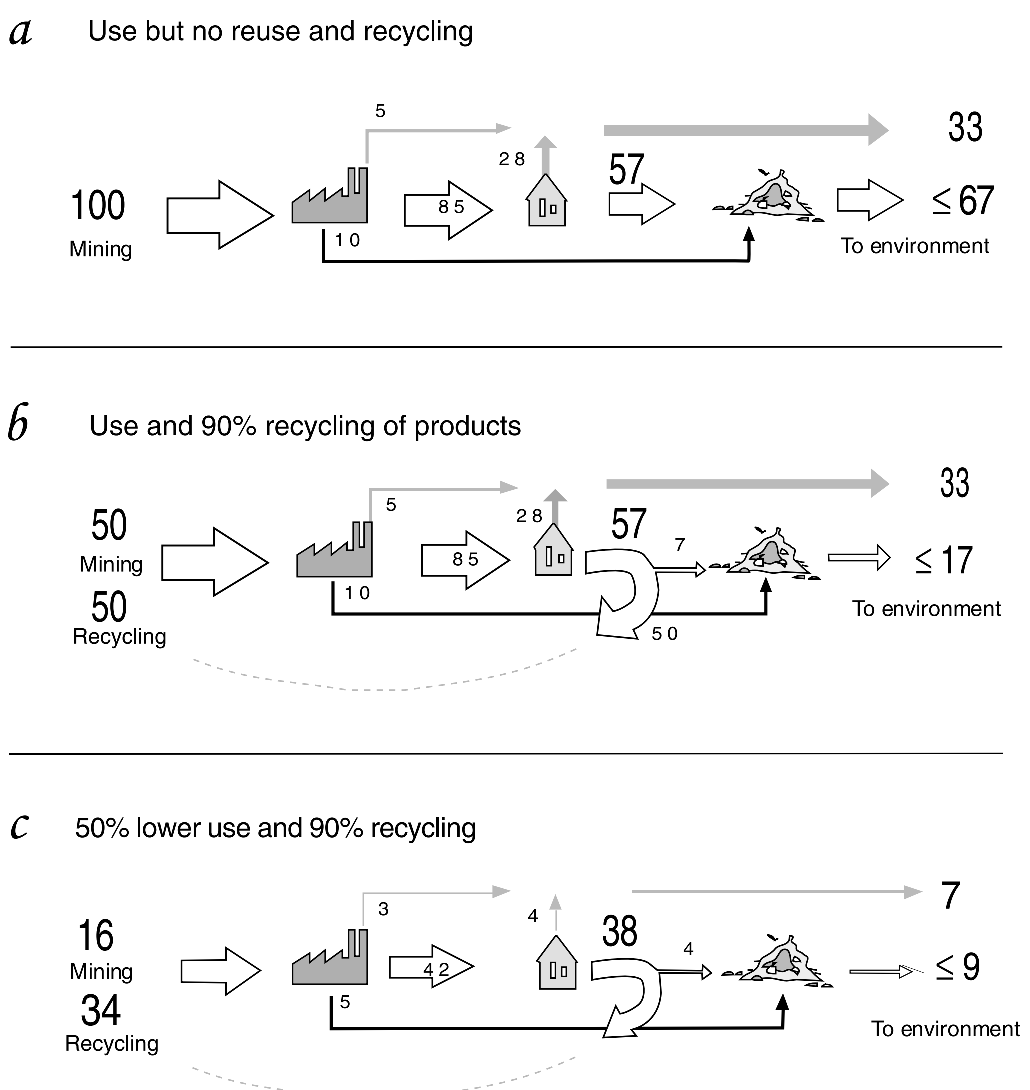
To a large extent many problems are avoidable – provided that the driving forces behind the problems are identified and understood correctly.

Avoiding future problems

Many of the problems described in this chapter have their origin in activities planned and undertaken with a limited or even erroneous understanding of the linkages between land, vegetation and water. To some extent they are avoidable provided that the driving forces behind the problems are correctly identified and understood.

Some current keywords are "reuse" and "recycle". However, as shown in Figure 2. 7, reuse and recycling are not enough to solve the problem of metal pollution. In all processing steps from the mine to the product, metals are lost to the environment. The mere use of products containing metal contributes further to the metal enrichment of land and water. These processes are accelerated by corrosion due to the present level of acid in precipitation. This means that even if we recycle 90% of the metals we use, it is nevertheless, only possible to reduce mining of a metal to a certain extent (50% in the example, Figure 2.7 b) if we want to maintain a constant consumption level. All metals, moreover, will sooner or later move from commercial products to other parts of the environment where they may cause problems (assuming that they are also gradually lost from landfills). Thus, the consequence of mining 1 kg of any metal is that we transfer that amount of metal (since metals are indestructible) from a geological turnover system to one that is much more rapid. Reducing the consumption, i.e., the input into the technosphere is the only viable solution to the problem (Figure 2. 7 c). Indeed, it is urgent to stop using very toxic compounds such as

...all metals will sooner or later end up in the environment ...



... phosphorus and nitrogen are limited resources that must be recycled...

Figure 2.7.
Different levels of use, reuse and recycling of metal with their resultant effects on the amount of metal released into the environment. (After Wallgren 1992.)

mercury or lead. An international ban on the use of mercury has been proposed. Experience from bans on DDT and PCB, however, shows that they must be enforced very strictly in order to entirely stop the use of such products.

In contrast, reuse and recycling nutrients such as nitrogen and phosphorus may go a long way to remediate eutrophication problems. The water resources of the world would benefit considerably if it was recognised worldwide that phosphorus is a limited resource that must be recycled. Recycling should also be the guiding word for dealing with nitrogen. That would drastically change the Western view of animal and human urine and faeces as being a waste problem. With recycling, they could be viewed as a flowing resource base.

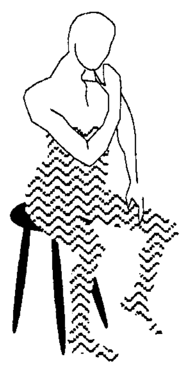
In relation to land degradation in humid tropical forest areas, there is growing recognition that the complex agro-silvi-cultural systems of indigenous peoples have a great deal to offer in the design of sustainable agroecosystems. This is also true for many of the other problems mentioned above. Humans have, for example, been living in arid areas for a long time and have developed techniques (security storage etc.) and methods to cope with water scarcity and extreme year-to-year variations in water availability. This knowledge must be acknowledged and improved with modern technology.

This is as much a question of understanding the way different societies work as it is about understanding ecohydrological linkages. Why is a destructive land-use pattern often continued even though the local stakeholders understand the negative consequences? And why are effective control measures not implemented even if they exist? What are the roles of changed land tenure patterns, legislation and economic incentives, and how can these means be put to use to support sustainable use of land and water resources? These and related questions are discussed in chapters 4 and 5.

3 Natural rules of the game

Environmental problems and regional climate

We live in a landscape that has evolved over geological time. This landscape has been shaped by the interaction between geological processes and climate. The process continues as the prevailing climate delivers water and energy to the land surface. Water then permeates the geological media and is taken up by the roots of the vegetation before its return to the atmosphere.



Water quality and quantity are thus naturally determined by climatological, geological and biological dynamics, which are all interrelated. In many parts of this volume we point to one important fact: humans have demonstrated that such dynamic systems can be drastically disturbed. We tamper with natural systems such as the hydrological and the hydrochemical cycles without knowing or considering the long term consequences of our actions. We break the natural rules at our peril. In this chapter we will discuss some of these natural rules and in the following chapter we will continue to discuss the consequences of breaking these rules.

Do we need to care about water?

In Chapter 1 we discussed the water cycle in its social and natural context. On planet Earth, water is cycling continuously between sea, atmosphere, and land, and then back to the sea. The water cycle passes through every living thing. It will continue as long as the sun irradiates the Earth. It has an integrity of its own, and everything caught by the moving water is carried onwards with that cycle towards the ecosystems on land, in freshwater bodies and in the sea. Water can stay in soil pores and be accessible to roots in spite of the force of gravity because it has a high surface tension and an ability to rise in capillary spaces. It is always on the move from uphill to downhill regions, from the ground surface to the groundwater. It is transported to lower parts in the landscape and returns to the surface and generates streamflow. It has a great capacity for carrying energy, and is therefore valuable as a heater or cooler. Water is thus an extremely versatile substance. In addition it has the unique potential to dissolve material. Many chemical reactions can only take place in the presence of water. Water that is passing through aquifers and rivers is feeding socioeconomic production and societies. This, so called “blue” water is essential for human activities, which will impact water quality and quantity in downstream areas.

Water is vitally important for the different life processes in the body; and land without water is useless.

Has the reader ever thought about the fact that most of her or his own body is just ordinary water? More than two thirds of our body is water – slightly more for men than women. The human body is crucially dependent on replacing the amount of water which is continuously lost from the body. Water is deeply involved in the different life processes in the body. It carries nutrients to the cells and waste products away from them, it plays an active role in keeping the shape of the protein molecules, and assists in regulating the body temperature.

Water plays an equally crucial role for plants. They depend on a column of water continuously passing through the tissues from the soil through to the air. Plant production is operated by water, which enters through the roots. This water carries nutrients and minerals to the plant from the root zone. Water is also a raw material for photosynthesis. When the stomata, i.e. small mouths in the foliage of the plants open to take in the other raw material for this process – carbon dioxide from the atmosphere – water leaves the plant. In hotter and drier regions more water is lost because of the larger evaporative demand of the atmosphere. Water passing through the root zone and back to the atmosphere, feeding plants and trees, is often refereed to as “green” water.

Since water is so crucial for life processes, land without water is useless. Immigrants to America found this out when they travelled west of the Mississippi and had to cope with a dry climate. In the end the inhabitants of the dry West had to build the huge engineering monuments in southwestern USA on which life in southern California is based: the Hoover Dam, the Imperial Canal, the All American Canal, etc. However, even when available, water may be of no use to humans, plants or animals due to the pollutants that it

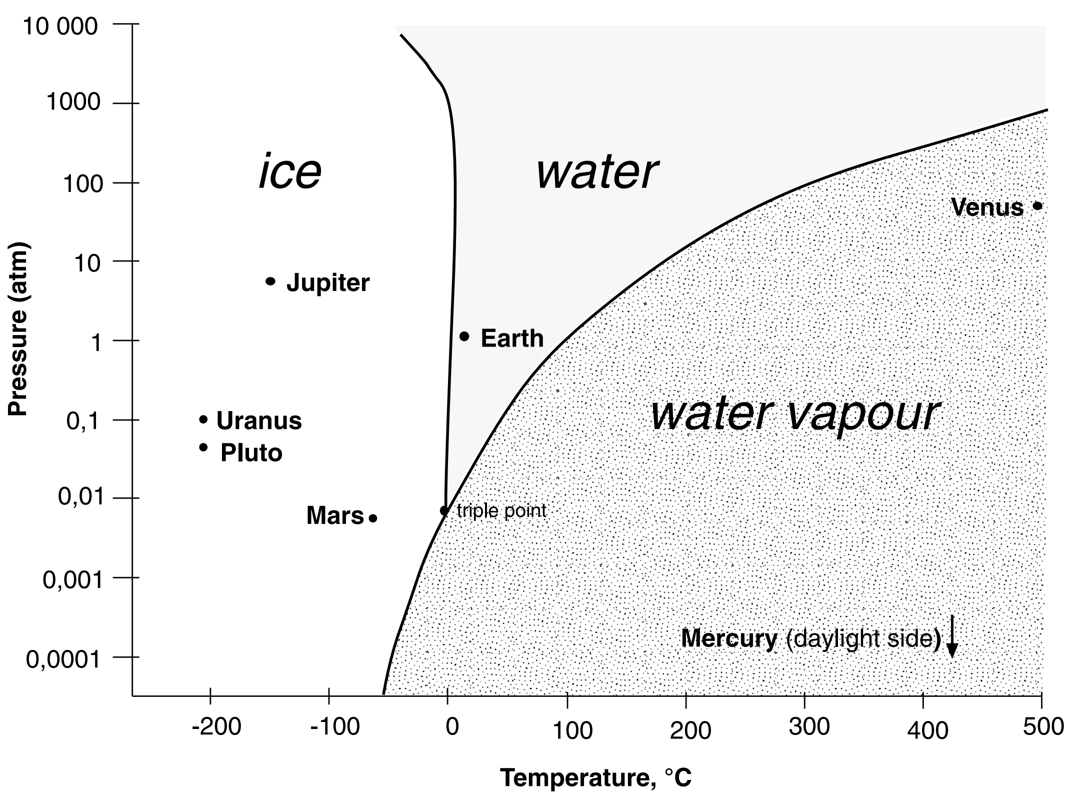


Figure 3.1.
Planetary position on the phase diagram of water.
(After Committee on Opportunities in Hydrological Sciences 1991.)

carries. Engineering projects have therefore been carried out to tap water resources further and further away from the point of use. Moreover, people in the temperate region, where water is abundant, often take water for granted. In studying the dynamics of the landscape interest has been concentrated on energy, nutrient and carbon flows and budgets. A serious analysis of linkages to the variability of water flow in space and time has been left out.

Since water is the very "blood of the biosphere", it is evidently crucial that we protect it. The finite amount that we now get through the water cycle will not change much. Future generations will have no other source of water to feed on.

The Earth is the only planet with liquid water

Liquid water is essential for life as we know it. The earth is the only planet in the solar system with temperatures that allow liquid water to exist (Figure 3.1). On our planet water can shift between all three phases: vapour, liquid, and frozen. Water transfers huge amounts of energy around the planet with fundamental effects on the climate. The earth is almost 35˚C warmer than it would have been without water vapour in the atmosphere. Most of the temperature difference is due to the protective role that water vapour plays against heat loss to space. Water is the main greenhouse gas. Carbon dioxide plays only a secondary role.

If there is an ailing river, a sick landscape may be the cause.

Where do problems arise, and where can they be identified?

"The generalist studies all processes at the largest scale at one time. The specialist studies fundamental processes at the smallest scale. Eventually the generalist knows nothing about everything and the specialist knows everything about nothing."
(Hillel 1991)

The above statement leads to the question, "at what scale do problems arise and at what scale can problems be identified and solved?" The feature characteristics of the landscape are shaped by a chaotic myriad of interacting processes. The knowledge that can help the planner must be at a scale relevant to the problem being addressed. Water quantity and quality are also created by a huge variety of interacting processes, from the area where the water outflow begins to the point where the problem arises. Some processes are natural, some follow human activities. Some influences may be attributed to a certain point in the landscape, whereas other influences have a larger extension in space. Although the problems mainly arise locally because of human activities, the effects can often be identified on a landscape scale at lower points in the river basin.

The integrated effects of hydrological processes is best viewed in the river, as the water has a trace memory of its contact with the land. Despite the complexity of the whole basin, the quality and quantity of water in the river represent the integrated response of all actions taking place in the basin. Measurements taken in the river are our clue to the health of the whole system. Human activities on land are changing the fundamental driving variables of the hydrological cycle. If there is an ailing river, a sick landscape may be the cause. The same can be said of regional aquifers: If there is a decline in quality and quantity in the aquifer, then human activity at the land surface is a likely cause. In management of human land and water interactions, component landscape processes can not be treated as being separate and locations can not be treated as isolated spots, because the land and the rivers are embedded within large and small hydrological cycles. Any change in one component will have a direct influence on other components in the local system and will influence life cycles both locally and downstream at lower locations within the basin.

It is common to separate human activity and nature, but in the following, human activity is treated as an integral process variable within the land and water systems. It will become obvious that human activity is an integral component of the hydrological cycle.

If we try to evaluate the effects of human land and water interactions it is crucial that we understand how the hydrological cycle and land-use or management practices are linked to each other. For this purpose we will bring into focus the most sensitive part of the system: the land surface itself.

Water flows through the landscape

The hydrological basin

First, we must define the base unit of any studies of interactions between land, water and human activities, i.e., the hydrological basin in which water flows from higher to lower points in the system. The water divide is the border of the hydrological basin. The spatial and temporal patterns of streamflow generation and river network vary between different climatic regions. In arid river basins, for example, there may not be any export from upper to lower regions, since all water is lost as evapotranspiration. Evapotranspiration is the combined flow of water via roots and the vegetation tissues, through the stomata to the atmosphere (transpiration) and the flow of wa-

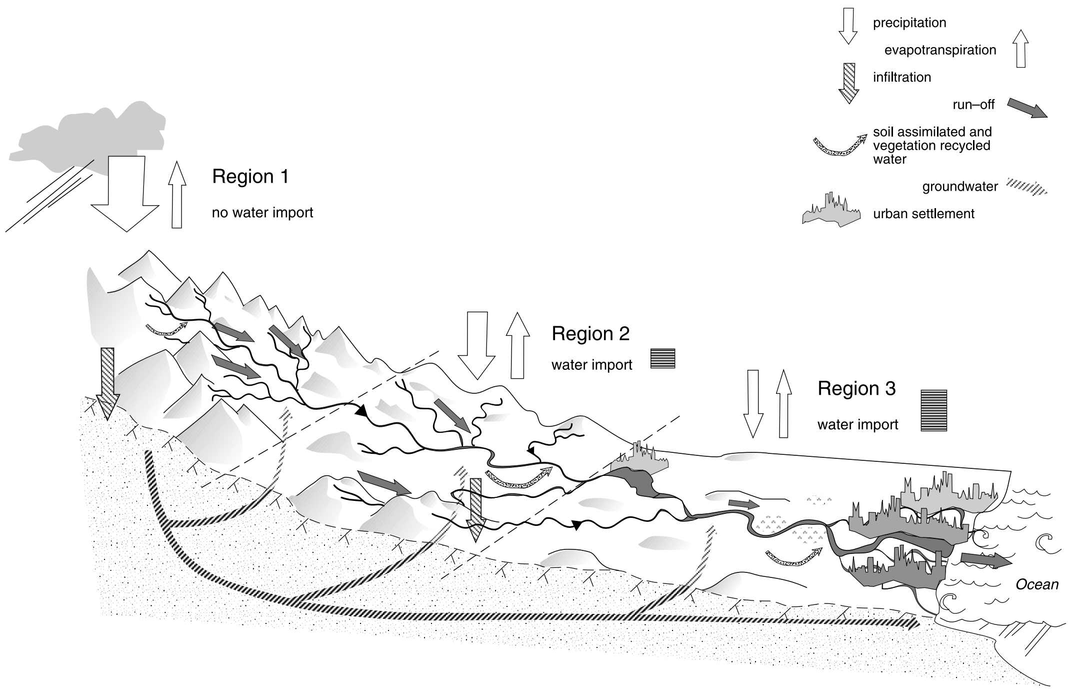


Figure 3.2.
Water flows through the river basin. This basin is assumed to be divided into three regions. The water availability of each region is determined by the local precipitation and evapotranspiration as well as the import of water from upstream regions. The rain water that falls on a region and which does not disappear as evapotranspiration generates runoff.

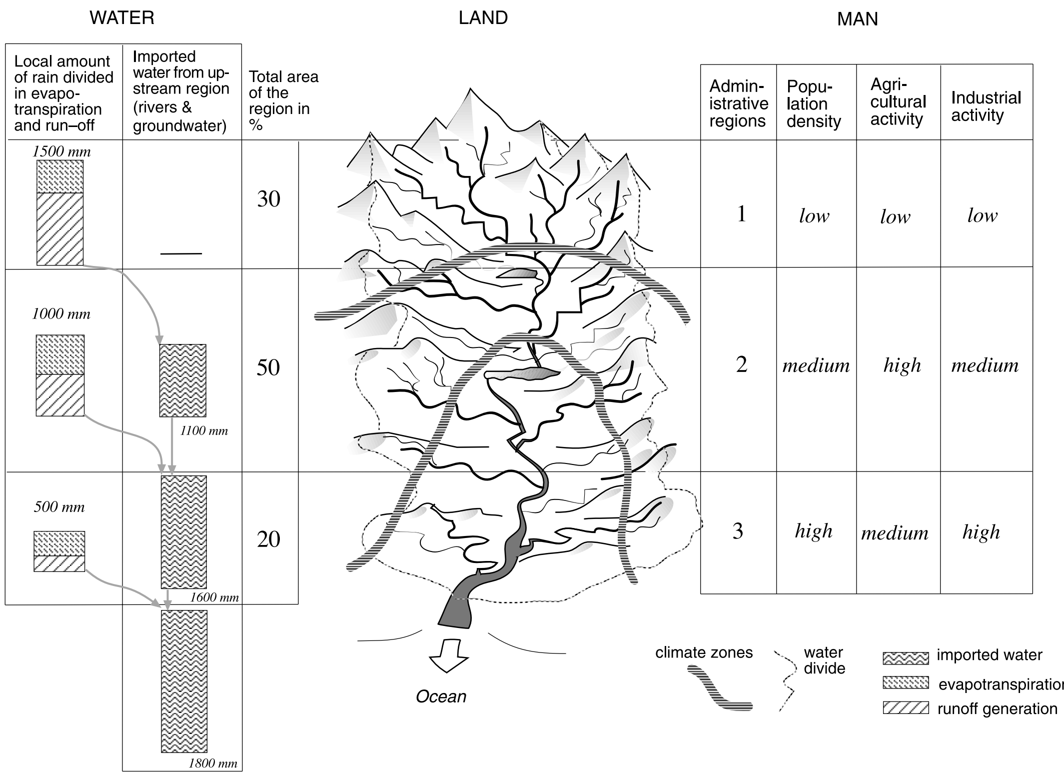


Figure 3.3.
Water availability in a theoretical river basin as determined by climate and human activities.

The lowest regions are strongly dependent on the amounts and the quality of water imported from higher situated regions.

ter from surfaces directly to the atmosphere. The water that flows through a basin is made up by a series of subcatchments connected by a cascading series of channels. Administrative borders do usually run contrary to hydrological water divides, which means that water will be imported across borders from upland regions to lowland regions. Often, there are climatic differences between upland and lowland regions.

Figure 3.2 shows how the whole basin is divided between three administrative regions. The locally produced water flow for each region is built up by the amount of precipitation on that area, minus evapotranspiration. Water that is not evapotranspirated back to the atmosphere is directed from the water divides towards the river channels, often as groundwater flow. In addition to locally produced water, there will be an import of groundwater and river flow from higher situated regions if their precipitation exceeds the evapotranspiration.

In Figure 3.3, the amounts of locally produced river discharge and the amounts of imported water to the three regions are shown. The schema also demonstrates that in addition to water availability, the potential water need and the potential for water pollution increase downstream, due to population growth, as well as agricultural and industrial activities. The figure shows that the lowest region is strongly dependent on the amount and the quality of water imported from the two higher situated regions.

Region 1 has high precipitation and low atmospheric demand for evapotranspiration. Since soils are constantly wet, the actual evapotranspiration is, however, quite high. Agricultural and industrial activities are limited, which means that this region exports water with a low degree of pollution to lower regions. This region is the natural reservoir of the basin and released water can maintain channel flow during long periods of downstream drought.

Region 2 has lower precipitation than Region 1 and higher atmospheric demand for evapotranspiration. The moisture availability sets a limit to the actual transpiration, which means that actual evapotranspiration may be lower than from Region 1. Since total rainfall amounts are smaller and the relative amount of evapotranspiration larger, less runoff will be produced. However, this region imports water from Region 1. Besides surface water, groundwater may be used as a resource. Water may be used by humans and vegetation and then evaporated or recycled back to the groundwater and the river. This affects not only water quantities, but also the quality of the water. On the way, the water may be stored in lakes or dams. The role of groundwater is critical in dry periods, when the streamflow depends on a slow release of groundwater. Extended dry periods will be matched by a progressive drying up of larger channels. Channel drying creates an obvious demand on local groundwater resources. If the extraction of groundwater during an extended time interval exceeds the groundwater generation, this may exacerbate the drying of the streams during coming years.

Region 3 has the lowest precipitation and the highest atmospheric evapotranspiration demand. Since the moisture availability is low, this demand can not be fulfilled. The actual evapotranspiration, and thereby the productivity of the vegetation is therefore low. Runoff generation is very limited, since most of the precipitation, except during extreme events, is evapotranspirated. Due to the limited rainfall and a high atmospheric moisture demand, irrigation, using river or groundwater is necessary for agricultural production. This region, with its dense population depends on imported water. The quantity and quality of that water are strongly influenced by human activities in Region 2. The region probably also depends on agricultural products from Region 2. Population and industrial activities will be centred close to major rivers and large aquifers.

In summary, there is a system of export and import of water, where lowlands are at the end of the chain and depend on water from the highlands. The climate and human activities in higher administrative regions will thus affect the availability and quality of water in lower regions.

Partitioning of incoming precipitation

The precipitation that hits the ground can either evaporate, run off on the surface or infiltrate into the ground. The flows have very different transit times before they leave the river basin. Different plots in the landscape have different water partitioning depending on landscape factors, e.g., soil, topography, and vegetation. The partitioning varies over time, depending on the actual weather conditions and the soil wetness, determined by earlier weather conditions.

There are three different partitioning points (Figure 3.4). The first partitioning takes place at the soil surface, which water either can leave as evapotranspiration back to the atmosphere, or as overland flow, or by infiltrating through the soil surface to the root zone. Moisture in the unsaturated root zone is used for the survival of vegetation and organisms in the soil. A second partitioning takes place in the root zone, where some of the infiltrated water returns to the atmosphere after it has been taken up by the vegetation or is transported up to the soil surface to be evaporated. The remaining water percolates downwards to become groundwater, which is the primary store for water that is directly available to humans. Below the groundwater table, water is transported laterally and downhill towards the river channel. Downslope ecohydrosystem thus become dependent on upslope activity. Along with a local, typically quite dynamic groundwater table, a deeper regional groundwater table may exist. The division between local groundwater flow and regional groundwater generation is the third partitioning point in Figure 3.4.

A river basin is thus built of a mosaic of landscape elements with different hydrological responses to precipitation. For a time scale of years, the integrated response for the whole river basin will show a balance between the incoming precipitation and the water that leaves that basin. This balance between incoming and outgoing water is a fundamental tool for analyses of water flows within a basin. The water balance should, however, not be misinterpreted as something static. The balance only exists in a time scale of years. For a any given moment there is an imbalance, because precipitated water may remain in the river basin as snow, or in the unsaturated root zone, in the groundwater, as well as in lakes and rivers, before it leaves the basin.

Links between wetness, soil, vegetation and human activities

The human influence on land-use is partly controlling the water balance. If humans change the natural vegetation, those changes will control the state of the ground (bare or covered by vegetation), the size of the interception storage in the vegetation canopy, and the amount of water that is evapotranspired

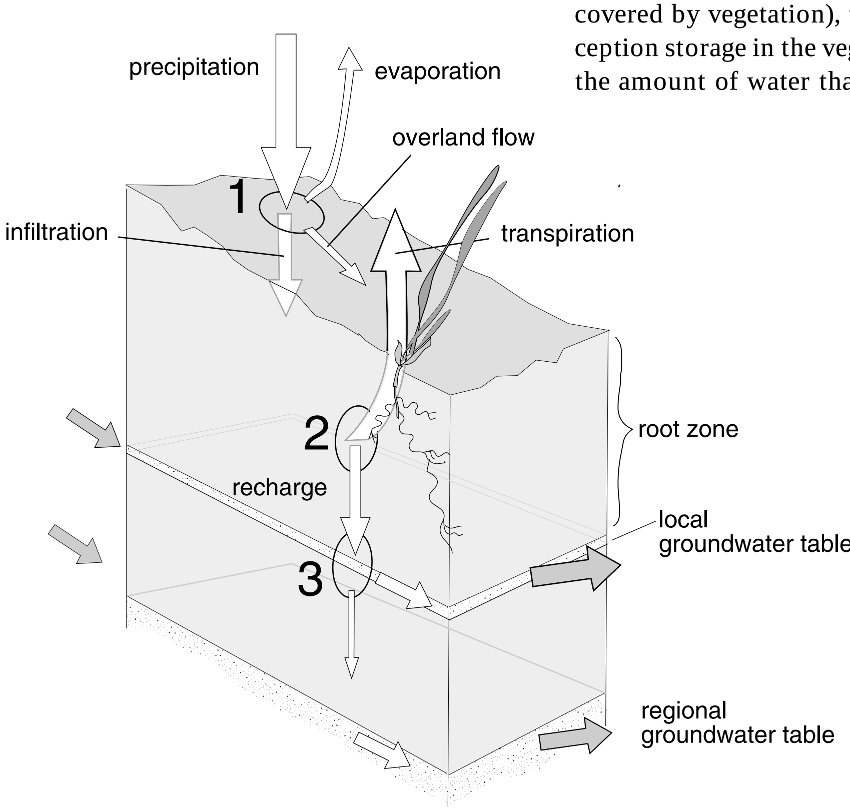


Figure 3.4.
Water partitioning at the soil surface (1), in the rootzone (2), and between local and regional groundwater generation (3).

back to the atmosphere. In addition to changing the natural vegetation, there are other land-use activities that result in significant effects on the infiltration and storage of water such as urban cover, soil compaction by grazing animals, drainage, ploughing, logging, and building of reservoirs.

To survive, vegetation must be adapted to the prevailing wetness conditions, which vary seasonally, and with the soil depth. In a landscape where human influence is moderate, the pattern of vegetation reflects this adaptation well: not only the type of vegetation, but also the number of plants per area is determined by wetness availability. If the natural vegetation is changed, the water demand will change, both seasonally and considering water availability at different depths in the soil horizon. In addition, infiltration and water holding characteristics will change.

Figure 3.5 (a-d) shows some different types of vegetation, in terms of strategies to cope with the water availability. Type (a) promotes low overland flow and high infiltration, although some water is intercepted and evaporated back to the atmosphere. There is a high evapotran-

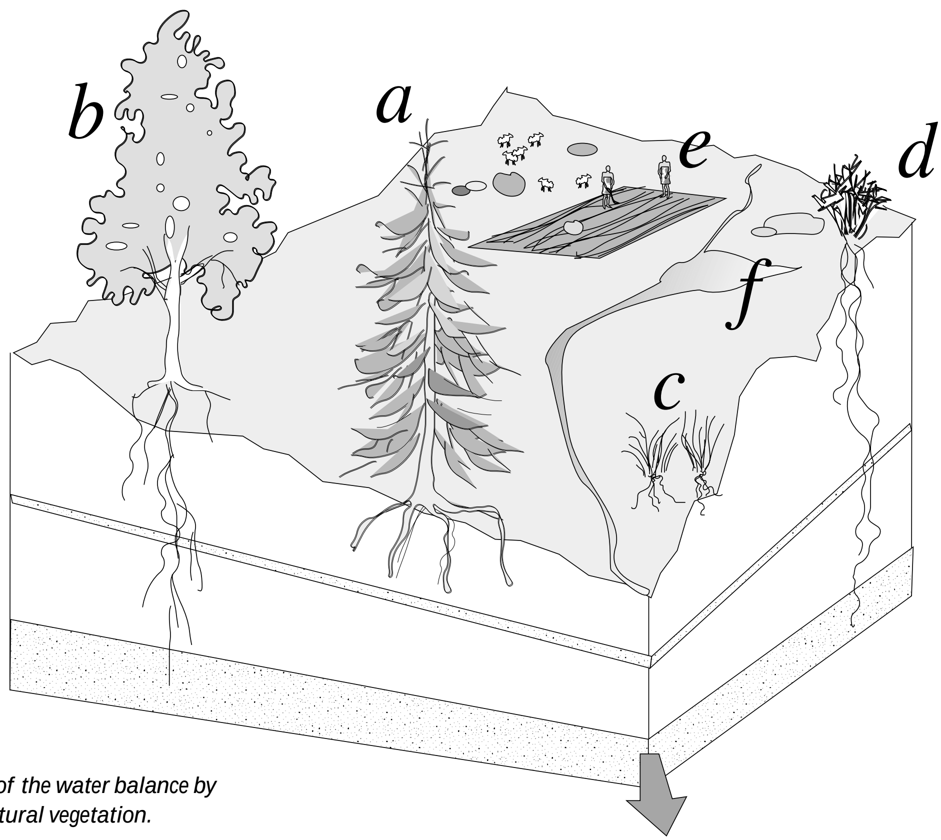


Figure 3.5.
Human control of the water balance by changing the natural vegetation.

a. Tall vegetation, shallow roots
b. Tall vegetation, deep roots
c. Low vegetation, shallow roots
d. Low vegetation, deep roots
e. Bare ground
f. Lakes and reservoirs.

spiration as long as the upper soil is wet, but if it dries out, evapotranspiration will rapidly decrease since the root system is shallow.

Type (b) is similar to (a), but has high evapotranspiration also during dry spells, since it has access to deep soil moisture and may well tap into the water table.

Type (c) with its short roots may, if situated in an semi-arid area, only be growing during the wet season. If the soils becomes crusted, this might lead to erosion and reduced soil infiltration capacity, causing overland flow. Interception losses are small, and evapotranspiration will be moderate and only take place during the wet season.

Type (d) has deep roots, which means that evapotranspiration will continue also after prolonged dry spells, and the soil will be covered by vegetation also after that the upper horizon of the soil has dried out. If the vegetation is totally removed (Figure 3.5 e), transpiration will cease, but evaporation from the soil surface may be high as long as it is wet. Since the ground is uncovered, it is vulnerable to soil erosion and compaction, which may lead to reduced infiltration capacity and increased overland flow.

From lakes and reservoirs (Figure 3.5 f), the atmospheric demand of water will always be met. Open water bodies act as traps for eroded sediments, and will increase transit times for the water on its way to the sea.

