PART ONE: INTRODUCTION

1.A. What is the goal of this Manual

ECOHYDROLOGY & PHYTOTECHNOLOGY PROGRAMMES

The concept of ecohydrology and its scientific foundations were developed by International Hydrological Programme (IHP) of UNESCO. According to ecohydrology, through the manipulation of biota and hydrology interactions in a landscape, the possibility of augmenting ecosystems resilience to anthropogenic changes can be achieved.

Phytotechnology, on the other hand, as the use of vegetation and its natural services for environmental quality improvement, is being developed by the UNEP International Environmental Technology Centre (UNEP - IETC). This can complement ecohydrology through, for example, development of techniques of vegetation use to reducing erosion of shorelines, preserving and restoring soils and landscapes, controlling and preventing pollution, as well as restoring habitats.

ECOHYDROLOGY & PHYTOTECHNOLOGY GUIDELINES FOR IWM

The complementarities of ecohydrology and phytotechnology, together with the similar interests in water resources management of UNEP-IETC, UNESCO-IHP and UNESCO-Regional Bureau for Science in Europe (ROSTE), led to a joint project that produced the „Guidelines for the Integrated Management of the Watershed". The Guidelines provided a strong scientific basis for the concepts of ecohydrology and phytotechnology as well as a theoretical background for their application in Integrated Watershed Management (IWM). They presented ecohydrological approach to understanding of processes regulating dynamics of water basins, as well as the mechanisms for increasing absorbing capacity of ecosystems against human impacts.

THIS MANUAL

Being a continuation of the scientific background provided in the „Guidelines", this publication does not present to a reader any detailed theoretical considerations about the mechanisms of the ecohydrological and phytotechnological processes. Discussion of the theoretical aspects of the concepts in this publication is limited to an essential minimum. The Manual complements the Guidelines and focuses on the methodology and practical aspects of implementing ecohydrological and phytotechnological concepts in watershed management.

Therefore, the objectives of this manual are to:

- provide examples of ecohydrology and phytotechnology in water resources management;
- assist decision makers, technical experts and scientists to manage watersheds and related water bodies; and
- facilitate and promote the better understanding of the opportunities that the application of ecohydrology and phytotechnology offer for this purpose.

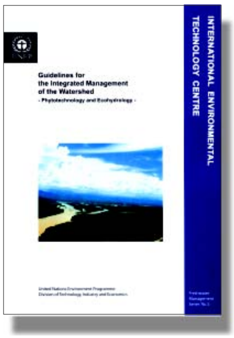
HOW TO USE THE GUIDELINES AND MANUAL

In order to benefit from both practical information presented in the Manual as well as the scientific background provided by the Guidelines, it is recommended to get familiar with both of the complementary publications.

Therefore, in the section named:

MAKE SURE TO CHECK THESE RESOURCES:

located at the end of each chapter, you will find references to corresponding chapters of the UNEP / UNESCO Guidelines for the Integrated Management of the Watershed – Phytotechnology and Ecohydrology.



UNESCO/UNEP
Guidelines for the Integrated Management of the Watershed
Phytotechnology and Ecohydrology
Freshwater ManagementSeries No. 5
UNEP, 2002

1.B. WHY IS THIS MANUAL NEEDED?

FRESHWATER DEGRADATION IS MUCH MORE THAN JUST POLLUTION

At the beginning of the 21st century, the increasing human population has become a major factor in progressive environmental degradation on the global scale. Although the traditional perception of freshwater degradation has been usually linked to pollution, increasing human activities in a catchment have more profound effects on environmental quality. Most river basins in the world have been dramatically modified due to unsustainable development of agriculture, grazing, deforestation, and urbanization. These disturbances have been changing local and regional climates, hydrological cycles as well as evolutionary established biogeochemical cycles in a catchment.

Therefore, it became evident that the degradation of river ecosystems has been of a two-dimensional nature (Box 1.1):

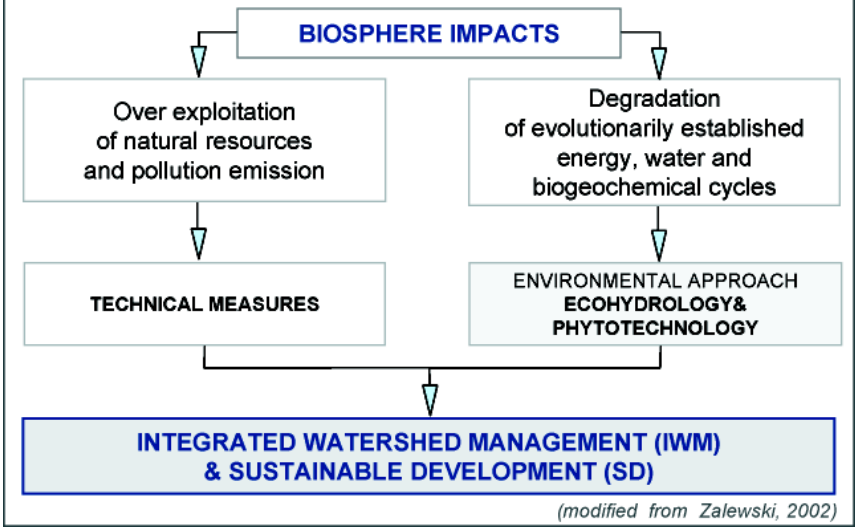
- first - pollution, which can be eliminated to a large extent by technologies;
- second - and much more complex, degradation of evolutionary established water and nutrient cycling.

WHY DOES THE DEGRADATION OF ECOLOGICAL PROCESSES CAUSE RISK TO HUMANS?

Degradation of biological structures and ecological processes means a reduction in an ecosystem's carrying capacity. As a consequence, with the present rate of society development and environmental degradation, it is expected that during the next 30 to 60 years, human imperatives may clash with the carrying capacity of the global environment (see Guideline, chapter I). Such a clash would be nothing less than catastrophic for humanity. Today changes of ecological processes at a catchment scale have become strongly manifested by the continuous decrease of water quality and the enhanced risks of floods and droughts in many regions of the world. It is evident that water is becoming scarcer for society in some developed and many developing countries. This results in a higher risk to not only human health, but also to economic and societal development.

In this situation, development of an integrated approach to environmental management, based on the harmonization of technical and ecological measures, is necessary to achieve sustainable development. Integrating different branches of environmental science (such as, e.g., ecology and hydrology) can help provide an understanding of environmental changes as well the knowledge-base necessary to apply efficient measures to improve the quality and, at the same time, increase absorbing capacity of the environment for human impacts.

BOX 1.1
Identification of ecological problems at global, regional and local scales



(modified from Zalewski, 2002)

1.C. WHAT IS COVERED BY THIS MANUAL?

This manual provides a new approach based on application of across disciplines knowledge in holistic management of water resources. It encourages a reader to have a broader, interdisciplinary view on various aspects of IWM, with special emphasis on practical use of understanding relationships between hydrology and biota and their use in order to control environment quality.

According to the presented approach, for sustainable management of water resources quality and stabilization of hydrological cycle, it is necessary to harmonize technological and ecological measures. Ecological measures should be based on understanding of biota-water interplay in various scales of a catchment. Therefore, the manual has been organized hierarchically, in order to easily identify the necessary measures in the particular areas of a catchment, such as (Box 1.2):

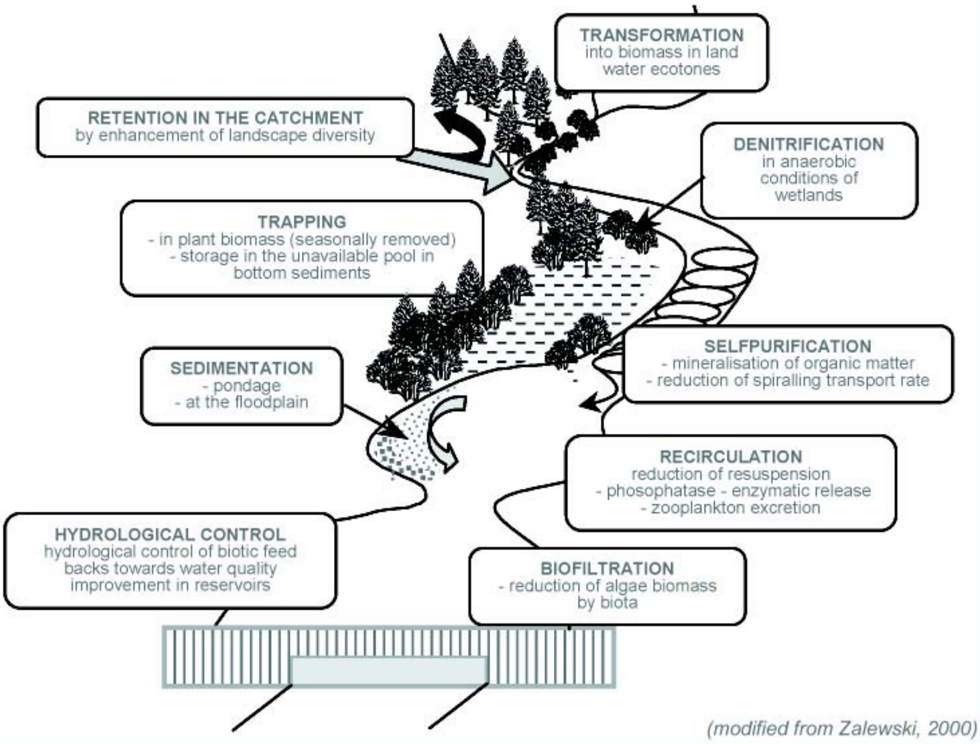
- **LANDSCAPE**
- **LAND-WATER INTERFACE**
- **STREAMS & RIVERS**
- **LAKES & RESERVOIRS**
- **ESTUARINE & COASTAL AREAS**

The manual has been divided into the following major sections:

- **PART ONE: INTRODUCTION:** presents basic theory for ecohydrology and phytotechnology concepts and introduces basic definitions essential for understanding in order to apply ecohydrological and phytotechnological measures.
- **PART TWO: SURVEYS & ASSESSMENT:** presents an overview of methods for assessment of potential issues in watersheds, focusing a reader's attention on possible variations and interpretations of results from the point of view of ecohydrology and phytotechnology.
- **PART THREE: MANAGEMENT:** presents practical suggestions and recommendations for application of ecohydrology and phytotechnology in IWM.

BOX 1.2

Ecohydrology and phytotechnologies as a tool in IWM



(modified from Zalewski, 2000)

1.D. WHO SHOULD USE THIS MANUAL?

Anyone who is involved in Integrated Watershed Management (IWM) should find this manual of interest. In particular, those who deal with **improvement** of degraded aquatic and terrestrial environments, as well as those interested in **sustainable management and maintaining** good quality water recourses, will find this manual useful.

In the traditional approach to water resources management, hydrotechnical engineers have usually been the major target group. Although they still play a fundamental role as those who **eliminate threats**, such as for example, point sources of pollution, it has become obvious that to achieve high-quality results with environmental issues, the technical approach alone is not enough. This manual encourages and provides an understanding of the need for a **broader view** on catchment management. This involves the application of new strategies that amplify the opportunities provided by an understanding of ecosystem properties in order to enhance their **carrying capacity** against increasing human impacts.

