Centre for Development, Environment and Policy

P109
Water Resources Management


Some units are partially based on the previous module versions:

- Water Resources Management revised by Laurence Smith in 2013
- Water Resources Management prepared by Mike Stockbridge in 2004
- Economics of Water Resources prepared by Laurence Smith in 2002.
ABOUT THIS MODULE

This module provides an opportunity to study and understand fundamental theories, concepts and tools relevant to the management of water resources. This study will support professionals in undertaking assessment and management of water, and in understanding relevant water policies and politics. The themes of poverty, gender, equity, development and sustainability are treated as cross-cutting in this module.

This module is about water resources, their complex relationship with the environment and the economy, and the growing problem of water scarcity. It considers the various options that exist to deal with this problem. The module examines how water is allocated between various competing demands and explores the role that water plays in food security, public health, people’s livelihoods and other aspects of social and economic development. The module seeks to critically evaluate the benefits, costs and impacts of water resources development, particularly those aspects most relevant to social and economic development in rural areas. Coverage includes the key water management challenges communities are facing today and the solutions that people have developed.

Parts of the module concentrate on the ways in which economic concepts, methods and judgements can inform water resource management strategies and policy decisions that affect the resource. Economic efficiency in resource allocation is only one of many criteria used by policy-makers to evaluate the appropriate approach to a given issue. However, the insights given by the application of economic theory are often ignored in the face of conflicts over the use of water.

The module also introduces a range of techniques, methods and information resources that can be used by professionals for the assessment of water resources and planning. Good information and good applied science are keys to improved water resource management and should be considered as necessary but not sufficient. It is also vital to develop the institutional arrangements and policies needed for sustainable water use and environmental conservation. Thus, governance arrangements in relation to water management are also a leading theme of the module.

MULTIMEDIA

Video: a short video is provided with your module material. In this video, the module authors, Laurence Smith and Sophie Nguyen Khoa, introduce and discuss the content of the module and how it is organised.
STRUCTURE OF THE MODULE

The module consists of ten units.

Unit 1: Understanding water resources and aquatic ecosystems

This unit provides key elements to understand the structure and functioning of water resources and aquatic ecosystems. The first section outlines the fundamental and unique characteristics of water resources, starting with the hydrological cycle and the necessary hydrological concepts and tools that will serve as a knowledge platform for the rest of the module. The second section explores water resources across the range of services provided by ecosystems. Section 3 takes a further step by explaining the nature of water requirements for ecosystem conservation, and by presenting existing approaches to define and manage such needs.

Unit 2: Social and economic characteristics of water

This part of the module introduces some important social and economic concepts and tools and discusses the ways in which they can assist professionals in their decisions over the allocation and management of water resources. This unit covers the range of private and public good characteristics of water resources, and some basic economic concepts that can be used to analyse water resources problems, provide insights into complex issues and lead to policy recommendations. The unit discusses the logic for using price and market mechanisms in water allocation and highlights practical limitations to such policies. The determinants of demand for water in different sectors are assessed and the concept of price elasticity of demand for water is defined and applied to debates about pricing policy.

Unit 3: Global issues

This unit provides an overview of global issues related to water. The first section identifies the major global drivers and pressures on the availability of water resources and the health of aquatic ecosystems. These are essentially demographic pressure, climate change, economic development and urbanisation. The second section emphasises climate change, including specific impacts on water resources and measures to mitigate and adapt to subsequent changes. Section 3 completes the identification of major global impacts, essentially water scarcity, pollution, degradation of aquatic ecosystems and emerging issues of food security. Section 4 closes this unit by looking at the trends in water resources, and asking whether we are facing a global water crisis.

Unit 4: Water use in agriculture

This unit first develops the role and contribution of water resources in rainfed and irrigated agriculture, including the use and management of water in multiple ways. Considering a continuum between rainfed and irrigated systems, the second section focuses on rainfed agriculture, a critically important activity for many rural people and for poverty reduction. After presenting the different types of irrigation systems, Section 3 identifies the differences between individual- versus community-based systems including key considerations in design and management. Section 4 discusses large-scale
irrigation systems, analysing positive and negative implications vis-à-vis social, economic and environmental needs. The section also explores investments in irrigation considering various drivers, priorities, and social and environmental considerations.

**Unit 5: Water use in fisheries and aquaculture**

This unit presents the water resource requirements of inland fisheries and aquaculture, and the major implications for the management and governance of water. The first section introduces the key characteristics of fisheries and aquaculture providing understanding of their significance in rural farming systems. The second section considers the kinds of water requirements involved in each of the two activities. The next section discusses methods and tools available to assess such water requirements, considering possible trade-offs for water allocation. The final section identifies the respective challenges for water governance and policy, opening to new perspectives for fisheries and aquaculture.

**Unit 6: Water supply and sanitation**

This unit starts by assessing the scale of the global deficit in water and sanitation, and why it matters. It emphasises the human development costs of the problem and the potential benefits of resolving it, in terms of public health, education, livelihood opportunities and economic growth. The next section assesses the arguments for treating access to clean water as a human right, and identifies the implications of formal recognition of such a right. It also reviews some of the key characteristics of urban and rural water supply systems, and considers the debate regarding the merits of public versus privatised provision. The third section assesses whether access to sanitation can, like access to clean water, be regarded as a human right. The final section concentrates on the supply side of water provision from a more generic perspective through the application of key economic concepts and analysis. It also identifies the importance of regulation, and considers alternative objectives and means for water pricing and cost recovery.

**Unit 7: Water and energy**

This unit is concerned with the interactions between water and energy as resources and as sectors of the economy, and their major implications in terms of the management and governance of water. The first section explains why water needs energy and why energy needs water, considering rising demands for both water and energy. Section 2 introduces and defines the ‘nexus’ concept as essentially applied to the linkages between water–energy and water–food–energy. Section 3 focuses on management implications, particularly in the application of nexus frameworks. Lastly, Section 4 identifies governance and policy implications of such interconnected water and energy systems.

**Unit 8: Tools and frameworks for assessing and managing water**

This unit presents key methods and frameworks for assessing and managing water in an integrative manner at local, catchment and river basin scales. The first section introduces assessment tools and frameworks. The following two sections focus first on management tools and then on management frameworks at the different scales:
Integrated Water Resource Management (IWRM), river basin management, catchment (or watershed) management, nexus frameworks between water resources and other interconnected sectors, and multiple use of water at household and community level are all considered. The unit concludes by considering the need for adaptive management and ecosystem-based approaches.

**Unit 9: Water governance, policy and politics**

Previous units have demonstrated why water is a complex and unique resource. In this unit, we show why successful models of water governance need to be complex as a result, and why they may differ from those used to manage other resources. After defining water governance, institutions and policy, the first section highlights a range of water’s unique properties in terms of governance. This leads, in the next section, to providing a framework for thinking about the various sources of water governance and policy, and how they interact with each other to determine actual water outcomes. Section 3 describes governance across institutional levels and national boundaries introducing the concept of multi-level and polycentric governance. The final section introduces water politics and the purpose of water diplomacy, and it critically assesses the relevance of water governance at global level.

**Unit 10: Challenges for future water professionals**

This final unit of the module links back to Unit 1 on global issues related to water, first positioning the central role of water in sustainable development and in green economies. In the second section, the concept of social-ecological resilience is introduced and applied to water systems, with implications for analysing water challenges across scales. The unit provides keys to how to address water issues dealing with (predictable and unpredictable) changes and uncertainties. The unit also presents major challenges for future practitioners, such as the need for ‘out of the box’ assessment and management approaches, innovative water governance, and enhanced integration and collaboration in science, policy and practice.
WHAT YOU WILL LEARN

Module Aims

- To describe the range of global issues facing water resources and aquatic ecosystems.
- To describe and explain key hydrological and biophysical characteristics of water resources and of aquatic ecosystems.
- To introduce and critically evaluate the economic characteristics of water resources.
- To identify and critically assess the major uses and users of water resources.
- To introduce and critically evaluate a range of well-established assessment and management tools and frameworks.
- To define, introduce and critically discuss the governance, policy and politics of water.
- To identify and reflect on the major challenges future water professionals will likely have to address.

Module Learning Outcomes

By the end of this module, students should have:

- critical appreciation of the global drivers and pressures on water availability and aquatic ecosystems health
- knowledge and critical understanding of the complexity of the water resource in its physical, ecological, social, economic and governance dimensions
- critical appreciation of the role and management of water throughout the continuum of rainfed to irrigated agriculture, from community to basin scales, across potentially competing sectors, and of past, present and future prospective outcomes
- ability to understand and critically assess water–energy nexus issues and their implications for management and governance
- ability to critically apply a range of assessment approaches and analytical methods for use in the planning and implementation of improved water resources management
- ability to explain critically the rationale for an integrated approach to water governance, policy and politics
- critical awareness and understanding of challenges for future water professionals.
**ASSESSMENT**

This module is assessed by:

- an examined assignment (EA) worth 40%
- a written examination worth 60%.