Most forests have lower groundwater generation than the surrounding open land due to the transpiration from the trees, i.e., less streamwater is generated from the forest. The linkage between vegetation and streamflow generation, however, depends on many factors. With insufficient land management, soil crusts may develop after deforestation, and increase overland flow. If this is the case, less water will infiltrate into the soil. If the infiltration at the soil surface (water partitioning point 1 in Figure 3.4) is less than the evapotranspiration from the soil surface and the root zone (water partitioning points 1 and 2 in Figure 3.4), the recharge to the groundwater will decrease, and there will be a reduction of the dry-season flow due to the deforestation.

Soil, vegetation, topography and wetness all depend on each other. Water and biological phenomena convert rock into soil that sustains the life cycle. Fine particles in the soil are washed toward the low and flat parts of the landscape that also have the highest wetness. This is due to the fact that water is transported to the lower parts by the forces of gravity, and only slowly drained away because of the low slopes and the fine soils with their low transmissivity. The example in Figure 3.6 is taken from a study of the tundra in Alaska, showing that the pattern of fit between topography, the degree of wetness and the vegetation pattern are closely linked. The vegetation is controlled essentially by the degree of wetness and the redistribution of nutrients within the system. Since undisturbed systems are a rarity, we have to include human activities, such as land-use or land management, when analysing flow paths of water and substances. This artificial cycle may be sustainable or at least give the impression of being sustainable, while often long term degradation of the system is occurring. This is discussed in Chapter 5.

Time scale differences

Water flow varies not only between years and seasons, but also within much shorter time intervals. This variation, which can be crucial for water availability to agricultural or industrial use, is not possible to detect or understand if the chosen time scale for water balance analyses is longer than the time for such fluctuations. The most suitable time scale for a water flow analysis should reflect how fast a basin responds to rainfall or snowmelt events. In a basin where water has long transit times, e.g., as groundwater or surface water in lakes and reservoirs, the flow in the river will be relatively stable between short time intervals. If the amount of overland flow is high or no lakes exist, the temporal variability of flow

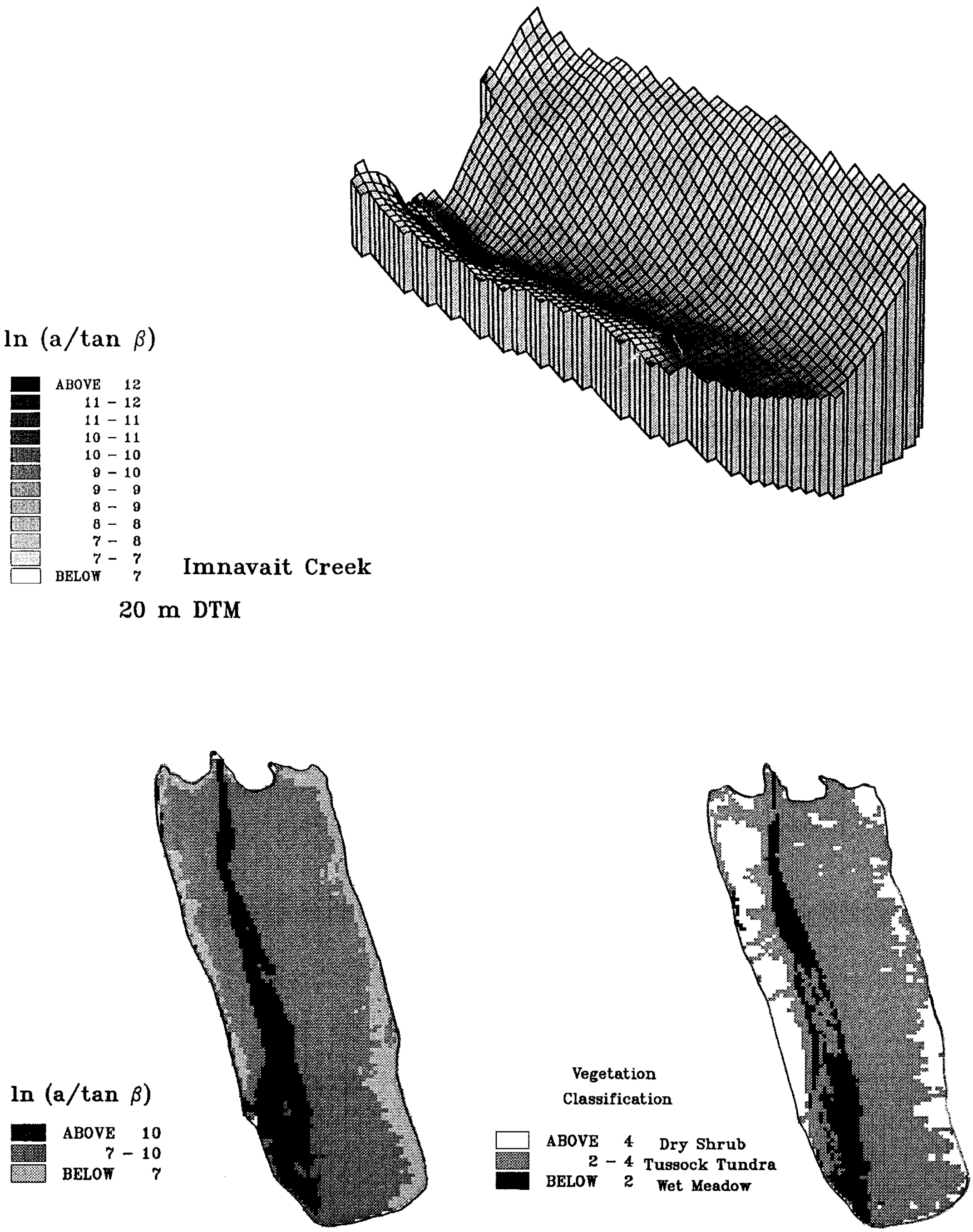


Figure 3.6.

A catchment in the Alaskan tundra divided into a mosaic of grid cells. The wetness index is calculated from accumulated areas that drain through a cell and the slope to the surrounding cells. The vegetation pattern is strongly dependent on the wetness distribution, which in turn depends on the spatial variation in the topography. (P Quinn et al. 1996.)

will be high. Also the size of the basin is of importance, as small catchments respond faster than large river basins.

Annual water balances do not reflect the general make up of the hydrological cycle. The amount of water that will be available to man or to agriculture is not known. In Figure 3.7 we can start to unravel the importance of individual patterns of storm events. In Figure 3.7 we can see that there is strong seasonality in rainfall inputs which is itself an important factor in runoff generation and land cultivation terms. In Figure 3.7 A we can see two months that have the same rainfall, but one has high runoff and the other virtually none. The most probable cause for this is different wetness in the soil moisture zone. If the soil is dry, infiltrating water will increase the moisture content of the soil, but no water will be drained down to the groundwater. After prolonged dry periods, the vegetation cover will decrease and the soil surface may become

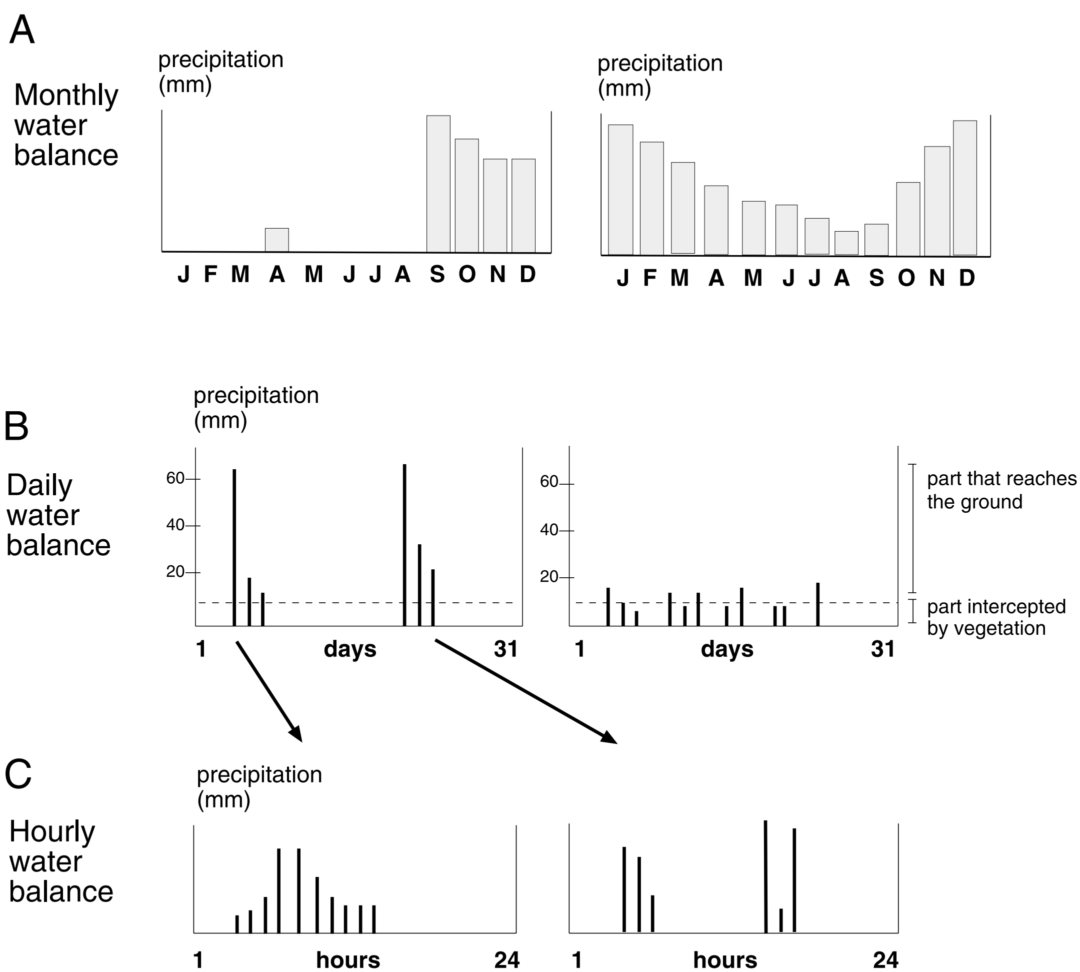


Figure 3.7.
Temporal scale considerations, where we see the same yearly volume of water originating from very different patterns of rainfall.

If rainfall is made up of several low intensity storms, substantial volumes of the water will never reach the ground and infiltrate; it will evaporate from the vegetation canopies.

crusted. In the beginning of a following wet period, this may cause high rates of overland flow and low evapotranspiration rates. A river basin's response to rainfall is thus changing and depends on previous wetness patterns, which can be seen as the memory of earlier weather conditions.

Even with similar soil wetness, the same amount of monthly rainfall can generate different river flow. This can be explained if we use a daily resolution, as in Figure 3.7 B. When rain falls over the landscape, part of it is intercepted in the vegetation and evaporated back to the atmosphere, without reaching the ground. If the forest is dense, a major part of the precipitation will not reach the ground until the canopy storage has been exceeded. If rainfall is made up of several low intensity storms, substantial volumes of the water will never reach the ground and infiltrate; it will evaporate from the vegetation canopies. If the same amount of rainfall is concentrated to one event, the soil moisture store will be substantially recharged, and percolation to the groundwater may well follow. For optimum groundwater recharge, the rainfall intensity should, however, not be higher than the soil's capacity to infiltrate water.

Figure 3.7 C, shows flow peaks during two days generated from the same amount of precipitation and with similar soil wetness conditions. The rainstorm in the first day has an intensity that is lower than the soil's capacity to infiltrate water. Therefore, most of the rainwater is infiltrated and the groundwater replenished. The rainstorm in the second day has a very high intensity and causes surface runoff. The water from this storm is quickly exported from the local system with limited use for humans, vegetation or animals.

Variations of water flow within a basin

The water flow from a basin is the integrated result of all processes within that basin. To assess how human activities within the basin affect the quantity and quality of the water, we need to know the flow paths and transit times of the water on its way from rain to river.

Topography as well as the spatial distribution of geological phenomena and land-use create three general zones:

(1) a zone where infiltrated water mainly is returned to the atmosphere. Infiltrated precipitation is mainly stored in the root zone and returned to the atmosphere. Only during exceptionally heavy rainstorms is there a recharge to the groundwater. Since the soil never becomes saturated, recharge takes place through voids in the soil that leads the water directly to the groundwater. When rainfall intensity exceeds infiltration capacity, water may flow as surface runoff instead of infiltrating. If the soil surface has low permeability (e.g., due to surface crusting or compaction), surface runoff is produced even at relatively low rainfall intensities.

(2) a zone with significant groundwater recharge. Infiltrated water is partly returned to the atmosphere and partly pushed downwards to the groundwater. Surface runoff is possible, although less common than in the first zone.

(3) a zone with groundwater discharge. Groundwater that has been transported from the zone with rapid evapotranspiration and the recharge zone will be pushed up to become streamwater. Rain and meltwater will quickly runoff at or close to the soil surface since all voids in the soil below are filled with water.

The large differences in water partitioning between these zones cause very different relationships between human activities, land and water. The spatial distribution of these zones is very different globally, mainly due to climatic differences. It is therefore crucial that planning decisions are based on models developed for areas with similar climatological conditions. The size and extent of the zones are dynamic and change with the season. The management strategy for a catchment must be sensitive to these differing zones. It must be asked where in the system and during which time of the year it is appropriate to carry out certain land-use activity.

In the zone with rapid re-evaporation the amount of available water is very limited, which means that even a small change of the water partitioning may be critical for the capacity of the land to support life. This zone is highly vulnerable, for land-use changes affecting the soil surface change the capacity to infiltrate water. Land use and management in the recharge zone will affect groundwater locally and thereby also groundwater and streamwater in lower locations. Industrial and agricultural activity in zone three may seriously affect streams and rivers, since transit time from rain to stream is short. The spatial extensions of the zones are dynamic especially where the area of the discharge zone extends after prolonged wet periods.

In humid areas, groundwater is recharged across the basin, except for a small discharge zone close to streams and in wetlands (Figure 3.8 A). It is the push down of moisture from the soil moisture zone to the groundwater table that is the dominant process generating runoff. The whole catchment is recharging water that finally will reach the streams. In semiarid areas only a minor part of the catchment is active in groundwater recharge and runoff generation. The major part of the catchment returns water back to the atmosphere. The high atmospheric demand and the seasonal precipitation will cause the land to act as a sponge. It soaks up moisture during the wet season, when it will be used for evapotranspiration. Groundwater recharge will only occur during heavy rainfalls, and predominately in the wettest, lower parts of the catchments. Surface runoff will also occur especially from crusting zones where the infiltration capacity is low (Figure 3.8 B).

Global differences of the water balance

Global differences in the relationship between incoming precipitation and the evaporative demands are shown in Figure 3.9. As discussed in the time scale section above, this

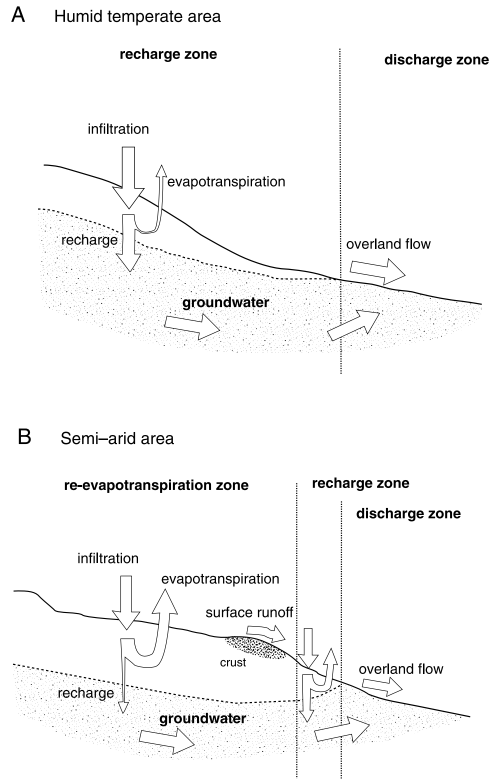


Figure 3.8.
Recharge and discharge zones in different climate. Different water pathways: (A) a humid temperate hill slope; (B) a savanna hill slope, as in the southern margins of the Sahel.

Management strategies for a catchment area must be sensitive to its differing zones.

map can be misleading since seasonal and annual variations are large. The most characteristic trait about water flow is that nothing such as normal exists. In water management, it is therefore often more crucial to consider deviations from the mean since it is the deviations and not the mean that set the rules of the game. If water is available only during a small part of the year, and if most of it then leaves the basin in the form of quick runoff, there can be a water shortage even during a year with comparatively high precipitation. In Figure 3.10, an example of non-existing “normal” precipitation is shown from Namibia.

Figure 3.11, shows examples of water flows through ecosystems in the temperate, semiarid and humid tropical zones. As a conse-

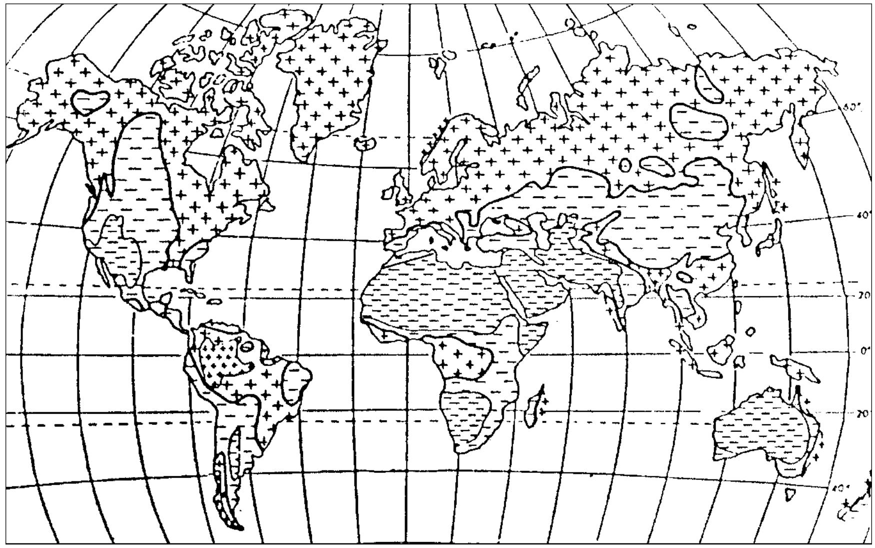


Figure 3.9.
The relationship between incoming annual precipitation and the annual atmospheric evaporative demand for different parts of the world. After Falkenmark 1977. The atmospheric demand increases if the solar radiation is high, air is dry and wind speeds are high.

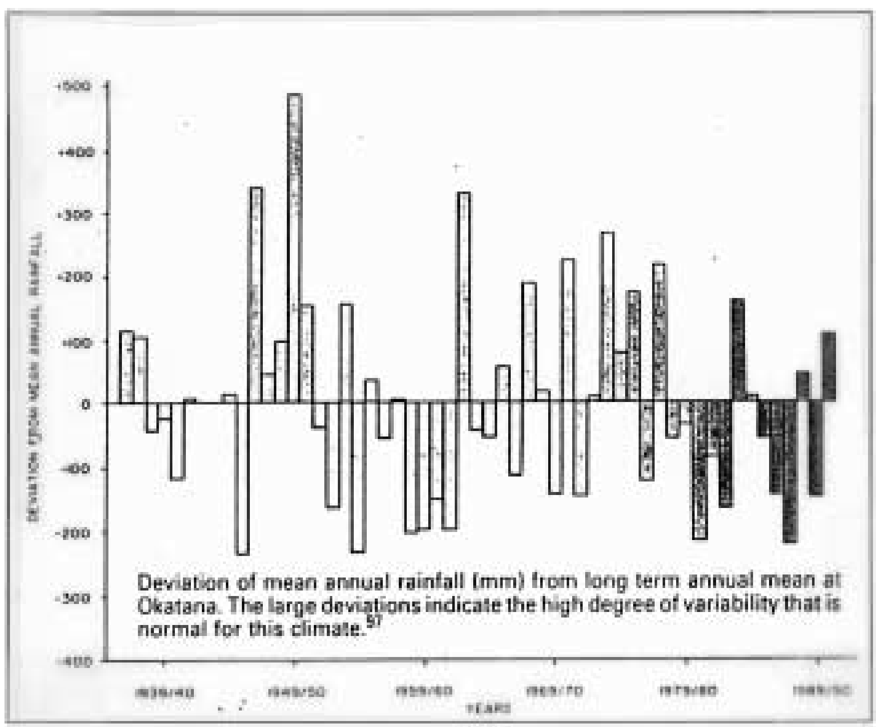


Figure 3.10.
Deviation of mean annual rainfall (mm) from the long term annual mean at Okatana, Namibia. The large deviations indicate the high degree of variability that is normal for this climate. From DRFN, SIDA Report. (Marsh, A, Seely, M (ed.), 1992.)

quence of a rather low atmospheric demand in the temperate zone the groundwater recharge and streamflow generation are considerable even when precipitation is moderate. In the semi-arid zone precipitation is highly variable in space, highly seasonal and subjected to long-term fluctuations. It should be noted that there is a runoff component also in the semi-arid zone, although the annual average atmospheric demand of water is larger than the precipitation (Figure 3.9). This is explained by seasonal and often high-intensity rainfall.

Also in areas which on average have a water deficit, there might be times when there is a surplus. This again shows that the selection of time scale is crucial for assessment of water availability. In the humid tropical zone both precipitation and evapotranspiration are extensive and water is quickly partitioned either to the atmosphere or to the rivers.

Tropics are vulnerable to land-use changes

As described earlier, precipitation input is partitioned into (a) that which returns to the atmosphere through evaporation or transpiration (vertical return flow, green water flow), and (b) that which recharges soils, aquifers and rivers (semi-horizontal flow, blue water

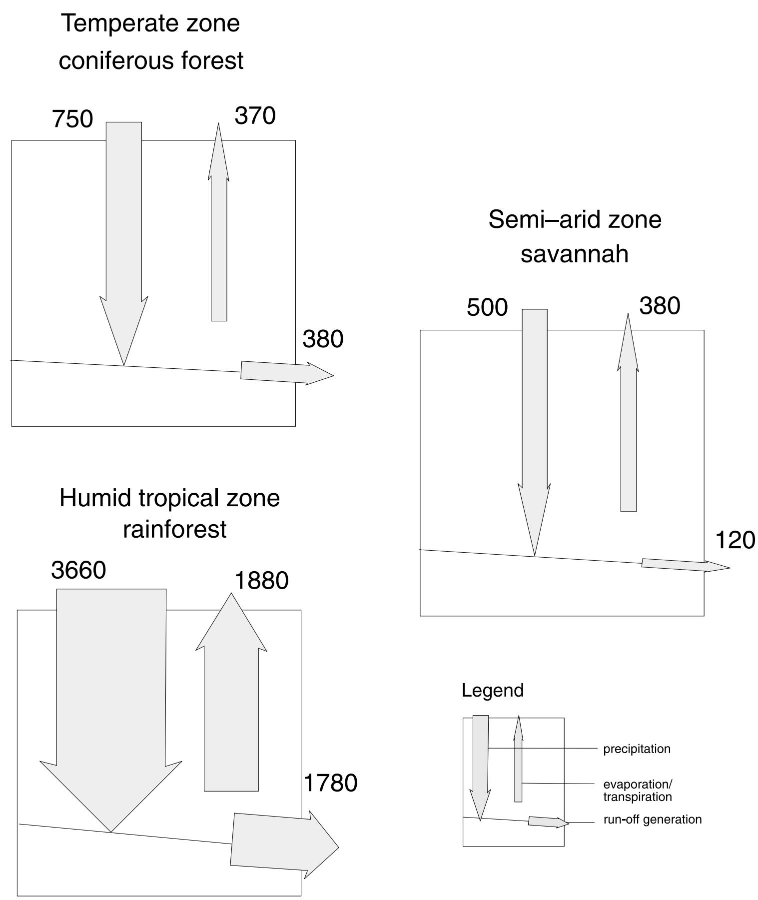


Figure 3.11.
Examples of principal differences in water flow through ecosystems in different hydroclimates. Data from L'vovich.

flow). For a set amount of precipitation input, semi-horizontal flow decreases when the vertical return flow increases, and vice versa. This complement creates a link between land-use change and partitioning of water. The hydroclimate of a region greatly affects water partitioning even before human activities are involved. The reason is that sunlight affects the evaporative demand of the atmosphere. Consequently, flow patterns in the tropics and subtropics are much more vulnerable than in the temperate zone. In dry-climate regions most of the rainfall returns to a very thirsty atmosphere (Figure 3.12). Only a very limited portion recharges groundwater and rivers. Therefore, a small change in the vertical return flow in the tropics and subtropics can have a major effect on recharge of groundwater and rivers.

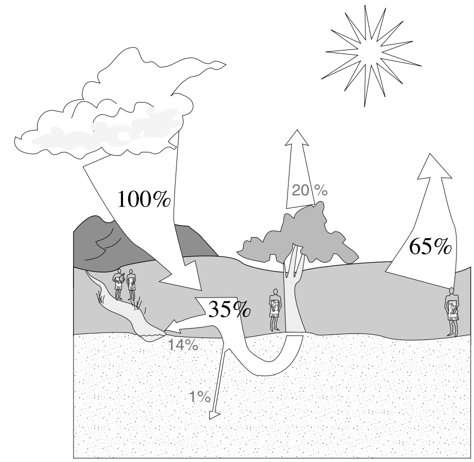


Figure 3.12.
Schematic water partitioning of the rainfall into different main pathways in Southern Africa. This is the typical situation for an arid environment. (After Piet Heyns 1993.)

Components dissolved in water

The origin of water quality

Water chemical composition in natural or "virgin" conditions is highly variable and influenced by several factors. Water flow along pathways is a key concept not only for water partitioning but for the genesis of water quality as well. Factors such as the physical and mineralogical/chemical composition of soil and bedrock, the topography and vegetation have a primary effect on water quality (Figure 3.13.) As water travels from recharge to discharge areas, it interacts with geological media and causes elements to dissolve and precipitate as part of the weathering processes. Water is a solvent for ions and a medium for transfers of mass and heat. Ions are exchanged at the surface of soil particles, e.g. when acid rain is neutralised in the soil by exchange of acid ions for neutral ions such as potassium, calcium and others. The latter are then leached from the soil horizon to receiving waters. Profound changes in both chemistry and biology takes place as water passes from the aerated soil to the air-free groundwater zone. In the latter, physical and chemical processes are thought to be dominating for water quality changes. Living organisms also affect water quality genesis, e.g., by uptake and release of nutrients and other elements that are specific for a plant or geographic region, or by generation of products such as humic acids during the decomposition of organic matter. One example is the lower pH of water passing through the upper layer of organic residues in a pine forest or rainforest in comparison with a grassland. In the latter, the organic matter is more rapidly and more completely decomposed to gaseous carbon dioxide leaving lower amounts as acid humic substances.

Consequently, changes in vegetation, due to natural succession or human activities, can affect water composition very significantly. The quality of groundwater or surface water at any point in the landscape reflects the combined effect of many processes along the water pathways.

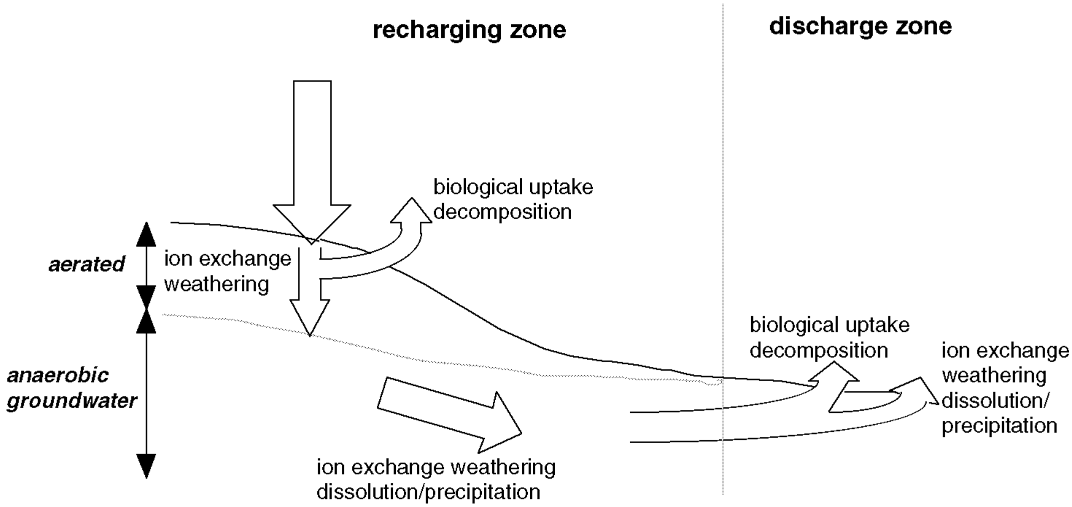


Figure 3.13.
Changes in both chemistry and biology take place as water passes from the aerated soil to the air-free groundwater zone.

Retention of substances in the terrestrial environment

A fundamental concept in water quality genesis is the retention of various substances in different elements of the landscape. This is closely linked to the concept "transit time". A water sample from a stream or river reflects a mixture of direct precipitation, surface runoff and shallow and deep groundwater that has flowed through the soil with a transit time from days up to decades. The transport time through the soil is a crucial parameter for the transport and retention of various substances and thus, the composition of water. Shallow groundwater substances are rendered soluble as a result of reactions on the soil surface and in the root zone. Deep groundwater, however, transports substances made soluble through interactions with the bedrock surfaces, which results in another, different water composition.

Temporal variations in water quality

Natural variations in water quality occur on a wide range of timescales. Long-term changes in water quality can occur on geological time scales due to factors such as soil evolution, glaciation, geologic uplift, and mass wasting. Intermediate changes can occur due to forest fires, floods or droughts and to successional changes in vegetation. Seasonal and shorter-term variations in water quality of streams and rivers are partly explained by variations in the mixture of contributing waters, each of which has a different composition due to transit time, the contact materials and the growth cycle of vegetation. Additionally, for catchments with a large proportion of open water compared to catchments with proportionately larger groundwater contributions, relatively more precipitation falls directly on the surface water without passing through soil and this contribution has a very short transit time. Consequently, changes in precipitation chemistry, e.g., decreasing pH or increasing pesticide, micro-organic pollutants, and nitrogen or sulphur concentrations may rapidly affect surface water chemistry. Also, in tropical areas where rainfall intensities exceed soil infiltration capacity and large amounts of surface runoff occur, water quality may change due to erosion and to substances dissolved from eroded soil particles.

Retention of substances in the aquatic environment

So far, we have discussed water quality genesis as water passes through the terrestrial part of the landscape. However, significant changes also occur in the aquatic environments, where the transit times may vary from hours in small streams to years in certain lakes. Biological and chemical transformations and retention of substances may have very profound downstream effect on water quality. For example, lakes may effectively trap sediment, thus reducing the transport of suspended matter and adsorbed elements to downstream areas. Nitrogen transformations in the sediments have also been emphasised as an important function of lake ecosystems. When there is a lack of oxygen, as is often the case in lake sediments, many bacteria can replace oxygen for nitrate for their respiration, denitrification. In doing so, nitrate is transformed to nitrogen gas, which diffuses to the atmosphere. This process can cause a significant reduction in the load of nitrogen to downstream waters, and the amount reduced increases with the load of nitrogen.

Transition zones: a key element for chemical and biological transformations

Recently, the importance of transition zones have been highlighted in studies of substance transport in the environment. Important here are the zones where water alternates between being saturated and unsaturated with oxygen. This situation can be found in both recharge and discharge areas. Such alterations between saturated, oxygen-free and unsaturated, oxygenated conditions have a profound effect on both chemical and biological reactions in transforming, releasing and adsorbing various compounds.

Intermediate zones between habitats are called ecotones. Ecotones are border areas between different ecosystems, such as land and streams. Those zones are particularly important for transformations and retention of substances, and are in addition important for maintaining a high biodiversity of the landscape. Wetlands have been proven to act as important sites for denitrification, where the high production of plant biomass provides organic matter to support a high activity of the denitrifying bacteria. In addition, wetlands act as traps for sediments and associated substances, just as lakes do. Likewise, water movement and interactions with the area immediately below and adjacent to the stream, can affect transit times and transformations of water quality.

Destruction of such transition zones, due to draining of wetlands, and cultivation of streambanks and river plains contribute to the observed degradation of water quality in surface waters of the world. The negative effects are double. Not only are the function of the ecotones as buffers between land and water lost, but often the nutrient losses are higher from such areas than from other soils. In virgin conditions the soils are water-logged and organic matter and nutrients are accumulated. Drainage and cultivation initiate a high decomposition rate in the soils, and large amounts of nutrients are set free – larger than can be absorbed by the common agricultural systems. A vast amount of information shows that agricultural lands are releasing large amounts of nutrients compared to forested and undisturbed watersheds (Figure 3.14). Other factors than the ones mentioned here are also of great importance, which we will return to later in the book.

Restoration of streams and wetlands is one of the available means to take advantage of natural processes to improve water quality and reduce the negative impact of e.g. agriculture on surface waters. Buffer strips with riparian vegetation in combination with reduced side-slopes along streams and rivers will reduce erosion and nutrient losses associated with this. Further, this will have a clearly positive impact on the wildlife in a monotone agricultural landscape, creating refuges for protection and feeding.

These are the rules of the game

When managing interactions between humans, land and water, we must consider that water flows within a basin are determined by a mosaic of various combinations of climate, landscape factors and human actions. Human actions that change water quantity or quality take place locally, but the effects may be relevant for groundwater and surface water in the entire downslope drainage basin. Human activities dependent on water will rely on the quantity and quality of the received water from upstream areas, and they will modify the quantity and quality of the water that is passed on to downstream water users. Local, regional and global differences of wetness and water partitioning are considerable. The effects of human activities on the quantity and quality of water differ, depending on where and how they are carried out. It must be remembered that the most significant characteristic of water flows is their temporal variability, which is most pronounced where water is scarce. These are the rules of the game that must be respected if we are to manage human land and water interactions.