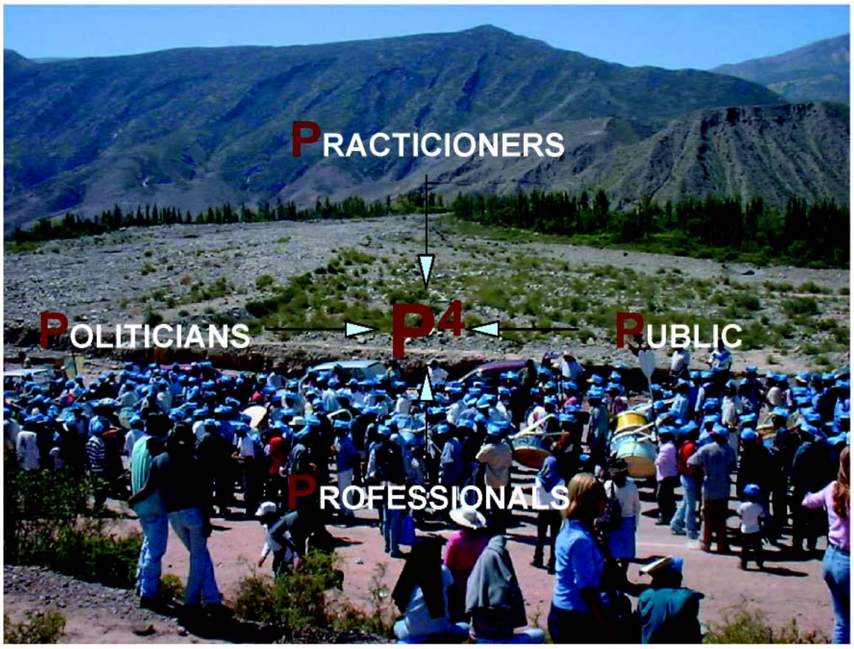
Successful implementation of any strategy in IWM depends on participation of various groups of people working and living in a catchment (Box 1.3). Therefore, we believe, that not only professionals with various expertise, but also a wide range of practitioners, politicians and the public will find the manual of interest. In particular, the manual has been dedicated to:

- environmental managers and technical experts;
- local and regional authorities, decision makers in government agencies and non-governmental organizations;
- coordinators and consultants; and
- landowners.

BOX 1.3

Changing the stakeholder involvement in IWRM

Stakeholder music festival with 2000 sicuris in front of the River Huasamayo



2.A. WHAT IS ECOHYDROLOGY?

INTEGRATION OF SCIENCES...

According to the strategy defined by ICSU, science in the 21st century should actively participate in creating a vision, strategy and implementation methodology essential to the support of sustainable development. The approach that accelerates the above actions should be based on the integration of various interdisciplinary and transdisciplinary fields of science. The developmental conditions required for comprehensive, integrative and interdisciplinary scientific research is „maturity" of the empirical disciplines that participate in the integration process.

The progress that took place in ecological sciences in the last years of the 20th century, allowed for major advancements of knowledge. A level was attained that permitted an attempt to integrate ecological sciences with the more advanced scientific fields to great extend expresses by phisics and mathematics hydrology. This integration created a platform for the development of a new discipline (Zalewski et al., 1997; Zalewski, 2000). Ecohydrology (EH), has been formulated and developed within the framework of UNESCO's International Hydrological Programme, IHP -V.

DEFINING ECOHYDROLOGY...

The basis for the development and advancement of interdisciplinary science and related research should be the defining of a new scope and formulation of new key questions to be answered (Keyfitz, 1993). In the course of the genesis of ecohydrology, it was assumed that the questions should meet the two following fundamental conditions:

1. They should be related to the dynamics of two entities in such a way that the answer without consideration of one of the two components (both ways E <-> H) would be impossible. In other words, this question should enable the defining of relationships between hydrological and biological processes in order to obtain comprehensive empirical data at the same spatial and temporal scales.
2. The results of the empirical analysis should test the whole range of processes (from a molecular to catchment scale), should enable their spatial/temporal integration and should be convertible to large-scale management measures in order to enable further testing of the hypotheses.

Taking into account the above conditions, the key questions for ecohydrology have been defined based on an in-depth understanding of the interplay between biological and hydrological processes and the factors that regulate and shape them. The hypotheses have been defined in the form of the following questions:

Hypothesis H1: „The regulation of hydrological parameters in an ecosystem or catchment can be applied for controlling biological processes".

Hypothesis H2: „The shaping of the biological structure of an ecosystem(s) in a catchment can be applied to regulating hydrological processes".

Hypothesis H3: „Both types of regulation (H2 and H3) integrated at a catchment scale and in a synergistic way can be applied to the sustainable development of freshwater resources, measured as the improvement of water quality and quantity (providing of ecosystem services)" (Zalewski, 2000).

It should be stressed that according to the ecohydrology concept, the overall goal defined in the above hypotheses is the sustainable management of water resources. This should be focused on the enhancement of ecosystem carrying capacity against anthropogenic stresses.

WHAT IS ECOHYDROLOGY?

Ecohydrology is a scientific concept applied to environmental problem-solving (Zalewski et al., 1997). It quantifies and explains the relationships between hydrological processes and biotic dynamics at a catchment scale.

The concept is based upon the assumption that **sustainable development of water resources is dependent on the ability to restore and maintain evolutionarily established processes of water and nutrient circulation and energy flows at the basin scale**.

This depends on an in-depth understanding of a whole range of processes involved that have a two-dimensional character:

- **temporal**: spanning a time frame from the past to the present with due consideration of future global change scenarios; and
- **spatial:** understanding the dynamic role of aquatic and terrestrial biota over a range of scales from the molecular- to the basin-scale.

Both dimensions should serve as a reference system for enhancing the buffering capacity of ecosystems against human impacts by using ecosystem properties as a management tool. This, in turn, depends on the development, dissemination, and implementation of interdisciplinary principles and knowledge based on recent advances in environmental science.

ECOHYDROLOGY KEY ASSUMPTIONS AND PRINCIPLES

Up to the time when the ecohydrology concept was defined, hydrologists considered aquatic biota mostly as an indicative system for monitoring while hydrobiologists considered hydrological processes as a disturbance factor.

The ecohydrology paradigm, which is based on functional relationships between hydrology and biota (Zalewski et al. 1997, Zalewski 2000; 2002), can be expressed in three key assumptions.

Key assumptions of EH

- **REGULATION** of hydrology by shaping biota and, vice versa, regulation of biota by altering hydrology.
- **INTEGRATION** - at the basin scale various types of regulations (E <-> H) act in a synergistic way to improve and stabilize the quality of water resources.
- **HARMONIZATION** of ecohydrological measures with necessary hydrotechnical solutions (e.g., dams, sewage treatment plants, levees at urbanized areas, etc.)

Following these assumptions the concept of ecohydrology is based on three principles.

Principles

1. **FRAMEWORK** - Integration of the catchment, water and its biota into one entity, including:
    - **Scale** - the mesoscale cycle of water circulation within a basin is a template for the quantification of ecological processes;
    - **Dynamics** - water and temperature are the driving forces for both terrestrial and freshwater ecosystems;
    - **Hierarchy of factors** - abiotic (e.g., hydrological) processes are dominant in regulating ecosystem functioning. Biotic interactions may manifest themselves when abiotic factors are stable and pre-dictable.
2. **TARGET** - Understanding evolutionarily established ecohydrological processes is crucial for a **proactive approach** to the sustainable management of freshwater resources. It assumes that it is not enough to simply protect ecosystems but, in the face of increasing global changes (such as increasing population, energy consumption, global climate change), it is necessary to **increase the carrying capacity of ecosystems, and their resistance and resilience, to absorb human-induced impacts**.

3 **METHODOLOGY** - ecohydrology uses ecosystem properties as a management tool. It is applied by using biota to control hydrological processes and, vice versa, by using hydrology to regulate biota. Scientific basis for the methodological aspect of using biota for water quality improvement has been seriously advanced by ecological engineering (e.g., Mitsch & Jorgensen, 2004).

Technical approach is not enough...

The importance of the effort to develop the ecohydrology approach increased with the publication of the paper by Meybeck (2003) in which he justifies the name of Anthropocene for the present era. Based on an in-depth analysis of published studies, he demonstrated that the modification of aquatic systems by human pressures (e.g., flood regulation, fragmentation, sedimentation imbalance, salinization, contamination, eutrophication, etc.) has increased to a level that no longer can be considered as being controlled by only natural processes (climate, relief, vegetation, limnology), thus defining a new era that we have already entered.

The decline in water quality and biodiversity, observed at the global scale in both developed and developing countries, has provided evidence that the traditional „mechanistic" approach focused on **elimination of threats**, such as point source pollution and flood control, is crucial but not sufficient. This is because purely technical control, without understanding and considering biotic dynamics, constitutes a more trial and error approach to water management than the imple-mentation of a policy toward sustainable water use. While elements of this approach remain valid and viable, a technical solution alone is clearly insufficient for the sustainable use of the world's water resources. To guarantee the sustainability of freshwater resource use, it is necessary not only to reduce or eliminate the discharge of pollutants, but also to extend the number of potential tools to manage the degradation of ecological processes in landscapes. Such a more efficient approach must be based on an understanding of the temporal and spatial patterns of catchment scale water dynamics.

ECOHYDROLOGY - CREATING OPPORTUNITIES

Human survival and the preservation of biodiversity on Earth are dependent on our ability to maintain the integrity of ecological processes. Therefore, one of the fundamental tenets for the sustainable development of water resources is the main-tenance of a homeostatic equilibrium within an ecosystem.

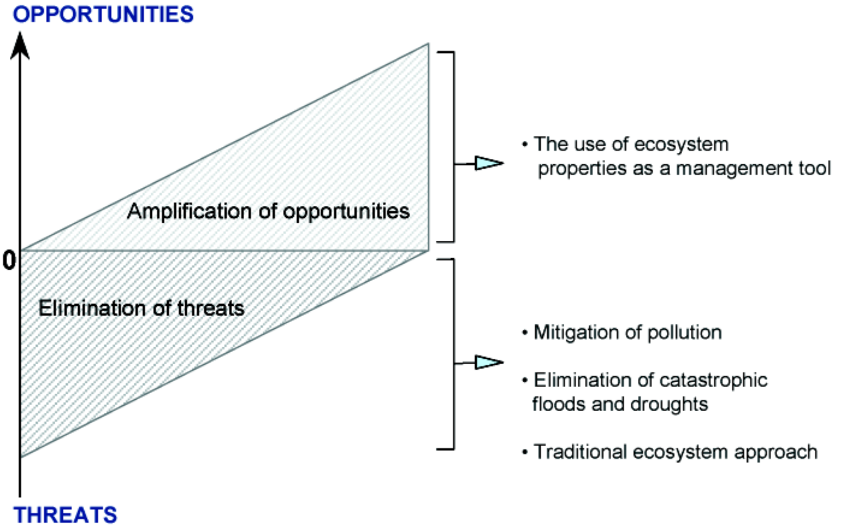
At the present level of human impacts on ecosystems, it is necessary to **increase the opportunities** for ecosystems (Box 2.1). It can be achieved by increasing the absorbing capacity of ecosystems against human impacts that continue to increase. Ecohydrology as an approach provides tools to achieve this goal by defining new approaches to freshwater protection, restoration and management.