Since the EA is an element of the formal examination process, please note the following:

(a) The EA questions and submission date will be available on the Virtual Learning Environment (VLE).

(b) The EA is submitted by uploading it to the VLE.

(c) The EA is marked by the module tutor and students will receive a percentage mark and feedback.

(d) Answers submitted must be entirely the student’s own work and not a product of collaboration.

(e) Plagiarism is a breach of regulations. To ensure compliance with the specific University of London regulations, all students are advised to read the guidelines on referencing the work of other people. For more detailed information, see the FAQ on the VLE.
STUDY MATERIALS

There are no textbooks for this module. Instead, the module study guide provides the main resource that students should use for the study of this module.

Check the Key Study Materials for the provision of audio files and presentations and guidance on how to use these as you commence study of each unit.

For each of the module units, the following are provided.

Key Study Materials

Key readings are drawn mainly from the textbooks, relevant academic journals and internationally respected reports. They are provided to add breadth and depth to the unit materials and are required reading as they contain material on which you may be examined. Readings are supplied as digital copies and ebooks via the SOAS Online Library. For information on how to access the Library, please see the VLE.

For some units, multimedia links have also been provided. You will be invited to access these as part of an exercise or activity within the unit, and to discuss their implications with other students and the tutor.

Further Study Materials

These texts and multimedia are not always provided, but weblinks have been included where possible. Further Study Materials are NOT examinable; they are included to enable you to pursue your own areas of interest.

References

Each unit contains a full list of all material cited in the text. All references cited in the unit text are listed at the end of the relevant units. However, this is primarily a matter of good academic practice: to show where points made in the text can be substantiated. Students are not expected to consult these references as part of their study of this module.

Self-Assessment Questions

Often, you will find a set of Self-Assessment Questions at the end of each section within a unit. It is important that you work through all of these. Their purpose is threefold:

- to check your understanding of basic concepts and ideas
- to verify your ability to execute technical procedures in practice
- to develop your skills in interpreting the results of empirical analysis.

Also, you will find additional Unit Self-Assessment Questions at the end of each unit, which aim to help you assess your broader understanding of the unit material. Answers to the Self-Assessment Questions are provided in the Answer Booklet.
In-text Questions

This icon invites you to answer a question for which an answer is provided. Try not to look at the answer immediately; first write down what you think is a reasonable answer to the question before reading on. This is equivalent to lecturers asking a question of their class and using the answers as a springboard for further explanation.

In-text Activities

This symbol invites you to halt and consider an issue or engage in a practical activity.

Key Terms and Concepts

At the end of each unit you are provided with a list of Key Terms and Concepts which have been introduced in the unit. The first time these appear in the study guide they are **Bold Italicised**. Some key terms are very likely to be used in examination questions, and an explanation of the meaning of relevant key terms will nearly always gain you credit in your answers.

Acronyms and Abbreviations

As you progress through the module you may need to check unfamiliar acronyms that are used. A full list of these is provided for you in your study guide.
**TUTORIAL SUPPORT**

There are two opportunities for receiving support from tutors during your study. These opportunities involve:

(a) participating in the Virtual Learning Environment (VLE)
(b) completing the examined assignment (EA).

**Virtual Learning Environment (VLE)**

The Virtual Learning Environment provides an opportunity for you to interact with other students and tutors. A discussion forum is provided through which you can post questions regarding any study topic that you have difficulty with, or for which you require further clarification. You can also discuss more general issues on the News Forum within the CeDEP Programme Area.
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Check the VLE for submission deadline 15

**Examination entry**

- Jul
- Jul—Sep
- late Sep—early Oct
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UNIT INFORMATION

Unit Overview

This unit provides key elements to understand the structure and functioning of water resources and aquatic ecosystems. The first section outlines the fundamental and unique characteristics of water resources, starting with the hydrological cycle and the necessary hydrological concepts and tools that will serve as a knowledge platform for the rest of the module. The second section explores water resources across the range of services provided by ecosystems. This implies detailing the ecology of aquatic ecosystems, their structure, processes and biodiversity. Section 3 takes a further step by explaining the nature of water requirements for ecosystem conservation, and by presenting existing approaches to define and manage such needs.

Unit Aims

This unit aims to:

• demonstrate the unique characteristics of water resources, starting with the hydrological cycle and using the most relevant key concepts at local, catchment and river basin scales
• consider these unique characteristics of water within and across ecosystem services, and thereby introduce the concept of ecosystem services
• explain the nature of water requirements for conserving ecosystems.

Unit Learning Outcomes

By the end of this unit, students should be able to:

• understand the unique characteristics of water resources throughout the hydrological cycle and at all relevant scales
• define and critically assess the concept of ecosystem services, and consider water’s unique characteristics within and across ecosystem services
• be critically aware and able to understand methods to assess water requirements for protecting and conserving ecosystems.
Unit Interdependencies

Unit 2
Unit 2 provides an overview of key economic concepts and tools, and the ways in which they can assist professionals in their decisions over the allocation and management of water resources. This unit contributes concepts that can be used to identify the characteristics of water as an economic good, including both public and private good aspects of this resource.

Unit 3
Unit 3 assesses the global context of water resources, and identifies the major global drivers of change and their impact on water resources and ecosystems. This unit helps understand the ways and processes through which the availability, use and quality of water resources are, and will be, affected by increasing pressures at the global scale.

Unit 4
Unit 4 looks at different types of agricultural use and water management at local, catchment and river basin scales. Understanding and considering the structure and functioning of water resources and aquatic ecosystems is critical to providing new perspectives in agricultural water management, such as the concepts of blue-green water, water ecosystem services and agro-ecosystems.

Unit 5
Unit 5 demonstrates the often overlooked significance of inland fisheries and aquaculture as water uses. This unit helps to explain why and how water resources and their management influence the production and delivery of the social and economic benefits of fisheries and aquaculture.

Unit 6
Unit 6 provides an overview of water supply for domestic use and sanitation. Knowledge of the structure and functioning of water resources and ecosystems, acquired in this unit, is necessary to understand how the different sources of water can be supplied to households and cities, and how different water resources can be used for domestic and sanitation purposes.

Unit 7
Unit 7 is concerned with the interactions between water and energy, as well as water, energy and food, and their implications in the management and governance of water. Knowledge of the characteristics and functioning of the different sources of water underlies the multiple and complex interconnections between the water, energy and food sectors.
Unit 8

Unit 8 provides an overview of frameworks, tools and approaches for the assessment and management of water resources at all scales. All types of water resources described in this unit need to be considered in any assessment or management. This requires a clear understanding of the functioning of the different water sources and resources, as well as the identification of linkages with aquatic ecosystems.

Unit 9

Unit 9 provides critical discussion of the key concepts, challenges, perspectives and issues associated with the governance of water resources. The design of various options for water governance and policy must draw from a solid knowledge of the characteristics and functioning of the water cycle, the different sources of water and their related ecosystems.

Unit 10

Unit 10 concludes the module by highlighting the central role of water in broader goals, such as sustainable development and green economies. The basic knowledge provided in this unit contributes to explaining why and how water plays such a role beyond the water sector and throughout the social, economic and environmental three pillars of sustainable development. This raises enormous but also exciting water challenges for future researchers, practitioners and policy-makers.
**Key Study Materials**


Drawing from a new conceptualisation of water resources, this seminal article changed perspectives on water planning and management. Conventional water resource planning and management had focused on liquid water, although represented only one-third of the freshwater resource. This article argues that a second form of water resource needs to be incorporated in planning and management: the rainfall that naturally infiltrates into the soil and that is on its way back to the atmosphere. Thus the proposed concept distinguishes two types of water resources: the ‘blue water’ resource, present as liquid in rivers, aquifers, lakes and reservoirs, and the ‘green water’ resource, present as moisture in the soil and as vapour when water flows back to the atmosphere. Therefore, the water resource challenge is not only a question of blue water allocation among users in irrigated farming, industry and municipalities, but involves wider decisions for balancing green and blue water for food, nature and society. In practice, water resource planning must incorporate land-use activities consuming green water and their interaction with blue water, in terms, for example, of generating or limiting surface runoff and groundwater recharge.