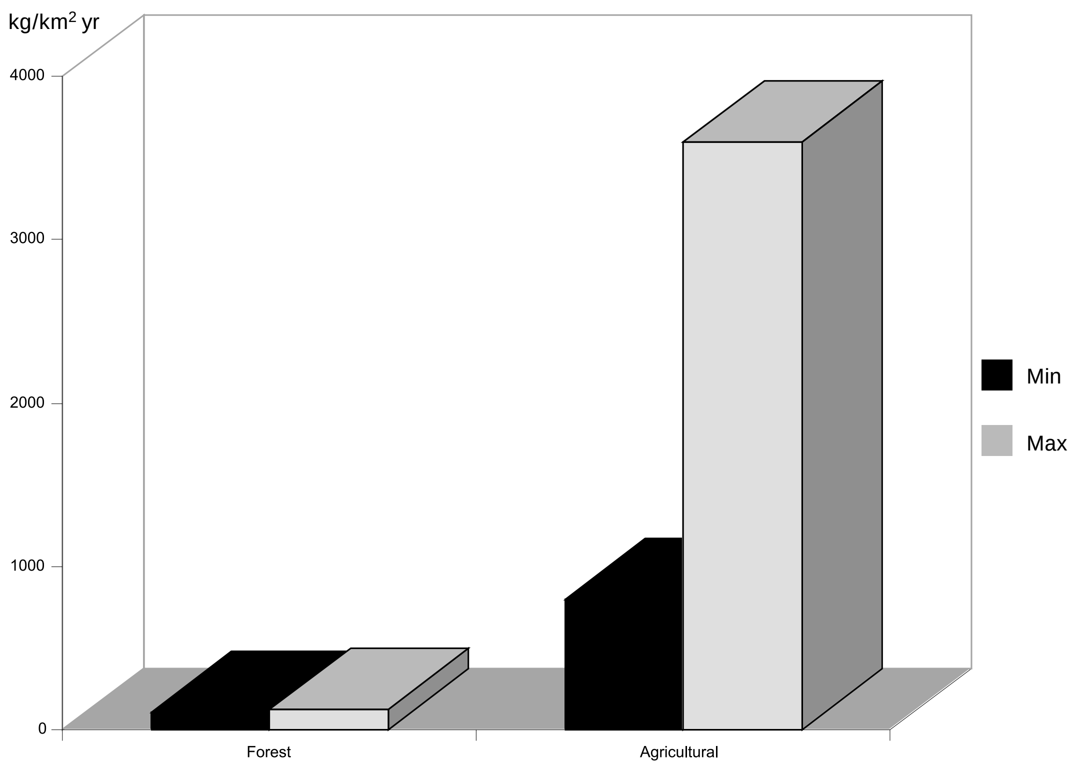


Figure. 3.14.

Some examples of observed nitrogen losses (minimum and maximum) in forested and agricultural catchments in countries from the temperate region. (After Petersen, 1992.)

4 Current policies: inconsistent with natural rules

The inconsistency problem

Efforts to link interdependent activities for which there are no legislative provisions tend to encounter severe bureaucratic difficulties.

The world community is presently struggling with widespread symptoms of poor management of land, water and waste products which have existed for many years. Water management problems cut across many sectors of society:

- health, depending on access to safe household water and sanitation;
- food production, depending on the merging of water from the soil and carbon dioxide from the air through the photosynthesis process to form plant biomass;
- socio-economic production, depending on easy access to water for industry, urban activities and energy generation; and
- protection of valued ecosystems that are threatened when the quality of the surrounding water is degraded. Indeed, degraded quality of the water moving through the landscape has repercussions on most of the sectors where water is key.

This chapter will show that societal rules as manifested in legislation and administration are quite inconsistent with natural laws. Even though the same water is used for a whole set of different uses while running down the river basin, these uses are administered by different authorities as if they were not connected. The right to use water may be linked to land ownership but the effects of land use on water is seldom handled by the same legislation. The "right to pollute" that goes with a permit system is regulated in separate legislation from the right to use water. The environmental legislation is often concentrated to point sources only, whereas polluting land use in forestry or agriculture is seldom regulated. Land use regulations generally focus on building activities.

The overall result of this situation is that water is lawless. Water quality has no constituency – it is not possible to stop the creeping pollution of groundwater now intensifying under the main agricultural regions in the world. It is no wonder that decision makers are more or less paralysed by the complexity involved in water resources management and its linkages to land use.

Past mismanagement

The current dilemma has several parallel causes: (a) Pollutants have been introduced into water pathways; (b) Manipulations related to land use of water flows and pathways have changed river yields and have caused floods and drought; (c) In regions with vulnerable soils, changes made to the vegetation and soil have caused the land to become impermeable and have given rise to so-called desertification and (d) Poor management of irrigation systems has caused water logging and salinisation of previously fertile soils.

Simplistic water resources management models of the past have led to this dilemma. The models are characterised by a sector-by-sector approach to water management and fragmented administration. Efforts to link interdependent activities for which there are no legislative provisions tend to encounter severe bureaucratic difficulties.

Part of the mismanagement originates in a land/water dichotomy characterised by a mental image of land as opposed to water. Policy makers often tend to treat land and water as entities which are managed in different ways and by different management systems. In the management systems of the past, land and water are administratively linked mainly through the use of environmental impact assessments in the case where land use changes produce side effects on water.

In some recent definitions, land as a unit is seen as intermixed with water. Many land use strategies depend on access to water but affect at the same time the quality and quantity of the water flowing from one land unit to the next.

Land is a physical and spatial entity in terms of topography and natural attributes. As a two-dimensional spatial resource it has a living space function. Land is the physical basis for human settlements, industrial establishments and social activities such as sports and recreation. Also, it has a connective space function by providing space for the transport of people and produce and for the movements of plants and animals between discrete areas of natural ecosystems. Land also has a third dimension and the soil column forms the basis for many life support systems through the production of biomass (the production function). It has a biotic environmental function as the basis for terrestrial biodiversity.

In contrast to land, water is a mobile resource passing as groundwater through aquifers under the ground, and as surface water through rivers and lakes – so-called blue water. In relation to water, land is involved in partitioning of precipitation between infiltration and plant water uptake, evaporation, and runoff. The water in soil available to roots – so-called green water – has in the past been thought of more as a hidden attribute of soil rather than water, as such. Further, the role of moving water as a transmittor of nutrients and pollutants links different land areas in the landscape.

Administrative fragmentation

Administration is fragmented at all levels: different water issues are handled by different authorities. In such systems, interdependencies have been difficult to handle properly. Water impacted by land use has been handled through environmental impact assessment with limited influence in terms of managerial response. The negative effects of land use on water is now reflected in accumulation of both waste water components, nutrients and pesticides in groundwater and surface waters. Most coastal pollution, in fact, originates from land-based sources.

This mismatch between administrative units and the natural hydro-ecological units of the landscape is the first type of administrative fragmentation.

Local and regional administration of water is usually based on a tradition of political and economic realities. In democratic countries the public administrative structure is composed of a heritage of decrees issued by central power holders either religious or secular. The main purpose of public administration was, and still is, tax collection and implementation of decisions designed to solve common problems. Currently in many countries, political power and decision-making are based on democratic elections and democratic decision-making.

All public administrations have a territorial delimitation and at least three hierarchical levels – national, regional and local. To be workable, the territorial delimitation should be unequivocal. Administrative units should fit together like Chinese boxes among the hierarchical levels, and there should be no ambiguity about territorial boundaries. At each administrative level there are units with primary sectorial responsibilities and some units with intersectorial responsibility.

Over time, public administration has been restructured. It has had impacts on both the distribution of political and administrative responsibilities between various administrative levels as well as on the size and delimitation of each administrative unit in the territorial organisation. The delimitation of public administrative units seldom coincide, however, with natural hydroecological units, that is to say the water drainage basins. The drainage basin is not based on taxpaying capacity or other economic considerations, but on the topography of the landscape and its water divides. This mismatch between administrative units and the natural hydroecological units of the landscape is the first type of administrative fragmentation.

The second type of administrative fragmentation is the sectorial split. Not all, but many human activities organised in sectors with narrow responsibilities are related to water pollution, groundwater depletion, etc. For example, industrialised agriculture is the land use with the most leaching of pollutants. The overriding goal for the agricultural sector has been until now to maximise food production. Environmental impact of high yield agriculture has not been regarded as an important issue for the agricultural sector.

Ongoing globalisation of the economy seems to have strengthened the sectorial split. Public inter-sectorial units are still not strong enough to regulate sectorial interests that are growing stronger and increasing in political power or influence.

International rivers, upstream-downstream relations

International river basins versus national units is another example of the inconsistency between natural ecohydrological management units and political/economic units. Through international law each country has special rights or sovereignty related to its natural resources including water. Each country claims sovereignty so that downstream countries can not force upstream countries to change their water use. Instead, when countries want to use peaceful means to settle disputes, they must begin international negotiations or must establish a transnational organisation for international cooperation.

Around the world there are many international conflicts related to disputes between upstream and downstream water resource users. A typical international water resource conflict concerns water quantity or availability. For example, when an upstream country begins to withdraw significant quantities of water for irrigation or urban use it diminishes water flow and impacts downstream water users.

Another type of international water conflict concerns water quality. An upstream country may have polluted a river by effluent from industrial or urban polluters. Instead of investing in waste water treatment plants the upstream country uses the river as a cheap recipient of pollutants. The pollutants are transported downstream by the river flow and severely restrict water use options for users downstream.

More than 60% of all land in the world belongs to international river basins. Africa has 57 international river basins, Europe 48, Asia 49, South America 36, North and Middle America 33. Examples of river basins with typical upstream-downstream conflicts are Euphrates and Tigris, the Nile, and the Colorado River.

Table 4.1.
International river basins and their number of countries.

River basin	*No. of countries*
Donau	15
Niger	10
Nile	9
Zaire	9
Rhine	8
Zambesi	8

(Source: Ymer, 1992.)

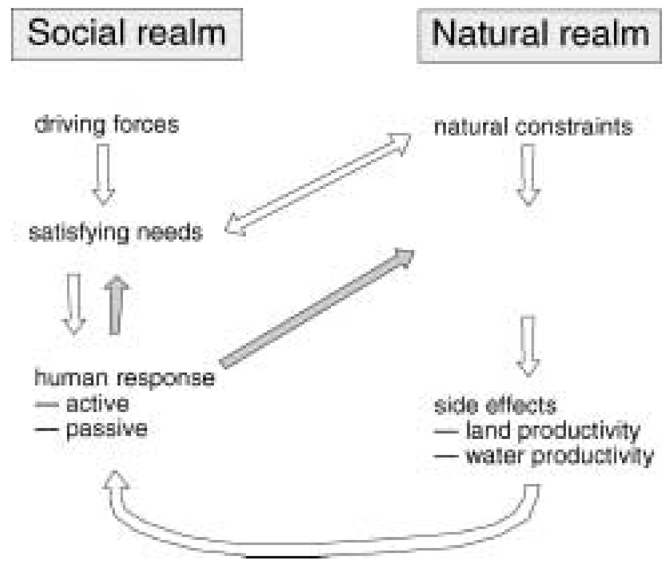


Figure 4.1.
Life-support problems are encountered in the interaction between the social realm and the natural realm. Grey arrows indicate policy change.

The split between different decision-making bodies prevents coordinated and long-term sustainable water use.

Necessary steps towards a new water paradigm

A sustainable use of scarce land and water resources will not be possible unless decision-makers are aware of the crucial relationships between natural land-water constraints, the actual technology for land and water manipulations, and increasing human need. The negative side effects in terms of pollution, desiccation or water logging – manifestations of environmental effects of land management and land use changes – will reduce the long-term productivity of an area. A politician or an administrator in a decision-making situation must always consider what is possible, from a political point of view and what is necessary, given the constraints of the natural water resources.

New development strategies and concepts are required based on long-term sustainability and recycling as well as on new, environmentally efficient “bottom-up” strategies. They should be the foundation of the new Agenda for the 21st century.

Laws set the rules of the game

Water legislation doctrines

Water legislation and the socio-economic distribution of water-rights form the framework for actions taken by political and administrative decision-makers. For a political decision-maker, a private entrepreneur, a civil servant and others, water legislation defines the rules of the decision-making game. In some countries, the qualitative and quantitative aspects of water use are regulated by a general water law and a special water court. In other countries, water legislation and decision-making may be separated due to qualitative or quantitative aspects of water use. The split between different decision-making bodies prevents coordinated and long-term sustainable water use.

Water legislation doctrines vary from country to country but, generally speaking, there is a correlation between actual water legislation doctrine and macro-hydrological conditions. Significant international efforts have been made in order to harmonise water law principles and standards for different water use purposes. One of the most important fundamentals in all types of water legislation is the concept of a water-right. Being a water-right owner means having the legal right to use water for specific purposes to a specified degree. Being a water-right owner also means being legally protected from illegal water users.

Priority groups defined by law

In the humid zone, riparian water legislation is predominant. Under this doctrine water-rights are indirectly connected with the water body by land ownership. Consequently, only land owners are water-right holders for surface water and groundwater connected with the property. The socio-economic distribution of riparian water-rights reflects the socio-economic distribution of land ownership. In many countries water quality legislation is separate from water-right legislation. This legislative division often leads to an unwanted administrative split.

Rural areas dominated by land-use for agriculture and forestry are seldom regulated by environmental authorities.

In the arid zone, the prior appropriation water legislation is predominant. Water-rights under this doctrine are directly connected with the water body. Water-rights are based on a priority list of "beneficial water uses." This list is based on a historical record of water shares within a specific river basin used for economically viable production. Examples of beneficial water use are irrigation, hydropower, and urban water supply. Compared with the riparian water-right doctrine the water-body is itself the object of water-rights. Moreover, water-rights are transferable among water users like shares on a stock market.

The value of an approparian water-right depends on priority rank. High ranking water-rights are more valuable because they guarantee the water-right holder safer access to water supply every year compared with low ranking water-rights. For example, during dry years low ranking water-right holders can not get any water because there is not enough water to satisfy all water-right holders within the catchment or river basin.

Distribution of water-rights is one of the important means for a central government to regulate use of the nation's water and the relationship between water-right holders and the public. In the riparian tradition, decision-making concerning redistribution of water-rights within a river basin takes place in water courts, or in appointed public water-resource corporations. In the approparian tradition, redistribution of water-rights is based on market value of each water-right. Approparian water-rights can be sold and bought on a local water-right market, similar in function to a stock exchange.

Water pollution: permits and reactive or proactive approaches

Water pollution from human activities and societies are of two types:

(a) from *point sources;* for example, outlets of waste water from industries and urban areas;

(b) from *non-point sources;* for example, deposition of atmosphere-borne pollutants, a leakage of water polluting substances from waste deposits, and leaching of agrochemicals.

The means for combating water pollution are different depending on the type of water pollution. Point sources are easiest to control. They have a clearly defined geographical location. The rule for control and prevention from point source pollution is usually found in environmental legislation. The common legal construction of water pollution prevention laws is based on every water polluter needing a special "water pollution permit". Before a water pollution permit is issued, an official scrutinises the application and investigates on the spot in order to find out if the most technically and economically sound solution for waste-water treatment and control has been selected. The water pollution permit issued has a time limit for its validity. The permit also includes procedures for control of the biochemical state of the treated wastewater. The results of the control are reported subsequently to environmental authorities.

Water pollution prevention systems with corresponding permits are reactive. Water pollution permits only address and legalise situations where water pollution is ongoing. The strategy of environmental authorities is to force polluters to increase their efforts to clean waste water every time a new water pollution permit is issued. This reactive strategy does not include any specified standards for long-term water quality.

Proactive water pollution control systems are oriented towards defined environmental goals or water-quality standards. Instead of pollution permits, a proactive water pollution control system works with both legal and economic incentives. A polluter may be offered a choice between letting water pollution continue and paying for environmental damages caused by the pollution of the water, or he may choose a subsidised loan to invest in the installation of water-treatment equipment. Proactive water-control systems have adopted the “polluter pays” principle.

The other type of pollution from human society, water pollution from non-point sources, is often related to inadequate land management. During the past few decades, pressure on land for agriculture and urban settlement has increased significantly. Pressure on land-use is correlated with increasing of food needs of a growing world population and rapidly-growing megacities.

Regulation of land-use is mainly restricted to built-up areas. Regional plans, master plans and building plans are all examples of authorities regulating construction of houses, roads, water and sanitation equipment, and parks and squares. Rural areas dominated by land-use for agriculture and forestry are seldom regulated by environmental authorities.

The different modes for environmental control in urban and rural areas indicate that prerequisites for efficient control of non-point pollution sources should also be different. Now, great efforts are made to reduce environmental pollution from urban traffic. But efforts to reduce water pollutant leakage from industrialised agriculture are insufficient. Pollution from non-point sources can not be fought with technical solutions such as filtering of pollutant treatment. Instead, the non-point pollution sources have to be reduced by changes in human behaviour and by restrictions on water polluting land-use. These changes are much more difficult both to attain and control.

Barriers to action

Actions can be legal or illegal. Legal ones apply the rules of the law; actions opposing or neglecting the legal rules of the game are illegal. Opposing or neglecting the legal rules for sustainable water use will deplete water resources for coming generations.

Different administrative levels – vertical action barriers

Joint actions or actions with two or more administrative levels involved are special types of action which need very specific goals and multilevel management adapted to the situation. In traditional hierarchical organisations the power to initiate actions is usually concentrated at the top levels of an organisation. If top level leadership decides to take joint action it must overcome communication barriers between administrative levels. Overcoming vertical barriers to action needs strong leadership.

Sectorised framework – horizontal action barriers

Another category of actions are those taken between different sectors of a society or socio-economic segments. The sectors may consist of parts of public administration, different interest groups or private enterprises.

In a sectorised framework, barriers to action are extremely difficult to overcome. The reason is that each socio-economic sector looks upon itself as an independent entity. This means that no one has the authority or political power to give orders to another sector. A common way to overcome horizontal action barriers is by establishing a special committee or commission for intersectorial cooperation.

From a legal standpoint, the primary stakeholders within a catchment area/basin are the water-right holders.

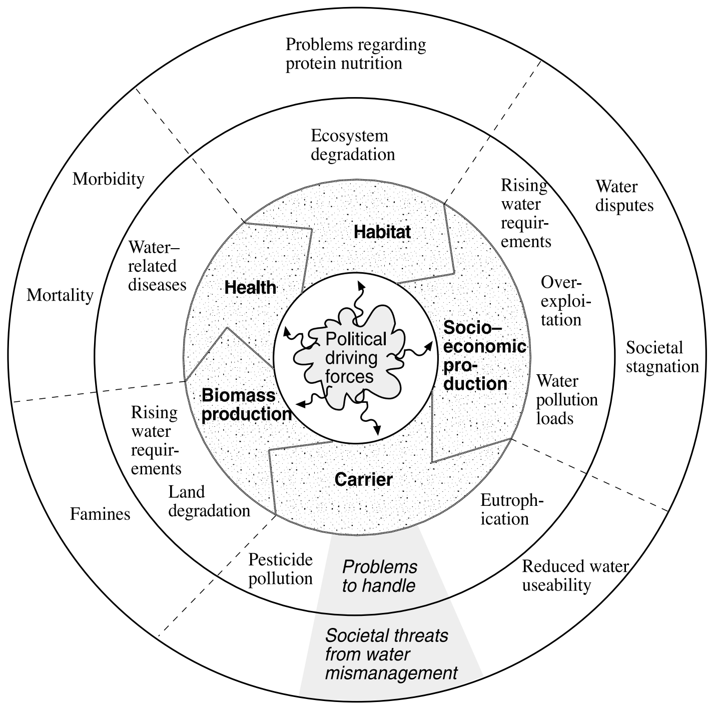


Figure 4.2.
Cycling water – its multiple functions and the sectorised political driving forces.

Three main groups in the decision-making arena

From a legal standpoint, the primary stakeholders within a catchment area/basin are the water-right holders. Stakeholders are persons with specific interests in the outcome of decision-making. In general, they are defined by law to have specified rights to take action, to influence the use of water and to transfer water-rights. Actions of water-right holders are regulated in the water laws.

Another group of stakeholders are public institutions who deal with, for example, the decision-making concerning transfer of water-rights, giving permits for different types of water use or imposing sentence for unlawful water use, etc. A third group of stakeholders are those with a special interest in water matters such as persons with land-use interests, farmers, environmentalists, commercial associations, and consultants. Such groups are often large enough to influence public opinion.

Strategies for stakeholder involvement vary from one water decision-making arena to another. In some cases admission is free, in others, quite restricted. For the water courts, appearance is strictly restricted to a specific group of stakeholders. Other water decision-making arenas such as political assemblies or opinion meetings freely admit individuals from all groups of stakeholders without charge. Everyone has the chance to put the case for his interests and to participate in democratic decisions.

Safeguarding national interests

National governments are responsible for:

- safeguarding economic, environmental and social aspects of the national interest including negotiating and entering into international treaties;
- working cooperatively with states to satisfy national environmental needs, ensuring that actions of one state do not result in a significant adverse impact on another;
- ensuring that natural resources are maintained to support national economic development, protecting life support and food production resources, and protecting the interests of future generations.

In instances where river basins cross state boundaries, the national government should convene a basin management organisation which is responsible for coordinating management of basin states.

Providing vertical coordination

State governments are generally responsible for policy, development of legislation and implementation of administrative arrangements for environmental matters that are not the responsibility of the national government. In practice and because of the complexity of managing land and water resources in an integrated way, administrative arrangements very often involve catchment or basin organisations. These organisations are responsible for advising on catchment needs and on the integration of land and water management, particularly the off-site impacts of land use within the catchment. State governments have a responsibility for consulting with local communities and facilitating their involvement by providing coordination, technical and financial support for developing and implementing local action plans.

Local governments have the potential to play a major role in managing land and water degradation.

Local leadership role

Finally, local governments are responsible for the development and implementation of locally relevant policies and planning schemes within their jurisdiction. They are also responsible for collecting local taxes and for managing engineering work such as urban water supply and waste management. Local governments have the potential to play a major role in managing land and water degradation. They can combine local knowledge and understanding with rating and land use planning powers. Additional roles could include acting as local information brokers, supporting community groups, participating in catchment, regional and state advisory committees and generally to undertaking a leadership role in local management and protection of the environment.

5 A land-use decision is also a water decision

The challenge: contending successfully with environmental problems

In this chapter, the effects on hydrology and hydrochemistry caused by changes in the landscape are discussed. The discussion will focus on the problems arising when interventions in the landscape are transformed into unintended and undesirable side effects on land and water resources. Such effects are conventionally referred to as "environmental impacts". Whatever their name, their origins will have to be understood. Without such an understanding, it is difficult to set priorities for an effective integrated system of management.

Manipulation of the landscape is unavoidable

The landscape is a composite system where ecohydrological phenomena form important components. It can be thought of as a geological matrix, represented by its topography, its geomorphology, its mineral composition as well as the permeability characteristics of its various layers or components. When climatic forces such as rain and evaporation act on this matrix, the water flows are partitioned along pathways on the surface or in the ground. This has a systematic impact on hydrochemical and ecosystem characteristics.

The landscape contains the natural resources on which we depend: water, biomass, energy sources, and minerals and other basic raw materials.

We exploit or harvest such resources. Exploitation creates undesirable effects and therefore it is essential for us to understand how humans interfere with the landscape system. We must understand how our activities produce waste, and how, over various timescales, the natural rules interact with human activities to cause unwanted physical, chemical, and biological side effects on land or in water.

Land-use can modify ecosystems. First of all, many land-use activities depend on water. Consequently, water management is crucial for the support of proper or sustainable land management. Land-use also affects physical determinants of water flow, and can alter hydrochemical behaviour, for example, by introducing pollutants along water pathways. For that reason, a land-use decision is a water decision. Conversely, land-use regulations are needed for water protection purposes.

Symptoms of past mismanagement

Today's environmental problems resulting from human activities, reflect three particular management failures:

(1) unsuccessful coping with complicated hydroclimatic restrictions, in particular water scarcity;

(2) poor management of waste production which is a by-product of all human activities and which introduces chemical and biological wastes into the atmosphere and into the terrestrial and aquatic components of the landscape;

(3) imprudent actions to satisfy biomass demands that necessitate interventions in the soil and vegetation.

Regionally fundamental differences in causes and vulnerability occur (Table 5.1). In the temperate zone waste handling is a prima-

Table 5.1. *Fourfold water crisis – Threats and risks.*

problem	cause	threat	at stake
Water quantity crisis	*finite resource escalating demands*	*increasing disputes and conflicts*	*development peace, food security*
Water quality crisis	*expanding water pollution*	*increasing morbidity/ mortality*	*human health aquatic ecosystems*
Urban scale/water supply crisis	*urban growth out of control*	*social unrest persisting poverty*	*social order overall development*
Land fertility degradation crisis	*degradation of soil permeability and water holding capacity, erosion*	*decreasing crop yields/agricultural production*	*food security*

It is time to start focusing on proper identification of the causes of the problems and on how to reverse the degradation....

ry cause of water quality degradation, which in turn has effects on water availability. Vulnerability of water resources is generally limited. In some regions poor buffering capacity of soils may exacerbate the effects of acidifying waste gases. In the tropics and subtropics population growth causes additional need for increased biomass harvesting and for increased water withdrawals. A region is rendered highly vulnerable to manipulations of the landscape by an accumulation of vulnerability components. For example, seasonality of rainfall, high evaporative demand, and large fluctuations in annual rainfall all cause recurrent droughts and create soils prone to crust formation and erosion.

Action paralysis

In the past the scale and number of environmental changes have expanded rapidly. Environmental research initially focused on the biological consequences of disturbances in the landscape and the atmosphere. It was largely problem-driven and effect-oriented. Thus, impacts received more attention than the understanding of causes. Scientists were pushed by immediate reality more than pulled by their desire to understand the entire Earth system. The lack of interdisciplinary approaches has retarded both the necessary scientific and public understanding.

Major obstacles to effective integrated system management have been compartmentalisation of problems and a concentration, one at a time, on narrowly focused problems. Addressing individual problems such as desertification; salinization; clearing of rainforests; protection of water quality and supply; protection of sea water; and individual endangered species without regard to the linkages among them poses considerable risk to ecosystems. In such an approach solutions are only partial, and focus on a narrow range of time and space, rarely considering fundamental and influential factors such as population growth and water cycle integrity.

... instead of discussing one problem at a time.

However, even when the problem is well understood and the countermeasures well known, there is often an inability to act. The inaction is caused by such blocking effects as strong stakeholder interests, or – where environmental legislation is already in place – lack of enforcement mechanisms, and a fragmented administration or bureaucracy.

Considerable efforts have been made to develop methods for environmental impact assessment. This tool has not been very effective in solving "overall" problems, because it has a single project focus and does not consider the total effect of planning strategies and policies.

Preventive or curative action?

The public's expectations on today's politicians are tremendous. They have to balance between the need for:

curative action – by finding remedies to environmental problems generated by past land, water, and waste mismanagement; and for

preventive action – by trying to avoid that environmental problems get even worse, because of powerful forces acting in society. Such forces would be population growth, growing expectations for improved life quality, or political aspirations.

Resources are limited. If more resources are used to cure past ills, then less will be available to prevent current and future degradation.

Human influences on landscape change

Leaders must secure people's access to food, water and energy, but they should also provide hazard protection and prevention

Human activities in the landscape are driven by several factors:

- population growth increases demands on resources for life support needs;
- societal demands, which are what members of the society want, increase demands on the resource above the level of mere life support needs; and
- economic growth aspirations, which include both the needs and what people want, also increase demands on resources.

In Chapter 4 we introduced the main linkages between the social and natural spheres. Life support of the population is imperative and is expected from leaders of society as shown in Figure 5.1. Leaders must secure, or at least facilitate, people's access to food, water and energy, but they should also provide hazard protection and prevention. Failure to do so may be costly: morbidity, famine, poverty, disputes, riots, and even revolution.

Provision of such life support components demands interventions in the landscape: physically by manipulation of land and water, and chemically by the introduction of agricultural chemicals and waste. The benefit of landscape interventions is the satisfaction of the needs of society. However, because of the natural rules operating in the landscape, environmental side effects develop from interventions.

When society reacts to environmental consequences, the responses may be either passive or active. The passive responses are: morbidity from polluted drinking water or food; famine due to land fertility degradation; and disputes due to controversies over land and water use. The active responses are, for example, when individuals migrate or reduce fallows. Development of policy is an example of active response on the societal level.

Many side effects are unavoidable

Because humans depend on water, energy, minerals, and biomass produced by natural processes in the landscape, they have always modified it. Examples include manipulation of soil and vegetation to increase yields, to make communities safer, or to improve transportation. Humans have affected water resources directly by water withdrawals for basic life support needs, (for example, irrigation), and have changed water storage to extend water supplies from the wet to the dry seasons and years.

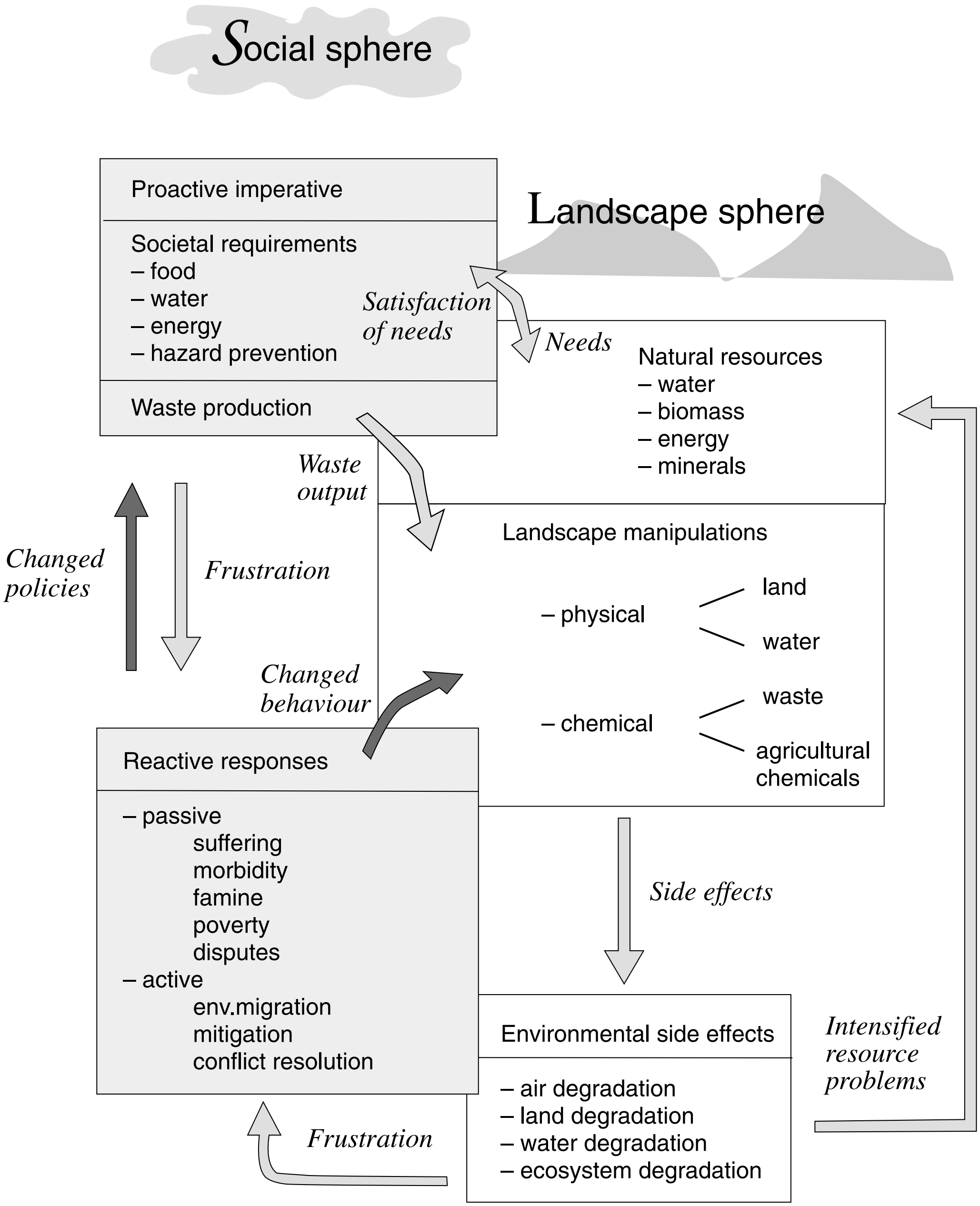


Figure 5.1.
Human activities in the landscape. The life-support problems encountered are produced by the interplay between society and nature. The natural resources necessary for development and for human livelihood are available in the landscape. Manipulations of both land and water systems are unavoidable in order to take advantage of these resources. Any disturbances created by such manipulations will affect the water and any introduction of waste material will circulate through the landscape to downstream water users and ecosystems. There they cause side-effects and responses. These problems have to be taken into account at the beginning of the process. (M. Falkenmark 1996.)

Table 5.2. *Result of human action on physical and chemical determinants of water flow.*

human activity sector	altered physical flow determinants			input of chemicals		
	relief	*vegetation soil cover*	*drainage density*	*air*	*land*	*water*
urbanization	♦	♦	♦	♦	♦	♦
industry	♦			♦	♦	♦
agriculture	♦	♦	♦	♦	♦	♦
forest management			♦		♦	
tourism		♦			♦	♦

Land preparations, plant cover and artificial ground-covers change the flow.