ECOHYDROLOGY AS AN INTEGRATIVE APPROACH

The formulation of the ecohydrology concept defined in UNESCO IHP V was to a large extent a logical consequence of the progress of river ecology (Zalewski, 2000; Zalewski & Robarts, 2003). The awareness of a need for integration of hydrology and ecology appears in the hydrobiology and hydrology scientific papers of the 1970`s (Zalewski et al., 1997). However, only in the 1990`s did

BOX 2.1

Application of Ecohydrology as a Factor Maximizing Opportunities
in a Successful Strategic Scenario of Sustainable Freshwater Management



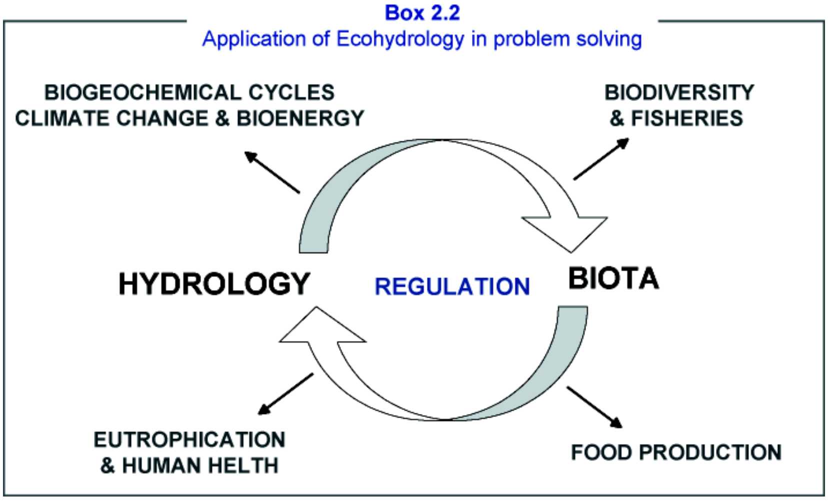
(modified from Zalewski, 2002)

independent research directed to the interactions between the hydrosphere and biosphere become a subject of research for scientists in various fields. This created a basis for the holistic approach to understanding interactions between ecological and hydrological processes at a catchment scale and directed at the development of practical approaches for sustainable watershed management (Box 2.2). Among others, the broad scope of the research covered the following aspects:

- The relationship between vegetation, soil and water based on an understanding of the physiological properties of plants was presented by Baird & Wilby (1999).
- Considerable progress was made in understanding the role of vegetation in water cycling processes in a landscape through research by Rodriguez-Iturbe (2001) and that done within the IGBP BAHC programme (Vorosmarty, 2000).
- The multidimensional role of the buffering by ecotone zones between land and water have been well defined within the framework of the UNESCO MAB Programme (Naiman et al., 1989; Zalewski, Schiemer Thorpe, 1996, 2001; Gilbert et al.,1997).
- Application of ecological engineering, e.g., to the management of wetlands for water purification from excessive nutrient loads based on ecological theory and mathematical modelling, has been developed by Jorgensen & Mitsch (1996).
- Effect of hydrological regimes on vegetation succession of grasslands and swamps has been analysed by Witte & Runhar (2001).
- Reduction of nutrient loads to lowland reservoirs by enhancement of their retention in floodplains has been demonstrated by Wagner & Zalewski (2000).
- Control of eutrophication symptoms (elimination of toxic algal blooms through regulation of water levels for control of trophic cascades) has been evidenced by Zalewski et al. (1990, 2000).
- Some research has been undertaken on the control of water quality and dissolved oxygen content under ice cover during winter in dam reservoirs by regulation of the outlet (Timchenko et al., 2000).
- Regulation of the timing of water release on the Parana River (Porto Prima Vera Dam) in order to maintain fish migration, preserve biodiversity and fish production, has been investigated by Agostinho et al. (2001).
- Examination of the possibilities of managing coastal waters and diminishing their eutrophication using ecohydrology at a basin scale has been initiated by Wolanski et al. (2004).

Box 2.2

Application of Ecohydrology in problem solving



MAKE SURE TO CHECK THESE RESOURCES:

Guidelines: chapters 1, 2

■ 2.B. WHAT IS PHYTOTECHNOLOGY?

WHAT IS PHYTOTECHNOLOGY?

In general, the term **phytotechnology** describes the application of science and engineering to examine problems and provide solutions involving **plants**. The term itself is helpful in promoting a broader understanding of the importance of plants and their beneficial role within both societal and natural systems. A central component of this concept is the use of plants as **living environmentally sound technologies** (ESTs) that provide services in addressing environmental issues. In the context of this manual phytotechnologies are related to environmental problems and the provision of solutions within Integrated Watershed Management.

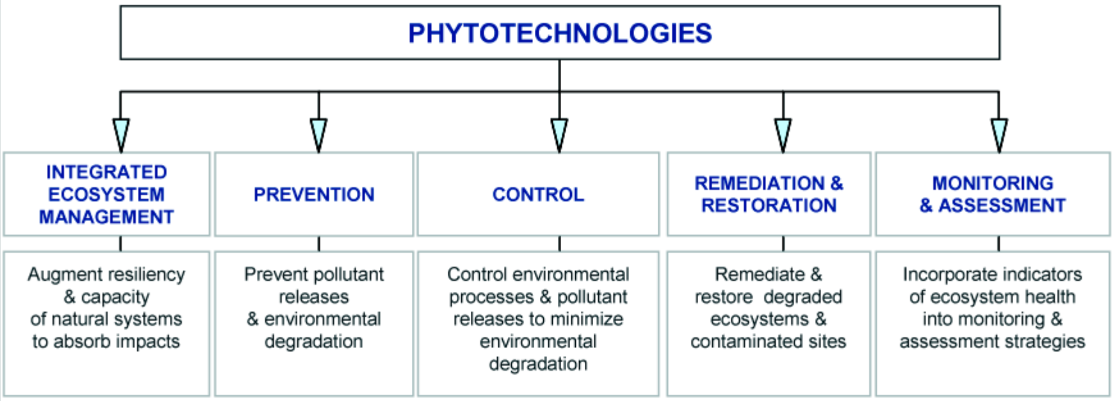
Phytotechnological applications employ **ecological engineering** (Mitsch & Jorgensen, 2004) principles and are considered to be ecotechnologies. Ecotechnologies are dependent on the self-regulating capabilities of ecosystems and nature. The focus on, and use of, biological species, communities, and ecosystems distinguishes ecotechnologies from more conventional engineering-technological approaches, which seldom consider integrative ecosystem-based approaches (UNEP, 2003).

WHAT ARE THE ENVIRONMENTAL APPLICATIONS FOR PHYTOTECHNOLOGIES?

General categories for phytotechnological applications

Environmentally beneficial applications of phytotechnology can generally be divided into five categories (Box 2.3). The **integrated ecosystem management** component focuses on the use of phytotechnology to augment the capacity of natural systems to absorb impacts by serving as natural buffers. The **prevention** component is related to avoiding degradation effects originating from the release of pollutants into the environment or destruction of habitats (this also brings together the need to modify non-sustainable habits and behaviours of society). The **control** component mainly addresses the management of pollutants releases while rendering them harmless through natural processes. The **remediation and restoration** component considers methods and applications to bring back degraded ecosystems or the construction of artificial ones. **Monitoring and assessment** involves the use of bioindicators to follow up and assess conditions and changes in the environment due to natural and/or anthropogenic disturbances.

BOX 2.3
Environmentally beneficial applications of phytotechnology



(modified from UNEP, 2003)

Benefits of the applications of phytotechnologies

Their application may increase the functioning of ecological systems and hence the value of natural capital and natural services provided by ecosystems as a whole. The term „ecosystem services" or „natural services" refers to the conditions and processes through which natural ecosystems sustain and fulfill human life (Daily, 1977). These services are the result of complex natural cycles driven by solar energy, influencing the functioning of the biosphere in a number of different ways. Ecosystem services maintaining biodiversity and the production of ecosystem goods, such as food, timber, energy and natural fiber, as well as many pharmaceuticals, industrial products, and their precursors. The harvest and trade of these goods is based on „natural capital" and hence are an important part of the global economy. In addition, ecological services include life support functions, such as protecting watersheds, reducing erosion, providing habitats for wild species, as well as the cleaning, recycling, and renewal of systems.

Plants are a fundamental part of the world's natural capital base due to the services they provide. The value of natural capital is increased by augmenting the capacity of ecological systems to function effectively. Some examples of the benefits of ecological services are:

- purification of air and water;
- mitigation of floods and droughts;
- detoxification and decomposition of wastes;
- generation and renewal of soil and soil fertility;
- translocation of nutrients;
- pest control;
- biomass production from simple elements through photosynthesis, and
- moderation of temperature, wind force and wave action.

Examples of phytotechnological applications

Phytotechnology can be applied for solving several ecological problems by the direct use of plants for in situ (or „in place") removal or degradation of contaminants or improving the physical structure of an ecosystem and hence it's functioning. Phytotechnology covers a variety of low cost, solar energy driven cleanup techniques. At some sites with low levels of environmental degradation they can be used in place of conventional technical solutions. In other cases, they can be applied together with them a final step towards refined environmental improvement. Some specific examples of phytotechnological applications include (UNEP, 2003):

- Reduction and management of problems related to **point and non-point sources of pollution** through the use of natural or constructed wetlands (usually coupled with conventional methods).
- Facilitating the **recovery of degraded ecosystems and soils**, such as brown fields or post industrial sites, or, for example, in the case of mine-tailing fields and dumping sites. Also they are widely used for aquatic and terrestrial ecotone recovery.
- **Sinks for carbon dioxide** to mitigate the impacts of climate change through refo restation and afforestation.
- Augmentation of the **environmental capacity of urban areas** to mitigate pollution impacts and moderate energy extremes. An example is the use of rooftop vegetation, or „green roofs" to thermally insulate buildings as well as to avoid or reduce the formation of „heat islands". They can also be used to increase land beautification and urban biodiversity.

WHY IS PHYTOTECHNOLOGY USED IN IWM?

Specific applications of phytotechnologies in integrated watershed management are complementary to ecohydrology. The biota, hence plants, are key players in restoring water and biogeochemical cycles augmenting the carrying capacity, resilience and functionality of ecosystems (UNEP, 2003). In Box 2.4 the role of phytotechnology in IWM is presented in schematic form while in the following information some of the reasons behind their application are given:

- ▶ Plants form the first level of ecosystem structure (primary producers) and, therefore, control energy flow and nutrient cycling in landscapes. Control of vegetation structure can be used for **transformation and retention of nutrients and pollutants**.

- Plant cover is one of the most dynamic and vulnerable components for the regulation of the water cycle in a watershed. It is fundamental to the evapotranspiration rate and, therefore, can help to **mitigate effects of floods and droughts**.
- Production of plant biomass provides **alternative sources of energy (bioenergy)**, resulting in reduction of CO_2 emissions from burning fossil fuels.
- Some **other benefits** from using plants include: production of materials for housing, food, forage medicine production and the creation of employment opportunities.