This book aims to synthesise our current state of knowledge and probe the key area of how recent insights from social-ecological systems and resilience research influence our understanding of water resource governance and management in a world subject to rapid global environmental change. It advances a proposed new framework on ‘water resilience’ as an integral part of sustainable water resource management. The book focuses on ecosystem services in productive landscapes, especially food production (and bio-resources), seen from the perspective of land, water, ecosystem interactions and resilience building. As you read, consider the perspectives provided on water resources from local to global scale, exploring dynamic interactions between sectors and components of the Earth system at different scales.


View and listen to this presentation after your study of Section 2 of this unit. This is an additional resource provided to illustrate a practical application of the concept of ecosystem services.
1.0 FUNDAMENTAL CHARACTERISTICS OF WATER RESOURCES

Section Overview

This section introduces the fundamental characteristics of water resources by first presenting the central role of water in the Earth’s biosphere. It then explains the hydrological cycle and its interactions with other natural resource cycles. Different types of water resources are distinguished, as this is relevant to how water is managed and governed. Lastly, the section critically reviews why the scale of assessment and management matters.

Section Learning Outcomes

By the end of the section, students should be able to:

- understand the role of water in the Earth’s biosphere
- explain the hydrological cycle
- describe the different types of water and water uses and explain why it is important to distinguish between them
- critically explain why scale matters in the assessment and management of water resources.

1.1 Water in the Earth’s biosphere

The occurrence and distribution of water on Earth is governed by a globally functional hydrological cycle that is intertwined with other biochemical cycles. Water connects multiple scales and hence constitutes a ‘global water system’. Global interconnections exist for hydro-meteorological phenomena, stream flow and groundwater movement, as well as for water use and stewardship, and hydrological dependencies and vulnerabilities. For example, regions where land-use change, deforestation or other relevant developments may occur can influence hydro-meteorological phenomena thousands of kilometres away.

The hydrological cycle is driven by a complex, interrelated ensemble of dynamic natural processes. The Earth’s tilt and rotation around the Sun are among the primary drivers of seasonal variations in precipitation and water availability. Atmospheric and oceanic circulation patterns (e.g., the El Niño Southern Oscillation) and their interactions are equally important drivers of weather, climate and the hydrological cycle.

Almost all of the Earth’s water (97%) occurs as salt water in the oceans. Of the remaining 3%, two-thirds occur as snow and ice in polar and mountainous regions, which leaves only about 1% of the global water as liquid freshwater. Almost all of this (more than 98%) occurs as groundwater, while less than 2% occurs in the more visible form of streams and lakes which often are fed by groundwater. In the end, only a tiny share of all the water on Earth, less than one-hundredth of 1%, is fresh and renewed each year by the solar-powered hydrological cycle.
While freshwater is renewable and present everywhere, this resource is finite. Of importance for humans is the part of the hydrological cycle which is available for use by human society. The quantity of water available today is virtually the same as when civilisations first arose thousands of years ago. As Rockström and colleagues (2014: p. 5) recall ‘water is not only the bloodstream of the landscape […] it is also the bloodstream of human societies and of the human enterprise on Earth’.

The state of water resources constantly changes, resulting from the natural variability of the Earth’s climate system and the anthropogenic alteration of that system and the land surface through which the hydrological cycle is modulated. These sources of change and the interactions between them create a new level of uncertainty associated with the use and availability of water resources, in addition to existing uncertainties related to the Earth’s climate system and hydrological cycle. As a result, it is no longer possible to assume that the future hydrological record will follow the course of the historical record (UN, 2012).

1.2 The hydrological cycle

We cannot understand and discuss water resources without a firm understanding of the forms in which water exists and the ways in which it moves throughout ecological and social systems, including its changes in form. The quantity and quality of water resources are defined by properties governed by biological, chemical and physical laws.

The hydrological cycle, also called the water cycle, describes the continuous movement of water on, above and below the surface of the Earth. It has no beginning or end, as illustrated in the figure in 1.2.1. The cycle involves the combined flows, use and storage of water above and below the ground, and in the atmosphere. It also involves changes in the state of water among liquid, vapour and ice at various stages of the cycle. Water is thus constantly in motion, passing from one state to another, as well as from one location to another.

Precipitation which includes rain and snow is the ultimate source of water. Once rain has fallen, water moves in different ways within the system:

- The water settling on the surface of the land and that starts to flow is known as runoff and contributes to river flow and lakes.
- The water infiltrating the ground forms two parts:
  - One part is stored temporarily within soils, and is converted into liquid vapour through evaporation from soils and transpiration by plants and trees. This combination is called evapotranspiration.
  - Another part infiltrates the ground further. This groundwater may later be extracted naturally by plants, evaporation or human use, or it may infiltrate deeper into the ground and eventually percolate down to the groundwater formations called aquifers.
- Evaporation back to the atmosphere occurs from water and land bodies, and from evapotranspiration. Evaporation and transpiration occur simultaneously and are an important component of the water balance in a river basin. They can occur from natural vegetation, agriculture and forestry.
• The water assimilated during the photosynthesis of plants becomes part of carbohydrates stored in these plants, and ultimately reverts to water again as plants decompose.

• Water may be stored in natural ponds or lakes, or in artificial water bodies, such as reservoirs and tanks.

Groundwater is thus formed by ‘excess’ rainfall, that is: total precipitation minus surface runoff and evapotranspiration. Groundwater has been referred to as an invisible or hidden resource because it is largely unseen, making its measurement, valuation and management difficult. For temperate, humid climates, about 50% of the precipitation ends up as groundwater. For Mediterranean climates, it is more like 10–20%, and for dry climates it can be as little as 1% or even less (Bouwer, 2000). These natural recharge rates give an idea of the safe or sustainable yields of aquifers that can be pumped from wells without depleting the groundwater resource.

The Sun plays a key factor in the cycle by heating the water and driving processes such as precipitation, canopy interception, snowmelt, runoff, infiltration, subsurface flow, evaporation (including transpiration and evapotranspiration) and condensation. However the climate system puts an upper limit on the circulation rate. The ‘renewable freshwater resource’ (RFR) is renewed by rainfall and runoff each year, but its distribution in time and space is uneven.

1.2.1 The hydrological cycle

Units: '000 km\(^3\) for storage, and '000 km\(^3\)/year for exchanges.


An animated version of this diagram is available on your e-study guide.
Indeed, the hydrological cycle also determines the **different degrees of accessibility and availability of water resources** depending on their form, location and phase of water within the cycle:

- water stored in glaciers and deep groundwater
- water stored in natural and artificial reservoirs
- water runoff.

Water availability is also concerned with **who needs water**, **what water is needed for** and **what form of water is required to fulfil these needs**. For example, while humans require freshwater resources in liquid form for drinking and domestic purposes and usually for food production, we have seen that plants can obtain water in the form of soil moisture and animals can supplement their water needs with moisture gained from eating plant material.

The water cycle described above has been considerably modified by human activities. For example, water withdrawals from rivers and lakes have been increasing significantly since the 1950s. Such activities can intensify the hydrological cycle and disrupt the natural balance of water systems. Further, once used in this way water loses properties, such as purity, heat and potential gravitational energy. These are again recharged as the Sun's energy drives evaporation of water back to the atmosphere.

The concept of the hydrological cycle is thus not only an important tool for understanding the origin, states and movement of water resources, it is also necessary for assessing renewable freshwater resources and water availability. This is needed to understand and quantify the water resources of an area in order to manage them.

### 1.3 Different types of water resources and water uses: why is it important to distinguish among them?

We can now take a closer look at the various terms and concepts involved in describing water resources in the hydrological cycle. It is important to distinguish between them because they result in different availability and accessibility for water uses and users, and these have major implications for their assessment and management.

**Different types of water resources**

As we have seen, in the natural hydrological cycle, the renewable freshwater resources comprise: **rainwater**, **surface water** and **groundwater**. In addition, water scientists (Falkenmark & Rockström, 2006) have proposed concepts to describe the different sources and flows of water using the terms **‘blue water’** and **‘green water’**.

- **‘Blue water’** refers to water flowing in rivers, lakes, reservoirs and aquifers. Blue water is the main source of water for irrigated agriculture, which currently accounts for about 90% of the global consumption of this water resource. Blue water is also used for domestic water supply and sanitation, and for industrial purposes. It is typically managed by means of water infrastructure.
• ‘Green water’ refers to the soil moisture generated from rainfall that infiltrates the soil and remains potentially available to the soil biota and plant roots, after precipitation losses to runoff and deep percolation have occurred. Green water is the main source of water for rainfed agriculture and contributes to irrigated agriculture. It is primarily managed via land-use and agricultural practices. It has been estimated that the global flow of green water accounts for about 65% of the total global flow of all freshwater. Green water flows, aside from those induced by soil water redistribution, take place by evapotranspiration.