Disturbances which impact on water have their origin in many sectors of society. Water flowing through a landscape system is influenced by human activities in that landscape, and also by polluting activities upwind or upstream, e.g., urbanisation, industry, agricultural intensity or tourism. The main relations between components that determine flow and the human inputs are shown in Table 5.2. and compared to fields of human activities.

We will now discuss two major interventions which have effects on the water cycle: (1) manipulations which influence flow determinants and (2) manipulations which result in chemical influences.

(1) Influencing flow determinants

Water-flow characteristics are influenced by several physical factors, which in turn, are influenced by human activities. The landscape relief (depressions and elevations), for example, is influenced by industrial activities and agricultural farming systems. Preparation of the land for economic development adds man-made structures such as buildings, parking lots, streets, and sport grounds (football, baseball and hockey arenas and golf courses). These changes alter water pathways, increase surface runoff from impervious areas, such as roofs and asphalted parking lots and streets, and decrease groundwater recharge. In vulnerable areas, land subsidence may also occur.

Flow is affected not only by the extent of the plant cover but also by: improper forest management practices such as clearing, fertilisation, deforestation and reforestation; intensified agriculture and changes in technology for crop production; overgrazing; and air pollution, causing forest dieback. Many effects are increased by changes in the soil and vegetation system. Problems begin with changes caused in evapotranspiration and water partitioning and result in higher-order effects on runoff: yield, seasonality, erosion and nutrient leaching. Soil is affected by changes of the land surface, which in turn, alter infiltration and water partitioning. The effects are increased as they cause changes in groundwater recharge and water table levels. Soil structure is affected by vegetation through changes in root density and root depth. In agriculture, soil characteristics are affected by plowing and tilling, aimed at improving local infiltration, airing of the root zone and facilitating meltwater infiltration. Drainage is affected by tilling or piping and ditching, aiming at water table regulation. These methods also allow rapid evacuation of water from rainstorms and meltwater accumulation.

(2) Chemical influences

Human activities almost always result in waste production, but the types of waste vary substantially. For example, human and cattle wastes differ from industrial wastes. Disposal of waste products and related pollutants also vary markedly and as a consequence, so do their effects on water pathways.

Waste-gas emissions are transported over long distances and the resulting atmospheric deposition alters the chemical composition of water which is partitioned at the ground surface. Atmospheric deposition produces increasing effects:

- on plants, which can affect forestry and crop production;
- on groundwater quality, which can affect water supply; and
- on surface water in rivers and lakes, which can affect fisheries and aquatic ecosystems.

Chemical substances also reach the ground as dry waste, as discarded consumer products and as fertilisers and pesticides. Each source causes chemical interactions with water and the effects can be followed from the surface through the groundwater to rivers and lakes. Wherever water is altered chemically, it is likely that biota will be affected as well. The cooling process in power generation directly affects water temperatures. Chemical reactions and biological activities are partly controlled by temperature and will therefore be affected by temperature changes.

Output of waste water to rivers and water bodies may contain organic or inorganic contaminants. Some of these may be treated and changed to less pernicious or noxious forms. However, many organic pollutants may not be ameliorated by standard waste-water treatment. This is particularly the case with pollutants originating from human habitats, or from agricultural production and from the agro-alimentary industry. This overloads the self-purification capacity of surface water systems.

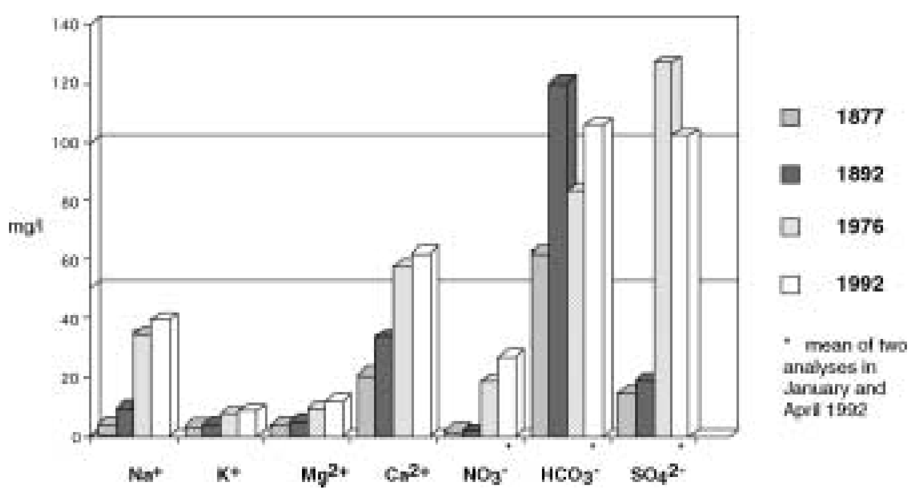


Figure 5.2.
Water quality trends of the Elbe river over 115 years. The latest data from 1992 show that both agricultural nitrate pollution as well as urban and industrial pollution by base cations are still increasing. (After T. Paces 1994.)

Inorganic pollutants are produced from various activities, ranging from the fertiliser industry to heavy metal production in industry. Each contaminant has a unique impact on biological systems. Nutrients primarily affect biological degradation and cause eutrophication of surface waters. Heavy metals pose a serious health risk to all life forms. Increase of pollutants on land or in water degrades water quality and decreases the availability of high quality water.

Pollutants introduced into the biosphere are caught by air circulating in the atmosphere and by water in the continental part of the water cycle. The different scales of pollution dispersion systems on land and in the air makes it

Box 5.1. Pollution heritage in Central Europe

Careless socialist land and water management activities were common prior to 1989, especially in the areas of power production, heavy industry and military activities. For example, in the Czech Republic, oil scarcity led to extensive coal and uranium mining for energy production. The mining influenced annual and seasonal water flows and water quality, and resulted in severe groundwater pollution. The overall impacts encompass a large part of the Czech Republic (Paces 1994). Environmental problems in the Black triangle in Central Europe along the borders of Poland, Czechoslovakia, and the former German Democratic Republic are some of the worst in Europe (Balek 1994). Loads of hydrocarbons, heavy metals and other pollutants, leaking from industrial enterprises in the region, have degraded groundwater resources adjacent to factories. In the Czech Republic, the major sources of pollution are adjacent to sources of high-quality mineral water used historically for drinking and medical treatment. Soviet military units present for almost 25 years, contaminated large areas locally with leaking fuel depots and inadequate care of hardware and munitions. In addition, acidifying gases are emitted from thermal power plants fuelled with untreated low-quality (high sulphur content) brown coal. In some places, packs of heavy metal (often chromium) have remained stored in the unsaturated zone, and from time to time have been washed away after heavy rainfall or snow melt. In the Czech Chalk region, hydrocarbons and toxic substances including PCB's have been found in both saturated and unsaturated layers. More than 200,000 cubic meter of polluted soil has been identified. Hydrocarbons were found floating on groundwater in an area of nearly 20,000 m^2. Throughout the open country, careless waste management has contributed to the formation of uncontrolled deposits of chemicals, PCB derivatives, and waste of all kinds.

The hydrochemical changes in water draining the Czech republic are illustrated in Figure 5.2. The figure shows concentration trends during the last 115 years in the river Elbe, which drains 65% of the Czech Republic. Strong acid anions, originating from industrial emissions and fertilisers, increase significantly while the acid neutralising capacity (alkalinity) of surface waters decreased, causing acidification. A Cretaceous cancerous sandstone aquifers, which produces high alkalinity, is one of the main groundwater sources for river water. Without the groundwater contribution from that aquifer, acidification would have been even worse. Since 1992, increases in nitrate concentrations reflects increases in fertiliser use and increases in base-cation concentrations reflect continued industrial and urban pollution.

possible to distinguish the following types of pollution problems:

- *global:* pollution dispersed by processes in the upper atmosphere, for example, greenhouse gases and chlorinated hydrocarbons;
- *continental:* pollution dispersed by processes in the lower atmosphere, for example, acid rain, and radioactive fallout from bomb testing and accidents such as the one in Chernobyl;
- *regional:* pollution dispersed in surface water along river systems, for example, nutrients and sediment;
- *local:* pollution dispersed in groundwater from general or specific sources in small surface-water systems, for example, storm water runoff and leaching from land fills or other solid or liquid waste disposal on the land surface.

Changing water flows and pathways

Intended and unintended changes

Interference in the water flow is extremely widespread as shown by a sequence of illustrations in this chapter from different parts of the world. We withdraw water from aquifers and rivers for water supply. We build reservoirs and canals for storage and transport of water in dry climates or during dry spells, or in order to protect areas from flooding and inundation during intense floods. We drain wet or water-logged soils. However, interference with flow patterns may also be unintended and may develop as a consequence of those changes in soil and vegetation that affect water partitioning at the ground surface. Leaking pipes for water supply and sanitation introduce an additional recharge of the groundwater.

Upstream irrigation may strangle the downstream lake

Irrigation has unavoidable and most often undesirable downstream effects. For example, the Don River basin has a population of more than 20 million people and is very important for agricultural production. It is, however, subject to recurrent droughts. In order to have a secure crop production, increase in the irrigated area has been necessary. At present, 1.2 million hectares are irrigated. The Azov Sea receives most of its water from the Don River. Annual runoff of the Don into the Azov Sea has decreased by about 30% when compared to the pre-irrigation period. The salinity of the Azov Sea has been increasing because it is a closed basin having no outlet. The increasing salinity causes other effects such as reduced biological productivity.

The Aral Sea is another closed basin where water levels have declined because of decreased inflow. The catchment basin of the Aral Sea has 35 million inhabitants in five different republics and is, mainly due to large scale irrigation, the second largest cotton producer in the world. Water is withdrawn from the two main tributaries of the Aral Sea, the Amu Dar'ya and Syr Dar'ya. Flow in these tributaries has decreased from 60 km^3 per year to a mere trickle. More than 80% of the water is used for irrigation of cotton, fodder crops and rice. The consequences of the massive decrease in inflow are dramatic. As much as 30,000 km^2 or 67% of the former lake bed is now dry and covered with salt. The remaining third is split into lifeless lagoons. The lake used to be the fourth largest lake in the world and produced more than 200 t/day of fish. The regional climate may be changing as well. The Amu Dar'ya is contaminated not only with agricultural chemicals from Uzbek and Turkmeni fields, but also with untreated industrial and municipal wastes. As a result, the aquatic ecosystems of the delta are poisoned and local drinking water sources are contaminated. The noxious water quality is reflected in a public health crisis. An old Uzbek proverb captures the situation: “at the beginning (of a river) you drink water, at the end you drink poison”. A five nation body now exists to look after the lake, but has no power to make effective changes.

Irrigation may also deplete groundwater

Groundwater exploitation by farmers can cause a significant lowering of water tables and deterioration of groundwater quality.

In arid Kuwait irrigation for farming depletes and salinises groundwater. Local aquifers are recharged by runoff from occasional winter rainstorms. In low lying terrain the runoff forms playa lakes (shallow collections of water which rapidly evaporate), from which water infiltrates the soil and recharges groundwater. Lenses of brackish to fresh groundwater are formed that float over the saline groundwater. Irrigated farmlands were established in the early 1960s to use this brackish water. Groundwater exploitation by private farmers, however, was not controlled. Overexploitation caused a significant lowering of water tables and deterioration of groundwater quality. A recent study indicates that the regional water table has declined some 20 m. Originally, lateral groundwater flow from the South controlled the level of the water table and the salinity of the area. As groundwater withdrawals continued, several things happened. Upward seepage of groundwater from lower formations increased salinity. Return water from the irrigated fields increased the nutrient content. The return water also became more saline because of the high evaporation rates (3–16 mm/d).

In the Indian Punjab combined rice-and-wheat cultivation is rapidly lowering the water table. The crop combination of rice and wheat in monsoon regions requires extensive irrigation to supplement limited rainfall. The existing surface irrigation network is, however, insufficient to meet today’s water demands. Consequently, farmers have turned to more “reliable” groundwater resources and have installed 800,000 private wells, most of which are electrically operated and financed by government subsidies. As a result, groundwater levels in large parts of the region are falling at about 1 m/year.

On the other side of the border, in the Pakistan Punjab, where rice-and-wheat farming is practised, good quality canal water has become increasingly inadequate and has led to groundwater irrigation. As a result, groundwater is becoming more saline.

Drainage: two opposite attitudes to the landscape response

The Florida Everglades – the largest wetland systems in the continental US (20,000 km^2) stretches from the Kissimmee River in the north, through Lake Okeechobee and south to Florida Bay. At the time the area was settled by Europeans in the mid-1800s, the wetlands were considered inhospitable and without intrinsic value. At the beginning of the 1900s, draining the Florida wetlands was considered essential to commerce and safety. In the 1920s loss of lives due to hurricanes accelerated the drainage projects. These human activities have affected both the hydrology and the original ecosystem in southern Florida. Today much of the original Florida Everglades is a highly managed hydrologic system with canals, levees, and pumping stations, which can move parcels of water in any direction (Figure 5.3). The rest of the Everglades, a major part of the original, has been drained or dried up for the use of development and agricultural activities.

There are more than 1,400 miles of canals and over 100 water control structures. The native flora is highly appreciated with a major national reserve lying downstream of the major land and water disturbances. Balancing the demands of society on the water resource against the unique ecology is complicated. For example, the flora has critical timing requirements for the duration of flooding, called hydroperiods. Moreover, agricultural activities produce nutrient laden waters while sensitive components of the Everglades' flora require low-nutrient waters. Recently, a consensus has been reached among federal and state agencies and environmental groups. The resulting plan includes support for research on the function and needs of this sensitive ecosystem to provide a sound technical basis for the future governance of the region, and an engineering solution for the restoration of the original Everglades' flow pattern.

In other situations originally unwanted ecological liabilities may later be viewed as assets. In the central Netherlands drainage of

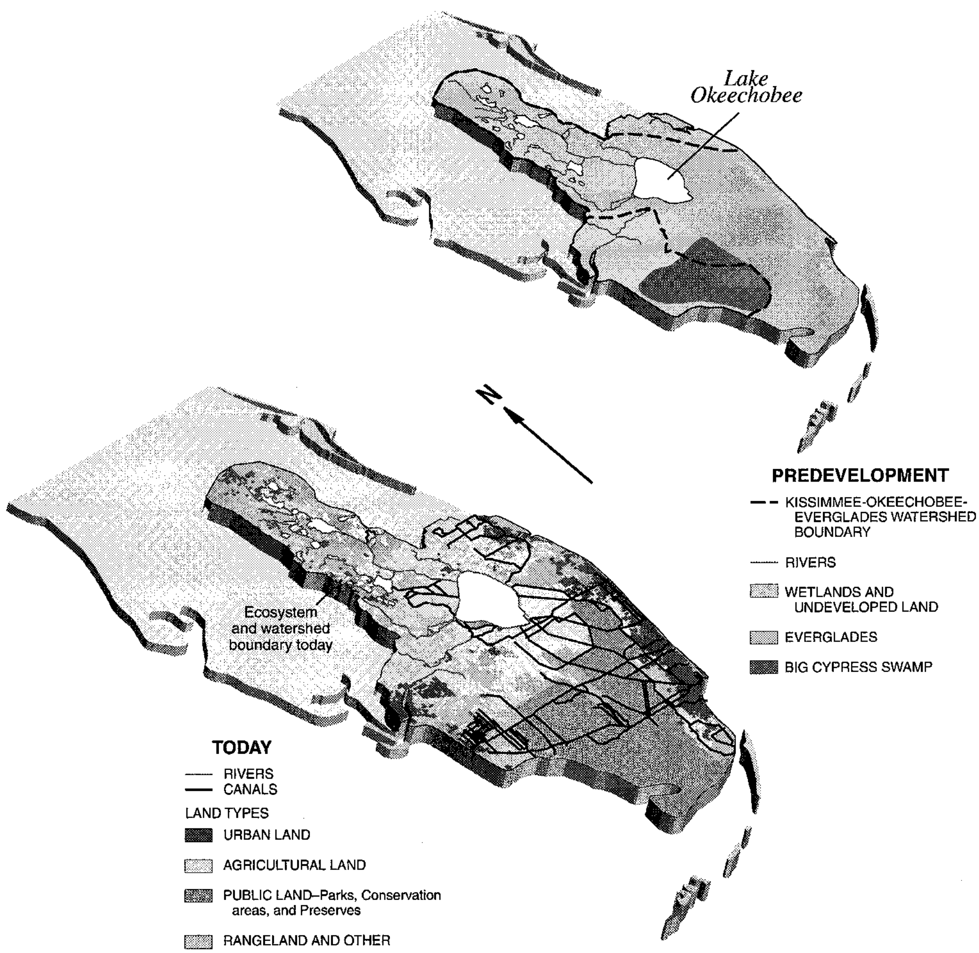


Figure 5.3.
Today much of the original Florida Everglades is a highly managed hydrologic system with canals, levees, and pumping stations, which can move parcels of water in any direction.

A change in land use has consequences on altered runoff or groundwater recharge. The link is created by what happens to the precipitation in the water cycle.

the low lying plains and valleys for agricultural land-use (the Vecht plain, the Eem valley) began in the Middle Ages. Lowlands were divided into polders, each with its own artificially controlled water level. Peat mining of these areas produced many lakes, and by vegetation regrowth some of them changed into important fen ecosystems, dependent on groundwater seepage. Today these areas are highly appreciated as nature reserves surrounded by agricultural land, lakes and urban areas. Atmospheric exposure of the polders caused soil shrinkage, which has caused the bottoms of the polders to lie several meters below mean sea level. To maintain water levels in the polders, large quantities of fresh groundwater must be removed, and at the same time, large quantities of groundwater must be withdrawn for water supply, which further decreases the seepage of fresh groundwater into the peatland reserves. As a countermeasure, the provincial government has now more than halved groundwater withdrawal to stimulate the groundwater flow into the nature areas. To compensate, new abstraction wells are located at the end of groundwater flow paths where groundwater discharges into rivers and lakes.

Unintended side effects of vegetation change

Large-scale changes in land-use produce changes in river flow. In Russia, linkages between cultivation and river flow were noted during the last century. Mass cultivation and deforestation of virgin steppes resulted in sharp increases in surface runoff, floods and erosion. In contrast, decreasing river flow has resulted from ploughing that was aimed at improving soil permeability and making it possible for more water to reach the plant roots. For example, in the Don basin which has 60–70% of the land under the plow, river flow decreased more than 10%. Agricultural practices aimed at increasing water infiltration thus resulted in river flow decrease while drainage of lands, deforestation, and urban growth resulted in an increase of river flows.

In Australia land-use changes have caused salinisation. Deep-rooted trees were replaced by shallow-rooted grasses, and excess irrigation water recharged the groundwater. (cf. figure 3.5.) This has been the case in the Murray-Darling basin, which drains more than 1 million km^2 in South East Australia, and contributes some 60% of the total agricultural production of Australia. As soil salinity increased, plant growth was inhibited, and water and wind eroded the top soil. The major reason for the salinisation is that saline groundwater is seeping from the ground. In the rainfed or groundwater recharge areas where deforestation has occurred, reduced return flow evapotranspiration to the atmosphere leaves more water to feed the aquifers. Excess irrigation water in the irrigated areas also recharges groundwater. The increased recharge has caused groundwater levels to rise to the land surface, where it starts to evaporate, leaving the salts behind on the land. To deal with the problem, water has to be taken out of the system. The aim would then be to return more water to the atmosphere. This can be done either by installing drains to intercept the water before it reaches the groundwater table or by pumping shallow groundwater into evaporation basins. Planting trees, shrubs and perennial pastures in strategic parts of the landscape to increase evapotranspiration is another method.

Forest regrowth after wildfire consumes a large amount of water in the tropics. Widespread wildfires in 1939 in South East Australia wiped out extensive areas of old growth mountain ash forests. During the following regrowth there was clear evidence of declining water flows in the rivers until the forest had matured. This raised concern about the need to balance timber harvesting practices against water demands. A 26 year research effort indicates that the present harvesting technique, in fact, promotes dense-forest regeneration, and a prolonged reduction in water runoff. Baseline flow from a mountain ash forest in the Melbourne area is about 1,200 mm, but flow during the 27 years of regrowth after a disturbance (fire or timber harvesting) amounts to less than 50% of the baseline flow. Complete flow recovery is estimated to take about another 150 years. Consequently, water flows can be maximised by maintaining old growth forests. These results affect the management policies of Melbourne's water supply. Timber harvesting has been prohibited on 75,000 ha of the water-supply catchments and wildfire prevention is a high priority. In general, a 67% reduction in the rate of clearfelling would be desirable as well as the introduction of thinning practices in the regrowth forests. These two additional management practices should provide an appropriate balance between runoff production for the Melbourne water supply and timber production.

West Indian rivers may have been depleted by irrigation to support a boom in banana production. In the well-watered Caribbean island of Saint Lucia, which receives more than 2,000 mm of rainfall annually, farmers depend on small basin streamwater for irrigation. Because of the steep slopes, groundwater resources are limited. The island, however, has been experiencing progressively lower dry season streamflow. Has the decrease in streamflow been caused by the boom in banana production and related land-use alterations? Increased banana production involved transformation of secondary forests, rain forests and sugar cane plantations into banana plantations, which possibly altered the water partitioning pattern.

In Vietnam, flash floods are generated when rain falls on tropical forests growing on steep slopes that have been extensively developed. Flash flooding is a special natural disaster typically occurring in mountainous areas in Vietnam and other parts of Southeast Asia. The magnitude and frequency of flash floods has increased, resulting in casualties, economic losses, and environmental degradation. Preliminary studies indicate that many factors contribute to flood generation, but the primary causes of flooding are extensive human development of high-risk areas, deforestation and changing land-use from forest to agriculture. Each primary alteration of the landscape decreases infiltration by developing bare and impermeable soil surfaces. Decreased infiltration causes soils to erode and increased surface runoff.

Introducing chemicals into water pathways

Agricultural practices aimed at increasing water infiltration can result in river flow decrease while drainage of lands, deforestation and urban growth can result in river flow increase.

We will now focus on human activities in different parts of the world that cause changes in the chemical composition of water flowing through the landscape. The most important human activity in this regard is waste water disposal into rivers and lakes. Another activity is the production of waste gases emitted into the atmosphere, where they react with water, particles and gases and introduce chemical substances to water pathways. The best known example is the acidifying gases derived from the burning of fossil fuels. Surplus agricultural chemicals left in crop lands and dry solid waste deposits left in the landscape are subject to the leaching action of rainwater on the move.

Examples of direct waste water disposal to surface waters are numerous in environmental decision making. However, waste water may also pollute groundwater. Tannery effluents are causing increased concerns for ecosystem and human health in Tamil Nadu because they are discharged into the Palar River. The Palar River drains 10,000 km^2, and is ephemeral, flowing only 1–2 weeks each year. It is one of the most polluted rivers in Asia carrying wastes from 600 tanneries and five major towns on the river. Although groundwater is the source of public water supply, some of the groundwater recharge occurs from the highly polluted river. Contamination of both surface and groundwater has reduced availability of usable drinking and irrigation water.

Kuwait has been suffering an increased degradation of groundwater quality as a result of the Gulf War. Massive oil spills from damaged and burning oil wells formed oil lakes on the land surface. Combustion products covered large areas around the oil fields. Although oil from those lakes is unlikely to penetrate the unsaturated soil more than about 2 m, rainwater that infiltrates after heavy rains reaches the groundwater table within only three to four days. The hydrophobe organics are then able to move everywhere water can pass. The risk for groundwater pollution was estimated using field observations and mathematical models. Leaching of contaminants by infiltrating rainwater is a major factor degrading groundwater quality. The model predicts that for undisturbed conditions, pollutants will spread very slowly, i.e., 5 km in 80 years, but extraction of groundwater will accelerate the movement.

Leaking pipes: unwanted groundwater recharge

Residential areas of Kuwait have been affected by rising groundwater levels in recent years. The additional groundwater is derived from leaking water pipes that have caused flooded basements and waterlogged soils. Recent studies indicate that the principal aquifer has been recharged by lateral groundwater inflow from the south and the west, and seepage upward from underlying formations. Due to the arid climate, groundwater recharge from occasional rainstorms is small to insignificant. Today, several human activities add to the recharge: excess irrigation in gardens and parks, seepage from septic tanks, and leaks from water and sewage distribution systems. The water conveyed in these systems is desalinated sea water and brackish groundwater piped from distant sources. Since 1961, the combined recharge, however, exceeds discharge from the aquifer, (including such factors as outflow to the sea, evaporation losses, percolation into lower formations, leakage into low lying storm and sewer pipes) and has resulted in a rising groundwater table. The present challenge, therefore, is to determine how to manage the rising water table.

The city of Karachi, Pakistan, suffers from a major dilemma: its water distribution system is submerged in a mixture of water and sewage. Leaky pipes have caused an unintended groundwater recharge and groundwater levels have subsequently risen in some urban and industrial areas. In addition, the sewage distribution system is overloaded, and the pipes are often deliberately perforated to relieve the backup in the system. The near absence of sanitary facilities as well as the large number of small industries scattered throughout the city provide additional potential for groundwater contamination. The industries, of which many are tanneries, produce hazardous waste.

Not only is there a general water scarcity, but the severely leaking water pipes lie just a few centimetres below the sewage lines and are frequently empty with no pressure to keep pollutants out. The end result is that the water supply system contains hazardous water, which is nevertheless used for drinking and food preparation. The poor drinking water quality is reflected in severe health problems.

Human waste may also contribute to water quality degradation. For example, human excreta pollute groundwater in both Tamil Nadu, India, and Botswana. In eastern Botswana, deep leaching from pit latrines causes nitrate concentrations that exceed WHO health limits in water wells. In this area, about 10% of the nitrogen from human excreta (or 1.5 kg nitrogen per ha annually) is leached into the groundwater. The situation is similar in Tamil Nadu, where humans customarily excrete on the ground surface. Leaching from agriculture and villages is more diffuse than in Botswana. Leaching from livestock wastes, however, does not contribute substantially to groundwater degradation, possibly due to deep-rooted shrubs and trees in these areas which remove the nitrate. Because groundwater degradation is not observed in vegetated areas, nitrate leaching and bacterial pollution of groundwater might be minimised in other areas by planting vegetation.

Land use as a pollution source

Not only "point sources" (such as a single outlet from a factory or from a latrine) but also extended land-based sources of pollutants add to water quality degradation. Agricultural fertilisers and chemicals cause considerable problems. The intensively fertilised agriculture in Denmark, for example, has generated high nitrate concentrations in shallow groundwater. They are high enough to make the groundwater a health hazard. Main nitrate sources are animal waste and synthetic fertilisers used for field and crop production. Preventive measures have been taken to secure a decrease. Monitoring, however, shows that rather than the expected nitrate decrease, the concentrations continued to increase. We will return in Chapter 6 to the analysis of how to come to grips with the serious threat to the future water supply of this country that entirely depends on groundwater for its water supply.

In Australia, blue-green algae bloomed along 1,000 km of the Darling River in November 1991. The bloom focused the attention of the entire nation on eutrophication of streams in the Murray-Darling basin. Algal blooms have long been a part of the Australian landscape. However, their frequency and extent are believed to be worsening. The principal causes of the blooms are: reduced flow in certain rivers caused by irrigation; withdrawals in upstream areas; and increased nutrient influx to rivers from urban and agricultural sources.

A more complex situation exists in the severe pollution of the Laguna de Bay, the Philippines. Laguna de Bay is the largest lake in Southeast Asia with 21 river inflows draining 3,000 km^2. The lake is shallow, averaging only 2.8 m at low water. It is under severe environmental stress due to unabated fluxes of harmful wastes from domestic, industrial, and agricultural sources, and from watershed development in general. Monitoring has revealed rapid concentration increases of chemicals in the lake and it has become hypertrophic. Management of the lake is beset by a plethora of ecological, social, institutional, and political problems. Conflicting interests among the multiple users of the lake complicate the issue: fishery and aquaculture; power generation; industry; irrigation; livestock; navigation including oil barging; recreation; waste dumping; and flood control. The situation is especially worrying because the lake is the future domestic water supply for the city of Manila. Currently, the mountain streams provide most of the water for the city, but anticipated growth will require the use of lake water. Protection of the lake will require drastic measures and strict implementation of land-use policies and regulations such as those for forestry and agriculture will be necessary. Also necessary will be: infrastructure development; housing programs; control of industrial and agricultural wastes; and domestic waste water treatment to get rid of nutrients and pathogenic organisms.

Human waste may contribute to water quality degradation. Deep leaching from pit latrines has caused nitrate pollution of groundwater that exceeds health limits in water.

Another example is the eutrophication of a Singapore reservoir. Land is scarce in Singapore and the pressing need for domestic water has always been a primary concern. Before 1969 raw water for the city water supply was taken only from natural catchments. Rapid increases in demand, however, made large reservoir development necessary. The Seletar reservoir was the first to be built. It drained eight catchments influenced by farming, particularly pig farming. The Kranji-Pandau reservoir, the most recent project, consists of damming an estuary and transforming it into a freshwater reservoir. The 110 km^2 catchment was completely unprotected. Runoff

Extended land based sources of pollutants such as, e.g., agricultural fertilisers and chemicals, add to water quality degradation.

from the catchment had extremely low quality with very high nutrient concentrations and quickly resulted in an advanced stage of eutrophication. An assertive conservation program is currently being implemented. The first stage of the program is to alleviate the nutrient loads from pig farming by encouraging farmer resettlement.

The leaching from waste deposits is one example of a specific source, a "point source", of pollutants. In eastern Massachusetts, present and past human exposure to arsenic is a concern in the Aberjona catchment. It is typical of many urban industrialised areas in the USA. A study revealed that most of the arsenic was released from a hazardous-waste site in the headwaters of the catchment. Both surface water and groundwater carried the arsenic downstream. Arsenic transferred between these two media at several locations in the watershed. Other natural redox, sorption and alkylation processes affect arsenic movement by making it more mobile and more easily soluble in water. The conclusion from the study was that risk assessment restricted only to certain designated waste disposal sites provided an inaccurate picture of the overall risks and a biased focus for remedial action. The appropriate unit for investigation of chemical contamination is the entire catchment.

The forced abandoning of long fallows due to increased population pressure explains why millet yields have progressively declined almost three-fold during the last 7-8 decades.

Metal leaching for hundreds of years from mine tailings in Bersbo, Sweden is another example of pollution from a "point source" but where there is a need for entire catchment investigations. "Acid rain" over the southern part of the country has accelerated the leaching of metals from mine tailings. Weathering of sulphide minerals in copper mine tailings, discarded since the 13th century, have produced an acidic leachate rich in metals that drains into two streams.

Disturbing land fertility

The vulnerability of rainfed farming

Rainfed farming systems in dry climates produce most of the food in developing countries, where external inputs of fertilisers and pesticides are either not used or used only in small amounts. One of the major goals for most farmers is to achieve food self-sufficiency. The sustainability of these farming systems requires protection to maintain land productivity. For centuries, agriculture here has been largely based on maintaining soil fertility through the fallow system, often in the form of "slash and burn" practices. Land availability per capita is decreasing as population increases.

Cultivation systems were historically based on long fallows (> 20 years). This practice has now been abandoned in response to demographic pressure in favour of shorter fallows, or no fallows at all (Figure 5.4). The current practice involves manure and mulch application from postharvest biomass left on the fields. The competition for biomass and the lack of sufficient amounts of manure, makes this practice difficult. The amounts applied to the fields are not enough to compensate for exported nutrients and the oxidation of organic matter. The agrarian system thus converts to continuous cultivation with "nutrient mining" as a consequence. Decreasing yields are common, and probably result from several factors such as hydroclimate fluctuations; altered water partitioning; altered capacity of the soil to hold water; and ensuing decrease of soil fertility.

This population-driven land degradation is a "vicious spiral" accelerated by droughts (Figure 5.5). It is easily understood by analysing the dynamics of the agricultural systems. Fallows diminish or disappear with ensuing loss of organic matter and nutrients. The exportation of biomass from the land has increased because of the demand for fodder by

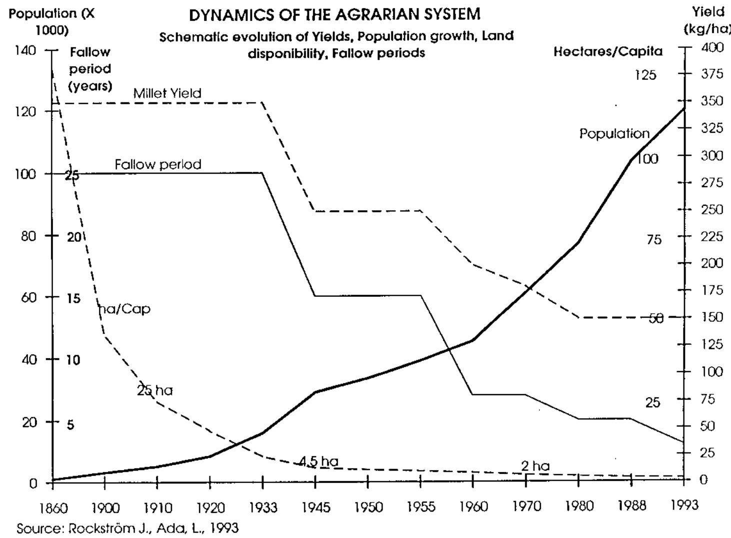


Figure 5.4.
Dynamics of the agrarian system. Co-variation of reduced fallow period and millet yield for a rainfed agrarian system in the Sahel (Niger) for the period 1860-1993. (Rockström & Ada 1993.)