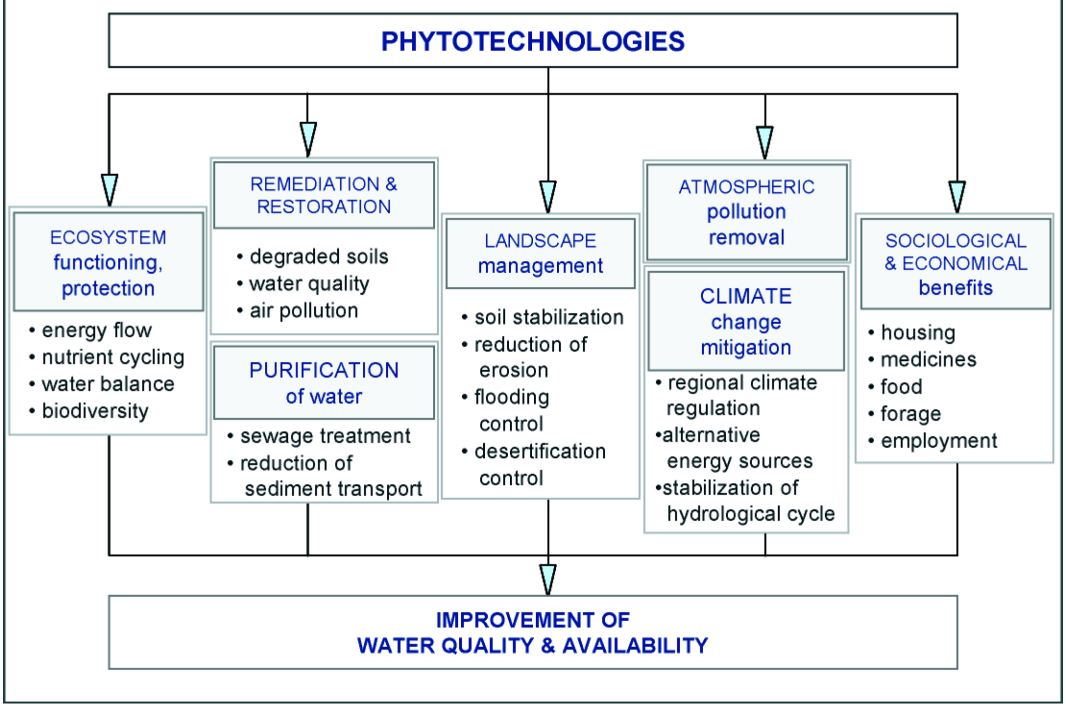
An understanding of the potential and the limitations of phytotechnologies would ensure success when they are applied. Insufficient knowledge and expertise regarding selection of species, distribution and disposition requirements, factors influencing plant growth, as well as public and regulatory acceptance of their use, will cause the use this technological approach to fail. Each application of phytotechnologies involves site-specific considerations and should be evaluated on a case-by-case basis. The developers and proponents of phytotechnological applications must be able to demonstrate environmental performance of the selected technique based on objectives and economic benefits and minimizing potential environmental and human health risks (the latter particularly in cases of phytoremediation applications that are undertaken to clean polluted sites).

The effectiveness in the short and long term of the application of phytotechnologies would also depend on having both broad-based and expert input into their development, adoption, maintenance and monitoring by those utilizing them. The involvement in some cases of local citizens will also ensure their performance and sustainability.

Specific examples of phytotechnological applications in IWM

The major goal of applying of phytotechnologies and ecohydrology in IWM is to improve water quality and quantity as well as to stabilize the hydrological cycle. To achieve this, applications of

BOX 2.4
Role of phytotechnology in IWM



phytotechnologies should cover activities at all spatial levels in the watershed (see chapter 1.C), which include the landscape, land-water ecotone zones, freshwater bodies and estuaries. The most commonly used applications of phytotechnology for management of water resources include the following:

- **phytoremediation of soils** to reduce landscape pollution impacts on fresh waters (e.g., chapter 9.A);
- **vegetation cover management** (forestry and agriculture practices) in order to control the water cycle in landscapes and reduce nutrient leaching and erosion from a catchment (e.g., chapters 9.B, 9.C);
- **ecotone protection and rehabilitation** for reducing diffuse pollution from agricultural lands and others (e.g., chapters 10.B, 11.C);
- **water quality improvement** and eutrophication control through the use of **natural and constructed wetlands** and **floodplains** (e.g., chapters 10.A, 10 C);
- **enhancement of biodiversity** through the growth of aquatic vegetation (e.g., chapters 11.B, 12.C); and
- **production of alternative fuels** or bio-energy production to reduce oil and charcoal use as the main sources of energy mainly in rural areas (e.g., chapters 2.C).

Socio-economic benefits of phytotechnological applications in IWM

Phytotechnologies are considered as low cost environmentally sound technologies and may provide high environmental efficiency at reduced costs. While applied together in some cases with conventional methods, they can provide socio-economic benefits on their own. For example:

- provision of **alternative sources of energy** (bioenergy), resulting in a decrease of per capita outflows of capital for fossil fuel use;
- **fertilizer** source for agriculture, forestry and bioenergetic plantations;
- production of material for **housing, food, forage and sources of medicine**;
- creation of **employment** opportunities for local residents;
- increase of the **quality of life through** rural development and more livable cities; and
- contribute to the **inflow of capital** resulting from the activities based on the quality of water and environment (e.g., tourism).

MAKE SURE TO CHECK THESE RESOURCES:

Guidelines: chapters 1, 4, 5
http://www.unep.or.jp/ietc/Publications/Freshwater/FMS7/index.asp
http://www.unep.or.jp/ietc/Publications/Freshwater/FMS2/index.asp
http://www.rtdf.org/public/phyto/bib/default.cfm
http://www.itrcweb.org
http://www.ec.gc.ca/etad/default.asp?lang=En&n=510541DD-1

2.C. APPLICATION OF ECOHYDROLOGY AND PHYTOTECHNOLOGY FOR WATER RESOURCES MANAGEMENT AND SUSTAINABLE DEVELOPMENT. UNESCO / UNEP DEMONSTRATION PROJECT

Demonstration projects aims at developing, validating and implementing ecohydrology and phytotechnology in integrated watershed management, and are joint UNESCO/UNEP initiatives. Based on the above concepts, demonstration projects endeavour to develop a cost-effective, comprehensive strategy, not only for improving water quality and quantity, but also for meeting local concerns in a given region.

The Pilica River Demonstration Project was designed to mitigate point and non-point sources of pollution entering a river, reduce the risk of toxic algal blooms appearing in a shallow reservoir and converting these threats into opportunities for the regional economy.

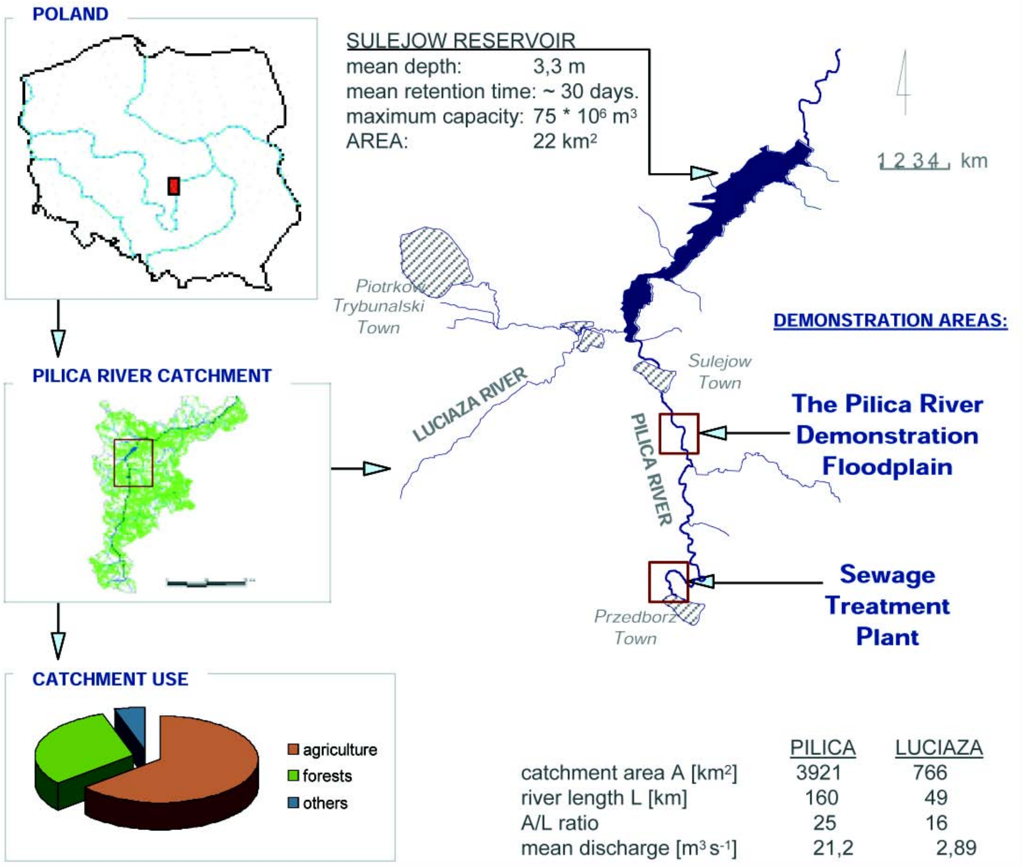
Fig. 2.1
The Pilica River
(photo: B. Sumorok)

LOCATION OF THE DEMONSTRATION PROJECT

The Pilica River Demonstration Project is located in **central Poland**. It is comprised of a **catchment - river - reservoir** system, including the Pilica Ri-

BOX 2.5

UNESCO / UNEP Demonstration Project on Ecohydrology and Phytotechnology - location of two demonstration areas in Poland



	PILICA	LUCIAZA
catchment area A [km^2]	3921	766
river length L [km]	160	49
A/L ratio	25	16
mean discharge [m^3 s^{-1}]	21,2	2,89

ver (Fig. 2.1) and a lowland reservoir located in its middle reach (the Sulejow Reservoir; Box 2.5). For nearly 30 years the main function of the reservoir has been to supply the City of Lodz (about 800 000 inhabitants) with drinking water. This purpose has lately been restricted because of water quality concerns. It serves now as an optional source of drinking water and recreational area for about 1 million people.

KEY ISSUES

Key issues have been classified into ecological and socio-economic categories (Box 2.6).

BOX 2.6
Key issues in the Pilica River catchment

ECOLOGICAL ISSUES

Non-point pollution sources of the river resulting from agricultural use of the catchment

- high nutrient loads transported by the river, especially during flood periods;

point sources of pollution severely impacting water quality of the river;

- unstable and outdated treatment technologies at the sewage treatment plants;
- exceeded chemical and biological standards in the sewage released to the river from the treatment plants;
- eutrophication and periodically increased bacterial numbers in a river;

toxic algal blooms in the reservoir;

- Eutrophication and toxic cyanobacterial blooms restricting use of the reservoir as a drinking water supply and recreational area;

SOCIO-ECONOMIC ISSUES

unemployment ratio over 20%

agriculture development limited by low soil quality

limitation of the development of tourism by low water quality of the Pilica River and the Sulejow Reservoir

Ecological issues

The Pilica River catchment is a beautiful, picturesque area, with several landscape parks and preserved old forests, as well it has high cultural and historical values. The river itself - although over most of it's length has an undisturbed character - it is, however, impacted by **point-sources of pollution** due to unstable and outdated sewage treatment technologies. These affect the chemical and physical components, bacteriology and biotic structure of the river. A large part of the pollution also comes from **non-point sources**, which is derived mostly from agriculture in the catchment (Box 2.5).

The pollution not only effects the quality of the river, but is transported to the Sulejow Reservoir located downstream. Large amounts of the inflowing sediment and nutrients are retained in the reservoir, resulting in eutrophication and the occurrence of **intensive cyanobacterial blooms** during summers. The maximum cyanobacterial biomass observed in 1995 reached 60 mg L^{-1} (Tarczynska, 1998). Several studies revealed **cancerous and toxic effects** of the toxins produced in the reservoir by the cyanobacteria (Microcystis aeruginosa) (Mankiewicz, Tarczynska, Walter, Zalewski, 2003; see chapter 7.D).

Socio-economic issues

The area is characterized by a high unemployment rate, locally reaching more than 20%. At the same time agriculture, considered traditionally to be the main income for a large part of the local population, has been limited by low soil quality in a competitive economy.

High value of the region's natural resources could make it a good area for future development of recreation, tourism and eco-tourism. However, there is a need to **improve the water quality** and reduce the occurrence of toxic algal blooms, which reduce the appeal of the area for potential investors and can restrict the development. Another opportunity is development of alternative agricultural production, e.g., **production of biomass**.