In order to take into account all water used and transformed by human activities, we also consider the following major types.

• Wastewater. Much of the vast quantity of water being used for agriculture, and for domestic and industrial purposes by cities, is released back into the environment as polluted wastewater. These large volumes of wastewater often find their way into river systems after insufficient treatment, where they alter and degrade ecosystems. Therefore, water re-use is becoming increasingly important for two reasons. Firstly, increasingly stringent regulations to protect the quality of receiving water for aquatic life, recreation and downstream users are making the discharge of sewage effluent into surface water more difficult and expensive. The cost of the treatment may be so high that it becomes financially attractive for municipalities to treat their water for local re-use rather than for discharge. Of course, the alternative treatment still needs to meet the quality requirements for the intended re-use. A second reason is that wastewater is often a significant water resource that can be used for a number of purposes, especially in water-short areas. The most logical re-use is for non-potable purposes, such as agricultural and urban irrigation (for parks and roadsides, etc, or peri-urban agriculture), industrial uses (cooling, processing), environmental enhancement (wetlands, wildlife refuges, urban lakes), fire-fighting, dust control, toilet flushing, etc.

• Virtual water. First introduced by Allan (1993), the concept ‘virtual water’ refers to the volume of water used in the production of a good or service. It is also known as ‘embedded water’. ‘Virtual traded water’ refers to water that is either incorporated into traded products that are removed from the catchment or water used for the growth of traded products, but which might return to the catchment after evapotranspiration. When commodities, such as agricultural products, enter the world market virtual water trade takes place with importing countries essentially purchasing, in part, water resources from exporting countries. Virtual water trade can potentially reduce water use at national and international levels. Since it takes between 500 and 4000 litres of water to produce 1 kg of cereal, a nation reduces its own water use substantially by importing food instead of producing it on its own soil.
• In simple terms, water savings through trade occur at the global level if production by the exporter is more water efficient than by the importer. In particular, trade saves irrigation water when the exporting country cultivates under rainfed conditions, while the importing country would have relied on irrigated agriculture. As economies and trade become more global in scope, global movement of food from water-rich to water-poor countries may be as feasible as moving petroleum products from oil-rich to oil-poor countries. Of course, this will remain subject to political concerns regarding potential international conflicts, and the security and reliability of trade in food and other commodities.

Different types of water uses

It is also important to distinguish the different types of water uses because these determine further availability for other uses.

• **Withdrawal** refers to water that is abstracted for a given use. It may then be wholly or partly used (depleted). In most cases, it is only partly depleted with the remainder returned to its source or other receiving water body. The quality of the returned water may or may not be the same as it was prior to removal. Water is withdrawn from rivers, groundwater and storage for delivery to a use such as drinking water, crops, livestock, aquaculture or industries. Water abstraction or water withdrawal occurs when freshwater is taken from any source (for example, a river, surface water or an underground reservoir) for any use, either temporarily or permanently.

• **Depletion.** As a result of the use, part of the water is depleted, that is, used in such a way that it is no longer available for re-use. Water is depleted when it is evaporated, transpired, incorporated into a product, flows to an inaccessible sink, such as a saline aquifer or ocean, or is degraded in quality to such an extent that it cannot be used again. Water that is not depleted is available again for re-use. Water is thus typically allocated according to withdrawals, and not based on depletion.

This has led to the concept of consumptive use or non-consumptive use of water as described below.

• **Consumptive use of water** occurs when water is abstracted or withdrawn but not returned to the catchment or the return is delayed. Consumption refers to water that disappears or is diverted from its source, for example, by evaporation, incorporation into crops or industrial processes, drinking water, etc. This includes all water incorporated in products, evaporated or evapotranspired via soils or vegetation, or discharged into seawater or another inaccessible sink. The source may or may not eventually be replenished. If replenished, the process could potentially take many years – decades, centuries or longer. Examples of consumptive use are crop evapotranspiration and incorporation of water into manufactured products. Evapotranspiration of green water by natural ecosystems is also a consumptive use. Agriculture is by far the largest consumptive use of water globally.
• **Non-consumptive use of water** utilises water resources without completely diminishing, degrading or changing them, and they can therefore be used by others or for other uses. Examples of non-consumptive uses include hydropower generation. Such power generation uses water, often in rivers, and the power of its flow to move turbines and create power. The water is returned to the system as liquid water, which can then be utilised by other users. However, there may be a degree to which non-consumptive use can compromise the water resources for other uses, for example, through pollution, change in temperature, change of location and timing of releases. In situ, in-stream or non-consumptive use occurs when there is no water withdrawal. Examples include using a water body for navigation or to transport timber, fishing, recreation, effluent disposal and some hydroelectric power generation. For example, water demand in cities is a combination of consumptive and non-consumptive use. People require water for sanitation, which is mostly non-consumptive, but entails degradation in water quality. Typically 80–90% of city water is available for re-use, as wastewater.

**Availability of different types of water resources**

While the hydrological cycle allows us to explore the various inputs, storage, changes in state, use and outputs of water resources, the water available is not necessarily simply what exists within the hydrological cycle. Not all water within the hydrological cycle is available at all times, or ever in some cases, nor is it available for all intended purposes at all times. Therefore, water availability is also concerned with who or what water is needed for and what form of water is required to fulfil their needs. For instance, while humans require freshwater resources in liquid form for drinking and domestic purposes and usually for food production too, plants can obtain water in the form of soil moisture and animals can supplement their water needs with moisture gained from eating plant material.

Some important notions and concepts regarding water availability are:

• **Renewable resources**: Those water resources which even when used for certain purposes will be available within the hydrological system for use again. However, these resources may not be available in the same state (changed from liquid to vapour or soil moisture) or same quality (polluted). Even if initially used, these resources are not completely depleted and may have further uses. Therefore they may often represent a vital part of water availability.

• **Potentially utilisable resources**: This is the amount of water available in the system which it is possible to use. This amount reflects water which is reasonably accessible (not too expensive or difficult to obtain), in terms of source and state.

• **Developed resources**: They represent the proportion of available water supplies which are already being used or are earmarked for particular uses. These resources are considered developed since they are already ‘allocated’ to certain uses or sectors and cannot be used for other purposes (at least at that particular time). Therefore, while a certain amount of water may look available and we can identify what is potentially utilisable, the actual assessment of water availability involves recognition of what resources are already committed to certain activities (e.g., a country’s domestic supply).
• **Variability and reliability of supply**: While a certain amount of water resources may be available according to calculations based on the hydrological system, some factors may contribute to variability and affect reliability of supplies of water resources. These factors may be natural, such as variability in rainfall (both in space and time) or caused by human activities due to technical, infrastructure or human resource failings. This needs to be considered when planning the use of water resources, as delays in accessing water, or too much or too little being supplied at certain times, can affect activities dependent on the water resources.

• **Variability of water quality**. In river basins where there is a dense population, pollution becomes a big concern. As rapid urbanisation continues globally, the demand for water for cities is increasing. The vast quantity of water being used for domestic and industrial use in cities is released back into the environment as polluted wastewater. These large volumes of wastewater often receive insufficient treatment and find their way into river systems, where they contribute to altering and degrading ecosystems. Intensive agricultural practices also tend to pollute water bodies. With greatly reduced outflow of the river system to the sea, there is also often insufficient water for dilution of waste and pollution tends to concentrate and peak near the tail of rivers or in lakes and reservoirs where the residence time is high (i.e., there is slow passage of water into and out of the water body). The best treatment plant processes for unrestricted non-potable re-use must be treated to make sure that the effluent is free from pathogens (viruses, bacteria and parasites). Such treated wastewater can then be used for agricultural irrigation of crops, urban irrigation of parks, playgrounds, sports fields and road plantings, or for firefighting, toilet flushing and industrial uses others.

Lastly, availability of blue water and green water is defined as follows:

• **Blue water availability** is understood as the volume of natural runoff, through groundwater and rivers, minus environmental flow requirements.

• **Green water availability** is the percentage of the nominal transpiration requirement for maximal yield of a crop that is actually available during the growing period. Green water availability is thus intrinsically dependent on both weather and climate, as well as on crop characteristics and soil hydrologic behaviour.

### 1.4 Why scale matters

Hydrologists have defined the **river basin** as the main natural hydrological unit that should be considered in terms of scale for the assessment and management of water resources. A river basin encompasses the land area drained by a river and its system of streams and tributaries, from the source of each stream to a final destination in the sea, an estuary or inland lake. Most of the Earth’s land surface falls within the area of river basins.