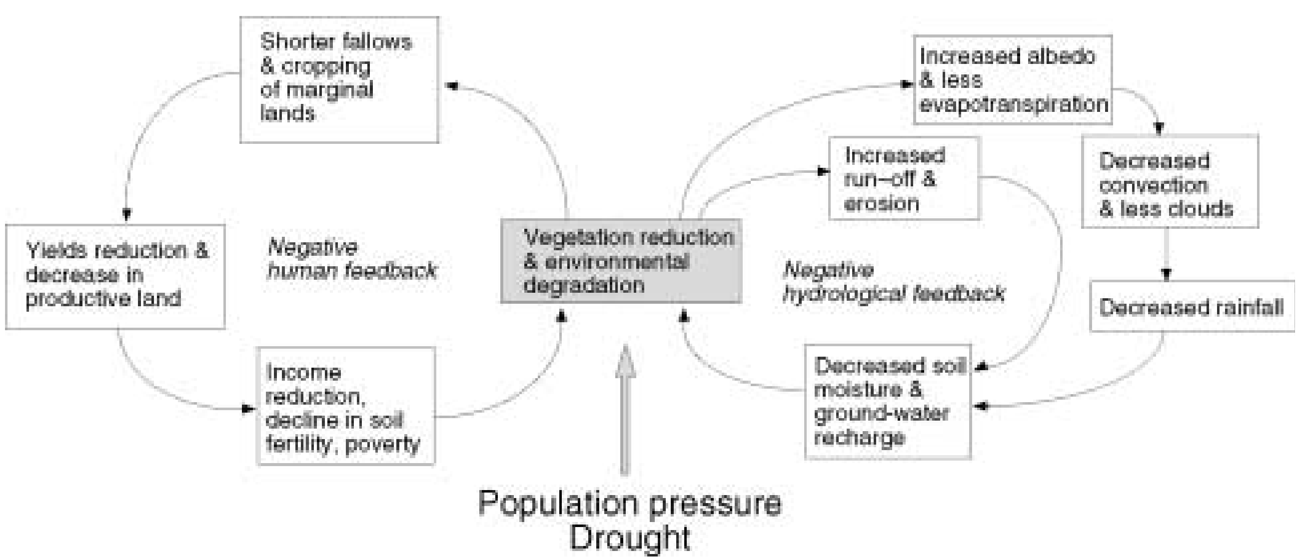


Figure 5.5.
Mechanisms of dryland degradation. (After C. Batchelor 1995.)

ever larger numbers of livestock. Increased demand for fuel, and increased demand for construction wood also contribute to the biomass export.

The cost of not replacing nutrients

Progressive abandoning of fallows is probably the most significant "structural transition of dryland agriculture". Long-term problems of tropical soils are not clearly visible until the practice of long fallows is abandoned. Abandoning fallows in temperate regions has no noticeable effect because nutrients have been replaced by fertilisation. Without fertilisers agriculture in the tropics can be equated to "nutrient mining".

Health problems may be generated by bacterial and toxic pollution of drinking water...

The evolution of agriculture in the Sudano-Sahelian region of Burkina Faso, where precipitation is 750 mm annually, estimated that pearl millet yields were about 1 t/ha until the 1960s. Fields were cultivated for five years, then left fallow for more than 20 years. Since the end of the 1960s, fallow periods have shortened, and nutrients have not been replenished by fertilisers except in the case of some rich farmers. Yields declined to 0.2-0.4 t/ha in many areas, cultivation was extended to marginal lands, and rural migration increased. Degradation of the soils combined with the effects of the 1982–84 drought have increased food deficits.

A similar evolution has occurred in the Sahel region of Niger, where millet yields have declined progressively from around 0.4 to 0.15 t/ha during the last 70-80 years. The decreasing yields are attributed to increased population pressure that causes forced abandoning of long fallows and to the lack of access to uncultivated lands downstream in the landscape.

Social effects of human interventions

Health effects of polluted water

Changes in the life support capacity of land and water, such as those discussed in this chapter, will have societal consequences. For example, the poor water-quality situation of Karachi has severely affected human health. High nitrate concentrations in ground and surface waters, as observed in several agricultural regions of Europe, constitute a serious health hazard unless countermeasures are found. This is the dilemma of Denmark which is dependent on groundwater for its water supply.

Unsafe drinking water causes health problems in regions where water sources are polluted, or the domestic water distribution systems are polluted by leaks into the system. Contamination of seafood is another source of effects on health. Health problems may be caused by bacterial contamination of the water sources due to poor sanitation and poor waste treatment facilities. Toxic pollution generates diseases through the introduction of cancerogenous substances. These have a long lead time, and are difficult to identify as are the cause and effect linkages.

It is difficult to make the increasing population refrain from using polluted water sources. This is the case even when alternatives are present, as is illustrated by the situation in Cotonou. Cotonou, the largest city in southern Benin, is located in a poorly-drained area on sandy dunes and marshes with a shallow water table. Solid waste is dumped at sites throughout the city, but liquid waste is disposed of everywhere. Consequently, groundwater is heavily polluted by leaching, the decay of solid waste and the percolation of liquid waste. Although potable water is distributed by a public water-supply system, the population believes that water is a gift from God and they do not accept to have to pay for their drinking water. They use polluted water from wells rather than pay for good quality public water. The risk of drinking the polluted water is not understood.

Human health effects in the Aral Sea region are also important. From the dry lake bed salts spread as dust over the region. This dust also includes toxic pesticides once transported to the sea from upstream agriculture. In Uzbekistan on the southern side of the lake, health problems have reached an unprecedented high level. The problems are believed to be environmentally induced and related to heavy metals, salts, other toxic substances in the drinking water, and to organochlorine pesticides such as DDT used in vegetable production. Womens' health has deteriorated in the region with cases of kidney disease, thyroid dysfunction and anemia. The region has the highest levels of maternal and infant mortality in the former USSR and 21 out of 1,000 live births are babies with birth defects.

Economic losses and vanishing income

In regions supported by tourism, pollution problems may result in economic losses. For example, a recent cholera epidemic in South America shut down the tourist industry. Another example is the economic deterioration around the Caspian Sea, a closed lake which is fed by the Volga. The Volga drains the area from north of St. Petersburg in Russia and is the major source of pollutant inflow into the Caspian Sea. In addition, irrigation derived from the Volga has reduced the lake inflow, which has lowered lake water levels, similar to that of the Azov and the Aral Seas. The total waste input to the lake is approximately a 25%, or even more, of all the wastewater generated by Russia. In addition, the oil boom in Azerbaijan resulted in the industrialisation of the area around Baku on the Caspian Sea shore. As a consequence of all this pollution, the Caspian Sea fishery has collapsed. The most serious shock to the region has been the disappearance of its most valuable product, the sturgeon which produces caviar, an important export product. Also, the number of fish returning to the Caspian has declined dramatically as a result of the obstructed migratory paths in the Volga.

Risk for social unrest and environmental migration

The risk for social unrest and political upheaval is best illustrated by the future of water resources in Manila, where Laguna de Bay, the largest lake of South East Asia is on the threshold of an ecocatastrophe. In areas where land degradation reduces the agricultural yields, famines occur – especially during intermittent drought years – and cause populations to migrate. Ethiopia and the Sahel region provided many examples during the droughts of the past decades.

...in some countries people do not accept having to pay for potable water and disregard the risks.

In the densely-populated state of Anambra in the Nigerian rain forest, an annual 2,000 mm of heavy and torrential rainfall generate flooding and migration. Floods are usually uncontrolled and cause serious damage to lives and property both in rural and urban areas. Floods drown humans and livestock, they cause wash-outs of roads, dams, and houses, farmland destruction, severe erosion and gully formation as well as increased sediment deposition in streams, rivers and lakes. In urban areas buildings and other structures collapse, pavement is undercut and washed away, and water supply distribution pipes and cables for power and telecommunication are dislocated. Social stress results and inhabitants become refugees. The flood flow intensity and subsequent damages are increased by local topography and geology. Poor engineering and drainage practices, and the effects of excessive rural and urban growth have enhanced flood disturbance. Roofs of corrugated iron sheets intensify and channel the water causing heavy floods along roadways. Scientists are now developing methods to intercept flow and reduce erosion by multi-purpose, multi-objective concrete canal systems, by terracing, damming, reservoirs, and reforestation through agro-forestry.

Upstream – downstream disputes

Environmental disputes and conflicts may result from conventional competition for water between upstream and downstream users in the same river basin. Well known examples include:

- the dispute in the Ganges River basin between India and Bangladesh regarding Indian withdrawal of water from the Farakka dam immediately upstream of the border to flush silt from the Calcutta harbour;
- the dispute in the Eufrat River basin between Turkey and downstream countries due to flow reduction during the filling of the Anatolia reservoir; and
- the dispute between Israel and Jordan regarding water withdrawal from lake Tiberias by Israel to provide water for its coastal region.

Disputes may also be caused by upstream activities polluting the lifeline of downstream populations. This is the case with most large European rivers, for example, the Rhine. The Netherlands is the downstream recipient of basin activities in the Rhine: salt mine waste disposal in France, and heavy metal wastes from heavy industry in Germany. The river also transports a generally high load of polluted silt that clogs the Rotterdam harbour – one of the largest harbours in the world. The harbor is dredged to keep it deep enough for ocean-going vessels. The silt must be treated as hazardous waste rather than be used as a soil supplement.

Large scale water projects such as the water storage reservoirs at the Assuan High dam in the Nile cause disputes. Projects that aim at large scale water transfers always cause conflicts, for example, the cases of the Narmada River dam, or the massive water transfer now planned for Yangtse River in China which will provide water for Beijing. Hydropower projects like the Three Gorges project in China, or the dam on the Danube which is disputed by Austria, Slovakia and Hungary are other examples of environmental disputes related to water.

The way out: the integrated approach

Three sets of challenges

To summarise: this chapter has described different ways in which humans interfere with land and water, and how these activities produce unintended and undesirable side effects. Those side effects then turn into problems for politicians and have to be solved on a local, regional or national level. Table 5.1 gave an overview of what is at stake as a consequence of major failures in land and water management.

There are two issues to be discussed here. First we will present a summary in form of a typology of the environmental challenges. Secondly we will present some ideas on possible solutions. The solutions are all based on one major precept: the importance of an integrated approach.

Each of the environmental challenges and problems have multiple causes:

- Water scarcity evolves from three sets of causes:
  (1) population growth over time which causes an ever-increasing pressure on a finite water resource;
  (2) urban population growth which results in very high demands for water locally; and
  (3) desiccation of the landscape which leads to drought-like conditions even in high rainfall areas.
- Water pollution evolves from four sets of causes:

(1) airborne emissions;

(2) pollution related to land-based activities;

(3) human waste – seized and carried by the water cycle; and

(4) direct distribution of waste water into water bodies.

Pollution from all four sources ends up either in the landscape, in the water bodies or in biological material, and will ultimately have a detrimental impact on ecosystems and human health.

- Land degradation evolves from four sets of causes:

(1) salinisation or water logging caused by poor irrigation management;

(2) acid rain originating in gaseous waste emissions;

(3) reduced water-holding capacity of the soil because of reduced use of organic fertilisers and removal of organic matter from the soil; and

(4) degradation of land permeability because of landscape mismanagement.

Integrating land-use and water management

Water is essential for both human activities and ecosystem health. Thus, the various effects discussed above cause problems which have to be solved. Because of the multiple causes of most of these disturbing interactions it is absolutely necessary to take an integrated approach to solving the problems of land and water use and management. This approach was as well discussed in the UN Conference on Environment and Development in Rio de Janeiro in June 1992 and is formulated in the recommendations in Chapters 10 and 18 of Agenda 21.

This means, first, that we need to better understand the land and water linkages under different hydroclimates. Second, we need to find solutions to overcome administrative and legislative barriers to an integrated river basin approach. We will return to the latter issue in the next chapter.

In this chapter there is one clear example of the benefits of integrated land-water planning and management. In the watershed supplying water to Melbourne, Australia, the understanding of the competing functions of the forest contributed to the solution. The basic solution was to manage deforestation through control of the rotation time of the trees. However, the city inhabitants also took an administrative and legislative approach which made it possible to come to an agreement on forest management between the forest industry and the Melbourne water authority. As a result recharge of the river remains large enough to satisfy the needs of the city.

There are a wealth of success stories that are not treated here, such as the benefits of introducing waste water treatment plants to safeguard downstream water use. Another story not treated here concerns the importance of negotiations between upwind and downwind areas. Upwind areas often produce acidifying gases from fossil fuels which cause acidification problems in downwind areas: dying lakes, forest dieback, and unidentified damage on the fauna. There are obvious benefits for downwind areas to negotiate with upwind countries to convince them to minimize the output of such gases.

The well balanced landscape

Before we end this chapter, we focus attention on some new ideas in modern environmental research, which focus on spatial structure of the landscape, on the functions of its different components and on consequences of unintended leakage of water and nutrients from poorly managed and degraded landscapes. Forests, wetlands and riparian zones tend to dampen fluctuations and losses. Ecotones (border areas between habitats) such as wetlands and riparian zones adjacent to agricultural land are barriers to nutrient transfer. In contrast, ecotones adjacent to areas with human impact are not as effective since they depend on exportation of matter through artificial "pipe" systems instead of the natural terrestrial environment.

Therefore, ecotones are potential managerial entities in the landscape that link water pathways and could be used for integrated hydrological and water quality management. Wetlands and riparian forests are particularly important candidates for such integrated management. Gumbricht (1996) concluded that a key to effective implementation of this approach is finding the logical positions in the landscape for establishing or re-establishing such ecotones.

6 Reversibility and the time scales of recovery

Remedies for retarding, stopping, and ultimately reversing environmental degradation will be discussed in this chapter. Most of the degradation of land and water resources is not easily stopped or reversed. Radical changes in policy and overall administrative structure are needed for immediate action. Knowledge of what needs to be done exists now and is sufficient for efforts to stop the degradation of land and water. In certain regions of the world, degradation has been halted through innovative programmes and recovery is taking place. These may be successful given sufficient time and resources. This section of the book describes and identifies key factors affecting some of these examples while considering their unique position with respect to prevailing physical, social, economic, institutional, and political conditions. This chapter also discusses the potential for reversing land and water degradation and the main steps that are necessary to initiate environmental recovery programmes.

The effect of reduced discharges of nutrients in eutrophied lakes is sometimes only detectable after more than a decade. This is due to internal loading from nutrients accumulated in the sediments.

Reversible versus irreversible degradation

There are two major schools of thought on environmental degradation. The first, which is primarily concerned with the natural environment and species diversity, holds that any changes to the natural environment are potentially harmful. The second and more pragmatic view believes that degradation is the dege-

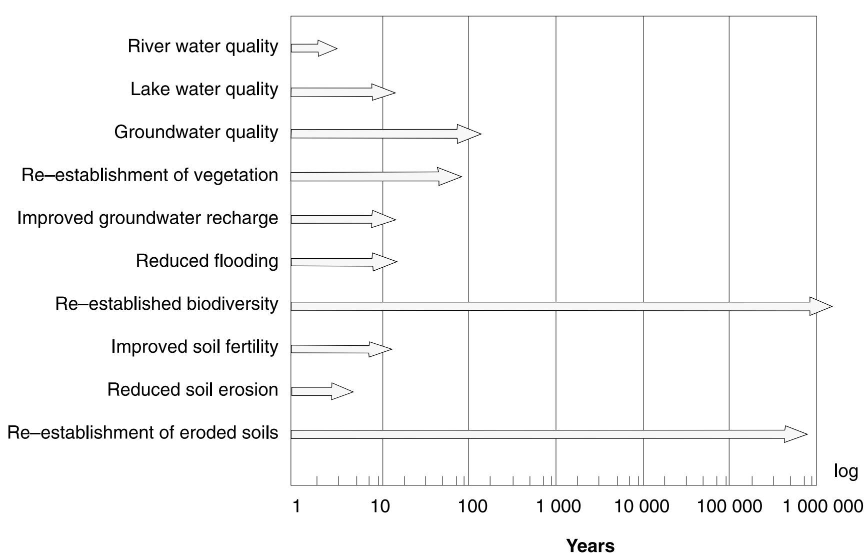


Figure 6. 1.
Logarithmic diagram showing the time scales of recovery after remedial measures.

neration of the natural resource base to a point where the costs of restoring it to a level where it can support people at a reasonable standard of living, becomes prohibitively high. This second school accepts that natural resilience exists in the environment and considers that the replacement of the natural environment by good agricultural practices or other sustainable land-uses is only development and not necessarily degradation. Degradation is no longer reversible once natural resilience is destroyed or exceeded, e.g., if severe erosion has removed top soil from a large area of a catchment. Although it is technically feasible to replace the soil, such an action is not economically viable. In contrast, degradation such as bacterial pollution of streamwater may be immediately reversed by stopping discharge of contaminated waste or wastewater. Between those two extremes, we find a range of time scales for reversing landscape degradation (Figure 6.1)

Identifying the root causes is an important first step in reversing land and water degradation...

It may take more than a decade before the effect of reduced discharges of nutrients are detectable in an eutrophied lake. This is because the internal cycling of nutrients, which have accumulated in the sediments will maintain the nutrient levels in the water for a long time scale. It may take several decades or even centuries to regain buffering capacity in a soil which has become severely acidified by "acid rain". The time lag between action and effect depends on many factors including the throughflow rate of water, geological conditions and the rate of chemical and biological processes affecting the transport and transformation of a particular pollutant. That means, for example, that the effects of resistant organic compounds like DDT will remain for a longer time than those of more easily decomposed and transported substances such as nutrients.

Identifying the physical causes of land and water degradation

An important first step in reversing land and water degradation is to identify the primary cause (or causes). Environment changes are often the net effect of many different actions that may work separately or symbiotically to cause the change. General relationships observed between environmental trends and agricultural practice or land-use may hide the true factors controlling the trends. Moreover, many causally unrelated land-use and environmental changes may nevertheless exhibit parallel time trends. It is all too easy, therefore, to make false interpretations because of spurious correlations.

Land degradation in semi-arid areas

An example of the number and complexity of factors and mechanisms that cause land degradation is given in Figure 6.2. This figure shows the climatic and human factors and feedback mechanisms that contribute to land degradation in semi-arid areas. Direct anthropogenic pressures resulting in overgrazing, soil erosion or deforestation as a result of poor or inappropriate land and resource management lead to loss of vegetation (mechanism 1). Loss of vegetation cover may in turn trigger feedback mechanisms, which can propagate further land degradation via the land surface-atmosphere feedback (mechanism 2). The negative feedback in the form of reduced vegetation occurs when a decrease in evaporation and an increase in the amount of radiation, which is reflected back to the atmosphere (albedo), reduce cloud formation and rainfall. A third possible mechanism contributing to dryland degradation is hydrological (mechanism 3). This can occur when a decrease in ground cover associated with poor land management results in a re-partitioning of water flows such as increased and more rapid runoff, decreased soil-moisture storage and reduced

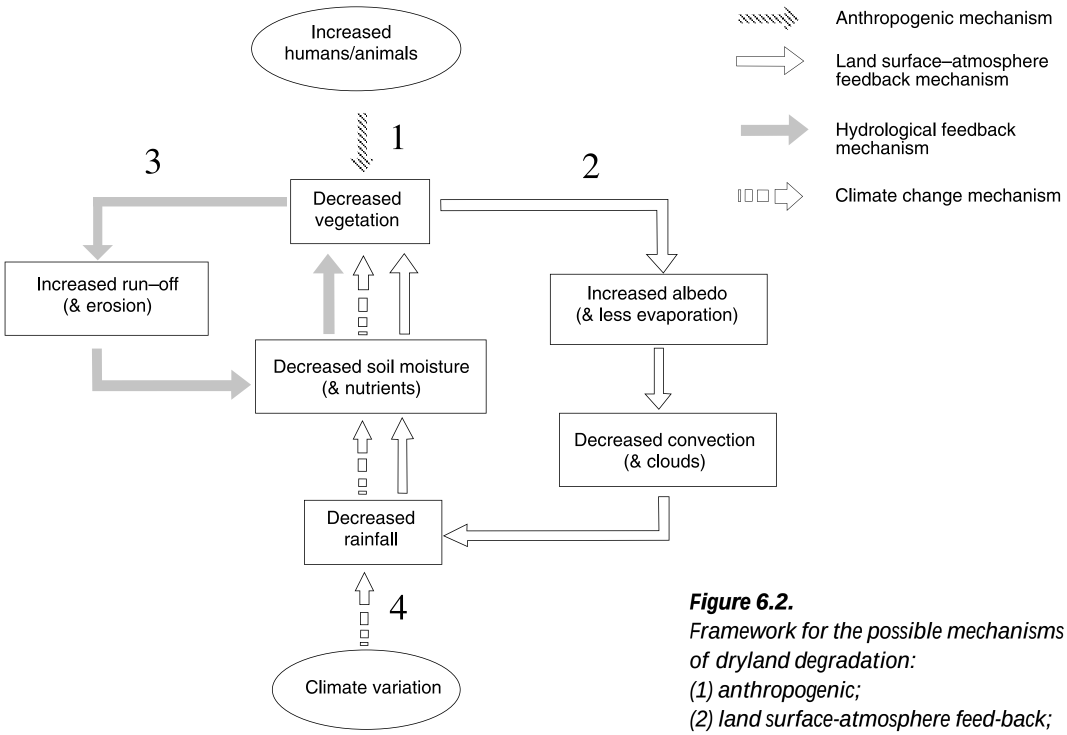


Figure 6.2.
Framework for the possible mechanisms of dryland degradation:
(1) anthropogenic;
(2) land surface-atmosphere feed-back;
(3) hydrological feed-back;
(4) climate change

groundwater recharge. Because of the increased runoff and lower infiltration in this situation, less of the rain that does fall on the degraded land is available for plant growth. The risk of severe soil erosion is increased and less groundwater will be available either for deep-rooting trees or as a resource that can be used by rural communities.

A hydrological feedback can also exist in the absence of any climatic change (the fourth mechanism in Figure 6.2). Here, external influences stemming from temperature anomalies at the sea surface, as well as humid tropical deforestation and climate change induced by carbon dioxide are thought to be associated with drought and degradation in arid zones such as the West African Sahel. The connection between rainfall and crop yields in southern Africa and sea temperatures in the eastern equatorial Pacific Ocean, the so-called "El Niño effect" is another example of a possible linkage between sea surface temperatures and rainfall.

In order to reverse land degradation, it is vital to identify the factors or sets of factors that control dryland degradation in a given region. For example, if degradation is primarily caused by overgrazing, then improving livestock management may facilitate the regeneration of vegetation and a reduction in soil erosion. In contrast, if the local climate change occurred due to external factors, reversal of the land degradation may not be possible.

The scientific challenge, therefore, is to understand the functioning of dryland ecosystems so that we can identify changes resulting from various sources. We must be able to distinguish between changes caused by natural

In order to reverse land degradation it is vital to identify the factors or set of factors that control dryland degradation in a given region.

variability (e.g., drought), human activity (e.g., poor or inappropriate land management) or climatic change induced "internally" by large-scale land degradation.

In contrast to these changes there are those which have their origin "externally" and which have been discussed above. However, many external factors can be controlled by effecting management strategies internally in other locations.

Nitrogen and phosphorus: vital for agriculture but harmful in excess

The overall causes for pollution of soil and water resources can be understood by setting up a material balance...

The overall causes of soil and water pollution can sometimes be understood by evaluating the fluxes of material. To illustrate this technique, the nitrogen balance for Denmark is examined in Figure 6.3. The size and direction of the arrows show the magnitude and transport direction of the annual nitrogen flux. Atmospheric nitrogen (N_2) is primarily involved in three processes:

(1) natural nitrogen fixation in plants that uses from 25,000 to 37,000 tons of nitrogen.

(2) commercial fertilisers for Danish agriculture that use 400,000 tons of nitrogen. The amount can be estimated from factory production data, and agricultural statistics of fertiliser use.

(3) high temperature combustion processes that convert 70,000 tons of nitrogen to NO_X. Fossil fuel combustion in power stations and for providing energy for aircrafts, cars, industry and private homes are the primary contributors. The amount can be estimated from statistics on the type of fuel and of the combustion process.

A compensating flow, whereby nitrogen in nitrate is returned to the atmosphere as N_2, is the natural process of denitrification, described in Chapter 3. The effect of denitrification is a flux to the atmosphere ranging from 90,000 to 250,000 tons N_2 annually.

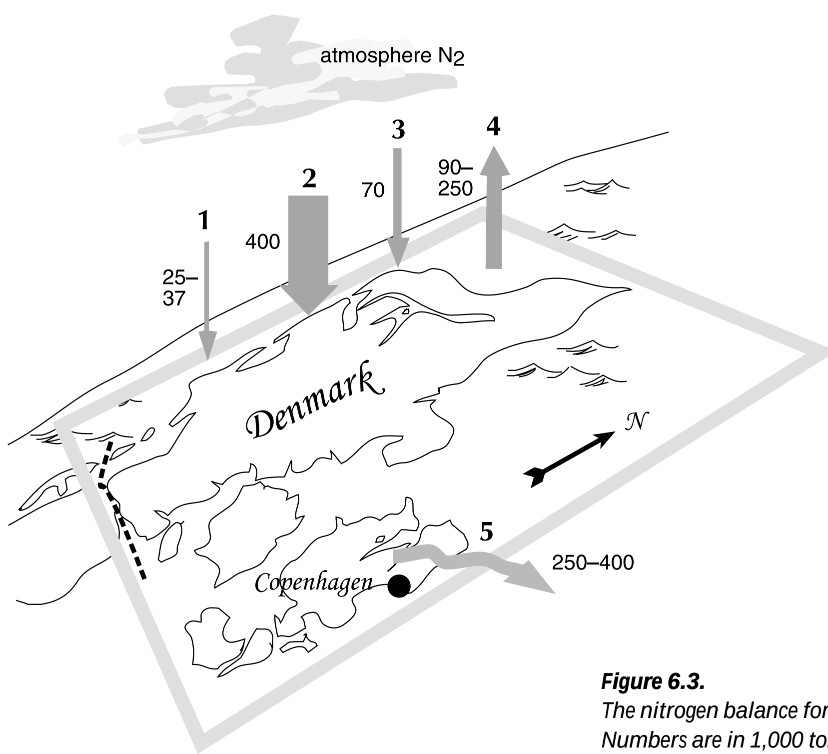


Figure 6.3.
The nitrogen balance for Denmark. Numbers are in 1,000 tons N per year.

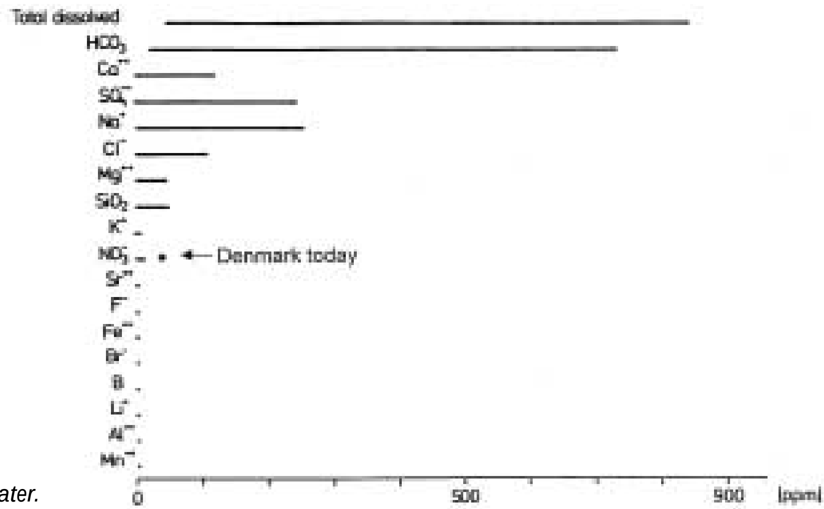


Figure 6.4.
Nitrate concentrations in Danish groundwater compared to normal concentrations in fresh water.

Denitrification takes place where there is a lack of oxygen in soils and sediments. It depends on climatic conditions such as temperature, precipitation. Geomorphology is also a condition as the position of the landscape influences the control of water in the soil.

In the Danish example, considerably more nitrogen is deposited in the landscape than is returned to the atmosphere. The nitrogen input fluxes minus the output fluxes range from 250,000 to 400,000 tons N_2 annually. The excess nitrogen in the landscape is transported in water soluble forms such as nitrate in water draining the land (flux 5 in Figure 6.3). As a result, the nitrate content in Danish groundwater has increased steadily over the last 60 years, and currently exceeds values considered normal in terrestrial waters (Figure 6.4).

What are the real causes for the increasing nitrate problem and general accumulation of nitrogen in Denmark? In Figure 6.3, the major influx is from fertilisers and NO_X resulting from fossil-fuel combustion. Actions must be concentrated on decreasing the influx or increasing the reflux to the atmosphere (flux 4). In order to be able to influence the influx, more knowledge about the process is needed, for example, "what is the most effective application of fertilisers?" Studies indicate that some primary factors contributing to nitrogen excess from commercial fertiliser use are:

- fertiliser application at the wrong time and in too large amounts;
- inadequate management of manure resulting in ammonia losses during storage and application;
- cultivation practices which annually leave fields for long periods without vegetative cover; and
- less use of nitrogen-fixing legumes in the crop rotation, which would reduce the need for fertiliser application.

For most of those practices, remediation measures are available and could lead to some reduction in the nitrogen losses from agricultural land. However, it must be recognised that cultivation of land will always lead to higher losses than if the land was left in a pristine state. In order to avoid contamination of groundwater and sensitive surface water systems the goal must be to minimise and localise pollution by using best management practices, and to adopt cultivation systems adapted to local geohydrological conditions.

Some factors contributing to the nutrient imbalance in modern agriculture are intimately linked to landscape ecohydrology. For example, when organic soils are drained and cultivated, soils become more aerated and thus decomposition increases and mineral nutrients are released and more readily leached during non-vegetation periods. Other examples of factors that increase eutrophication rates are: filling of ditches; installation of underdrain pipes; and removal of vegetation zones along streams and ditches. Removing ditches and vegetation zones will likely decrease denitrification (flux 4, Figure 6.2) and increase soil and sediment transport from the area, as described in Chapter 3. Re-establishing natural stream channels, planting buffer strips and creating wetlands and ponds in agricultural landscapes may be effective countermeasures for offsetting the negative effects of increased transport of water, nutrients and sediment.

However, the primary and underlying causes for both flux 2 and 3 are the increasing societal demands and economic growth aspirations (see Chapter 5). To exemplify this, we will take a more detailed look at the agricultural nitrogen budget in Upper Austria. The annual input of nitrogen from fertiliser ranges from 75,000 to 82,000 tons, but only about 15% of this actually reaches humans in marketable produce (Figure 6.5). In addition, the marketable produce is returned as waste which must be processed and treated as wastewater or solid waste.

Most losses in processing are linked to animal-protein production. Some losses are due to inefficient recycling of manure from animals. Moreover, excessive consumption of animal protein requires even more cultivation than otherwise needed. For example, the average Central European consumes 2.5 to 3 times more meat than advised by nutritional experts. Thus, altering life styles through changes in nutritional habits can significantly decrease nutrient losses from agriculture and slow the resulting eutrophication.

As discussed in Chapter 2, material balances for metals clearly indicate where problems may occur and provide sufficient warning to introduce a proactive programme for the reversal of land and water degradation. For very toxic metals, e.g., mercury and lead, the only long-term solution is to reduce their abstraction and use, as has been done in the production of lead-free gasoline. International bans already exist on some very toxic or damaging compounds which are persistent in the environment e.g., DDT, PCB and freons. However, the bans must be more strongly enforced to reverse future land and water degradation.

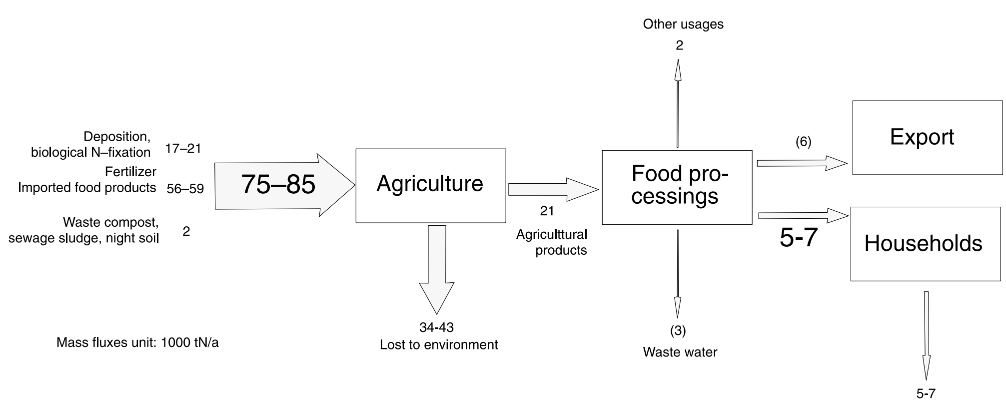


Figure 6. 5.
The flow of nitrogen in food production in Austria (thousand tons per year). (After Fleckseder 1994.)

Identifying the socio-economic causes of land and water degradation

Individuals are the most important problem solvers. They can significantly reduce the nutrient losses from agriculture and the eutrophication problems in waters through changes in their food habits.

Knowledge restricted to the physical causes is not sufficient for a programme to reverse land and water degradation. Socio-economic and institutional factors also play a key role. These factors include:

- land ownership and use of common resources;
- cultural attitudes;
- industrial development and urbanisation;
- local and national political and organisation controls;
- international trade and trade agreements;
- poverty and population growth; and
- wars, civil unrest and natural disasters.

In the search for viable strategies for reversing degradation, analysis of the human role is necessary at several different levels. Farm or business management decisions are largely influenced by economic considerations, which are determined in part by government policies. Moreover, farming and business practices and attitudes toward the environment are also strongly influenced by individual perceptions of the world. At the local level and over short-time periods individuals can often gain some understanding of the impacts of their decisions and management practices. However, larger-scale impacts, i.e., downstream effects, can rarely be appreciated with accuracy. As discussed above, most people do not realise that their nutritional habits could have a fundamental impact on ground and surface-water quality.