GOAL OF THE PROJECT

The major goal of the project has been to validate application of ecohydrology and phytotechnology for **converting of nutrients** from point and non-point sources of pollution into **biomass and bioenergy**. This is not only to **improve the quality of the environment**, but also to provide additional alternatives for **development of the region and employment**.

DEMONSTRATION AREAS

The project has been developed in the two demonstration areas (Box 2.5):

- **The sewage treatment plant in Przedborz Town** (4,000 inhabitants), where treated sewage from the plant has been disposed directly into the river, until now. According to the **phytotechnology approach**, establishment of a **constructed wetland together with a willow plantation** as the final step of treatment, could diminish the impact on the river. Additionally, the biomass produced in the wetland could be utilized as **bioenergy**, and cover part of the energetic needs of the treatment plant, reducing costs of it's maintenance.
- **Demonstration floodplain of the Pilica River**, where a method for **reduction nutrient loads transported by the river** down to the reservoir was to be developed and quantified. Nutrient retention can be enhanced by two groups of processes: physical ones (intensification of sedimentation by regulation of floodplain hydraulics) and biological ones (uptake of the dissolved fraction by **biomass** through the management of the natural floodplain vegetation communities and patches of planted willow).

PROJECT IMPLEMENTATION

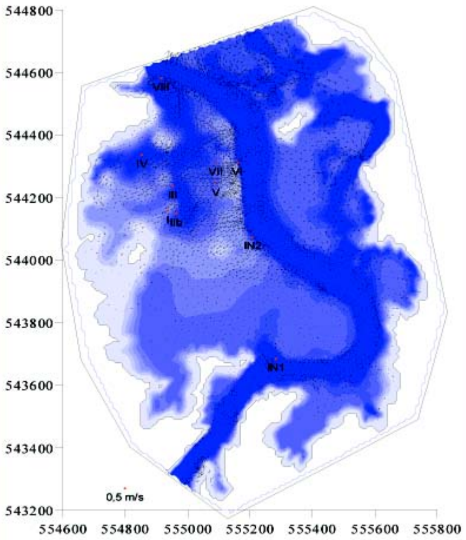
The implementation of the project has been developed through five parallel lines of action:

- **research** - providing scientific evidence of the hydrological and biological processes;
- **development and implementation of technologies** for applying ecohydrology and phytotechnology in the research areas;
- **Meetings** with local government, stakeholders and landowners, for dissemination of information and facilitation of implementation;
- **Training and education** - including primary and secondary schools in the region, national and international university students and young scientists;
- **Dissemination** of the information and experiences about the project at the national and international levels;

Fig. 2.2
Sampling of mycorrhizal samples on the Pilica River demonstration floodplain (photo: I. Wagner-Lotkowska)

BOX 2.7

Hydraulic model of the demonstration floodplain of the Pilica River



Example of the visualisation of the hydraulic model constructed for the Pilica River demonstration floodplain.
Co-operation with the Department of Hydraulics and Hydrology of Gdansk Technical University and Faculty of Geography and Regional Studies of University of Warsaw (Poland).

(Szydlowski, Magnuszewski, Wagner-Lotkowska, unpublished data)

GENERAL RESULTS

The results of the first year of project implementation include the following:

- **Development of hydraulic models of the demonstration floodplain**, for optimization of sedimentation processes and nutrient and water retention (Box 2.7);
- Elaboration of recommendations for **vegetation management** in order to enhance the ability of the system to retain nutrients in biomass.
- **Elaboration of a draft management plan for a water treatment plant in Przedborz**, including recommendations for both technical upgrades and justifications for a phytotechnological application.
- **Elaboration of a management strategy for the use of biomass produced in the area**. Following the idea presented in the summary of the UNESCO/UNEP Guidelines (Box 2.8), the strategy should generate a positive socio-economic feedback based on the use and management of environmental resources. The potential for bioenergy production in the region has been estimated using various scenarios of energetic needs.
- **Increase of knowledge and awareness about ecohydrology and phytotechnology, their application in IWM and benefits for sustainable development in the region**, by training, education and dissemination. Several trained target groups includes local, regional and national authorities, NGOs, stakeholders and landowners, which have been involved in implementation of the project during the latter stages. Another group of activities was aimed at researchers, young scientists, university teachers, students, youth and children, primary and secondary teachers. The outcomes and results of the project have been disseminated during a number of national and international meetings and conferences, by distribution of informative materials and a website written in both Polish and English.

Fig. 2.3. Education for primary schools (photo: I. Wagner-Lotkowska)

Fig. 2.4.
Extensive planting of willows on the Demonstration Floodplain (photo: I. Wagner-Lotkowska)

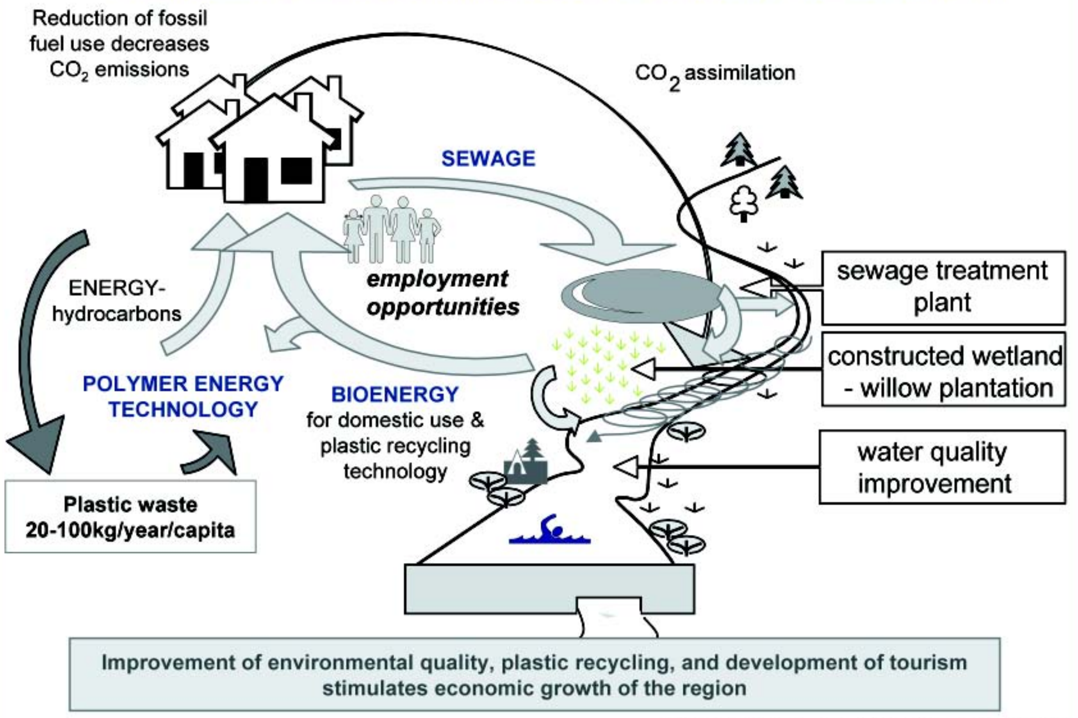
FUTURE PERSPECTIVES

The results of the first phase of the project implementation show the potential for the application of ecohydrology and phytotechnology measures in the Pilica Region, which has attracted the interest of local and regional authorities. Further development of the project is to be focused on the following aspects:

- **Continuation** of the tasks developed in the first phase of the project;
- Preparatory work for implementation of the achievements of the project's first phase at a **larger scale**;
- Elaboration of a strategy for biomass use for **solving other environmental problems** in cities in the region, such as conversion of polyolefin wastes into energy.

BOX 2.8

Incorporation of socio-economic aspects into constructed wetland planning



Zalewski 2002, see Guidelines: chapter 10

MAKE SURE TO CHECK THESE RESOURCES:

Guidelines: chapters 2, 7, 10

www.biol.uni.lodz.pl/demosite/pilica

3.A. WATERSHED

WHAT IS A WATERSHED?

Rivers can be seen as veins of a leaf, extending all over a drainage basin up to their divides. When rain falls on a watershed it finally ends up in a river system. A river channel is the lowest point in the surrounding landscape. Its purpose is to convey excess water from a drainage basin, which will include the products of weathering and additional loads of solutes produced by man. This property makes a drainage basin an integrator and its operation is reflected in the quantity and quality of the river run-off.

Drainage basin (catchment area) is the area which supplies a river system, lake or reservoir with water. The whole area consists of **smaller sub-catchments** supplying tributaries of the main river and **direct catchments**, which drain straight into a lake or main river (Box 3.1).

The purpose of the river system is to drain catchment areas. Surplus water in the drainage area forms **river run-off**, which is conveyed by a river system. Products of weathering (sediments and solutes) as well as man-generated pollutants, are transported with the water.

WHERE ARE THE BOUNDARIES OF A WATERSHED?

The boundary line separating catchments is called a **drainage divide** or **watershed divide**.

A watershed divide is delineated on a topographic map according to the relief of the landscape. This method helps to determine the **surface catchment**.

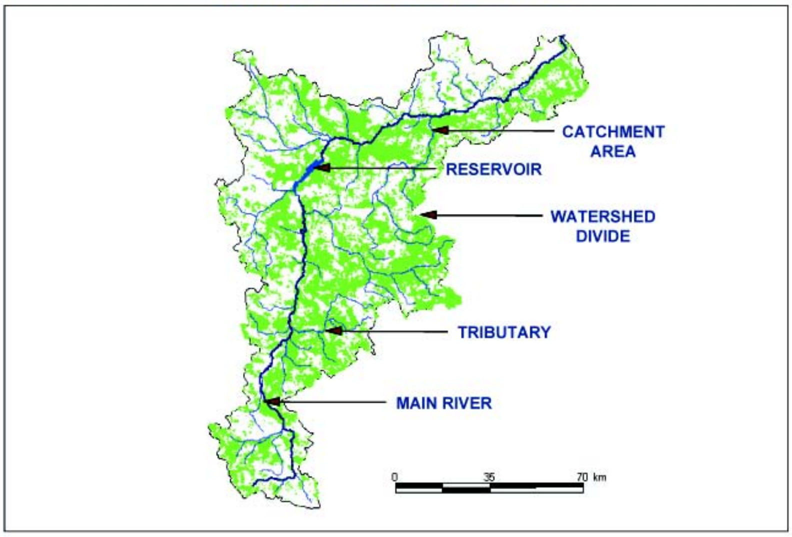
In many catchments the area which supplies a river system with groundwater is not coincident with the surface catchment. Ground water may flow from a distant area. In such a case a **groundwater catchment** should be delineated based on an analysis of the groundwater contour lines or piezometric surface.

WHY IS A WATERSHED A BASIC UNIT IN IWM?

A drainage basin is the primary unit for water and matter circulation, analysis and planning. In this unit mesoscale water circulation is created from a random and temporally uneven field of atmospheric precipitation. According to the first principle of ecohydrology, which defines the **framework for ecohydrological processes** in IWM, energy flow, water and matter circulation are integrated at a basin scale, as a major unit, and function as a single entity. The mesoscale cycle of water circulation within a basin regulates the coupling of terrestrial and aquatic ecosystems, provides a template for the quantification of ecological processes and creates the template for the application of **ecohydrology and phytotechnologies** in management practices.

BOX 3.1

Surface catchment of a river



3.B. CLIMATE

WHAT IS CLIMATE?

- **Climate** is defined as the average of weather variables over relatively long periods of time.
- **Climate variability** is defined as the range of values that the climate can take over time in a given area.
- **Climate change** means an alteration of atmospheric processes attributed to human activity, in addition to natural climate variability.