Smaller areas of land defined by the sub-basins of tributaries within a river basin are commonly called ‘catchment’ or ‘watershed’. The river basin terminology tends to be used interchangeably and at different geographical scales to refer to a drainage basin, a
catchment, a drainage area, a river basin, a water basin and a watershed. In some countries, including the United States and Canada, the terms catchment and watershed are also applied to the river basin itself. Elsewhere, ‘watershed’ may refer to the dividing line or ridge between catchments. Note that while a river basin is a physical landscape, water does not always have clear biophysical boundaries and groundwater, in particular, is not confined to the same boundaries as surface runoff.

As seen with the hydrological cycle, a basin is made up of: water from precipitation, rain or melting snow and ice; surface water from lakes, wetlands, rivers, reservoirs and estuaries; and subsurface water stored in soil and groundwater aquifers. It may also include water that has been diverted or transferred from one basin to another – i.e. from a basin with surplus water to a basin with a deficit – and sometimes even desalinated seawater.

There are several reasons why it is considered logical to take a river basin or catchment as the spatial unit of reference. Basins, aquifers and water control systems, together with landscape characteristics, shape quantity, quality and timing of water availability. Local biodiversity and ecological integrity are also strongly influenced by the river basin ecosystem and even larger scale ecoregional factors. For example, to gauge the conservation importance of a particular area, consideration should be given to the degree to which other developments in the river basin are likely to have impacted on the site and the extent to which a modification at the site is likely to affect the wider basin in the region.

Water users within the basin are linked to each other through water resources insofar as the actions of one user can affect the amount and quality of water available to others. Notably, upstream water users and land managers can affect the volume, quality or seasonality of water available to those downstream. For example, deforestation and change in upstream land use may affect the frequency and severity of downstream floods, while also increasing soil erosion and the sediment and other pollutants carried by the river system. This means that a river basin may appear to be a natural forum for conflict resolution, as within the basin water users may be able to perceive their dependence on a common resource and better understand their interdependence with others (Smith et al., 2015).

However, while social processes of water control can be spatially situated, there is often a mismatch between the boundaries of river basins (and catchments) and existing institutional and political boundaries. Indeed, it is within the cultural, political and historical context that integrates institutions that water resources are managed (Ludden, 1978). We also note that such institutional boundaries were usually established in eras before the relative scarcity or poor quality of water resources became a leading concern. Hybrid concepts that unite the biophysical and socio-political boundaries such as the ‘territory’ and ‘jurisdiction’ exist but are still exceptions. Some scientists thus believe that reconciling the diverse social boundaries in a physical landscape rarely reflects the ‘wealth and complexity of local networks of resource use, decision-making and social interaction’ (Cleaver, 1999: p. 603).

In addition, any single intervention in a basin can be expected to have foreseen and unforeseen consequences and side effects on lower and upper scales. In turn, the basin is subject to the effects of interventions at other scales. For example, global factors such as climate change, pollution and globalisation may have predictable and unpredictable impacts on the availability of water in the basin. This is further complicated by the fact
that many river basins are transboundary and may be located within several countries, necessitating international mechanisms to regulate and manage river flows and to support negotiation or conflict resolution.

Given such complexities and interdependencies, the logic of assessment, management and governance at basin scale extends to the need to be holistic and comprehensive in scope. This may involve working across scales, being aware that an optimum solution for one group of users, eg an irrigation system, is not likely to be the best solution for all water users at the same unit of scale. Despite taking the river basin or catchment scale as the reference unit, interventions at higher scales may be required, as well as effective polycentric and multilevel governance arrangements that are capable of coordination across scales, sectors and jurisdictions.
Section 1 Self-Assessment Questions

1 List the main components of the hydrological cycle, and explain in detail why this cycle is an important tool for the assessment and management of water resources in a defined area.

2 True or false?
   (a) All water in the hydrological cycle is available for use.
   (b) The hydrological cycle is a way of looking at the flow of 'liquid' water only, as it moves in and out of our Earth’s systems.
   (c) If water changes state (for example, evaporates), it is no longer considered part of the hydrological cycle.
   (d) People have varied perceptions as to what the 'ultimate' source of water is.
   (e) To assess water availability for humans it is necessary to look at the stocks of water held in various reservoirs.
   (f) If all water available is developed, it cannot be used for other purposes.
   (g) Blue water refers to water which is treated, while green water is natural water.
   (h) Non-consumptive uses of water allow for water to be used for other purposes but it may be compromised in quality.

3 Explain why it is so important to distinguish the different types of water resources and provide examples to illustrate your explanation.
2.0 WATER AND ECOSYSTEM SERVICES

Section Overview

This section considers water resources and ecosystem services, and introduces ecosystem structure and processes. This requires understanding of the concept of ecosystem services, as well as its relation with human well-being.

Section Learning Outcomes

By the end of the section, students should be able to:

- understand ecosystem structure and processes, and their relation with water resources
- explain the concept of ecosystem services
- critically evaluate the role of ecosystem services in human well-being.

2.1 Ecosystem structure and processes

An ecosystem is a complex natural system made up of plant, animal and microorganism communities set within the conditions of the non-living environment in a given location, with all elements interacting as a functional unit (see figure in 2.1.1). Wetlands or aquatic ecosystems in the broader sense can be defined as ‘areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water, the depth of which at low tide does not exceed six meters’ as agreed by the Ramsar Convention (UN, 1971: Article 1). They are among the most important ecosystems on Earth as they function as sources, sinks and transformers of many chemical, biological and genetic materials. Wetlands are extremely important for fish and wildlife protection, but they are also often downstream receivers of water and waste from both natural and human sources.
2.1.1 Three component basis of a wetland definition: hydrology, physicochemical environment and biota


The global extent of wetlands is estimated to be in excess of 1280 million hectares and includes inland and coastal wetlands (including rivers, lakes, estuaries and marshes), near-shore marine areas (including shallow coral reefs and seagrass beds) and human-made wetlands (reservoirs and rice paddies). Virtually all of the Earth’s ecosystems have been transformed to some degree by human actions and it is important to keep in mind that alterations to terrestrial ecosystems usually affect aquatic ecosystems as well. We also highlight that while coastal ecosystems are among the most productive systems, they are highly threatened because existing threats arising upstream in river basins are exacerbated by increasing human pressures associated with population increase in the coastal region.

When we talk about ecosystem processes we refer to the main natural cycles that occur in aquatic ecosystems. There are four main cycles that drive aquatic ecosystems: the water, carbon, nitrogen and phosphorous cycles. In this section, we will look briefly at the role of each of these cycles and how they have been changed or affected by anthropogenic influences (see 2.1.2).

2.1.2 The four main processes involved in aquatic ecosystems

- The water cycle (also called the hydrological cycle): this cycle has been described in Section 1.2. The natural water cycle has been significantly modified by people, with the most important increases in water withdrawals from rivers and lakes taking place since the 1950s. Most of the increased water withdrawals have been used in agriculture, followed by urban and industrial use.
- **The carbon cycle**: the carbon dioxide (CO₂) concentration in the atmosphere has increased recently by about 35%, with major change taking place since 1960. How terrestrial ecosystems impact on the carbon cycle has reversed in the last 50 years, from being a net source of CO₂ during the 19th and early 20th centuries to a net carbon sink around the middle of the 20th century. This is explained by the heavy deforestation and contributions from the degradation of agricultural, pasture and forestlands that took place in the 19th and early 20th centuries, followed by compensatory activities such as afforestation, improvements in forest management, reforestation and changes in agricultural practices, including the use of fertilisers. We must note that carbon losses from land-use changes continue to take place at a high level.

- **The nitrogen cycle**: this cycle deals with the reactive or biologically available nitrogen which has increased substantially as a result of human activity. Most of the increase is associated with the increased use of synthetic nitrogen-based fertilisers. This has a close linkage with and influence on the carbon cycle.

- **The phosphorous cycle**: the flux of phosphorus to the ocean may have tripled (22 teragrams per year) compared to the estimated baseline ‘natural’ rate of 8 teragrams per year. This increase can be attributed mainly to increased use of phosphorous-based fertilisers and the rate of phosphorous accumulation in agricultural soils.

Source: unit author

Any change that takes place in ecosystems unavoidably affects the species within those systems. There are feedback effects as changes in species will have implications for overall biological diversity and the ecosystem processes that this supports and, in turn, changes in processes will affect species and their diversity. The distribution of species on Earth is becoming more homogenous, in other words, the difference between the composition of species at different locations is reducing. There are two main reasons for this homogenisation:

- Extinction and the loss of species that were unique to locations. When species decline or become extinct as a result of human activity, they are typically replaced by a much smaller number of species that thrive in human-altered environments. Yet, in instances where diversity has been low, the biological diversity may actually increase as a result of invasions from non-native forms.