Furthermore, all efforts in the industrialised "consumption world" to recycle waste and use the nutrient content of the waste to cultivate new food depend on individual perceptions of the positive aspects of the strategy. A change in perceptions and habits is necessary in order to change strategies and this is a slow process. Meanwhile, political decisions, e.g., promoting changes in agricultural practices, will undoubtedly be important as is illustrated by the problem of Singapore's land and water management (see below).

Many of the worst cases of environmental degradation may be explained by: poor planning caused by ignorance; inadequate understanding of interrelated causes and effects in the environment; and adoption of inappropriate techniques. However, these factors alone do not explain why the same mistakes are repeated over and over again. The repetition may result from poor memory either in individuals or in institutions. Moreover, in a broader context, repetitive ecological blunders may result from an extremely low or non-existent value put on environmental resources. Environmental economics may help in identifying the root causes of land and water degradation. However, we can only hope that environmental economics, in conjunction with environmental science, will help identify viable strategies that put as much emphasis on people and economics as on technical innovations.

Many situations of land and water resource degradation throughout the world can be contrasted with examples of successful remediation. Examples range from making ends meet in agricultural systems under harsh climatic and socio-economic conditions, such as in semi-arid Africa, to managing wildlife protection and water pollution in the urban environment of New York City.

Trends of degradation can be reversed

Sustainable management of resources in semi-arid areas

...there is evidence that community gardens based on groundwater provide a vital first step to other community-led activities such as reducing environmental degradation or promoting sustainable agricultural development.

Many conventions and initiatives that resulted from the 1992 UN Conference on the Environment and Development in Rio de Janeiro, Brazil, recognised that the links between poverty, high population growth and environmental degradation are circular and reinforcing. Consequently, it was adopted that the most effective strategy for reducing poverty, protecting the environment and promoting sustainable development would be to target projects benefiting poor rural communities, and, in particular, women. The rationale is that poverty combined with frequent droughts force rural communities to take a short-term view of managing and exploiting natural resources. It is only when rural communities rise above the poverty-line that they can take a longer term view of environmental protection and resource management.

A programme of research and technology transfer that is aimed specifically at reducing poverty and environmental degradation can be found in southeastern Zimbabwe. This programme, which is being carried out with the participation of local institutions and communities, concerns the feasibility of using community or allotment-type gardens as an initial step towards improved environmental management. To date, ten community gardens have been implemented in an area that is typical of much of semi-arid Africa in terms of poverty and environmental degradation. The source of water for these gardens has been groundwater from collector wells. The collector wells are large-diameter, shallow hand-dug wells having horizontal boreholes drilled radially from the base to a distance of 30 meters, typically in four directions. Research during the last fifteen years has shown that collector wells can be used to maximise and optimise groundwater abstraction from the crystalline basement aquifers that are present throughout semi-arid areas of the world.

Collector well gardens in semi-arid areas are viable in technical, institutional and economic terms. The wells provide a range of benefits that can not be quantified by conventional economic analysis. These benefits include improved nutrition, reduced poverty, increased self-reliance and a source of income to pay for childrens' education. Although it is still early to report with total confidence, there is evidence that community gardens based on groundwater provide a vital first step to other community-led activities. The garden provides a stimulus in two ways. First, once the community is benefiting from a garden, it recognises the need to protect the groundwater resource that supplies the garden by taking measures that improve water recharge and reduce degradation in the vicinity of the well. Second, the confidence and the organisational skills gained from implementing and managing the garden can be used to tackle some of the long-term environmental problems.

Many of these problems can only be tackled by communities if they plan and make decisions together. Figure 5.5 shows schematically how feedback mechanisms lead to rapid degradation in semi-arid areas and Figure 6.6 shows how community gardening can reverse these mechanisms. Although the figure takes an optimistic view of the potential for reversing land degradation, experience from this project indicates that gardening based on groundwater has an important role to play in semi-arid areas in any programme of catchment regeneration or integrated catchment management. However, it must be emphasised that groundwater resources are not always sufficient to permit irrigation even of gardens. Figure 6.6 shows that this may be a good solution in some parts of semi-arid Africa, e.g., where the balance between precipitation and evapotranspiration allows some groundwater recharge. It may, however, be unsuitable in other parts.

Reversing land degradation in Kenya

A widely held belief is that rapid population growth inevitably leads to increased poverty and natural resource degradation, because of land scarcity, shorter fallows, deforestation and cultivation of marginal lands. However, experience from the Machakos District of Kenya have shown that this does not necessarily have to be the case. In the 1930s, this District was considered an environmental disaster. As well, famine relief and food imports were needed more or less continuously from 1962 to 1992. During the sixty years from 1930 to 1989, the population of the District increased more than fivefold, from approximately 240,000 to 1,393,000.

However, the environment in 1990 was in much better condition than in the 1930s. Soil erosion had declined because of soil conservation measures. The prediction of a fuel crisis was not fulfilled because of the planting and the protection of a large amount of trees. In addition, agricultural production per person and per hectare was higher, and new technologies and improved farming systems had been introduced. Key factors have been access to markets and to knowledge, which the increasing population density has helped to facilitate. In addition, the population increase has enabled a practice of farming that would not have been feasible with lower population densities. The message from the Machakos District is that semi-arid areas can support relatively large populations and even become more productive given suitable government policies towards land tenure and market prices and attention to water conservation and management of natural resources.

Semi-arid areas can support larger populations and become more productive if there are suitable government policies for land tenure and for market prices and if attention is given to water conservation and management of natural resources.

Integrated land-water management: solving eutrophication problems in Singapore

In Singapore, with a land area of only 621 km^2, a rapidly increasing water demand has prompted the use of surface water from agricultural catchments for household water supply. In 1970s, the Kranji Reservoir was formed providing about 165,000 m^3 of water per day from the catchment. A thorough survey of stream water quality and pollution sources was initiated by the water department with full cooperation from several other official departments. The survey revealed that most

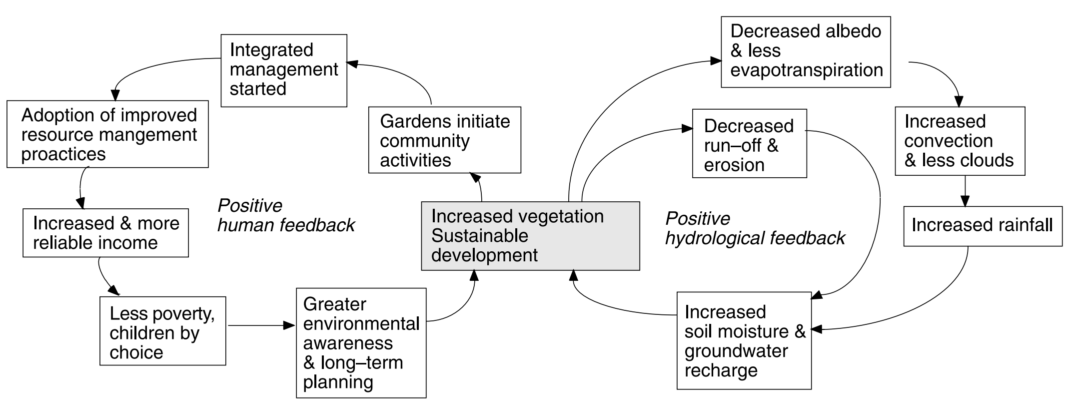


Figure 6.6.
The effects of community gardening. (After Batchelor 1995.)

tributary streams to the reservoir carried very nutrient-rich water with concentrations >2 mg/l of phosphate and >13 mg/l total nitrogen, causing severe eutrophication of the reservoir. Pig farms contributed 85% of the phosphorous load and 38% of the nitrogen load, while the 78,000 inhabitants contributed an additional 12% of the phosphorous load. Various government departments agreed on antipollution measures that included encouraging small pig farmers to switch to other activities and resettling big pig farmers outside the catchment. More recently a law was adopted banning pig farming anywhere in Singapore because of its severe impact on water resources. New regulations controlling industrial effluents were adopted that forced upgrades in wastewater treatment. Biological control methods were used to control plant growth in the reservoir.

A multipurpose use of land and water is feasible by adopting a rational approach to water pollution problems and by involving important decision makers and practitioners.

Six years after banning the pig farms, no such farms existed in the catchment and stream water nutrient concentrations have decreased more than tenfold. As a result of the longer turnover time and possibly internal loading of nutrients released from the sediments, water quality improvement has been slower in the reservoir. However, by 1993, the reservoir was clean and had low nutrient concentrations. (Figure 6.7.)

This example demonstrates that multipurpose use of land and water is feasible if a rational approach towards water-pollution problems is adopted and if important decision makers and practitioners are involved. Ideally, on a larger scale, the strategy would also require the population to decrease its consumption of pig meat, otherwise the problems that existed in Singapore could be translocated to neighbouring countries.

Restoration of Jamaica Bay, New York

New York City has a long history of land-water management for the protection of its drinking water supply and other water resources. One example is the watershed management or strategic ecosystem approach used for the protection of the Jamaica Bay watershed. The watershed is part of the US Gateway National Park (the only National Park

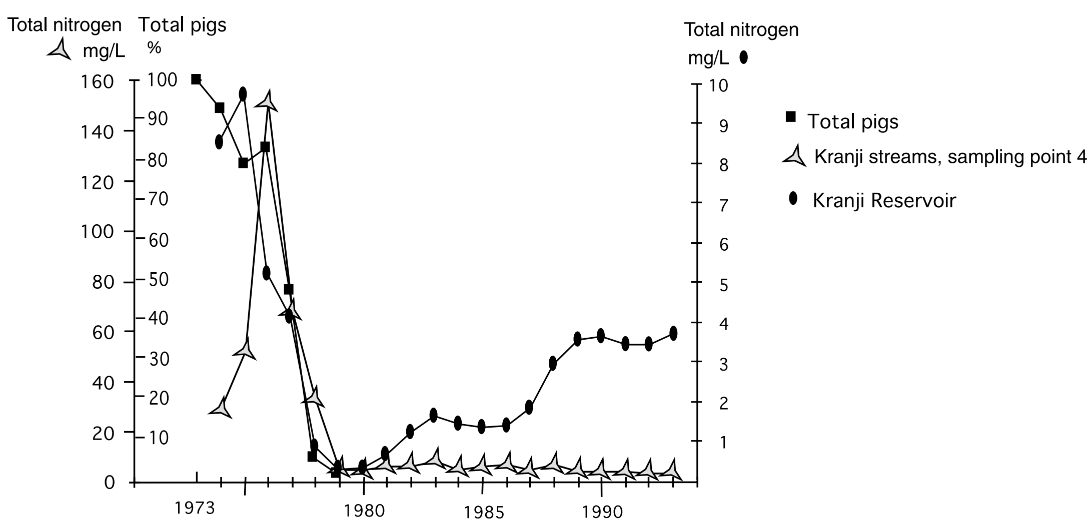


Figure 6.7.
The effect of restricting pig farming in the Kranji catchment, Singapore, and the changes in water quality of a representative stream and the Kranji reservoir. (After Appan 1994.)

entirely within a city's boundaries). The Park includes the J.F. Kennedy airport (one of the largest in the US) and has two million people living within a radius of eight km. The airport was built on the filled-in wetlands of the Bay. Although half of the original area of the Bay and 75% of its wetlands are gone, what remains is protected and still has a tremendous ecological vitality. It is a living proof that cities can responsibly coexist with the natural world. Today, the future of the Bay and surrounding wetlands depends on several water and land management decisions that affect the interaction between the City and its water resources:

- various uses in and of the water;
- waste from the land that is transported in runoff;
- land-uses and development adjacent to the ecosystem; and
- implementation of restoration and rehabilitation programs.

These decisions have a history of over hundred years in New York City's development and shape Jamaica Bay's problems and possibilities today. Until 1950, the Bay was viewed as an engineering problem which need only be filled in, or set aside for: garbage dumps (the Pennsylvania Avenue landfill closed only recently); airports (civilian and military); new space for communities; or for other human uses. Meanwhile, as the boroughs of Brooklyn and Queens grew and expanded, there was a steady increase of residential and industrial sewage loading into the Bay. As cumulative consequences of past actions degraded the Bay, government and private citizens began to change their way of thinking. Starting with the formation of the Jamaica Bay Wildlife Refuge in the 1950s, the protected area has gradually expanded through to 1990. Since the 1960s attention also included a focus on the pollution problem and four sewage treatment plants have been constructed or upgraded. These actions have resulted in the gradual improvements in the Bay's water quality (Figure 6.8).

In the 1990s, in pursuit of meeting both its Clean Water Act mandates and the larger environmental goals of the public, the City has engaged in several new broad-scale planning initiatives. The goal of these initiatives is to address treatment of: combined sewer overflows (CSOs); leachate from three old landfills; sewage to remove nitrogen; and airport and industrial runoff.

These improvements are part of the Jamaica Bay Comprehensive Watershed Management Plan. The major goals of this plan are to:

- revive natural habitats by enhancing and preserving the aquatic, wetland and terrestrial habitats (Figure 6.9);
- re-contour the Bay by reversing destructive past physical alterations, improving the Bay's natural ability to cleanse itself, restoring habitats and reducing toxic impacts;
- enhance pollution prevention and reduce damaging pollutant loads;
- improve drainage, collection and treatment systems and improve water quality and address drainage priorities by integrating drainage improvements, combined sewer overflow control, groundwater management and treatment plant alterations, and a nutrient treatment programme;
- expanding community use and participation to protect human health, improve public recreation, promote better quality of life, and improve environmental understanding.

The plan represents a significant cost saving by shifting resources more cost-effectively for broader environmental benefits and reordering priorities for the next decade. The total capital cost of the plan's recommendations is approximately USD 1.1 billion. Reliance on purely structural solutions would cost approximately USD 2.3 billion, but would not achieve all of the goals of the watershed management plan.

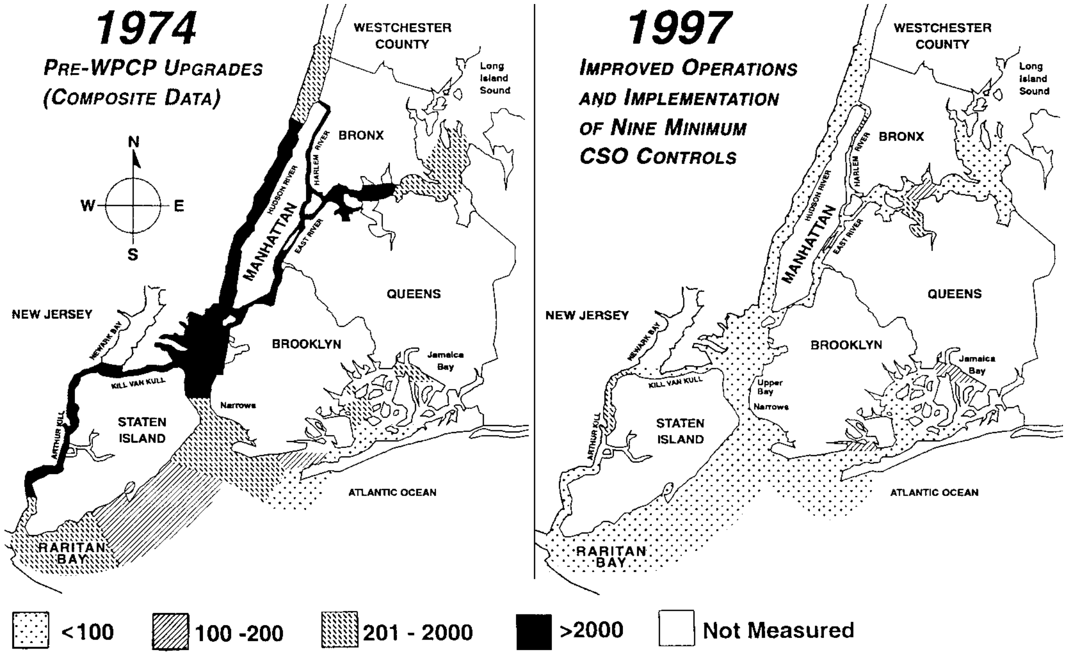


Figure 6.8. *Location of the Jamaica Bay and trends in total coliforms in surface waters 1974 and 1997. (Unit: MPN/100ML, WPCP: Water Pollution Control Plants.)*

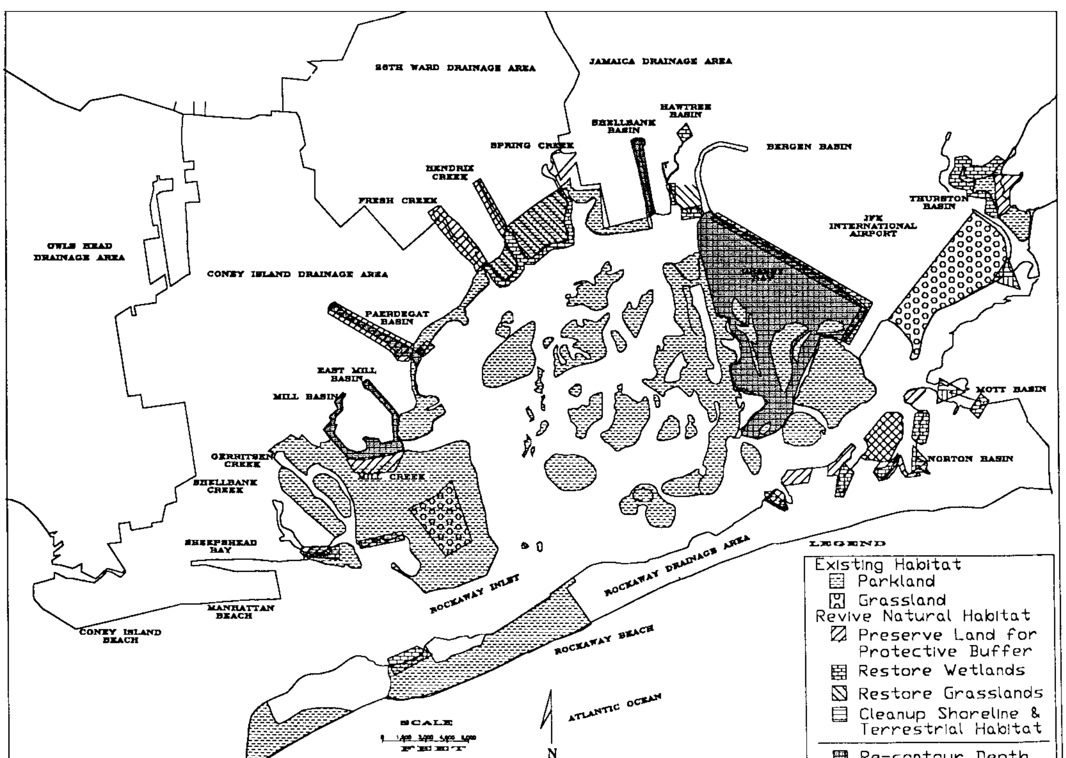


Figure 6.9. *Existing habitats in the Jamaica Bay and revive natural habitats.*

Timelag between knowing and action

Despite success stories such as those described above, a huge gap exists between recommended or improved practices of land and water management and actual practices in most areas of the world. For most of the practices causing eutrophication of water bodies, remedial measures are available. It is well known that changed farming practices can reduce the need for commercial fertilisers (flux 2 in Figure 6.2) and would eventually decrease, though not entirely, the transport of nitrate to ground and surface water. But it is only recently that regulations for the use of fertilisers and handling of manure are being implemented in some countries, such as Denmark. Economic incentives are used to promote more environmentally sound practices in sensitive areas.

As mentioned before, there may be a considerable time lag before effects are noticeable in the receiving water, particularly in aquifers having long residence times. In a few cases streams have been restored as a potential method to increase the substance retention capacity of the aquatic ecosystems. It seems, however, to be an even harder political challenge to use the means available to reduce the formation of nitrogen compounds from fossil-fuel combustion, because this implies an unavoidable reduction of fuel use.

Researchers, extension workers and policy makers often express concern over the reluctance to adopt improved land and water management practices. This reluctance is often seen as irrational. On the contrary, however, farmers and other land and water managers are generally rational decision-makers who have sound social or economic reasons for using or not using improved or innovative practices. It has to be recognised that diffusion or extension of even well proven and outstanding new practices may take many years.

In recent years there has been a marked interest in the use of participatory extension and integrated-catchment-resource-management (ICRM) approaches. These involve many land and water management stakeholders in evaluating, selecting and implementing new practices. Positive results from several projects in Africa and in other projects worldwide provide optimism that these techniques can successfully combat land and water degradation and improve the quality of life in rural and urban communities.

However, cooperation and coordination among individuals, communities and governments are crucial if integrated catchment resource management is to be a success. In the development of any environmental recovery programme, the overriding consideration must be service delivery and recognition of the fact that resolution of the current range of natural resource issues will take many decades to address. Only in a few cases can a short-term solution halt or reverse ecosystem degradation. In most cases, mechanisms or policies that enable long-term support for environmental recovery programmes must be established.

In most areas of the world, there is currently a huge gap between recommendations for improved practices of land and water management and actual practices...

7 Steps to be taken for integrated land and water management

An environmentally sustainable management system is a management that does not undermine the natural resource base of the region.

In this book a number of cases have been presented from different parts of the world in order to illustrate the fact that land use decisions are also often water decisions. Conversely, water management decisions often have a land use component. In order to minimise eutrophication of a water system, the use of agricultural fertilisers may have to be regulated. Likewise, land use decisions may have to include a water component. This is illustrated by the example of large scale forest plantations in dry climate tropical areas, where decisions have to be supported by an analysis of the expected changes in water table, as well as of runoff amount and seasonality.

The aim of this chapter is to provide new perspectives and examples which promote integrated catchment management. In order to achieve a fully integrated catchment management approach, new policies need to be developed and applied.

The daily decisions of the world's farmers and local communities determine the condition and sustainability of our land and water resources. Decisions such as diverting water for irrigation, clearing vegetation, draining wetlands for agriculture, tilling and fertilising the soil, or discharging urban and industrial effluents alter not only the land resource base but also the downstream water quality and quantity.

Problems such as soil erosion, soil salinisation and declining water quality are a by-product of agricultural and urban development. These problems have been caused by individuals and governments adopting inappropriate policies and practices, often through lack of knowledge or short-sighted, short-term planning.

The causes and effects of environmental degradation are now usually well understood. There is, however, a considerable difference between technical understanding with available technologies and the approaches used by natural resource managers in making management decisions. If the objectives of sustainable development are to be achieved, this gap between knowledge and daily management practices must be closed. For example, several salinity management schemes in the 1970s and 1980s in Australia found that a technical solution alone was insufficient. The support and participation of those closest to the land, the rural communities, was vital if any plan was to be implemented, regardless of its technical elegance.

Strategies for not-undermining land and water management

What is essential now in order to come out of the current mismanagement dilemma is to propose and defend – at the political level – a strategy for sustainable use of a nation's land and water resources. This is also essential wherever water is scarce:

- to enable a philosophy of maximum productivity per unit of water;

- to enable the formulation of an integrated water management plan;
- to suggest a course of action involving natural and human resources in a catchment;
- and to identify development options with impacts assessed in such a way that political decisions can be made.

An environmentally sustainable management system is a management that does not undermine the natural resource base of the region. It must not lead to a series of problems of reduced usefulness of the available water through pollution; degraded aquatic ecosystems, decline in land fertility; or to increased threats from droughts and floods. For the next generation of water resources management efforts it is essential to realise that the water passing through the landscape with its settlements and artefacts has a number of parallel functions related to human nutrition, habitat, socio-economic production, and as a carrier of anything that is soluble in water. The different functions of water are often linked to separate societal sectors that are driven by different political goals, have different groups of stakeholders and are managed by different administrations.

An integrated approach has to take into account all relevant factors. The involvement of all players who are active in these fields is indispensable in order to get broad support and commitment.

Sustainability: the new common language

At the Earth Summit, the 1992 United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro, government representatives from around the globe considered progress made in achieving sustainable development (SD). An action plan was drawn up, Agenda 21 (Agenda for the 21st Century), identifying the various ways in which sustainable development can be achieved and accepted by most countries. This has given legitimacy to the concept of "sustainable development" as a platform for building bridges between various sectors. There is, therefore, wide scope and much opportunity for exploring the potential of Sustainability in action.

The method of approach described in Figure 7.1 allows the stakeholder group to come to terms with effectively functioning as a group and stresses the need either to assess an option or options or to produce principles more specific to relevant functions. Simple and highly flexible, the approach contains a number of steps in which the group decides on basic principles, appropriate criteria and is able to work through its own strategies to determine relative sustainability characteristics.

The goal: avoid undermining human life support systems

In 1996, the United Nation's Committee on Natural Resources adopted a strategy for sustainable land and water management in order to avoid the now widespread undermining of human life support systems. The collective aim is to find ways to successfully cope with the particular environmental preconditions in a certain region while satisfying societal needs. The goal is not to undermine the natural resource base by pollution, groundwater overexploitation, or the degradation of valued ecosystems.

A strategy for land and water management that does not undermine the natural resource base has to be developed and attention has to be paid to the complexity of water-related issues. This can be done by successfully balancing the different functions, sectors and stakeholder groups.

How to do it

Management tools to be made available for implementation of such complex land-water-waste management include legislation that is consistent with the laws of nature. The systems needed must not only allow but also encourage an intersectoral approach and dia-

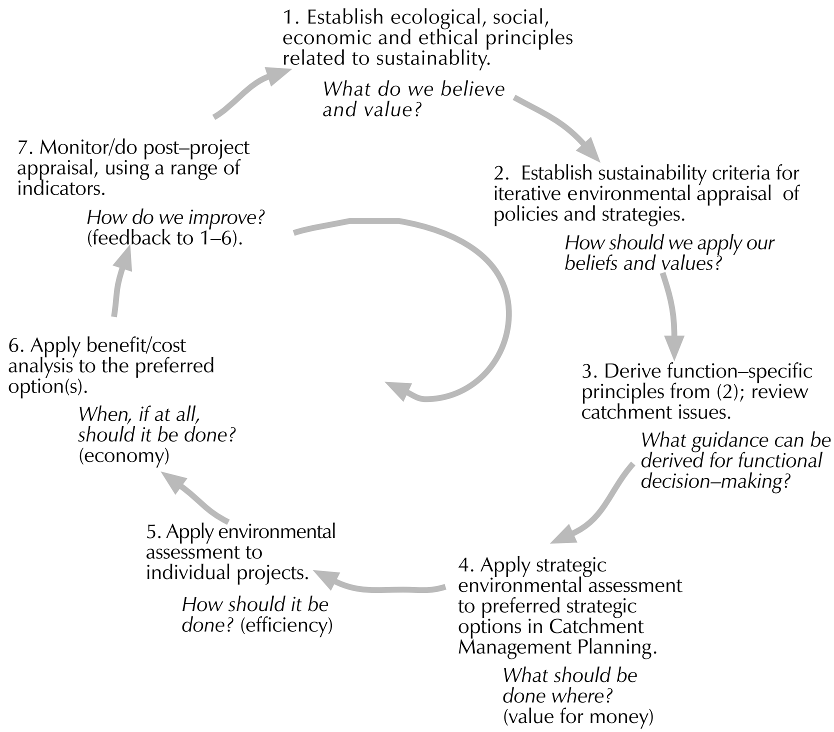


Figure 7.1.
Steps to determine the relative sustainability characteristics.

logue. They should be capable of handling complexity without bureaucratic paralysis, as well as educating all levels of society to create broad awareness of how water enters into everyday life.

Long-term sustainable land and water use is the goal. Implementation is heavily dependent on institutional influence which includes key political actors. In assessing whether a specific development is sustainable, its institutional acceptability must be evaluated. (Figure 7.2)

Important institutions for successful implementation of long-term, sustainable land-water use are local planning authorities, legislation and economic instruments. Governments must therefore develop the legislation

Box 7.1. National Action Programmes

"Water resources must be planned and managed in an integrated and holistic way to prevent shortage of water or pollution of water resources from impending development."

"By the year 2000 all states should have national action programmes for water management based on catchment basins or sub-basins and efficient water-use programmes. These could involve integration of water resource planning with land use planning and other development and conservation activities, demand-management through pricing or regulation, conservation, reuse and recycling of water."

Agenda 21

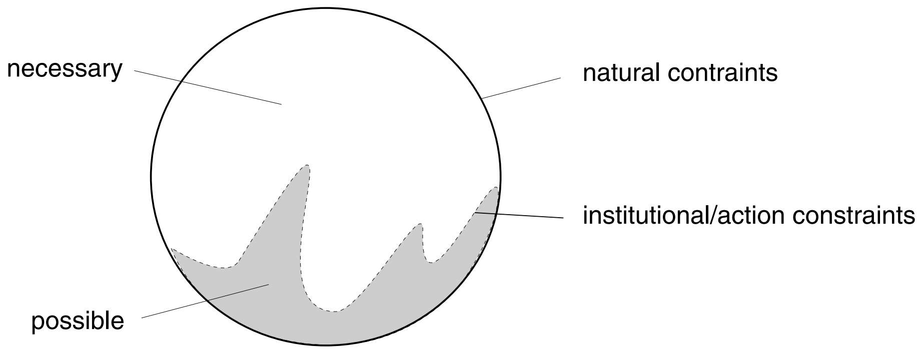


Figure 7.2
When identifying on the one hand what is necessary to do and on the other what is possible to do, it is seldom the natural constraints which set the boundaries, but rather the institutional and action constraints.

A strategy for land and water management that does not undermine the natural resource base has to be developed.

Box 7.2. Community participation in a South African shanty town

South Africa is experiencing a massive influx of people to urban and metropolitan areas. This has led to the mushrooming of shanty towns as squatters move onto vacant land near cities. Such newly and rapidly established urban areas often become environmental disaster areas, not only for the people who live in them, but also because of their pollution impact on neighbouring areas. Any effective re-planning strategies aimed at preventing such potential disaster must consider fundamental socio-economic aspects such as high levels of unemployment and poverty amongst the township residents; low levels of service provision; and lack of sewerage and water supply. Innovative strategies are needed to integrate socio-economic, environmental and technical issues in order to ensure sustainable management of intensive urban land use.

South Africa is experiencing the rapid influx of people into the greater Port Elizabeth metropolitan area. As a consequence the rapid growth of Soweto-on-Sea has happened without any pre-designed logical planning and according to a "first come – first served, land-grab" strategy. The situation is aggravated by the fact that up to now some 3,000 shacks have been erected below the 1:50 year floodline of the Chatty river, which could affect over 16,000 people. These people will inevitably have to be moved to serviced sites on higher ground. It is essential to ensure however that where land has been vacated, no further squatting would occur.

At present the flood plain has a high perceived value for squatting. The strategy devised to allow full community participation and prevent a new "invasion" of settlers in the flood plain, includes a new "3 D Visualisation Technology", combining computer modelling, graphics, scanned photographs and image processing. Animations can also be created to simulate for instance the rising of a river water level, or alternative land uses including grazing, parks, sport fields, vegetable allotments etc. Images can be further modified based on input from the community. The technique is capable of converting the planned investment propositions into simple, readily understandable graphic format.

Heath et al, 1994

and regulation that makes regional planning possible. National objectives and targets must be defined to secure development within the constraints given by environmental preconditions and vulnerability, and secure the necessary legislation for waste minimisation together with enforcing rules and regulations.

Not all countries have a strong developed planning system run by local government planning authorities. At Rio, however, local planning authorities were seen to be in the prime position to deliver long-term, sustainable land-water resources use, given their role in strategic and local planning of land use.

To become a reality, action plans for implementation must satisfy the beliefs and values of stakeholders and key actors whose criteria lie in at least three major dimensions articulated in the Brundtland Report: the ecological, social and economic dimensions.

The economic instruments for achieving long-term, sustainable land/water use are in the developing stage. Methods for economic valuation can place a value on damage and mitigation by measuring their subsequent cost. Similar problems can be solved by consideration of contingent valuation, or public willingness to pay for a better environment. Ecological economists state that environmental objectives are currently driven by political sensitivities rather than by economics. Politics is subject to many influences, not the least of which is the attitude of the electorate for whom refined environmental economics may prove inaccessible or unintelligible.

Pricing of water provided to users in water supply systems is an effective tool to ensure that water is put to the most valued use. It might also draw attention to societally valued ecosystems in the downstream natural water system. Transfer of property rights is another way to avoid wasteful use, e.g., when a farmer has access to more water than he really needs for irrigation of his crops, he can simply sell that surplus water to another water user.

Action plans oriented to river basins

The river basin plan offers a clear opportunity for balancing different interests.

From a socio-economic as well as from a hydrological point of view, a river basin represents a complexity of social, economic, jurisdictional and political relationships. These relationships are of two types: the intra-basin, or upstream-downstream relations and conflicts between water users; and the inter-basin relations which represent local, regional and national administrative levels. In order to achieve a fully-integrated catchment management approach all administrative levels have to cooperate.

Although much action generally has to be taken at the local level, actions have to fit into an overall regional plan and manifest a joint program for a river basin or management unit. The river basin plan offers a clear opportunity for balancing different interests, and even strives at shared visions between key stakeholder groups.

Planning and decision-making in a river basin or a management unit must be placed in a system in which all components are related. In order to get broad support and commitments, an integrated approach will be indispensable. It must take into account all relevant factors and involving all players who are active in these fields.