DOES CLIMATE CHANGE?

According to the most recent assessment of the Intergovernmental Panel on Climate Change (2001), the global surface temperature may increase by between 1,4°C and 5,8°C over the 21st Century as a result of human activities. Not only air **temperature**, but also **precipitation**, **evapotranspiration**, **wind speed** and **solar radiation**, are likely to be perturbed due to changes in the chemical composition of the atmosphere. Climate changes are likely to exaggerate **extreme weather fluctuations**.

HOW DOES IT CHANGE?

The impacts of climate change on hydrology and ecology are usually assessed by defining scenarios for changes in climatic inputs to physical and biological processes. There is a growing demand for credible regional-scale climate scenarios, which are reliant on techniques to downscale from **Global Climate Models (GCMs)** - the principal tools for climate change research.

There is much uncertainty implicit in the choice of GCM, further complicated by the variety of downscaling methods. One of the major policy implications of climate change is that it may no longer be assumed that the future aquatic resources base will be similar to that of the present.

HOW CAN CLIMATE CHANGE IMPACT ECOHYDROLOGICAL PROCESSES?

Global climate change is expected to affect directly both the **quantity** and **quality of water resources**.

It will affect particular elements of the hydrological cycle, changing river discharges, and hence also water retention times in reservoirs and water levels in lakes. It is predicted that the timing and intensity of **floods and droughts** will also change, which can have serious economic and sociological effects. Since water is the main medium responsible for the export of nutrients and pollutants from catchments, the above processes will alter **nutrient transport patterns** to fresh waters, and hence their physical and chemical parameters.

Due to predicted air **temperature increases**, water temperature and the number of ice-free days will also change. The rate of all physical, chemical and biological processes could be accelerated. Some **species may disappear** or the boundaries of their range could be shifted. All the above processes may seriously affect ecosystem functioning and structure, especially in the case of degraded ecosystems.

■ 3.C. HYDROLOGICAL CYCLE

WHAT IS THE HYDROLOGICAL CYCLE?

The hydrological cycle is a process of water circulation between the atmosphere, hydrosphere, and lithosphere (Box 3.2). It can be considered at two major scales:

- **global scale**, where the major elements are the oceans (97%), continents (0,02% as inland waters), and atmosphere (0,001%); and
- **basin scale (mesoscale),** where the major elements are water fluxes between the atmosphere, biosphere and lithosphere. Mesoscale water circulation can be considered as the **template for the quantification of fundamental ecological processes**.

WHY IS AN UNDERSTANDING OF THE HYDROLOGICAL CYCLE IMPORTANT FOR IWM?

Water quantity...

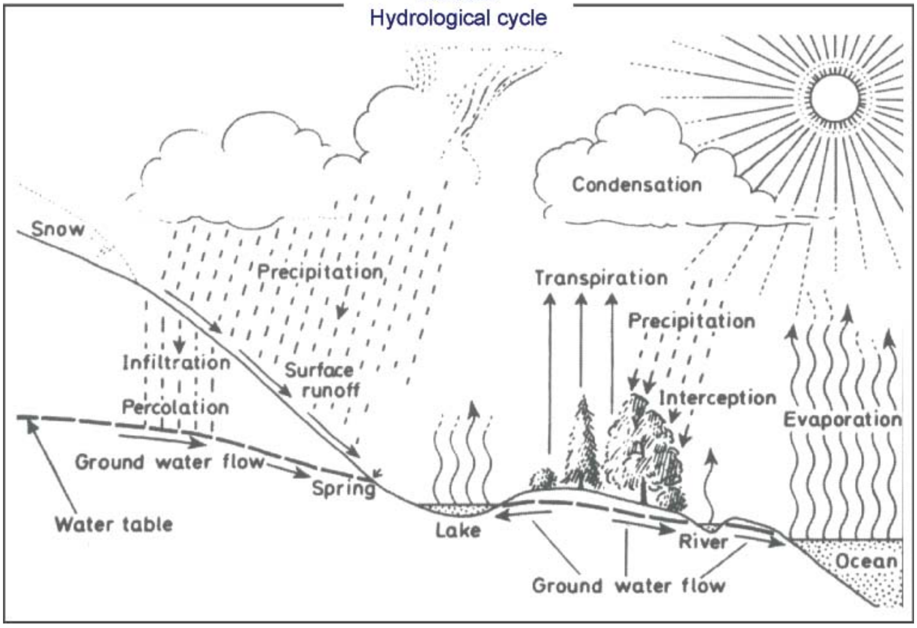
Sustainable water management should take into account the natural water balance that determines the amount of water resources and their availability in time. Hydrological cycle dynamics regulate **the amount of water** in freshwater ecosystems and the **availability of water** in terrestrial ecosystems, which is potentially a limiting factor for primary productivity and hence vegetation development. Therefore, water is one of the major driving forces for ecological processes at the catchment scale. On the other hand, biological processes can also regulate the hydrological cycle, especially at the mesoscale, by influencing evapotranspiration, evaporation, and the heat and water balances. Therefore, application of phytotechnologies (e.g., increase of water retention in a catchment by management of vegetation cover) can be a useful tool to regulate water circulation in a basin and, consequently, to increase the quantity of water.

From a socio-economic perspective, stabilization of the hydrological cycle by using ecohydrological and phytotechnological measures may reduce the risk of **floods and droughts**.

Water quality...

The hydrological cycle forms a template for biogeochemical cycles in a catchment and is linked with processes of **erosion** and **sedimentation**. Water is one of the most important driving forces for material circulation and the primary medium by which nutrients and pollutants flow within landscapes and into most terrestrial and water ecosystems. Therefore, without an accurate estimate of the hydrological cycle elements in a catchment, it is not possible to estimate biogeochemical cycles, the control of which is fundamental for the application of **ecohydrological and phytotechnological measures in IWM**.

Box 3.2
Hydrological cycle



■ 3.D. BIOGEOCHEMICAL CYCLES

WHAT ARE BIOGEOCHEMICAL CYCLES?

Biogeochemical cycles are the characteristic routes between **abiotic elements** of the environment and its **biotic components** through which **matter circulates**. Matter circulates as particular elements and occurs in the form of **continuously transformed organic and inorganic compounds**. Living organisms need 40 elements to sustain growth and reproduction. The most required **nutrients** include such elements as: carbon, phosphorus, nitrogen, oxygen and hydrogen, of which the last two are usually readily available in most environments.

HOW ARE NUTRIENTS TRANSFORMED?

Nutrient transformations in biogeochemical cycles are controlled by two groups of processes:

- **Abiotic** - geochemical cycles such as: precipitation, diffusion, dissociation and redox reactions.
- **Biotic** - resulting from the activity of live organisms such as: incorporation of inorganic and organic nutrients into the biomass of plants, grazers and predators or liberation of nutrients in microbiological decomposition.

All the above processes in both terrestrial and freshwater ecosystems are strongly controlled by **solar energy, water and temperature**. Solar energy is asimilated by plants and flows trough trophic levels and back to decomposers. Water serves as a medium determining the «routes» of the nutrients in biogeochemical cycles (e.g., the rate of erosion and nutrient availability for vegetation). Temperature determines the rate of both abiotic and biotic process.

Degradation of biogeochemical cycles

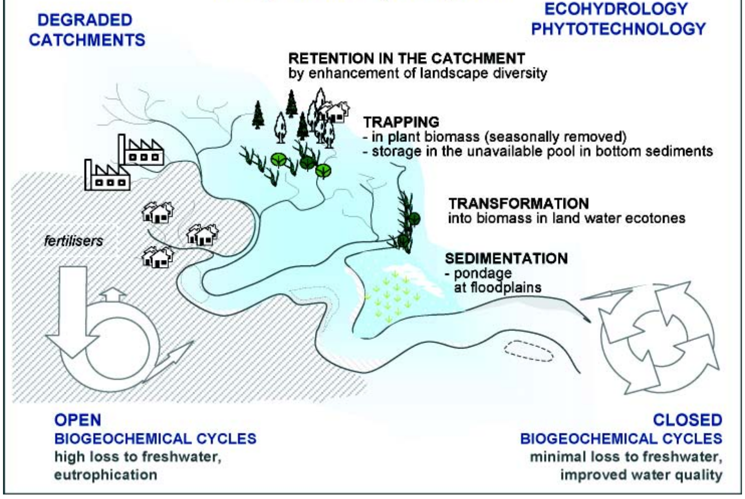
Anthropogenic pressure results in degradation of landscapes (e.g., deforestation, unsustainable agriculture and urbanization) and the biotic structure of fresh waters (e.g., river regulation), and thus leads to modification of evolutionarily established biogeochemical cycles.

The above processes open nutrient cycles that results in their increased export from the landscape to fresh waters and diminish the ability of freshwater ecosystems to self-purify, while nutrient enrichment will lead to eutrophication.

Role of ecohydrology and phytotechnology

Proper functioning of biogeochemical cycles determines water quality. The main role of **phytotechnology** is to reverse the effect of their degradation by retention of nutrients in vegetation. **Ecohydrology** defines how to optimize the assimilation processes by use of hydrological processes, e.g., for precise distribution of vegetation in a catchment. Therefore, understanding the functioning and factors regulating biogeochemical cycles is fundamental for application of ecohydrology and phytotechnology in IWM.

BOX 3.3
Application of ecohydrology and phytotechnology
in biogeochemical cycles regulation



3.E. LANDSCAPE STRUCTURE AND VEGETATION COVER

WHAT IS A LANDSCAPE?

A **landscape** is the total human environment including the geosphere, biosphere and technosphere. From an **ecological point of view**, it should be considered as a group of biotopes, which are the smallest spatial units of homogenous abiotic conditions **(physiotope)** with a related natural combination of **biota**.

This imposes the approach for **landscape analysis**, which requires a holistic and integrative approach focused on the entirety of biogeochemical processes, such as proposed in the concept of ecohydrology.

Fig. 3.1
Representation of a tropical Landscape, Bogor, Indonesia
(photo: V. Santiago-Fandino)

WHAT ARE LANDSCAPE FUNCTIONS?

- accumulation of material and dispersion of human - induced energy;
- receptacle of unsuitable wastes from populated areas and their rendering;
- filtration of energy, matter and organism flows;
- resource regeneration and recycling;
- provision of wildlife refuges; and
- support for regional settlement and recreation (Mander et al., 1995).

WHAT DECIDES LANDSCAPE STRUCTURE?

A landscape is a complex system of elements, which are **static** or **dynamic** in time and space.

- static elements include forms that are structural in character - **point, line and area elements** distributed homogenously, heterogeneously or in a patchy way;
- dynamic elements consist **of biota** reflecting relationships between biotic and abiotic components.

UNBALANCED AND BALANCED LANDSCAPES

The **elements** in each class consist of primary or **natural**, and secondary, or **human-made or man-modified**, structures. The unsustainable interaction between these two groups may create an **unbalanced** situation leading to devaluation of landscape processes.

The effect of this interaction is degradation of landscape structure, its fragmentation or homogenization (depending on the land - use system).

Both situations may lead to:

- increased leak of toxic substances and nutrients to waters;
- decrease of water retention in river catch ments;
- changes in solar radiation balance; and
- decline of biodiversity.

Freshwater ecosystems, which are located in land depressions, are good indicators of the quality of neighbouring terrestrial systems.

ECOHYDROLOGY & PHYTOTECHNOLOGY IN LANDSCAPE MANAGEMENT

Vegetation is one of the most important factors **protecting landscapes** and, at the same time, the most sensitive element affected by man's activities. Its role is influenced by: the reduction of forests, changes in species composition and quantitative properties of vegetation cover, land drainage or irrigation, and the degradation of land - water ecotone zones.