- Changes in the rates of invasion or introduction of species into new ranges, both of which are increasing rapidly with growing trade and transportation.

In terms of species extinction and threats, the greatest numbers of species affected and most severe threats are encountered in freshwater habitats. Freshwater ecosystems and biodiversity are the most vulnerable to human activities and environmental change because of the disproportionate richness of inland waters as a habitat for plants and animals. They currently support approximately 40% of the fish diversity and one-quarter of the global vertebrate diversity. All of this diversity is found within 0.1% of the world's water, covering only about 0.8% of the Earth's surface.
2.2 The concept of ‘ecosystem services’

*Ecosystem services* can be defined as *the benefits that people obtain from existing ecosystems*. They include: provisioning services, such as food and water supplies; regulating services such as regulation of floods, drought, land degradation and disease; supporting services, such as soil formation and nutrient cycling; and cultural services that include recreation and spiritual, religious and other non-material benefits (see 2.2.1).

2.2.1 Ecosystem services

- **Provisioning services**: refers to products that are taken from the ecosystem.
- **Regulating services**: the benefits obtained from the regulation of ecosystem processes.
- **Cultural services**: the non-material services to people that the ecosystem provides, notably for recreation and tourism.
- **Supporting services**: essential for the production of all other ecosystem services. These services are different from provisioning, regulating and cultural services, as they rarely have direct impact on people. The effects on people are often indirect or occur over a very long time.


Provisioning services, such as providing water and food (particularly food crops, livestock products and fish) and fibre, are clearly directly important for human well-being and have a range of direct and indirect impacts for economic and social development. Regulating and supporting services are essential in sustaining ecosystem functions that underpin provisioning services and often reduce risk and variability in their output. Among ecosystems, aquatic ecosystems are clearly highly important in terms of their contributions across the full range of provisioning, regulating and supporting services, but they are also often rich in terms of their contribution of cultural services, including aesthetic, educational, cultural and spiritual values or benefits.

2.3 Aquatic ecosystem services and human well-being

People are an integral part of ecosystems. Livelihoods and human well-being are dependent on ecosystems and the natural resources that they support. Aquatic ecosystems provide many services which contribute to human well-being and poverty alleviation. Some groups of people are highly dependent on these ecosystem services, especially those living near them and most significantly affected by their degradation. The two main provisioning services that directly contribute to human well-being involve the supply of fish and the availability of freshwater. Inland fisheries can be a major source of livelihoods as well as a key source of protein and other nutrition, especially in remote areas of developing countries. Similarly, the main source of freshwater for human use comes from inland aquatic ecosystems, although artificial structures that stabilise river flows contribute to the provision of freshwater to people. Today, many large and small dams have been built to serve the purposes of municipal, industrial, hydropower, agricultural and recreational watersupply, as well as flood control.
Other services provided by aquatic ecosystems contribute to human well-being. The diversity and relative importance of these in different wetland systems is illustrated by the table in 2.3.1 below.

The principal supply of renewable freshwater for human use comes from an array of inland wetlands, including lakes, rivers, swamps, and shallow groundwater aquifers. Inland waters and mountains supply water to about two-thirds of the world’s population. Inland wetlands serve many more people with water downstream than they do in the immediate vicinity through locally derived runoff, while groundwater, often recharged through wetlands, provides drinking water for many, as well as a source for industrial use and irrigation.

**Fishery products** are particularly important ecosystem services gained from inland water bodies and are often the primary source of animal protein for rural communities. Fishing and harvesting of other aquatic animals and plants from floodplains and swamps associated with major lakes can be significant sources of subsistence and income for local communities.

**Coastal wetlands** such as estuaries, marshes, mangroves and coral reefs also provide a range of valuable services. Capture fisheries are a major source of food and income. Estuaries, intertidal flats, beaches, dunes and coral reefs may also have spiritual and aesthetic value, in addition to recreational uses. Most coastal wetlands also deliver supporting services, notably nutrient cycling and soil formation. Coastal wetlands, coastal river floodplains and coastal vegetation can all play a role in reducing impacts of floods, tidal surges and storm events.

Wetlands often treat and detoxify a variety of waste products, such that water flowing through a wetland area may be improved in quality. De-nitrification can be very significant and metals and many organic compounds can be adsorbed by sediments. The relatively long residence time for water in wetlands also allows time for pathogens to lose viability or be consumed by other organisms. There remains a danger, however, that wetlands can accumulate contamination to levels detrimental for wetland ecosystem functions and critical thresholds are not easily determined.

Wetlands can also be **touristic destinations** because of their aesthetic value and their attractive diversity of animal and plant life. Tourism may support livelihoods and the local economy, although access to the benefits may not be equitable for all groups. Activities such as recreational fishing and scuba diving on coral reefs can be of very high value. Tourist demand to visit biologically rich sites can increase the value of intrinsically linked habitats, such as mangroves and seagrass beds, but tourist activity that is too intensive and poorly managed is likely to be both damaging to ecosystems and socially disruptive.

Wetlands also **contribute to regulation of global climate** by sequestering and releasing significant amounts of carbon. They can be significant sinks of carbon as well as sources of carbon dioxide (for instance, boreal peatlands), net sources of carbon sequestration in sediments and transporters of carbon to the sea. Wetlands can also either increase or decrease particular components of the water cycle. Thus, inland and coastal waters may both regulate greenhouse gases (especially carbon dioxide), influencing climate change and rainfall patterns, and play important roles in buffering climate change impacts. In particular, hydrological services include water storage,
flood attenuation and the augmentation of dry-season flows and groundwater recharge. Inland waters also contribute to local micro-climatic conditions and their regulation.

Overall, it is clear that wetlands provide many non-marketed and marketed benefits to people. The total economic value of unconverted wetlands, though rarely adequately quantified, can potentially be greater than that of converted, developed or otherwise modified wetlands. This does not mean that conversion of wetlands is never economically justified, but it emphasises the importance of taking account of the full range of economic and social benefits that are derived from wetlands and the need to bring these to the objective attention of decision-makers.

Evaluations of the range of ecosystem services provided by wetlands tend to suggest that, for most, demand by humans for the services is increasing. The exception may be capture fisheries, but in locations where this is true, it is a result of overfishing and degradation of the resource. Humans have been able to enhance the provisioning services of crop, livestock and aquaculture production through expansion of the area used for production or through technological inputs, but other provisioning, regulating and cultural services are often being degraded or used unsustainably at current levels of use and dependence.

**Linkages with livelihoods**

Ecosystem services are especially important for the economies of low-income, developing countries, where services such as inland fisheries and fuelwood production are particularly important to the livelihoods of poor people. Fisheries provide the primary source of animal protein for nearly 1 billion people. Similarly, more than 2 billion people depend on biomass fuels as their primary or sole source of energy. The linkages between livelihood and ecosystems are such that human activities affect ecosystems and, in turn, they will have consequences for the supply of ecosystem services, such as food, freshwater, fuel wood, and fibre. Ecosystem services and livelihood linkages are such that in exploiting one, you may have to compromise on another, especially with the growing demands which can no longer be met by tapping unexploited resources. For example, to increase food supply, there is a need to convert forest to agriculture, but by doing so, it may decrease the supply of goods of equal or greater importance such as clean water, timber, biodiversity or natural flood control.

Water is one of the necessities for rural livelihoods and is one of the most important production assets. Insecure access to water for consumption and productive uses is a major constraint on poverty reduction in rural areas in many countries. The provision of water for small-scale productive activities, such as smallholder farming, fishing, herding and village artisanal production, facilitates livelihood diversification and helps to address seasonal land-and labour-use peaks and constraints in livelihood systems. It can also alleviate seasonal shortages in relation to production and to consumption needs, fluctuating cash income flow, expenditure needs, and weather- and market-related risks. This can be especially true and important in female-headed households, which are common in rural communities.

Agriculture remains the main resource for supporting rural livelihoods; therefore, water resource productivity needs to be developed in this sector. Water is an essential input in crop and livestock production, though water scarcity is a feature of many livelihood realities. The lack of adequate water is linked to poverty, where households...
with water shortages are more likely to fall into further poverty. It is thus important to address access to water where this needs to be improved.

### 2.3.1 Relative magnitude (per unit area) of ecosystem services derived from inland wetland ecosystems

![Inland Wetlands Table]

Section 2 Self-Assessment Questions

4 Define the concept of ‘ecosystem services’. List and describe the categories of services it covers and give examples for the services provided by an inland wetland ecosystem.