The Catchment Plan: a Common Vision and a Land Use Statement

A catchment plan sets out a common vision for a river catchment. It identifies use-related objectives for water quality and physical features together with actions for the planning authorities and others to achieve the objectives. The catchment management plan also establishes a long-term vision specific to the catchment to influence and guide the thoughts and actions of private and public sector initia-

Box 7.3. What a Catchment Management Plan may include

- the determination of discharge consents and abstraction licenses;
- the promotion of industrial process-efficiency and waste minimisation audits to minimise pollution risks at source;
- the promotion of farm waste management plans to minimise agricultural pollutions;
- the use of source protection zones overlying major aquifers to protect vulnerable groundwaters.
- the plans for sustainable management of specific sites e.g., water level management plans to safeguard site of high conservation interest.

tives. It can also meet a country's responsibilities with respect to Agenda 21 to prepare integrated catchment plans by the year 2000. According to a State Government in Australia, the following detailed information should be prepared in order to develop an effective plan:

- characteristics of the catchment; such as the hydrological and geological characteristics, land and water use, economic and social profiles, condition of the natural environment, and downstream and off-site impacts on other communities;
- management options; such as identification and evaluation of plan options which includes the no-plan option. The no-plan option provides the benchmark for evaluating the benefits and costs of various plan options. On the basis of these analyses an integrated mix of options which most effectively meets the plan objectives is developed;
- implementation options; such as funding and cost sharing options, incentives and sanctions to assist implementation, and monitoring and reporting arrangements.

In producing an individual catchment management plan the following aspects are important.

A management plan

- reinforces the need to consider the impact of development on natural systems (i.e., catchments) rather than on political management units in line with section 18.9 of Agenda 21;
- provides an opportunity for professionals and local interests to review management needs in relation to detailed scientific analyses and relevant local knowledge and to develop partnerships to deal with environmental issues;
- enables the catchment authority staff to review work programs with their colleagues and to identify opportunities for integrated action in line with functional policies;
- provides local communities with an accessible and thorough review of water issues;
- enables an inventory of environmental assets, e.g., groundwater, wetlands, landscapes.

In building a "Land Use Statement" for the catchment the plan explicitly recognises the role land use planning decisions play on the water environment.

It is only by understanding the hydrologic cycle and its interactions with the natural resource base that management options can be developed and evaluated.

The role of hydrologists: proper water cycle understanding

While the effectiveness of catchment plans will ultimately rest with the adoption and implementation of best practices by the catchment community, it is also highly dependent on the technological information, understanding and analysis available to those preparing the plan. This input is required from specialists such as scientists and engineers, economists, sociologists, planners and policy advisors.

Hydrologists play a key role in the catchment planning process. It is only by understanding the hydrologic cycle and its interactions with the natural resource base that management options can be developed and evaluated. The depth of this understanding and resulting predictions will determine the usefulness and accuracy of the economic evaluation, plus environmental and sociological impact analysis. It will determine the effectiveness and ultimately the success of the plan.

The institutions are the switchboards

More attention has been given recently to the role of institutions. They have a key function as powerful nodes in the socio-economic network. They work as “switchboards” between stakeholders and politicians, between the public and the public administrators and between the market and the productions units. They usually formulate the decision-making proposals placed before politicians.

Box 7.4. Improving agricultural yields without causing degradation

In Tunisia, soil erosion and plant cover degradation constitute major problems for agricultural development. Aware of the danger of an erosion threatening 60% of the agricultural land in the country, the Government has since 1956 made major efforts to fight erosion, but efforts have remained insufficient. A new decennial program now involves an integrated approach to soil and water conservation. It links land use management with runoff mobilisation, and includes pasture and range management practices; fencing highly deteriorated lands; protection of dams against sedimentation; direct use of runoff to increase infiltration; but also the creation of employment in the most disadvantaged areas. Land users are encouraged to carry parts of the costs of the soil and water management on their land themselves. Progressively, soil conservation is introduced into the habit of farmers, their technical training is intensified, and a legislation is under preparation which defines the rights of farmers and their obligations to comply to certain rules of environmental protection.

Habib Missoui

Politicians: the major actors

Integrated management of land and water resources requires coordinated action at the catchment level.

Initially, politicians are the key players because it is only through their action that an appropriate awareness can be instilled and powers devolved to the community. Sustainable management of land and water resources can only be achieved, however, by appropriately devolving responsibilities and power to local communities. This requires establishing clear roles and responsibilities of the key stakeholders based on this principle and a willingness of politicians and central policy makers to meaningfully delegate power and responsibility while providing financial support to local communities. For their part, it will be necessary for local communities to accept greater responsibility.

Demanded: willingness to act

The above changes will only be achieved when governments and politicians recognise that severe degradation has already taken place and that further degradation continues. They must be willing to act decisively and urgently. Firstly, their decisions must make resource managers more aware of the impact of their actions on land and water conditions. Secondly, governments must put in place institutional arrangements defining the roles of all stakeholders which result in local communities being responsible and accountable for the on-site and off-site impacts on their actions.

The key players in achieving sustainable management of land and water resources are national, state and county/local governments working cooperatively with the community and with individual land owners. Roles and responsibilities will vary for different systems of governments, but there are general areas of similarity.

Integrated management of land and water resources requires coordinated action at the catchment level. Complex policy and institutional arrangements are often required to cater to biophysical conditions where degradation processes and off-site impacts are often difficult to evaluate with confidence. Furthermore, government boundaries rarely conform to catchment boundaries and consequently, cooperation between governments is required but often difficult to achieve. As a consequence of this, the jurisdiction level lower in the catchment will often suffer the consequences of mismanagement occurring in upstream regions or nation states. Finally, arrangements are required which ensure that the many resource managers in a catchment are managing their land and water resources in a sustainable way.

Box 7.5. Public involvement in Toronto

Throughout the Commission's existence, all those involved in its work listened carefully to the views and advice of people – thousands of people. Therefore, the final report on regeneration of Toronto's future waterfront and the sustainable city is the work of many hands and minds; it embodies the values, aspirations, concerns and hopes of these thousands of citizens.

Royal Commission on the Future of Toronto Waterfront

Active participation around local action plans

Responsibilities of local communities include: developing and implementing local action plans; coordinating the activities of land owners so that land use is sustainable and off-site impacts minimised; promoting the adoption of improved management practices; monitoring and identifying local environmental issues that need managing; and communicating with government to enlist support.

Action plans are the building blocks for coordinating community and government action at the catchment level. Such plans integrate the management of natural resources; they consider land capability, degradation processes and hazards as well as management options such as benefits and costs of combining options. Plans outline roles and coordination of stakeholders, the cost-sharing for implementation, as well as research and monitoring needs. The Australian example has given ample evidence of the willingness of local communities to actively participate in managing their environment. Over 650 landcare groups are active in Victoria, Australia, where the area of privately managed land is 15 M ha.

A key requirement in the pursuit of sustainable water resources use, according to the Brundtland report is "effective citizen participation in decision-making". In addition to a democratic system, this implies a new common language. The message is that institutional capacity to achieve long-term sustainable development can not be provided by just one organisation. Partnership is the key to the process. A successful partnership needs a supportive institutional framework which will encourage not only the implementation of change, but its absorption into national, if not international, culture.

Input is required by a variety of people in planning and implementing integrated management schemes for development of land and water resources, as well as in decision-making regarding alternative projects or plans to be selected. The politicians have to be the major actors and primary movers since they are the ones with the power and authority to pass legislation, formulate the appropriate policies, allocate the necessary funds, and galvanise the general public in supporting a given project or plan. Groups of experts, such as hydrologists, land and water resources development experts, and professional planners have to provide their services and use their expertise in advising the policy-makers and the public. As well, they are needed to develop the best alternative projects and plans, devise the best implementation, produce management and operating procedures, and evaluate the positive and negative impacts possible.

The politicians have to be the major actors and primary movers since they are the ones with the power and authority to pass legislation, formulate the appropriate policies, allocate the necessary funds.

An important perspective is that of the water resources awareness at the individual level. A high level of awareness of water resources means good knowledge about natural hydrologic relationships; legal and administrative systems; and the short-term and long-term effects of human impact on hydrological systems and the environment.

Political awareness follows public awareness

The driving force behind the politicians must be the citizenry, the main stakeholder in all this, whose involvement in policy setting, and alternative project or plan selection will best guarantee that their interests are served. Politicians need the public's guidance and pressure in order to set priorities straight to really serve the general interests of society for a sustainable future against the influence of special interest groups and shortsighted political interests.

Box 7.6. Regular use of human impact assessment on the hydrological systems in water resources planning and decision-making

An impact assessment should:

(1) Assess catchment resources, uses, activities, and past impacts due to these;

(2) Balance conflicting uses and identify actions that may minimise adverse environmental impacts or improve conditions created by past uses and actions;

(3) Create a long-term vision and plans for integrated management of a catchment's water resources, to guide the various activities and anticipate adverse environmental impacts in order to achieve successful sustainable development;

(4) Ensure that use-related environmental objectives (i.e., alleviation of expected adverse impacts, improvement of existing conditions) are identified, agreed upon by the stakeholders and political authorities, and met;

(5) Facilitate effective and proactive planning to prevent future environmental damage and to provide lasting solutions to environmental problems;

(6) Environmental Impact Assessment information should also be useful and must be used in monitoring the implementation of projects or management plans and in continuing to evaluate, revise and update both the policy and action elements of an integrated management plan.

Box 7.7. Sustainability principles for water resources management

(1) ECOLOGICAL

- Conservation, in the sense of protection, is better than re-creation;
- The stock of environmental assets should be kept constant or increased;
- Unavoidable use of depletable resources (eg., sand, gravel, chalk, oil) should be minimised and made as efficient as possible;
- Thresholds of environmental capacity should be respected;
- Global, national, and regional systems as well as local criteria must be satisfied employing a holistic approach;
- Working with natural processes is better than trying to overcome or control nature;
- Biodiversity should be conserved and enhanced;
- Environmental protection should constitute an integral part of the development process, and not be considered in isolation from it or as an afterthought;
- Alien species which threaten ecosystems, habitats or species should be controlled;

(2) SOCIAL

- People should, now and in the future have a duty to care for other forms of the natural and man-made heritage;
- Opportunities to reduce disparities in living standards should be taken;
- The quality of human life should be improved;
- Communities should be enabled to care for the environment;
- Decision-making and information affecting the environment should be openly available;
- Public awareness and participation should be encouraged;

(3) ECONOMIC

- Economic policy should be related to social and environmental arrying capacity;
- Developers should pay the full social and environmental costs of the benefits they enjoy and the resources they utilise;
- Life-cycle costing of projects should be employed;
- The polluter should bear the cost of pollution.

Politicians need the public's guidance and pressure in order to set priorities straight to really serve the general interests of society for a sustainable future.

When legislating for the exploitation of any natural resource, the politician faces a practical dilemma. Without knowing enough of the technical issues, it is difficult to ignore economic arguments which, because of their short-term perspective, rarely support a sustainable strategy. The "survival of the industry" is often set against increased protection of the environment, yet recent projects have shown that industrial process audits can reveal environmental benefits from investing in pollution prevention projects with short-term payback. The conclusion is that ignorance, as much as anything else, is the main barrier to choosing best sustainable practices.

In a democracy, political awareness follows public awareness. A focus on educating the public on water issues obliges the politician to learn about it as well. In most countries, political decision-making about land use has not until quite recently had seriously to address the overall water environment. Thus, there is a generation gap between those who believe that the technical fix will get us out of trouble, and those who realise that not only it is unlikely to do so, but that the precautionary principle is not satisfied by bold experiments. Fortunately, most sustainability strategies seem to boil down to the application of common sense. The problem seems to occur when specialists in one discipline are left alone to pursue their particular interests with no need to defer to other stakeholders.

Key approaches to holistic management

A strategy which will stand the test of sustainability needs to address four basic areas which influence decision-making and the level of sustainability to be achieved: social, economic, institutional and environmental areas. There are several key approaches, each with supporting methods. When these are brought together in a holistic approach, they will allow the best practicable environmental option to be identified at all levels of decision-making.

The challenge is to build our "institutional capacity" involving the best mix of these key ingredients in wise, open decision-making and subjecting all we do to constant scrutiny.

The Murray-Darling Basin: A case study

In some places over 90% of all native vegetation has been cleared to make way for the introduction of European styled agriculture.

Communities and governments working together

The following case study illustrates one approach to managing land and water resources where the strong coordination of governments and communities was required.

The Murray-Darling Basin of Eastern Australia is an area of about 1,000,000 km^2 equivalent the size of France and Spain combined. The combined length of the two major rivers, the Murray and Darling is about 3,700 kilometres traversing four independent state governments: New South Wales, Victoria, South Australia and Queensland. Each state is responsible for the management of its respective environmental resources. The Basin is Australia's main agricultural area producing about 33% of Australia's agricultural output worth about AUSD 10,000 million annually. The Basin includes 75% of Australia's irrigated land, about 25% of its cattle and 60% of the agricultural products.

European approaches caused unexpected problems

European immigration settlement into the Basin commenced about 170 years ago and has had an enormous impact on the hydrological balance that formerly existed. During this timespan about 50% of the trees in the previously forested Basin have been cut. In some places over 90% of all native vegetation has been cleared to make way for the introduction of European styled agriculture. Extensive irrigation schemes totalling over 1,100,000 ha of irrigated land were built in the lower Basin throughout this century.

Many of the rivers of the Basin are highly regulated with 80% of the water committed to irrigation in the Southern Basin. In an average year, South Australia, the state situated at the lowest end of the Basin, depends on the upper Basin for 43% of its water. In a drought year this rises to a 90% dependency. The River Murray Commission was formed in 1917 as an intergovernmental organisation (with statutory backing under national New South Wales, and Victorian and South Australian legislation) to share the water resources between the three states involved and to ensure that South Australia, in particular, received its fair share.

From the mid 1960's governments and communities in the lower Basin have been increasingly concerned about deteriorating water quality in the lower Murray River due to salinity. The economic costs of this salinity to water users is estimated to be in excess of AUSD 35 million per year. Water quality in the lower river was estimated to deteriorate at a rate of 1–2% per year.

Further upstream, communities were calling for action to control shallow water tables which were causing economic losses due to waterlogging and salinisation. It has been estimated that 560,000 ha (30% of the irrigation areas) are currently underlain by shallow water tables. This will increase to 1,320,000 ha over the next 30 to 50 years. In this time, production losses due to salinity will increase from AUSD 44 million to AUSD 123 million annually.

Investigation of these problems showed that control of the water tables was indeed feasible using established technologies, but that disposal of effluent to rivers would further degrade water quality downstream. This stymied any action to either remedy downstream water quality or control land degradation due to shallow saline watertables upstream.

Changing the management structure

With these pressures to resolve the apparently conflicting problems of both improving water quality in the lower Basin and providing drainage to irrigation areas in the upper Basin, governments agreed that a joint and coordinated approach was essential and would result in the most efficient solutions.

In 1988, agreement was reached between the Australian national government and the governments of New South Wales, Victoria and South Australia to form the Murray-Darling Basin Ministerial Council to promote effective planning and management for the equitable, efficient and sustainable use of the water, land and environmental resources of the Basin.

This first crucial step of agreement resulted in a management structure for the Basin with the Ministerial Council as the top level body. It was comprised of members from each of the participating governments representing land, water and environmental portfolios. The second or executive level in the management structure is the Murray-Darling Basin Commission which comprises the Departmental heads of the same portfolios.

The Commission is supported by a small technical secretariat, the Office of the Commission, which is responsible for coordinating and facilitating the activities of the Commission. The Office of the Commission also carries out a number of statutory functions with regard to the operation of the Commission's storages, water sharing between the States and the development of long-term resource management plans for the Basin's resources.

The third component of the Commission is the Community Advisory Committee composed of representatives from major special interest groups and representatives from the 19 catchments which make up the Basin. This Committee reports directly to the Ministerial Council on the effectiveness of the policies and programs developed and implemented by the Commission.

Catchment approach for salinity mitigation

One of the first activities of the new initiative was to resolve the conflict between the need for improved water quality in the lower river and the drainage returns from the upper river irrigation areas. Their strategy strikes an equitable balance between the competing needs of river protection and land management. Balance was achieved from an economic evaluation of a range of feasible river protection and land management schemes together with their environmental effects. As well as the collaborative tackling of such urgent problems, the

Box 7.8. Bottom-up strategy as a means for land-water integration

Australia is a federal system of six States and two Territories. State boundaries continue to be a problem to solutions to our land and water problems. One optimistic element is the Murray-Darling Basin Commission where relevant State and Federal Ministers agree on sharing water resources as well as operation costs involved in managing water across this large basin.

Peter Cullen

strategy also provides each state with a clear definition of its obligations and rights.

In essence, the strategy adopts the Murray River salinity levels of 1975–85 as the baseline against which any future activities which may affect river salinity are judged. The joint government's initial program of work involved the construction of groundwater interception works along the river to improve water quality for the benefit of South Australia. These schemes intercept highly saline water before it enters the Murray and are the most efficient way of improving lower river salinity.

These works are unique in that the upper states are contributing financially to construction that takes place in another state.

These works are unique in that the upper states are contributing financially to construction that takes place in another state. As a consequence of this jointly funded program, the upper states have the right to salt disposal into the Murray River within defined limits. This enables each state to pursue its own internal land and water management programs and to drain some of the high value irrigated land with disposal to the river within prescribed limits. Beyond this initial program, states will have the option of contributing to the cost of additional schemes which improve river salinity and will receive a salinity credit in proportion to the cost of the scheme.

The net result of implementing this strategy will be to reduce salinity of the Murray River by up to 20% in those reaches of the river where salinity is currently high enough to cause urban, agricultural and industrial costs. Groundwater studies showed that the most effective option for improving water quality was to intercept highly saline groundwater before it seeps into the lower river. It was necessary to involve the three states in order to achieve solutions addressing land and water management for the total catchment.

This strategic land management program involves community groups developing comprehensive land and water management plans for their regions. Currently there are 14 such plans being developed or implemented. A feature of these plans is the leadership taken by the community with government providing support as necessary. In practice, because of the limited number of salt disposal entitlements available, every opportunity to reduce salt disposal to the river is explored and this has forced major improvements to irrigation practices and water use efficiency. A strong feature of such plans is the approach taken to cost sharing with a major share of the costs of implementation being provided by the community.

Algal blooms also call for a catchment approach

At the time of developing the above strategy, irrigation salinity was the key concern. Since that time management of algal blooms in rivers has become an equally important and higher profile issue. This has confirmed the importance of taking a comprehensive view of the catchment to control nutrient as well as saline discharges to the river. The land and water management plans are now being adapted to include control of nutrient inputs.

Lessons for the future

Prerequisites

The Murray-Darling Basin example highlights a number of principles which are necessary prerequisites to a successful catchment management:

- Government Leadership. Mature and forceful leadership is required of government. This may involve relinquishing some sovereign rights to others. It also includes raising community awareness of environmental issues and providing the means for local communities to manage local environmental issues. Government must also define a framework which ensures that downstream impacts are considered in upstream management decisions.

- Community Leadership. Successful environmental management is much easier to achieve where the local community is demanding action and committed to developing and implementing action plans. Raising the awareness of local communities of the need to act is a crucial first step. Community-based monitoring of water quality and involvement of schools have been shown to be effective ways of expanding community awareness.

  Some of the features of successful public participation in land and water management plans are that consultation should commence early in any planning process; guidelines and planning procedures are required at the outset; the community should be well aware of the objectives of its involvement and the level of power being offered; efforts should be made to include all stakeholders; information should be available to everyone; and adequate administrative and technical resources should be available for the required tasks and meetings.

- Technical knowledge. Impacts often occur distant from the site of mismanagement, but the symptoms of mismanagement are often treated rather than addressing the cause. For this reason, successful plans can only be built on a strong knowledge base which provides a depth of understanding of the causes, effects and impacts of the various management options. It is rare, however, for knowledge to be complete. Consequently, an assessment of the risks of incomplete information should be made and flexible plans must be adaptable and regularly updated on the basis of new information.

- Use of market instruments. Rarely do the costs paid by resource exploiters include the full range of costs incurred in that use. In particular, off-site costs and the costs of degradation which will not appear until some time in the future are rarely included in the costs of production. For this reason, government is well-placed to ensure that these costs are included in day-to-day decision-making as an incentive for resource users to find the most efficient and least costly management options. In the same way, government extends subsidies and tax-breaks to encourage certain activities.

Procedures to gain public acceptance

In the United States and other countries, the trend in planning is toward a more open process usually referred to as a "public participation process", in which the organisation sponsoring a plan or project and its staff seek an increasing level of interaction with all the parties who have an actual or perceived interest in the plan or project. This process allows for and facilitates the implementation of innovations and overcomes the status quo. Such a process may be formalised by legal mandates for public participation in natural water/land resources integrated planning. Effective participation is the way to gain public acceptance of worthwhile innovative projects and plans or, alternatively, to recognise in the early stages how to determine which projects are not likely to be acceptable.

More and more frequently, the major problems facing engineers, scientists and planners are not technical. They are problems of reaching agreement on facts, alternatives, or solutions. Public involvement and conflict management techniques are keys to servicing such needs and being able to introduce/implement innovations. Techniques of public involvement and conflict management can be viewed along a progression of having knowledge about a decision; being heard before the decision; having an influence on the decision; and agreeing on the decision.

The major problems facing engineers, scientists and planners are not technical. They are problems of reaching agreement on facts, alternatives, or solutions.

To promote innovative practices, it helps to "create" immediate changes in status quo through stakeholder or public pressure, new legislation and policy decisions. Also, community involvement from the beginning (planning) makes individuals more positive. They can push for innovations since they are not tied to the status quo of authorities. However, this costs money. The City of New York allocates a portion from the budget of major projects for "Citizen Advisory Committees", i.e., citizens, environmental organisations, and industry. The projects must have a philosophy of "prevention" versus the old attitude of "pollution control". This will allow promotion of more innovations in planning, projects, and long-term solutions due to "new" thinking.

Political boundaries are a problem to ecosystem/-catchment level management, and to innovation.

Agents of change and innovation

In order to be adequate and effective, measures or plans and policies of innovation have to be applied or conceived within units, usually catchment areas that are larger than regional or national governmental borders. Political boundaries are a problem to ecosystem/catchment level management, and to innovation. The authority planning and managing the catchment must perceive itself and its mission as an agent of change and innovation, not just another bureaucracy perpetuating the status quo.

Innovations are encouraged if:

- management is integrated across the boundaries of a basin;
- integration exists between functional state agencies (agriculture, forestry, water resources, environmental regulations, nature conservation, land use-government levels);
- integration exists between disciplines as agencies tend to be dominated by single expertise groups that reinforce functional boundaries of agencies, tensions between disciplines and poor communications;
- integration exists between knowledge providers and knowledge users and no destructive tension exists between the research community and the managers or planners of resources.

A successful model for changing poor management practices and adopting innovations thus involves: commitment, resources, a substantial knowledge base, and a well-planned change process including attitudes of land users, cost-sharing, and group activities. When one of these elements is missing, change either will not occur or will take place in a direction that is not sustainable.

8 Less ignorant towards the future

A recapitulation

From earlier chapters we can see how a majority of today's environmental problems are related to water and reflect three particular water management failures:

- unsuccessful response to hydroclimatic pre-conditions such as water scarcity;
- poor waste management, which allows chemical and biological waste to be introduced into the air, to the land and to the water bodies and from there to be picked up by the moving water – a unique solvent in continuous movement in contact everywhere with ecosystems;
- ill-advised interventions in soil and vegetation systems, which affect water partitioning and produce changes in groundwater recharge and river runoff.

When humans manipulate soil and vegetation, they influence not only water quality but also intervene in the partitioning of incoming rainfall. Arid areas have turned out to be highly vulnerable to deforestation which causes increased runoff and waterlogging as groundwater tables rise. Deforestation in the humid tropics creates huge problems when practised the European way and even threatens to change the local climate.

A set of case studies outlining a variety of environmental problems demonstrated where humans intentionally or unintentionally had influenced other factors determining water flow. We have examples that show how withdrawal of water for irrigation, for example, has dried up receiving lakes downstream in Central Asia or depleted groundwater in East Asia. We have seen the effects of large-scale drainage efforts in both Florida and the Netherlands and the corresponding response of the landscape in the form of environmental changes. In addition, we have seen the unintentional side effects of deforestation on arid steppes and savannas, on humid forests in East Europe, on a Caribbean island, and in South Asia and Australia. We have reviewed a number of cases showing the effects of introducing pollutants into water pathways: leaking pipes in East Asia; surrounding land-use as a pollution source in Europe, South East Asia and Australia; and leaching from old waste deposits in the USA and Europe.

The water that flows and percolates through inhabited landscapes can be put to use as it passes along.

Moreover, we have become acquainted with the vulnerability of rainfed farming in dry climate regions and the price paid for not replacing soil nutrients. Other examples of the social effects of changes induced by humans are: health effects of polluted water in cases from Africa and Central Asia; economic losses due to vanishing income in Central Asia; possible risk for social unrest and environmental migration in Africa and South East Asia; the risk for upstream-downstream disputes caused by upstream pollution or excess water withdrawals, which endanger the societal development of those living downstream.

The water that flows and percolates through inhabited landscapes can be put to use as it passes along. What happens later to the water raining over a particular area reflects, however, the way humans handle the vegetation in the catchment area or treat the waste produced by societal activities. These actions will affect the runoff generated from the area and the quality of both groundwater and river water. In other words, it is on land that humans are changing the fundamental variables of the water cycle. Humans are an integral component of that cycle.

This book has tried to clarify how the flow of water links various parts of the landscape. The chapter on the natural rules of the game showed that water is passing through the landscape above and below the ground surface. Moisture in the unsaturated zone above the groundwater table is available to the vegetation and organisms and is consumed by evaporation and by the transpiration of plants. Below the groundwater table, water is transported laterally in a downhill direction towards local hollows and towards the river channel. The landscape can be divided into three general zones:

Past approaches to pollution can be described as seeking simple solutions to complex problems.

- zones where groundwater is recharged;
- zones where groundwater is discharged and creates runoff; and
- zones with rapid re-evaporation.

Globally, the mixture and function of these zones are very different due to regional climatic differences. In humid areas, groundwater is recharged in the main part of the catchment, except in a small discharge zone close to streams and in wetlands. In semi-arid areas, groundwater is often recharged only in a minor part of the basin, whereas the major part returns infiltrated water to the atmosphere. However, some groundwater recharge may occur during heavy rainstorms. These are the rules of the game and the starting point for how to manage our interaction with land and water. The current experience in western countries are summarised in Box 8.1.

Radical change needed

Environmental problems have not gone away

Past approaches to pollution can be described as seeking simple solutions to complex problems. Pollution problems have been addressed through end-of-pipe solutions but pollution has not gone away even in western countries where waste water treatment has been widely implemented. In large areas, the biggest overall source of quality degradation of rivers, lakes and coastal waters is the over-enrichment by nutrients, mainly originating from agriculture and traffic exhausts. In other areas acidifying pollutants transferred through the atmospheric branch of the water cycle is a serious source of water quality degradation.

In the post-communist countries both agricultural chemicals and inherited industrial and military waste are dominant sources, whereas in the rapidly industrialising developing countries sewage and industrial waste water and waste deposits represent huge parallel pollution sources in addition to agricultural chemicals. In the poorest countries finally, sewage still remains the dominating pollution source not yet coped with but causing widespread unhealth and high morbidity and mortality.

Besides environmental problems generated by adding pollutants to the water pathways through the landscape, there are also problems related to physical manipulation of water flows and pathways through land use changes. There are two categories: those related to soil and vegetation manipulations, and those related to river flow regulation and the related structures. The former environmental consequences tend to be more serious in tropical than in temperate climates due to the thirsty atmosphere.

Box 8.1. Policy recommendations in a country in Western Europe

1. OPEN COMMUNICATION

- Promote open communication. The basis could be agreed-upon principles and criteria. The development of a new "common language" for decision-making through consensus is important in this respect.
- Support the interests of the water environment. Land use planning, legislation and economic instruments are very useful, as the implementation of "prevention rather than cure" begins at policy and strategy levels.
- Network with other countries. Progress towards sustainability on national and global scales is much helped by identifying best management practices and approaches to sustainable development.
- Identify indicators monitoring progress toward objectives to be measured.

2. CATCHMENT ACTION PLANS

- Develop Catchment Management Planning action plans. They are for realising potential opportunities for enhancement as well as for conservation. River corridor surveys, landscape assessments, fisheries surveys etc., contribute to the realisation of plans. It is a distinct advantage if issues can be addressed within a multi-functional framework – actions taken unilaterally based on considering only single functions cannot claim to have a sound basis in relation to their sustainability.

3. DECISION-MAKING PROCESS

- Promote community participation in decision-making and implementation of action plans. Ownership of decision-making by stake holders underpins sustainable development.
- Encourage sustainability at a regional level. It is important that policies and strategies undergo environmental appraisal. Strategic Environmental Assessments are important for the present and future development needs and corresponding impacts at the regional level.
- Show clear support for sustainable development of the water environment at the local as well as at the county level. Establishment of environmental carrying capacities in urban and rural areas is very important in this respect. The techniques for achieving this capability needs quantitative and qualitative source control supported by economic incentives.
- Promote the use of Environmental Impact Assessment as the proactive procedure for project alternatives, appraisal and development. This allows the meeting of minds necessary to identify the best applicable environmental option, rather than an "add-on" or reactive requirement for projects risking conflict between intangible ecological needs and tangible project benefits and costs.

4. PROFESSIONAL DEVELOPMENT TO COPE WITH COMPLEXITY

- Make it possible to continue the professional development of those who grapple with the multifunctional complexity of development proposals. Universities, professionals of various disciplines, their professional organisations and institutions have key roles to play to show strong leadership in assisting catchment management bodies.

Today's pollution situation in many regions can be described as a "wilful neglect" of averting a proceeding water pollution that is making the water in aquifers, rivers and lakes less and less usable.

Keeping water usable

Basically, the general tendency is everywhere more or less the same, although countries are differently positioned in terms of both climate-related vulnerability, phase of development and coping capability. There are basically two challenges: on the one hand making water accessible for use both for crop production and for other societal uses, and on the other coping with the unwanted side effects of the various landscape manipulations. Poverty eradication and economic development can be seen as climbing a water management ladder, where the steps look a bit different in different regions and where different countries have climbed up to different levels. A widely neglected goal is to keep water usable. If that goal is achieved, water-dependent biodiversity will automatically be protected.

Expressed in a different way, today's pollution situation in many regions can be described as a "wilful neglect" of averting a proceeding water pollution that is making the water in aquifers, rivers and lakes less and less usable. There is a lack of capability to overcome the implementation barriers for the action needed: poor legislation, lack of enforcement, financing problems, bureaucracy unable to cope with complexity; and lack of courage to address the inconsistency of upstream as opposed to downstream interests. As recently formulated in the US Clean Water Action Plan "Water has a voice. It carries a message that tells those downstream who you are and how you care for the land".

To avoid this undesirable situation it is particularly important to:

- create or increase awareness of water and the water cycle among both politicians and the general public as an essential precondition for overcoming the many current barriers to a well integrated land-water conservation and management;
- teach decision-makers to distinguish non-negotiable from negotiable elements in the land-water issue in order to find out where solutions can be found;
- re-double efforts to get engineers, scientists and planners to cooperate closer and seek agreement on facts, on feasible alternatives and on solutions.

Key actors

There are basically two key groups of actors: on the one hand politicians since they have the legislation and the administration in their hands, on the other the general public which may put pressure on the politicians to take key decisions and to secure their implementation. The public interests have to be protected in order to avoid serious problems like riots and upheavals. It is interested in livelihood safety of different kinds: water should be safe to drink; water bodies should be safe to swim; crops, meat and fish should be safe to eat. Today, the public in western countries is just becoming aware of the health and fertility threats emerging from endocrine-disrupting pollutants.

One fundamental key tool for action, now increasingly implemented in the western world, is catchment action plans to secure that land use is planned and managed in concordance with the water interests. Local stakeholders and inhabitants have to be involved in their implementation. In the Landcare movement in Australia local citizens are engaged in protection of the usability of the passing water as local land users. In USA a campaign is starting based on "citizens right to know" and encouraging their use of the Internet to follow the situation in the catchment.

Changes in policies

Today we expect a lot from our politicians. They must aim at land and water use that is sustainable in the long-term. They must encourage the involvement of the public and define the primary movers as well as the input that should be sought from advisors and interest groups. Politicians in general need the public's guidance and pressure in order to set priorities. One essential component in promoting innovations is to develop a public participation process. Whatever is decided at higher levels in society, practical measures of implementation will always be taken at the local level.

The basic task of policy makers is - as just indicated to make water accessible for use and to keep it usable and to find adequate ways to cope with environmental pre-conditions in every region while satisfying human and societal needs. It is thus crucial for them to learn to see and to anticipate problems. They need to understand the principal conditions underlying natural resource use and other aspects of life support systems. At the same time they need expert advise on where in the landscape different activities should preferably be concentrated, how manipulations or changes should be made, when they should be carried out, and what the consequences might be.

Legislation has to be developed that is supportive. As this book has shown, present water legislation may often be an obstacle to change that is needed due to a bias towards the users. In future planning and management, greater weight must be placed on the opinions of possible victims impacted by water use. The legislation addressing such environmental impacts has to be highly transparent, easily understandable, and as free of "buzz-words" as possible. At the same time, it must not be too rigid but must have built-in flexibility that allows the "best" solutions to be implemented, and be open for the constraints and particular circumstances of each case. The legislation should form a framework within which it is possible to act in such away that the resource base is not being undermined by any degradation caused.

Think regionally, act locally

It is equally important to escape from the current administrative fragmentation in water administration. Ideally, there should be a central body given the task to take an integrated land-water management approach. The integrated approach is best-suited if used at a regional or a catchment/basin level since all water-related human activities are connected at that level by the integrity of the water cycle, and by the "shock-wave" effects caused when water cycle elements are disturbed. Sectorial units will obviously still be needed for co-ordinated management of the various water-related activities at local levels in society. In other words, what will be needed is a blend of coordination at the local level and integration at the regional level.