Therefore, sustainable **landscape management**, as well as management of **ecotone zones** between a landscape and water, requires a better understanding and regulation of hydrology - biota interactions as proposed in the **ecohydrological** approach and put into practice through the application of **phytotechnologies** as one of major biotic tods.

The goal of sustainable management is to maintain the ecological functions of landscapes under increasing human aspirations and pressures.

3.F. STREAMS AND RIVERS

WHAT ARE THE STRUCTURAL COMPONENTS OF A RIVER ECOSYSTEM?

Streams and rivers are integrated flowing systems that create and maintain aquatic habitats within the structure of their flow as well as on and below their wetted boundaries.

Natural channel evolution is governed by climate, geology, topography, soil and vegetation conditions of a watercourse and watershed. The characteristic regime, or geomorphology, of a natural chanel can be defined in terms of the maximum water level contained between its banks, channel width to depth ratio, occurrence of an active floodplain, meander pattern, slope, bed material and bank material.

Streams and rivers are thus open systems characterized by a high level of heterogeneity across a range of spatio-temporal scales (Ward, 1989). Four dimensions are recognized:

- longitudinal dimension: along the direction of flow from source to estuary;
- lateral dimension: the system composed of the main channel and floodplain;
- vertical dimension: the interactions between river water and groundwater in the surrounding area; and
- temporal dimension: processes such as succession and rejuvenation.

Longitudinally rivers are divided into three zones:

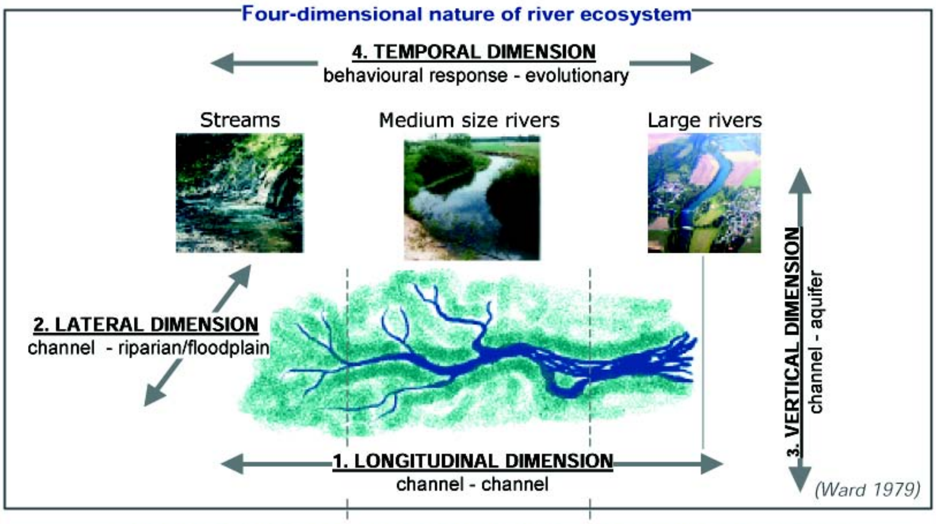
- headwaters;
- transfer; and
- deposition zones (Schumm, 1989).

Riverine habitats are organized hierarchically in a basin context (Frissell et al., 1986) and should be especially considered during restoration projects. The broad spatio-temporal scale of river ecosystems, especially their links and interactions with landscapes, determines the need to view and understand its processes in the larger scale and holistic context proposed, e.g., by ecohydrology concept.

The simplest way to estimate the size of a river is with the stream-order conception (Strahler, 1964). In this system, channels with no tributaries are numbered as order 1. Two channels of order 1 create a channel of order 2, etc.

BOX 3.4

RIVER: Structure and Scale



Three longitudinal geomorphological profile zones of river ecosystems

1. HEADWATERS ZONE	2. TRANSFER ZONE	3. DEPOSITION ZONE
Mountain headwater streams flowing and forming a V - shaped valley, with rapids, waterfalls, pool -riffle sequence.	Low -elevation streams and meandering rivers flowing in U-shaped valley.	Large meandering floodplain rivers.

(Schumm, 1977)

■ 3.G. LAKES AND RESERVOIRS

WHAT ARE THE DIFFERENCES AND SIMILARITIES BETWEEN LAKES AND RESERVOIRS?

A **lake** is a natural, standing, freshwater or saline water body found on the Earth's continental land masses (Table 3.1) .

Man-made **reservoirs**, also called „artificial lakes", are water bodies with different shapes and sizes that have been constructed by humans by damming a river.

Reservoirs that have been formed by diverting water from a river to an artificial basin are called **impoundments**.

FUNCTIONS OF LAKES AND RESERVOIRS

The functions of lakes and reservoirs usually includes:

- production of drinking water;
- fisheries and aquaculture; and
- recreation.

Additionally, reservoirs may also be used for:

- flood prevention;
- retention of storm waters; and
- production of electricity.

Some of the functions require maintaining high water quality.

MAN-MADE RESERVOIRS - MANAGEMENT ISSUES

Freshwater management strategies for dams have usually been focused on issues such as flood protection, drought relief, and energy generation. However, catchment degradation resulting in lowering of water quality in reservoirs has lately become an emerging problem. River damming intensifies sedimentation of particular matter and thus nutrient retention within a reservoir. Subsequent recirculation of the matter by the biota and increased productivity leads to so called „secondary pollution". The worst of these impacts are blooms of cyanobacteria that may produce carcinogenic toxic substances.

WHY RESERVOIRS ARE SUSCEPTIBLE TO WATER QUALITY DEGRADATION?

Limnological characteristics of reservoirs make them especially susceptible to the processes of eutrophication. This is because of:

- the high ratio of catchment to reservoir area resulting in high nutrient input;
- high suspended matter sedimentation;
- increase of water retention time; and
- lack of a littoral zone as a consequence of water level changes.

TABLE 3.1

General characteristics of lakes and reservoirs on a global scale

CHARACTERISTICS	LAKES	RESERVOIRS
location	especially abundant in glaciated areas	worldwide, often in areas with a scarcity of natural lakes
shape	generally circular	elongated and dendritic
drainage: surface area	ratio usually <10:1	ratio usually >10:1
shoreline	Stable (except for shallow lakes in semi-arid zones)	usually changing (artificially regulated water level)
water level fluctuation	generally small (except for shallow lakes in semi-arid zones)	can be high
water flushing time	long in deeper lakes	often short
rate of sedimentation	usually slow under natural conditions	often rapid
nutrient loading	variable	usually large
ecosystem succession	slow	often rapid
flora and fauna	relatively stable	variable
water outlet	at surface	variable
water inflow	typically from multiple, small tributaries	typically from large rivers

modified from UNEP, 2000

3.H. FRESHWATER BIOTA

PHYTOPLANKTON

Freshwater phytoplankton is the algal component of plankton, which are free-living organisms within aquatic environments. Phytoplankton is represented by prokaryotic cyanobacteria and several groups of eukaryotic algae.

Phytoplanktonic organisms are autotrophs, i.e., they fix solar energy by photosynthesis using carbon dioxide, nutrients and trace metals. They comprise the major portion of primary producers in most fresh waters. Like plants on land, they provide basic food for higher trophic levels such as zooplankton and fish.

Nutrients are necessary for algal development, however, their surplus (especially phosphorus) due to catchment degradation, for example, may lead to formation of blooms that degrade water quality.

Cyanobacteria

- filaments or round 3-4 µm diameter prokaryotic cells that can build large dense colonies, 100 to 500 µm in diameter (Fig. 3.2);
- they often form seasonal blooms in late summer in temperate lakes, reservoirs, and seas.
- produce toxic compounds that pose a health hazard to people and animals;
- colonies are not easily ingested by aquatic fauna due to their large size;
- destabilization of a reservoir’s hydrological characteristics may reduce cyanobacterial growth.

Diatoms

- the most morphologically varied group, including single-cell and colonial species (Fig. 3.3);
- the cells are covered with a cellular membrane hidden inside box-shaped silicate shell;
- unable to move actively, they may have a problem keeping suspended in the water column and that is why they prefer turbulent mixing conditions;
- The dominant group in spring-early summer and in autumn.

Phytoflagellates

- possess flagella, which enable migration through a water column;
- some taxa, especially dinoflagellates, cryptomonads and euglenoids, can be temporarily heterotrophic (Fig. 3.4);
- can dominate throughout the year, especially in winter (some dinoflagellates and cryptomonads), or early summer (chrysophyceae);
- may form blooms that sometimes can be toxic, e.g., *Peridinium* sp.

Green Algae

- characterized by their grassy green colour, they are among the main sources of food for filtering fauna (Fig. 3.5).
- high diversity of cell size and cellular organization (single cells, colonial and filamentous) and may be both motile and non-motile.
- in fresh water they are dominant, especially during the second half of summer-autumn. Sometimes they may reach bloom density.

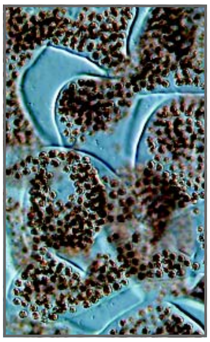


Fig. 3.2
Microcystis wesenbergi
(photo: P. Znachor)

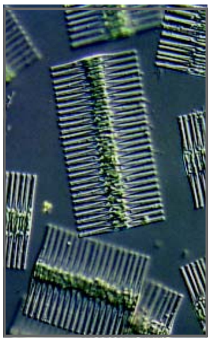


Fig. 3.3
Fragilaria crotonensis
(photo: P. Znachor)

Fig. 3.4
Ceratium hirundinella
(photo: P. Znachor)

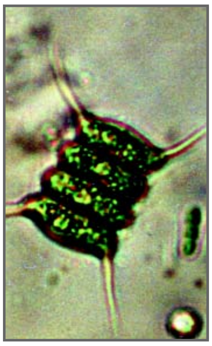


Fig. 3.5
Scenedesmus quadricauda
(photo: M. Tarczynska)

ZOOPLANKTON

Zooplankton occupy a key position in the food webs of lakes and reservoirs, transferring algal primary production to higher trophic levels. Filtering algae and suspended detritus, zooplankton strongly determine the amount and composition of organic matter in the water column.

Rotatoria

- small organisms (body lengh <0,2 mm) characterised by different body forms (Fig. 3.6). Among them one can find planktonic, crawling or sedentary genera, while a few are parasites. Rotatoria occur in lakes of different trophic status. Most rotatorians have a carapax, a taxonomic feature;
- they feed on algae, bacteria and detritus while some forms are predatory, e.g., *Asplanchna* sp. (Fig. 3.7). They are characterized by sexual reproduction - they may be partenogenetic or may have separate sexes. In lakes of temperate regions, Rotatoria peak in early spring and/or during autumn.

Cladocera

- they are the dominant mesoplankton (200 µm - 2 mm in length) in many lakes but are repre-sented by only three genera in the sea (*Evad-ne* sp., *Podon* sp., *Penilia* sp.);
- herbivorous cladocerans are filter feeders and form the most studied group of zooplankton;
- especially the genus *Daphnia* spp (Fig. 3.8), which is characteristic of mesotrophic lakes;
- small species of Cladocera, like *Bosmina* sp. (Fig. 3.9), may control the microbial food web as top predators;
- very large predatory cladocerans (8-16 mm in length), like *Leptodora kindtii* (Fig. 3.10) or *Bythotrephes* sp., can significantly reduce zooplankton population biomass by 50-60% due to their intensive consumption rates;
- Cladocerans have simple life cycles with partenogenetic reproduction through most of the year with no larval stages. Neonates are morphologically similar to adults.