5 Explain the linkages (positive and negative) between ecosystem services and livelihoods or human well-being.
3.0 Water Requirements for Ecosystem Conservation

Section Overview

Until recently, water requirements for ecosystem conservation have generally been assessed downstream of a river and not at ecosystem level. This section presents the ecosystem approach. This forms the basis of assessment of water requirements for ecosystems. Such assessments generally include ecological risk assessment, ecosystem valuation and environmental flows. Approaches for ecosystem management are also presented.

Section Learning Outcomes

By the end of the section, students should be able to:

• explain the ecosystem approach
• present assessment methods for ecosystems water requirements
• critically assess ecosystem management approaches.

3.1 The ecosystem approach

Full recognition of the services provided by aquatic ecosystems can provide a means to inform and achieve water allocation that balances competing uses. For example, conversion of natural ecosystems to intensive croplands or rice fields generally results in an increase in the production of provisioning services, such as food, fuel or fibre, but a reduction in the quantity and/or quality of supporting, regulating and cultural services formerly provided. This is represented in a generalised manner in the figures in 3.1.1 below.

As an example, rice fields that are managed in a multifunctional way may be able to sustain a wider range of ecosystem services than ecosystems that are managed intensively for food items. This requires the identification and management of trade-offs, in which increased output of one service leads to reduction in another. However, it also opens the door to innovative and integrated management solutions that could be ‘win–win’ in that they allow output of two more ecosystem services to be sustained.

The ecosystem approach and conceptual framework is thus highly relevant to sustainable management of water resources and minimisation of conflicts. Ecosystem-based approaches to water management do not have to constrain agricultural development, but can provide and inform opportunities for convergence for social equity, poverty reduction, food security, resource conservation, biodiversity conservation and carbon sequestration. These approaches aim to enhance diversity wherever possible and to build ecological resilience of agricultural landscapes, as well as of ecosystems altered by agriculture.
3.1.1 Comparison of intensive agricultural systems managed for the generation of one ecosystem service and to allow multifunctionality in ecosystem service provision


3.2 Assessment of ecosystem water requirements

The development of holistic approaches that truly integrate assessment of the biophysical and socioeconomic factors determining aquatic resource ecology, productivity, use and livelihoods benefits is thus required. In particular, the scope of the current environmental flow paradigm needs to be broadened to ensure the sustainability of downstream fisheries and the livelihood activities they support, especially in tropical developing countries.

Most tools developed to look at trade-offs involving ecosystems only work well in environments where ecosystem behaviour and response to change are well understood. Ecosystems are very complex and highly variable, and thus predictions of the impact of changes are difficult to make and subject to a high degree of uncertainty. However, to manage and sustain aquatic ecosystems effectively, while meeting other requirements for water, needs tools that can be used to assess trade-offs and provide
information for the formulation of management strategies, supporting policies and regulations. Trade-offs arise between the competing uses for water and the maintenance of a range of ecosystem services. It is some of the latter that have often been neglected in water management in the past. The development of tools or assessment approaches must address this issue.

The range of tools applicable to these problems includes: economic valuation and cost–benefit analysis of ecosystem services and competing water uses, assessment of environmental flows, risk and vulnerability assessments, strategic and environmental impact assessments, and a range of methods for planning and management under uncertainty.

It is important to recognise that in order to use suitable tools effectively there has to be an adequate information base and a predictive capacity to assess how ecosystems may respond to change. Though the use of such tools has been heavily promoted in international forums and conventions, in general, a lack of data, capacity and awareness has hampered application and effective usage. Three of the most important tools are described briefly in 3.2.1.

### 3.2.1 Key tools for the assessment of ecosystem water requirements

- **Ecological risk assessment (ERA):** this tool evaluates the potentially adverse effects that human activities have on living organisms within an ecosystem, providing a way to develop, organise and present scientific information to facilitate decision-making. When conducted on a river basin or sub-catchment scale, the ERA process can be used to identify vulnerable and valued resources, prioritise data collection activities and link human activities to their potential effects. ERA results provide a basis for comparing different management options and infrastructural development plans, enabling decision-makers and the public to make better-informed decisions about the management of water resources and the protection of aquatic ecosystems.

- **Economic valuation:** this is a potentially powerful tool that can be used to evaluate the trade-offs between competing water uses. In particular, we may seek to apply it to the potential trade-off between allocation of water for food production in irrigated agriculture and retention of water in inland water bodies to sustain other ecosystem services. The broad aim is to quantify and compare the range of benefits (both market and non-market) that society obtains from ecosystem services, thus enabling comparison of the economic costs and benefits of any proposed changes in water management and facilitating comparison with other public investments in economic development and environmental protection. Common reasons for attempting valuation are to assess the overall contribution of ecosystems to social and economic well-being, understand how and why economic actors use ecosystems as they do and assess the relative impact of alternative actions. It is, perhaps, most useful in situations where economic arguments favouring development initiatives that lead to ecosystem degradation have failed to take account of the full economic costs of that degradation.

Three situations can be identified for application of economic valuation methods:

- Assessment of total economic value (TEV) to determine the total contribution of ecosystems to the local or national economy and to human well-being.
● Trade-off analysis to evaluate the effects of alternative development options for a given wetland in order to make informed decisions about possibilities for the sustainable, multifunctional use of aquatic ecosystem services.

● Impact assessment to analyse the effects of proposed aquatic ecosystem drainage or other destructive practices on aquatic ecosystem services and their value (ecological, socio-cultural, economic and monetary).

- Environmental flows (EF): this concept refers to the quantity and quality of water needed for river systems to maintain their structure and function. In other words, EF aim to maintain the quantity, quality and seasonality of water considered to be sufficient for protecting the structure and function of an ecosystem and its dependent species and services, taking into account temporal differences in water requirements and spatial variability. There is no single standardised method for estimating environmental flows, rather there are many methods available, which are usually tailored to meet the specific requirements of each assessment. Current environmental flow approaches focus on river discharge patterns as the key driver of aquatic ecosystem processes and conceptualise impacts on the provision of ecosystem services resulting from impacts on ecosystem processes. Holistic approaches have considered socioeconomic impacts, but results are essentially derived from changes in the ecosystem. Methods have been mostly developed in arid or temperate contexts, especially South Africa and Australia, and are not necessarily adequate for other biophysical and climatic contexts such as Asian tropical floodplains.

Source: unit author

3.3 Management of water for aquatic ecosystems

In managing water for ecosystems, mechanisms are needed that can cope with uncertainty but are proactive, not just reactive. In general, proactive action to manage systems sustainably and to build resilience is advantageous, particularly when conditions are changing unpredictably. For this purpose, two approaches have been identified to assist managers: adaptive management and scenario planning. Both approaches examine alternative models of how the world might work and seek to develop policies that are robust to these uncertainties.

Consideration of the linkages and interactions between humankind, water and aquatic resources identifies four main areas of concern:

- Freshwater shortage: due to over abstraction of freshwater causing drying up of rivers, lakes, aquifers, etc. This is mainly attributed to the diversion of water for agricultural development.

- Pollution: mainly refers to eutrophication problems, which arise due to agricultural nutrients and sewage effluents entering streams and other water bodies. Other main concerns are microbial pollution often associated with intensive livestock production, population growth and urbanisation (especially in developing countries that lack effective sewage treatment facilities) and pollution from various chemicals used by industry and agriculture, the latter often from diffuse sources that are difficult to manage.
• Overfishing and other threats (over-exploitation of living resources): often large-scale commercial fishing is the main cause. This is a major problem given the heavy dependency of many people on fisheries for their livelihood. As the human population increases, the demand for food and, therefore, overfishing may also increase.

• Habitat and community modifications: aquatic habitats have already been extensively modified with a consequent reduction in biodiversity and alteration in community structures.

For example, the figure in 3.3.1 illustrates major causes of degradation of inland and coastal wetlands.

3.3.1 Pictorial presentation of some direct drivers of change in inland and coastal wetlands

Invasive species, climate change, and land conversion to urban or suburban areas affect all components of the catchment and coastal zone and are therefore not represented pictorially.

Five overarching questions that facilitate comprehension of the four main areas of concern in relation to water and aquatic resources listed above are set out in 3.3.2. The questions also provide a useful generic conceptual framework which you can apply in your study of each section of this unit.
## 3.3.2 Five overarching questions to guide sustainable management of ecosystems; maintaining both biodiversity and ecosystems services

1. What are the current conditions and trends of ecosystems and their associated human well-being?
   - What ecosystems and what contributions do they make to human well-being?
   - How have ecosystems changed in the past and how has this increased or reduced their capacity to contribute to human well-being?
   - What thresholds, regime shifts or irreversible changes have been observed?
   - What were the most critical factors affecting the observed changes?
   - What are the costs, benefits and risks of the observed changes in ecosystems, and how have these affected different sectors of society and different regions?