Vested interests seem particularly resistent when solutions are suggested to reduce the outflow of pollutants from industry and agriculture.

Today, the present institutional framework supports vested interests that are determined to oppose change. Vested interests seem particularly resistant when solutions are suggested to reduce the outflow of pollutants from industry and agriculture into groundwater aquifers and water bodies. An essential political challenge for the near future is to incorporate such interests in effective, integrated land and water management. It may also be necessary to create a new "water ethics".

Learning from success stories

From earlier chapters can be seen that it is difficult to reverse the common degradation of land and water resources, unless there are radical changes in policy and administration. It is, however, essential to recognise that we possess sufficient knowledge now of what we must do to halt the ongoing degradation of land and water.

Time delay between knowing and doing

A few examples were presented that demonstrate that integration had been successful once the physical and socio-economic causes of the degradation were identified. We have witnessed the stimulating effect created when water could be made available and put to beneficial use in a dry country, e.g., the community gardens based on groundwater in southern Africa that became a springboard to other community-led activities. We reviewed some examples where severe water pollution had indeed already been remedied: one from Singapore where pig farming was a key polluter; and the other from the New York City area where industrial pollution and over-development was the key problem but where natural aquatic habitats have now been re-established.

In integrated land-water conservation and management, success stories are few so far. The reason is that a huge gap exists between recommended practices of land and water management and actual practice. Also life styles are part of the problem. We saw for example that nutrition habits, in particular the levels of meat consumption, were a strong driving force behind the severe nitrate pollution of groundwater and rivers in Europe.

It is well-known what needs to be done. The problem is that it is not being done. A whole set of barriers in the implementation process and plain ignorance on the part of the decision-makers prevent action. There is, in other words, a lengthy time lag between knowing and doing. This time lag could be overcome by focusing on action for integrated catchment management. It was shown that politicians are the main actors; that problems originate from inappropriate policies; and that clear rules and well-defined responsibilities are needed. Ignorance is an effective barrier against sustainable practices.

Australia leads the way

It is encouraging to examine the direction taken in Australia – the very area where all three main management challenges have had to be met simultaneously. There, the struggle was to:

- contend with the difficult, drought-prone monsoon climate exacerbated by an extremely "thirsty" atmosphere;
- combat past mismanagement of waste and agricultural chemicals;
- rectify earlier ill-advised interventions in soil and vegetation systems that resulted from past ignorance of the highly vulnerable conditions.

Australians had to reverse the severe consequences resulting from widespread irrigation without parallel drainage of excess water; from wasteful fertilisation; and from temperate zone approaches to land clearing by European immigrants. The result of these ill-advised interventions was that land productivity was severely disturbed by salinisation and water logging, and that river water quality was degraded not only by salinisation but also by algal bloom due to eutrophication. The approach taken by Australia to get out of this severe situation has been catchment-based and directed towards an integrated approach to land and water. The general public is being deeply involved through the Landcare Movement where land users themselves are mobilised in efforts to protect the land from degradation.

Reconciling upstream-downstream conflicts of interest

In the past discussion of upstream-downstream relations has often had a strong flavour of international conflicts. Recently, international rules have been agreed upon in United Nations regarding "non-navigational uses of international waters". Key concepts in these rules are beneficial water use, damage caused to other stakeholders, and ways for their compensation. Focus is on direct use of water in the river without much attention to neither groundwater nor land use in the river basin.

Upstream manipulations cause downstream effects

The growing understanding of the relations between land use and water systems, highlighted in this book, will however introduce a new dimension to river basin development and management, and open opportunities for close and proactive cooperation on how the land and the water in the river basin could most productively be put to use.

Upstream manipulations are in fact most likely to cause downstream effects. As clarified in an earlier chapter, physical manipulations of the basin include land conversions through clearing, reforestation, agricultural intensifications etc, and river flow development and management through storages, canals, water transfers to and from the river, and flow control in general altering the seasonality of the flow. Chemical influences on the other hand include the introduction of pollution loads either indirectly by the water passing through the land picking up agricultural chemicals or pollutants from landfills, or as direct wastewater outputs to the river system.

A whole set of different types of downstream phenomena and activities may be disturbed by such land and water manipulations upstream. Downstream water use may run into difficulties when the accessible water is too polluted to be usable for the intended purpose. Downstream river ecosystems like aquatic flora and fauna may be impacted with effects for e. g. fishery and aquaculture. Riparian wetlands and their flora and fauna may be disturbed. And coastal ecosystems with their fishery and seafood may be disturbed.

Consumptive water use upstream may – besides downstream river depletion – influence also downwind rainfall patterns. When more water is added to the atmosphere from vegetation, rainfall might increase downwind. When the amount of water added decreases, the local atmosphere is depleted of water and downwind rainfall may diminish.

Best possible use from social and economic perspectives

In catchments and river basins, upstream land and water uses will have to be properly adapted to their influence on downstream opportunities and problems. Wherever water is a limiting resource, it should be put to the best possible use according to social and economic factors. A combination of these factors should govern the local allocation between different water-dependent sectors in a certain locality. However, at the same time, there is a need for thorough and detailed agreements regarding upstream-downstream water sharing (Figure 8.1).

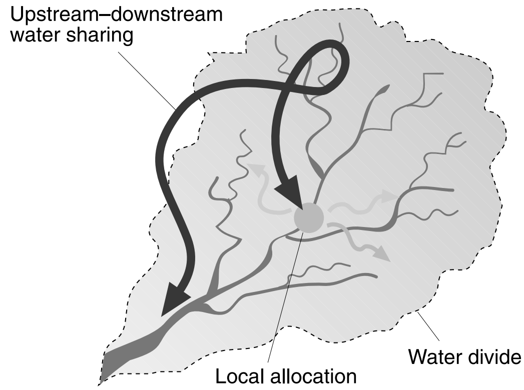


Figure 8.1.
There is a need for thorough and detailed agreements regarding upstream-downstream water sharing in a catchment basin.

Upstream land and water uses will have to be properly adapted to their influence on downstream opportunities and problems.

Arena for reconciliation of conflicts

The consequence of all this is that the most proactive river basin management would involve a stakeholder-based river basin commission equipped with a set of tools and mechanisms facilitating dialogue and the finding of compromises. In such an arena upstream and downstream stakeholders may come together – directly or through representatives – to negotiate the best solutions by which their different interests can be properly reconciled.

International river basin agreements

In an international river basin, i. e. a river basin encompassing several countries, there is generally more to gain through cooperation on water resources development than through conflict. Modern history gives some pertinent examples such as the Sudan-Egypt agreement on the water made accessible through the Aswan Dam on the Nile. In order to defuse disputes between Egypt and the upstream countries, all the nations on the Nile have now formed an International Nile Basin Association scheduled to be operating by 1999. The river development projects in the Senegal River are other positive examples. Here, an extremely complicated financing model did find international support.

The upstream-downstream set of problems tend to look different in the arid zone from those in the humid. Although water-sharing is basically a zero-sum game, that game is less complicated in the humid region where the river flow increases downstream. In the arid region the situation is the opposite, i.e., the river flow decreases downstream mainly due to evaporation losses. Consequently, arid countries in international river basins are utterly dependent on being able to negotiate a sharing agreement.

The desirable future

It would be more interesting to create a vision that characterizes the situation we want the world to be in say, 2025 AD.

In this section we will discuss some ways of relieving the paralysis through: a change in scenarios; a change in strategies; the help of eco-economics; and finally through a definition of the roles of politicians and scientists.

Backcasting instead of forecasting

Traditional forecasting in business and government has been for a long time based on extrapolation from the current situation. If “business as usual” is no longer feasible then this approach does not make much sense. It would be more interesting to create a vision that characterises the situation we want the world to be in say, 2025 AD. This approach is called “backcasting” and describes a desirable future state in terms of a whole set of characteristics. It then goes backward in time to identify the threats that have to be averted and the steps that must be taken in order to achieve that state.

The following ideas could form the basis for such a procedure:

- analysis must start with what is given, e.g., the projected increases in demand from population growth and improved quality of life, and the amounts of freshwater available that can be made accessible for use.
- the next step would be to ask:

  (a) what kind of development dependent on water, such as food production, health protection, industrial development, and poverty eradication, would be possible to incorporate within those constraints?

  (b) how can we minimise pollution of the vital freshwater systems to secure healthy drinking water, and healthy terrestrial and aquatic ecosystems?
- if we chose an integrated approach, this will lead to a number of criteria for future management of land and water. As has been said, the principal task is to find adequate ways to contend with the environmental pre-conditions in every region while at the same time satisfying human and societal needs.

The integrity of the water cycle is a non-negotiable component of the real world. We must therefore make more efforts to avoid predictable problems. The effects produced by development are predictable in principle although not in the specific.

Sustainable strategy

New strategies are also needed. Some components of a sustainable strategy of man-land-water interactions can be proposed based on the discussion in the previous chapters:

- the amounts of water needed for urban use and irrigation must be made accessible. This will involve creating water development structures such as water reservoirs, channels and pipelines for transfer of water to urban and agricultural areas. Side effects of these structures will have to be minimised, and unavoidable side effects seen as acceptable;

- demands for "blue" water have to be managed and adapted to the amounts that can be made accessible;
- non-productive water losses will have to be minimised in rural land-use. This is equivalent to maximisation of "green" water productivity within rainfed agriculture, i.e., to maximise the production per unit of water lost from the area by evaporation and transpiration;
- implications for policy dialogue will be concerned with adaptation of urban and agricultural water use as well as avoidance of pollution. Tools to be used may include pricing, tariffs, permits, etc.;
- at the regional level, the new strategy calls for an integrated approach to land and water on the river basin scale ;
- wherever the food production potential is not adequate, societal development has to be directed towards earning of the amount of foreign currency necessary to allow food import.

Benefiting from a possible breakthrough in ecological economics

One result of the acknowledgement of economic approaches to environmental issues is the principle that water, whenever scarce, has to be seen as an economic good. This suggests that water should be put to the most worthwhile uses. An economic analysis is required in order to find out how water should be allocated among different sectors of society. There are two main models for this analysis: a market-based assessment or one based on negotiations between the parties involved. A third idea of ecological economics concerns

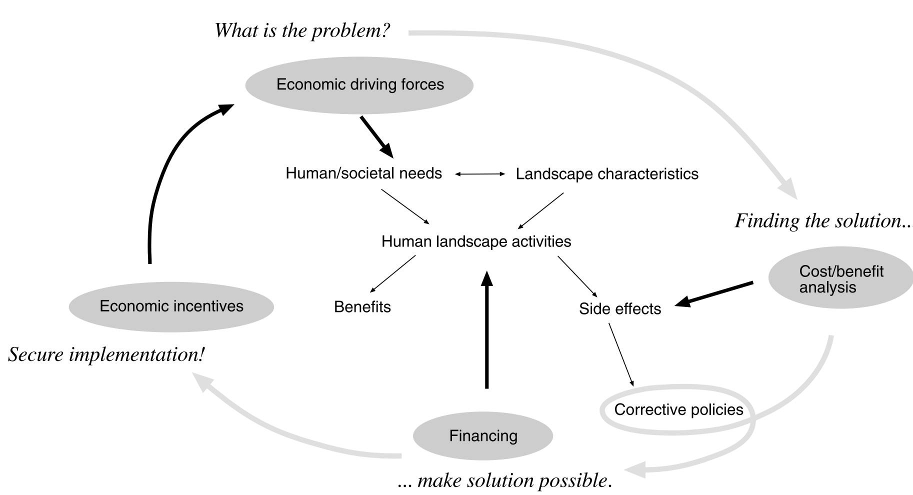


Figure 8.2.
Four economic factors (in grey) of importance to the interaction between human activities and the landscape.

the issue of how to finance water services. Through demand management the manifested demands can be minimised and water wastage avoided. Economic tools, such as subsidies or tariffs, can be used for this purpose.

Figure 8.2 illustrates four types of involvement of economics in the diagnosis-solution cycle:

- defining the problem: economic realities as a societal driving force to determine human behaviour;
- finding the solution: cost/benefit calculations of the most cost-effective solution;
- making that solution possible: financing the projects selected;
- securing implementation: economic incentives as the driving force for altering human behaviour.

The politicians and their policy-making experts have an obligation to understand the conditions for natural resources use and for life support of human societies. They are obliged to understand, in a broad way, the predictable consequences of their decisions or lack of decisions.

Educating key actors

We have earlier stressed that key actors in holistic, integrated land-water management are the politicians and the policy advisers supporting them. The politicians and their policy-making experts have an obligation to understand the conditions for natural resources use and for life support of human societies. They are obliged to understand, in a broad way, the predictable consequences of their decisions or lack of decisions. Their duty is to make it possible for local societies to solve their own problems. On the regional level, this calls for an integrated approach to land and water on the river basin scale.

It is crucial, therefore, that the key actors learn to see the problems in advance, enabling them to take an anticipatory approach. Scientists, working across disciplinary boundaries, are the ones who can provide the basis for this understanding.

Decision-makers are therefore increasingly caught between reactive and proactive imperatives.

The world is changing rapidly

The book has discussed at length the origin of most of the environmental problems that occupy public interest today. We have also reported on current conclusions. The world is however, changing quite rapidly through population growth, urbanisation and industrialisation. Decision-makers are therefore increasingly caught between reactive and proactive imperatives: on the one hand, to remedy problems caused by past mismanagement of water, land and waste; and on the other to take measures to avoid predictable future problems generated by the rapid change.

In this situation, a basic understanding of man-land-water interactions is indispensable for policy makers. Without it they will not be able to decide on action priorities and slowly lead the country out of the dilemma. To provide such understanding has been the aim of this book.

Looking again towards the future – say the next three decades, i. e. up to 2025 AD – two key water problems can be distinguished that will need attention. Both of them are linked to the expanding food production to meet the needs of the growing world population, the needs for better nutrition of famine-prone and undernourished population segments, and changing preferences:

- water pollution from agricultural chemicals which might escalate even further in response to intensified food production;
- water depletion from the larger and larger amounts of water absorbed in food production and returning to the atmosphere – a phenomenon that will exacerbate the challenges of upstream-downstrem water sharing.

As regards water pollution, most interest has been devoted towards pollution from end-of-pipe waste water. Methods for waste water treatment are well developed. A richness of barriers tends to delay implementation however, and economic development and population growth tends to increase the scale of the tasks. The agricultural chemicals is a more difficult task due to the relation to the urgent need to speed up food production. The way that western countries try to address that problem is by going for more efficient use of agricultural chemicals by introducing soil testing technology for farm-level application. Chemical pesticides are increasingly being replaced by biological methods.

The second key problem is the river flow and groundwater depletion, produced when more and more water is needed to increase food production. Already today are the emerging problems reaching regional scale. The most evident example is the dilemma of the Yellow river in China where the downstream stretches have during recent years been severely depleted for a considerable part of the year. In large areas with groundwater-based irrigation more water is being taken out of the aquifers than what is annually being recharged through infiltration of rainwater. The result is groundwater depletion, which is already widespread over large crop-producing areas of the world including USA, India and China.

Getting out of the vicious circle

The dilemma of a world with fragmented spheres of interest of different groups of expertise is visualised by the very simple graph in Figure 8.3:

- Fundamental human activities are water-dependent: households, industrial production, biomass production for food supply, pasture and timber. These activities all aim at poverty eradication and economic growth, studied by economists. The technical supply arrangements are handled by engineers.
- The landscape manipulations involved produce a whole set of visible side effects on wetlands, flora and fauna, which are described in increasing detail by nature conservationists.
- The land and water use involve both physical and chemical manipulations that generate water-related side effects or impacts which are hidden and may be slow to develop: both water-carried impacts on ecosystems of more or less invisible type, studied by ecologists, and impacts on water sources and biomass from which society is being supplied, still in the domain of ecohydrological research. The larger these impacts the more will human activities be disturbed.

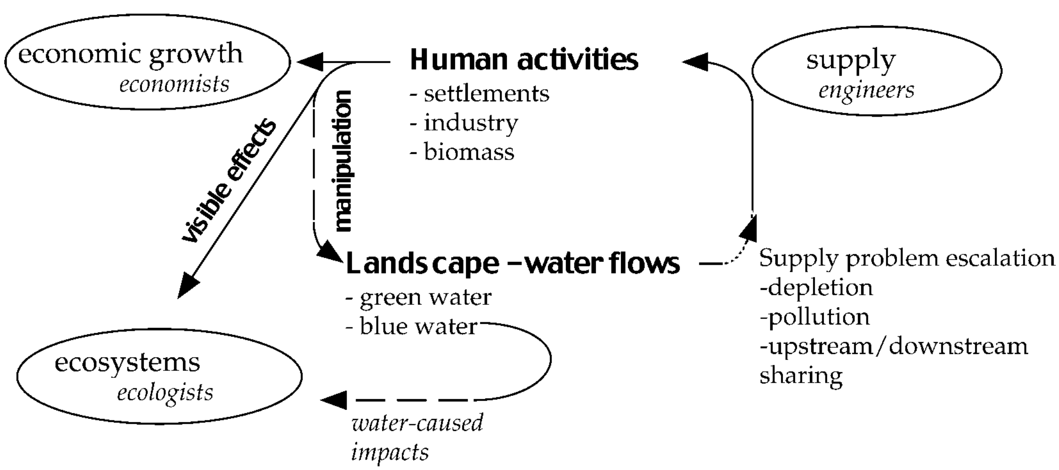


Figure 8.3.
Human dependence on landscape: Fragmented versus integrated approach.

As world population expands and world economy grows further it will be increasingly important that the emerging vicious circle is being properly addressed. To secure the continued supply of land and water based resources will be increasingly difficult whenever water depletion and water pollution problems are superimposed on already existing water management problems, that are related to water resources development, ownership/usership problems, economic problems etc.

The water cycle: the bloodstream of the biosphere

The fact that the earth is the only planet with liquid water is in itself thought-provoking. Water plays a crucial role in plant production as it is one of the two key raw materials in the plant production process. Plants depend on a capillary stream of water continuously passing through the tissues from the soil to the air while carrying necessary nutrients. Moreover, the water cycle has an integrity of its own. Everything caught by the moving water is carried onwards in the water cycle towards ecosystems on land, in freshwater bodies and in the sea. All disturbances to the components of that cycle are pushed onwards, causing a domino effect on the other components. In the future, regional water scarcity in dry climate tropics and subtropics will constrain agricultural production and, therefore, food self-reliance in poor countries will be adversely affected. Socio-economic planning will need to be adapted to actual water constraints in these regions.

To cope with the creeping impacts of water pollution and depletion on the life support systems of the next generation is a major challenge for expertise with different roles and background.

What this book tried to show is the high explanatory pover of looking at the environmental problems through a freshwater lens.

The increasingly complex task of feeding the world population with safe food and water, and securing that the water in rivers and aquifers is usable for industry and allows healthy ecosystems is a major challenge. Many different types of expertise will have to work together in order to overcome the many barriers that now impede us in going from knowing to doing.

The basic lesson is the following: you can never cheat the water cycle, but you may benefit from realising that we all live at the mercy of that cycle, the bloodstream of the biosphere.

References and further reading

Chapter 1
THE PURPOSE OF THIS BOOK

gleick, p. (ed.) (1993): Water in Crisis. Oxford University Press, New York.

Chapter 2
REGIONAL CHALLENGES

bergbäck, b., anderberg, s. & lohm, u., (1992): Lead load: historical pattern of lead use in Sweden. Ambio 21:159 –165

engelman, r. & leroy, p., (1995): Conserving Land: Population and sustainable food production. Population and Environmental Plan, Population Action International, Washington DC, 1995

fearnside, p. m., (1993): Deforestation in Brazilian Amazonia: the effect of population and land tenure. Ambio 22:537–545.

le houérou, h. n., (1984): Rain use efficiency: a unifying concept in arid-land ecology. In: Journal of Arid Environments 7, pp 213 – 247

lindh, g. & niemczynowicz, j., (1989): Urban Water Problems in the Humid Tropics Proceedings International Colloquium on the Development of Hydrologic and Water Management Strategies in the Humid Tropics. UNESCO, 15-22 July 1989, Townswille, Australia

niemczynowicz, j., (1992): New aspects of sewerage and water technology. Ambio 22:449 – 455.

parr, j. f., et al, (1990): Improving the sustainability of dryland farming systems: A global perspective. In: Singh R.P. et al. (eds.) Advances in soil science vol 13. Dryland agriculture strategies for sustainability. New York, 1990.

pettersen, b.w., (1994): Possibilities and advantages of dual water distribution system: handling a groundwater contamination form nonpoint sources. Groundwater Quality Management (Proceedings of the GQM 93 Conference held at Tallinn Sept. 1993). IAHS Publication no 220, 1994.

richardson & ærtebjerg, (1991): Effekten af kvælstof og fosfor i Kattegat og Bælthavet (Effect of nitrogen and phosphorous in Kattegat and the Belt). Report from the Konsensus Conference 31 Jan – 4 Feb. Copenhagen.

sandén, p. & carlsson, b., (1990): Modelling metal transport through a lake in a mining area. Vatten 1:18-26. (In Swedish).

wallgren, b., (1992): Natur och Retur – förutsättningar för kretsloppssamhället. (Return – fundaments for the recycling society). Miljövårdsberedningens rapport 1992:4. Swedish Ministry of the Environment, Stockholm. (In Swedish).

Chapter 3
NATURAL RULES OF THE GAME

committee on opportunities in hydrological sciences, (1991): Opportunities in Hydrological Sciences. National Academy Press, Washington DC.

falkenmark, m., (1977): Water and Mankind – A complex system of mutual interaction. Ambio, Vol. 6, No. 1.

falkenmark, m. & chapman t. (ed.), (1989): Comparative hydrology : An ecological approach to land and water resources, UNESCO, Paris

heyns, p., (1993): Water management in Namibia. Proceedings of the workshop on water resources management in southern Africa, Victoria Falls 5 – 9 July, 1993.

hillell, d., (1991): TIGER (Terrestrial Initiative on Global Environmental Research). Conference Bournmouth, UK, Verbal paper

l'vovich, m. i., (1979): World Water Resources and their Future, (Translation by the American Geophysical Union). LithoCrafters Inc., Chelsea Michigan.

marsh, a. & seely, m. (ed.), (1992): Oshanas, sustaining people, environment in central Owambo Namibia, DRFN and SIDA, ISBN 9916-709-0-4

moldan, b. & cerny, j. (ed.), (1994): Biogeochemistry of small catchments: A tool for environmental research, SCOPE reports 51, Wiley, Chichester

nelson, m., (1994): Hydrology and the river environment. Oxford University Press, 221 pages

petersen, r. c., petersen, l. b.-m. & lacoursiére, j., (1992): A building-block model for stream restoration. In: Boon, P.J., Calow, P. & Petts, G.E. (eds) River Conservation and Management, pp 293-309. John Wiley & Sons Ltd.

quinn, p. e., ostendorf, b. & tenhunen, j. d., (1996): Spatial and temporal variability and its functional representation. In: Aspects of Applied Biology 46, Modelling in applied biology: Spatial aspects.

sandström, k., (1997): Ephemeral Rivers in the Tropics. Hydrological processes and water resources assessment and management: A review and pathfinder. EPOS Research Report 8. Linköping: EPOS (Environmental Policy and Society), Linköping University.

ward, a.d. & elliot, w.j. (ed.), (1995): Environmental hydrology. Lewis Publishers, Boca Raton

wilby, r.l. (ed.), (1997): Contemporary hydrology: towards holistic environmental science, Wiley, Chichester

Chapter 4
CURRENT POLICIES: INCONSISTENT WITH NATURAL RULES

YMER, (1992): Miljö och utveckling (Environment and development). Svenska sällskapet för Antropologi och Geografi. (In Swedish)

Chapter 5
A LAND-USE DECISION IS ALSO A WATER DECISION

falkenmark, m., (1996): Global Water Crisis – Differences in regional predicaments. International Shiga Forum. Otse, Japan, 25 – 27 November 1996.

gumbricht, t., (1996): Modelling water and landscape reciprocity – A landscape synthesis in GIS. Dissertation, Divsion of Land and Water Resources, Royal Institute of Technology, Stockholm.

rockström, j. & ada l., (1993): Diagnostic sur le systéme agraire du "Zarmaganda Central" (Niger). Memoire finale, Institut National Agronomique – Paris/Grignon (I.N.A.-P.G.), Chaire d'Agriculture Comparée et de Développement Agricole. Paris, 1993.

Chapter 6
REVERSIBILITY AND THE TIME SCALES OF RECOVERY

appan, a., (1994): Integrated land and waste management towards enhancement of reservoir nutrient levels – a successful case study in Singapore. Proceedings Stockholm Water Symposium 1994. Stockholm Water Company.

fleckseder, h., (1994): Integrating land and water – a "Central European" view using nitrogen as an example. Stockholm Water Symposium 1994, Stockholm Water Company, pp 79 – 96.

Chapter 7
STEPS TO BE TAKEN FOR INTEGRATED LAND AND WATER MANAGEMENT

CNR, (1996): Intersessional strategy paper on future water resources management: issues and appropriate strategies and policies. Doc. E/C.7/1996/6. Committee on Natural Resources, United Nations.

cullen, p., (1994): A bottom-up approach to integrated land and water management. Proccedings Stockholm Water Symposium 1994. Stockholm Water Company, pp 525 – 534

falkenmark, m., (1996): Global water crisis ahead. Need to get out of the paralysing water illiteracy. IRDC Currents, No 12, Uppsala, Sweden

falkenmark, m. & lundqvist, j., (1998): Towards water security: Political determination and human adaptation crucial. Natural Resources Forum, Vol 21, No. 1, Elsevier, pp 37– 51

heath, r. g. m., macagnano, e. & mac kay, h. m., (1994): People and the environment: sustainable development of Third-World urban areas. Proceedings Stockholm Water Symposium 1994. Stockholm Water Company, pp 569 – 578

powell, j.m., (1998): Interregional environmental policy in Australia's Murray-Darling basin. The Arid Frontier, H.J. Bruins & H. Lithwick, Eds., Kluwer Academic Publishers

toronto, (1992): Regeneration. Toronto's waterfront and the sustainable city: Final report. Royal Commission on the Future of the Toronto Waterfront. Ontario, Canada

Chapter 8;
LESS IGNORANT TOWARDS THE FUTURE

falkenmark, m. & steen, p., (1995): To change direction. How to find the new water resources agenda towards a desired future. Proceedings, Stockholm Water Symposium 1995. Stockholm Water Company, pp 145-155

falkenmark et al, (1998): Water scarcity as a key factor behind global food insecurity – Round Table discussin. Ambio vol 27, No 2.

gleick, p.h., loh, s. & morrison, J., (1995): California Water 2020: A Sustainable Vision. Pacific Institute for Studies in Development, Environment and Security, Oakland, California

lundqvist, j., (1998): Avert looming hydrocide. Ambio Vol. 27, No 6, pp 428-433

l'vovich m. m. & white, g., (1990): Use and transformation of terrestrial water systems. The Earth as Transformed by Human Action. B. L. Turner II et. al, eds. Cambridge University Press 1990.

SIWI, (1997): Mar del Plata 20 year Anniversary Seminar. Water for the next 30 years. Averting the looming water crisis. Report 1, SIWI, Stockholm

USEPA, (1998): Clean Water Action Plan: Restoring and Protection America's Waters. US Environment protection Agency and US Dept. of Agriculture, Washington DC

UN, (1997): Comprehensive Assessment of the Freshwater Resources of the World. Stockholm Environment Institute

Case studies from IHP Committees and other sources

Countries put in brackets in the map indicate bilateral contributions (see list).

North and South America

Canada

gaboury m n, newbury r w and towle j: Restoration opportunities within the Dauphin Lake watershed using an integrated approach in water and landscape management.

cohen s j: Giving proposals on ongoing projects in 'global warming scenarios' with results 1996 the earliest.

the royal commission on the future of the toronto waterfront: Regeneration: Toronto's Waterfront and the Sustainable City.

USA

peters n e and miller t l: Land-use impacts of the ecohydrology of South Florida and the Everglades.

gellis a, hereford r, schumm s a and hayes b r: Channel evolution and hydrologic variations in the Colorado River basin: Factors influcening sediment and salt loads.

schumm s a and gellis a c: Sediment yield variations as a function of incised channel evolution.

yapijakis c: Land/water integrated management – The New York City Experience.

hemond h f: Movement and distribution of Arsenic in the Aberjona watershed.

wescoat j l Jr: Integrating land and water management in the Indus Basin: The human ecology of water management.

pielke r a and zeng x: Compounding of uncertainty in climate change scenarios.

pielke r a, dalu g a, snook j s, lee t j and kittel t g f: Nonlinear influence of mesoscale land use in weather and climate.

Cuba

suárez p, reyes j, ramírez c and pérez r: Linkage between land use and water management in humid tropical conditions. Case study: Manzanillo River basin, las Tunas, Cuba.

Santa Lucia, West Indies

spek t j: Summary on water impacting land use from a small island in the Caribbean region.

Europe

Denmark

pettersen b w: Solving the nitrate problem – Why are the remedies of today unsufficient and what measures can be sustainable?

Czech Republic

balek j: A remedial of polluted water resources in the Black Triangle of Europe.

paces t: Cases in Czech Republic.

Romania

stânescu v l and serban p: The impact of urban zone of Bucharest City and its surrounding areas on the physical determinants of the Arges-Ialomitza riverflow.

Scotland

quinn p f: Land-water linkages: –Where is the water? Examples taken from catchment hydro-ecological studies.

The Netherlands

van horssen p w, barendregt a, wassen m j and bleuten w: Sustainable water management in the Central Netherlands.

UK

gardiner j l: The River Thames strategic flood defence initiative planning. A model influence.

bateman g: The national rivers authority and its approach to catchment management planning – River Torridge case study.

Former Soviet Union OSS

koronkevich n i: Change of the river flow in the Russian plain and in the former USSR due to economic activity within the drainage area.

edelstein k k: The problem of a complex use of water and land resources in the basin of the Don River.

edelstein k k: Unified method of collecting and processing data on water, chemical and sediment flows from watersheds of small rivers.

colubash t y and lazareva e v: Water factor effect on the productivity of irrigated lands.

voropaev g v, ismaiylov g k and fedorov v m: Ecological–economic aspects of irrigation effect on water–land resources of arid zone (Aral Sea basin).

Ukranie

manukalo v: Information on investigations of land/water linkages for Ukraine

Arab States

Kuwait

al-sulaimi j: Ground water pollution from oil lakes, oil combustion products and damaged oil wells in Kuwait; Effects of farming in the aquifer potentiometry and ground water quality in the Al-Wafra and Al-Abdally areas of Kuwait; Sub-surface water rise in the residential areas of Kuwait.

Africa

Tunisia

missaoui h: Soil and water conservation in Tunisia.

Nigeria

egboka b c e and anike o l: An integrated flood and stormwater mitigation and environmental management in Anambra State, Nigeria.

South Africa

heath r g m, macagnano e and mackay h m: People and the environment: Sustainable development of Third World urban areas.

Asia

India

sivanappan r k: Ecohydrology – Linkages between land use and the circulating fresh water.

ambujam n r and ramachandran s: Reuse of water in the city of Madras: Linkage between land use and the circulating fresh water illustrating case.

Malaysia

appan a: Integrated land and waste management towards enhancement of reservoir nutrient levels – A successful case study in Singapore.

Vietnam

viet pho n: Flash flood in Vietnam and prevention, mitigation measures of their disasters.

Australia

cullen p: A bottom-up approach to integrating land and water management.

walker j and lyle c: The Murray-Darling salinisation problem and strategies for rehabilitation.

lyle c: The Murray-Darling basin initiative – A case study in integrated natural resources management.

benyon r: Information on the effects of disturbance on water production from the catchments near Melbourne and the influence of this on catchment management policies.

soroczynski t: Strategic issues for integrated land and water management.

Bilateral contributions

geyh m a, gu w and jäkel d: An ecohydrologically degenerative grassland Gurinai within the Gobi Desert, Inner Mongolia. (Germany, China).

neiff j j, iriondo m h and carignan r: Large Tropical South American wetlands: An overview (Argentina, Canada).

Index

Water, a reflection of land use

Options for counteracting land and water mismanagement.

A land use decision is also a water decision. Land and water are closely linked through the water cycle. In extreme cases, downstream effects of irrigation farming may be as serious as in case of the Aral Sea disaster. An increasing number of rivers are reported more or less depleted from upstream land use activities. At the same time, farmers are accused also of polluting the underlying groundwater beyond potability limits and of causing eutrophication of surface waters and enclosed seas. Industrialised landscapes are littered by landfills leaking pollutants to underlying aquifers. Their remediation has often relied on Superfunds due to the high costs involved.

In demystifying the water cycle, this book reviews issues in land-water management, clarifying the need for an integrated approach in line with Agenda 21. The links between water cycle, human activities and their effects on freshwater is explained and illustrated by a rich set of examples from different parts of the world. The book relates land use to sustainability issues and highlights current policy mismatches. It includes also a discussion of the time scale of recovery and provides an agenda for a better-informed political action.

The book contributes actively in filling the conceptual void between climate and ecosystems. It may severe as an introductory text to students and it may also be valuable both for teachers looking for a good overview of key causes and processes that lead up to ecological degradation and for a knowledgeable general audience interested in ongoing environmental degradation all around the world.

NFR Naturvetenskapliga forskningsrådet Swedish Natural Science Research Council

Unesco-IHP

A contribution of Sweden to the International Hydrological Programme

SWEDISH NATURAL SCIENCE RESEARCH COUNCIL (Naturvetenskapliga forskningsrådet, NFR)
NFR is a state-financed governmental agency under the Ministry of Education and Science. Its main object is the promotion and support of research within the natural sciences in Sweden.

ISBN 91 546 03587