Copepoda

- pelagic copepods belong to the two suborders Calanoida and Cyclopoida and occur both in the sea and in fresh waters. Most of the species are herbivorous (mainly Calanoida), although there are also some predatory and parasitic Copepoda.
- different dominance patterns are often observed along trophic gradients: calanoid copepods reach their highest biomass levels in oligotrophic lakes and cyclopoid copepods in eutrophic lakes.
- they are characterized by a complicated life cycle: obligate sexuality, larval nauplius stages and subadult copepodid stages.

Fig. 3.6
Keratella taurocephala
(photo: A. Wojtal)

Fig. 3.7
Asplanacha sp.
(photo: A. Wojtal)

Fig. 3.8
Daphnia longispina
(photo: A. Wojtal)

Fig. 3.9
Bosmina coregoni
(photo: A. Wojtal)

Fig. 3.10
Leptodora kindi
(photo: A. Wojtal)

FISH

Teleost fish are represented by about 20 000 species, which means that nearly half of all vertebrate species are fish. Fresh waters are inhabited by approximately 41% of all fish species (Wootton, 1990). Freshwater fish show multi-adaptations for living in highly variable habitats, utilizing all available food sources by means detritivory via herbivory to insectivory and piscivory (Box 3.2). Many are key major species in lakes and reservoirs, influencing their functioning and dynamics.

In many countries freshwater fish are of great importance as a source of food, but in recent years they also serve as a biomanipulation tool for improving water quality by changing the biotic structure of ecosystems. To achieve this goal, proper fish stock management based on a thorough knowledge of fish biology and ecology is required.

Depending on the position of a given fish species in the trophic structure of a ecosystem, it may play a positive or negative role in regulating water quality. Many piscivorous fish control zooplanktivorous fish reducing greezing preassure on zooplankton, thus can indirectly reduce algal blooms. On the other hand herbivorous fish by consuption of macrophytes and algae return readily available nutrients (up to 90%) to water and intensify algal blooms.

Fig. 3.11
Pikepearch
(photo: Z. Kaczkowski)

To promote a strong and vital population of fish species favourable for lakes and reservoirs, one can utilize the inherent properties of the ecosystem, e.g., the dependence of spawning success of given fish species on the availability of spawning grounds, which in nature is highly influenced by the hydrological regime. Water level manipulation in a reservoir in order to regulate fish spawning success is a good example of an activity based on this principle (Zalewski et al., 1990).

TABLE 3.2
Major trophic categories in fishes

DETRITIVORES	e.g., *Tilapia*
SCAVENGERS	e.g., *Anquila*
HERBIVORES	Grazers (e.g., *Plecostomus*) Browsers (e.g., *Ctenopharyngodon*) Phytoplanktivores (e.g., *Tilapia*)
CARNIVORES	**Benthivores** Selecting relatively small prey (e.g., *Gasterosteus*) Disturbing and then selecting prey (e.g., *Sufflamen*) Picking up substrate and sorting prey (e.g., *Lethrinops*) Grasping relatively large prey (e.g., *Balistes*) **Zooplanktivores** Filter feeders (e.g., *Engraulis*) **Particulate feeders** Aerial feeders (e.g., *Toxotes*) **Piscivores** Ambush hunter (e.g., *Cottus*) Lurers (e.g., *Lophius*) Stalkers (e.g., *Esox*) Chasers (e.g., *Salmo*) Ectoparasites *(e.g.,* Exodon*)*

modifited from Wootton, 1990

■ 3.1. ESTUARINE AND COASTAL AREAS

WHAT ARE ESTUARIES AND COASTAL AREAS?

Estuaries are commonly defined as areas where rivers discharge into the sea. Based on Pritchard's (1967) definition, Day (1980, 1981) considered „an estuary as a partially enclosed coastal body of water which is either permanently or periodically open to the sea, and within which there is a measurable variation of salinity due to the mixture of sea water with fresh water derived from land drainage". However, this „hydrological" definition must include the more „biological" approach suggested by Perillo (1995), that also considers estuaries as being responsible for „sustaining euryhaline biological species for either part or the whole of their life cycle".

According to water circulation patterns, estuaries can be classified as salt wedge estuaries, partially mixed estuaries, well-mixed estuaries, and fjord - type estuaries (Box 3.5). Salt wedge estuaries occur when circulation is controlled by a river that pushes back the seawater. Partially mixed estuaries, usually deeper estuaries, have a tidal flow: salt water is mixed upward and fresh water is mixed downward. Well-mixed estuaries are frequently shallow, have strong tidal mixing and reduced river flow resulting in vertical homogeneous salinity. Fjord-type estuaries are deep and have moderately high river input and little tidal mixing.

Estuaries are commonly subdivided into upper, middle and lower areas. The upper estuary includes most of the freshwater section, although the effects of tides are still observable. It is an area where riparian vegetation is abundant. This vegetation constitutes a buffer zone, „controlling" nutrient inputs into an estuary, thus representing a particularly important target for application of phytotechnology. The middle estuary is a transition area in terms of salinity (mainly brackish water) and vegetation. The lower estuary is characterized by a marine influence.

The coast is where land meets the sea. However, as in estuaries, land and ocean processes change this line over time and space, affecting the area considered as coastal.

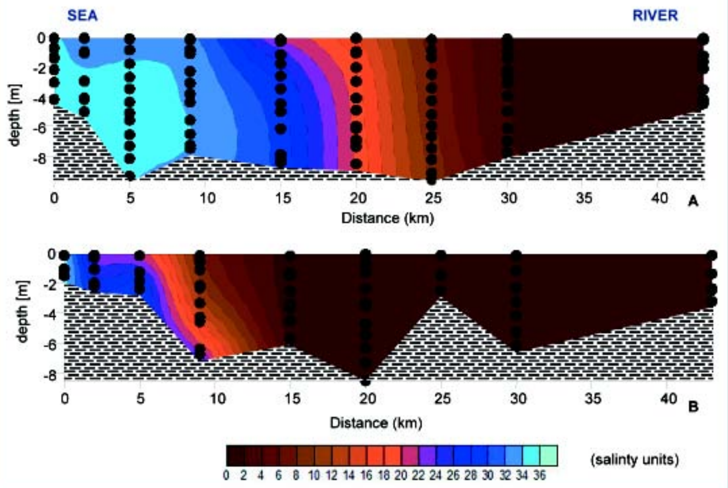
WHY ARE ESTUARIES AND COASTAL AREAS IMPORTANT?

The dynamic nature of estuaries forms the basis of a very complex food chain based on high primary and secondary productivities

Estuaries are perceived as highly productive ecosystems because they are often nutrient rich and have multiple sources of organic carbon to sustain populations of bacteria and other, heterotrophs. These sources include riverine and waste inputs and autochthonous primary production by vascular plants, macroalgae, phytoplankton and benthic microalgae (Cloern, 1987).

BOX 3.5

Longitudinal gradient of isohalines of the Guadiana estuary (South Portugal), in flood (a) and low inflow (b)



Sediments in the water column, of organic and inorganic origins, can be trapped in a strong upstream bottom flow and forced into the Maximum Turbidity Zone (MTZ). This occurrence affects the structure and functioning of the microbial community, may be limiting to photosynthesis (suspended particulate matter > 50 mg L^{-1}), contributes to the increase of heteretrophic processes and results in the degradation of organic material, what may lead to depletion of oxygen concentrations. In this zone the transition between freshwater and marine environments occurs. Phytoplankton and bacterioplankton transported down a river will experience salt stress. The freshwater microbial population will lyse and die in this zone.

The composition and spatial distribution of groups of organisms like phytoplankton, zooplankton and benthic invertebrates in estuaries are primarily regulated by salinity and only secondarily by habitat factors, such as sediment structure and depth. Due to their ability to osmotically regulate, fishes are less affected by salinity changes.

Estuaries are also important nursery areas for several invertebrate and fish species. Protection against predators and loss by outwelling currents increases success of larval development and recruitment. River discharge and the consequent river plume, associated with tides, export estuarine nutrients and organisms to coastal areas, enhancing coastal food web dynamics, supporting coastal fisheries and contributing to global ocean productivity.

The structure, broad range and biodiversity of coastal habitats provides a large number of ecological tools and services, such as storage and cycling of nutrients, filtration of pollutants from inland freshwater systems, and protection from erosion and storms. Coral reefs, mangroves, tidal wetlands, seagrasses, estuaries and a variety of other habitats, each provides its own distinct goods and services and faces different pressures. Human modification on shorelines changes currents and sediment loading, affecting coastlines and habitats in some areas.

WHY ARE ESTUARIES AND COASTAL AREAS CONSIDERED SUSCEPTIBLE?

Many coastal areas are ecologically productive, biologically diverse and climatically and physically attractive and, therefore, are preferred places for the settlement of human populations. Thus, estuaries and coastal areas became the final receptacles of innumerous human and natural factors from land, riverine and oceanic origins.

In the last century, development of cities with millions of people on estuarine margins contributed to the massive destruction of vegetation cover and other habitats. Cumulatively, construction of river diversions (barrages, dams, etc) aimed to provide enough fresh water for human consumption and uses, affects water quality and quantity in estuaries and coastal areas. This human migration to the coast occured both in developed and developing countries. The resulting stress has become apparent as populations increase, watersheds are deforested and fisheries are over exploited.

Considering the expected human population growth and the increasing need for food, water and space, pressure on estuaries and coastal areas will continue to rise. The consequences could be aggravated under predicted global changes and sea-level rise scenarios.

WHAT FACTORS INFLUENCE ESTUARIES AND COASTAL AREAS?

Estuaries and coastal areas are affected by both continental and oceanic factors, from exogenous and endogenous origins. As noted above, continental (land and river) originating factors and processes (e.g., run-off, changes in riverine discharges, changes in agricultural practices, etc.) affect estuaries and coastal areas. Moreover, oceanographic factors and processes (e.g., longshore or upwelling currents) also influence water characteristics and affect coastal biological communities and sediment composition and distribution. Endogenous fluctuations in estuarine and coastal communities are expected, for example, as a result from seasonal reproductive cycles. Exogenous impacts caused by anthropogenic activities (e.g., water canalization, pollution, destruction of riparian and salt-marsh vegetation or construction of piers) influence water quality, quantity and circulation and modifies habitats, affecting the basic structure of species organization in estuarine and coastal ecosystems (Box 3.6).

WHY DO WE NEED A STANDARDIZED MANUAL FOR ECOHYDROLOGICAL AND PHYTOTECHNOLOGICAL APPLICATIONS IN ESTUARIES AND COASTAL ZONES?

Implementation and development of mitigation and restoration techniques based on ecohydrology and phytotechnologies can provide an adequate basis for the integrated and sustainable development and management of estuaries and coastal areas. These concepts use intrinsic characteristics and processes of ecosystems to solve ecological problems. This is accomplished by increasing the natural response of a system and, by doing that, increasing the capacity to absorb impacts and their consequences.

However, application of these management techniques needs an in-depth knowledge of a system's functioning and the technical skills to make interventions as precisely as possible. In estuaries and coastal areas the complexity of processes and factors involved adds an extra difficulty to the application of these techniques. Basic to the general application of ecohydrolgical and phytotechnological solutions to estuaries and coastal areas is the need for harmonization of sampling methods, sample processing and analysis of information, as proposed in this manual. This will allow comparisons and exchange of ecohydrolgical and phytotechnological successful solutions between different estuaries and coastal areas.

BOX 3.6

Biological and key hydrological factors and processes affecting estuaries and coastal areas