2. What are the plausible future changes in ecosystems and in the supply of and demand for ecosystem services? What are the consequent changes in health, livelihood, security, and other constituents of well-being?
   - Under what circumstances are thresholds encountered or are regime shifts or irreversible changes likely to occur?
   - What are the most critical drivers and factors affecting future changes?
   - What are the costs, benefits and risks of plausible future human-induced changes in ecosystems, and how will these affect different sectors of society and different regions?

3. What can we do to enhance well-being and conserve ecosystems? What are the strengths and weaknesses of response options, actions and processes that can be considered to realise or avoid specific future scenarios?
   - What are the trade-off implications of the response options?
   - How does inertia in social and natural systems affect management decisions?

4. What are the most robust findings and key uncertainties that affect provision of ecosystem services (including the consequent changes in health, livelihood and security) and other management decisions and policy formulations?

5. What tools and methods can strengthen capacity to assess ecosystems, the services they provide, their impacts on human well-being and the implications of response options?

Source: adapted from MA (2003) p. 35.
Section 3 Self-Assessment Questions

6 What are the four main interactions of concern between human water use and conservation of water resources for natural ecosystems?

7 True or false?
   (a) In freshwater systems, high levels of local endemism and species richness are typical for several major groups, including decapod crustaceans, molluscs and aquatic insects.
   (b) The five major threats to freshwater biodiversity are over-exploitation, pollution, organic farming, flow modification and habitat degradation.
   (c) Estimates of global wetland area show that the Neotropics (the biogeographic region of the Americas that stretches southward from the Tropic of Cancer and includes southern Mexico, Central and South America and the West Indies) are the highest contributors to wetland resources in terms of area.
   (d) The biodiversity of coastal ecosystems is more threatened than freshwater ecosystems.

8 In the following two examples, match the example to the correct ecosystem service category for aquatic ecosystems.

Example 1

   Ecosystem service category
   (a) Provisioning service (i) capture fisheries
   (b) Regulating service (ii) provision of habitat
   (c) Supporting service (iii) recreational activities
   (d) Cultural service (iv) reduction of nutrients and pollutants in water

Example 2

   Ecosystem service category
   (a) Provisioning service (i) aesthetic of natural landscape features
   (b) Regulating service (ii) food for bees and other pollinators
   (c) Supporting service (iii) smoothing of flood peaks in river flows
   (d) Cultural service (iv) supply of sand and gravel for construction

9 Assess the relative importance of the different categories of ecosystem services provided by aquatic ecosystems and provide examples of the trade-offs that have occurred as a consequence of the pressure to expand agriculture.
UNIT SUMMARY

This unit introduced the fundamental characteristics of water resources and the key principles of their origin, functioning and availability. While water connects the whole range of scales, the resource is governed by a unique and globally functional hydrological cycle that is intertwined with other biochemical cycles at the scale of the planet's biosphere. The hydrological cycle on Earth was explained through the different forms taken by water resources and the ways in which they move throughout ecological and social systems. The various terms and concepts involved in describing the different forms and types of water resources were defined. It is important to distinguish them because they have different availability and accessibility for water uses and users, and there are major implications for their assessment and management. The section also explained why consideration of scales matters so much in the assessment and management of water resources.

The second section presented water resources across ecosystem services. This requires understanding of the structure and processes of ecosystems. The four main natural cycles driving aquatic ecosystems are water, carbon, nitrogen and phosphorous. The section focused on their role and how they have been changed or affected by anthropogenic influences. The concept of ‘ecosystem services’ was introduced focusing on the services provided by water resources, and providing examples of the four categories of services: provisioning, regulating, supporting and cultural. The presentation of the role and value of aquatic ecosystem services was completed through consideration of their direct and indirect linkages with human well-being. Full recognition of the services provided by aquatic ecosystems can provide a means to inform and achieve an allocation of water that balances competing uses.

The last section presented the ecosystem approach as it forms the basis of assessment of water requirements for ecosystems. Such assessments generally include ecological risk assessment, ecosystem valuation and environmental flows. The development of holistic approaches truly integrating assessment of the biophysical and socioeconomic factors that determine aquatic resource ecology, productivity, environmental flow, water use and livelihoods benefits is thus required. Different approaches for the management of water in ecosystems were then presented. They include mechanisms that can cope with uncertainty proactively.
UNIT SELF-ASSESSMENT QUESTIONS

1. Draw from memory a diagram that captures all of the following:
   - the hydrological cycle
   - (some of the) key hydrological concepts
   - blue and green water.

2. Give two examples each of consumptive and non-consumptive uses of water and explain why they fall into that category.

3. List and define the key concepts that are used to describe and estimate water availability.

4. Make a list of possible negative impacts on aquatic ecosystems arising from human land and water use. Then, for each, make brief notes on a suitable real world example drawing from your reading or own experience.

5. List three tools (analytical approaches) that can be used to assess aquatic ecosystem degradation and briefly explain the purpose of each.
<table>
<thead>
<tr>
<th>Key Terms and Concepts</th>
<th>Definition</th>
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<tbody>
<tr>
<td>aquatic ecosystems</td>
<td>A broad term that includes a range of inland, coastal and marine ecosystems but, for the purpose of this module, concentrates on inland and coastal aquatic ecosystems, such as bogs, marshes, swamps, lagoons, lakes and rivers, as well as mangroves, coastal tidal flats, artificial reservoirs and rice fields.</td>
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<tr>
<td>blue water</td>
<td>The total quantity of surface water and groundwater.</td>
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<tr>
<td>developed resources</td>
<td>The proportion of available water supplies which are already being used or are earmarked for particular uses.</td>
</tr>
<tr>
<td>ecosystem processes</td>
<td>The main natural cycles that occur in ecosystems, namely the water, carbon, nitrogen and phosphorous cycles.</td>
</tr>
<tr>
<td>ecosystem services</td>
<td>The benefits that people obtain from ecosystems. These include provisioning, regulating, supporting and cultural services.</td>
</tr>
<tr>
<td>environmental flows</td>
<td>The quantity, quality and seasonality of water considered to be sufficient for protecting the structure and function of an ecosystem and its dependent species and services, taking into account temporal differences in water requirements and spatial variability.</td>
</tr>
<tr>
<td>evapotranspiration</td>
<td>Involves both processes of evaporation and transpiration and represents a combined loss of water resources from a watershed.</td>
</tr>
<tr>
<td>green water</td>
<td>Otherwise known as soil water, is all water stored in the root zone that is evaporated by natural vegetation and/or agriculture.</td>
</tr>
<tr>
<td>hydrological cycle</td>
<td>The combined flows, use, change in state and storage of water above and below the ground and in the atmosphere, as water resources naturally circulate.</td>
</tr>
<tr>
<td>non-consumptive use of water</td>
<td>Water use can be described as consumptive or non-consumptive. A use is consumptive if that water is not immediately available for another use. Evapotranspiration by a crop is consumptive. Water returned as surface water after use is generally considered non-consumptive. Subsurface seepage and flows are more difficult to classify and this may ultimately depend on the time period before re-use of the water is possible.</td>
</tr>
<tr>
<td>potentially utilisable resources</td>
<td>That part of the annual renewable water resources that can be used.</td>
</tr>
<tr>
<td>renewable resources</td>
<td>Those water resources which may be used again.</td>
</tr>
<tr>
<td>virtual water</td>
<td>This refers to the volume of water used in the production of a good or service. It is also known as ‘embedded water’.</td>
</tr>
</tbody>
</table>
FURTHER STUDY MATERIALS


This first chapter of the MA Framework for Assessment introduces the conceptual framework for the Millennium Ecosystem Assessment (MA), which places human well-being as a central focus while acknowledging the intrinsic value of biodiversity and ecosystems. The framework assumes a dynamic interaction between people and ecosystems driving both ecosystem change and human well-being. It looks at the necessity of a multi-scale approach in making a full assessment of the interactions between people and ecosystems, as this better reflects the multi-scale nature of decision-making, allows the examination of driving forces and provides a means of examining the differential impact of ecosystem changes and policy responses on different regions and groups within regions.


This further reading provides a concise guide to the ecology of wetlands and the services supplied by these ecosystems, taking into account issues associated with human well-being. It summarises the condition, distribution and extent of wetlands and their species, and the extent of wetland services and their value, and identifies the drivers of loss and change to wetlands. Given future scenarios and the implications of changes in wetlands for human well-being, responses are identified for the wise use of wetlands. As this reading has colourful graphical content, it is also available as a pdf in your e-study guide.
REFERENCES


