What Science
Can Tell Us

Water for Forests and People in the Mediterranean Region

– A Challenging Balance

Yves Birot, Carlos Gracia and Marc Palahí (editors)

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Contents

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Preface

The issue surrounding forest and water has been identified for a long time by professional foresters and policy makers as a key question related to the management of natural resources, taking into account both society needs and environmental concerns. Today, the topic is gaining a renewed attention as reflected by the series of international events dedicated to it (see Box 1).Despite significant progress being made in the scientific understanding of forest and water interactions, uncertainty – in some cases confusion – persist because of the complexity of the issue and the limits in extrapolating research findings to various contexts: countries and regions, geographic scales, forest types and the geo-morphological situation. In addition, there has also been a failure to effectively communicate new scientific results to policy makers and planners, and to challenge entrenched views.

Box 1. International momentum in the forest and water agenda

The topic of forests and water interactions has received increasing attention at the international level and has gained momentum over the last few years. Important milestone events were the following:

- The International Expert Meeting on Forests and Water, November 2002, Shiga, Japan;
- The International Year of Freshwater in 2003;
- The Endorsement of Warsaw Resolution 2 “Forests and Water” by the Ministerial Conference on the Protection of Forests in Europe (now Forest Europe), November 2007, Warsaw, Poland;
- The 26th Session of the European Forestry Commission’s Working Party on the Management of Mountain Watersheds, August 2008, Oulu, Finland;
- The III International Conference – Forest and Water, September 2008, Mrągowo, Poland;
- The Plenary Session on Forests and Water held during the European Forest Week, October 2008, Rome, Italy;
- The International Conference “Water and Forests: A Convenient Truth?”, October 2008, Barcelona, Spain;
- The Workshop on Forests and Water, May 2009, Antalya, Turkey;
- The Forests and Water Sessions and Side Event at the XIII World Forestry Congress, October 2009, Buenos Aires, Argentina;
- The Forests and Water Segment during the 35th Session of the European Forestry Commission, April 2010, Lisbon, Portugal.
- The Plenary Session on Forests and Water during the 20th Session of the Committee on Forestry (COFO), October 2010, Rome, Italy.

There is a need therefore to provide more comprehensive knowledge to policy makers on the forest/water interface within the framework of different policy initiatives (e.g. the EU Water Framework Directive, Green Infrastructures, and Forest Europe). This need becomes urgent in the Mediterranean region, which is permanently confronted with the scarcity of water – the main limiting factor for life and the most strategic resource for ensuring the sustainability of the region. In this context, EFIMED – The Mediterranean Regional Office of EFI – has taken steps towards improving the science-policy dialogue regarding the crucial issue of water, forest ecosystems and societies by conceiving and publishing a book entitled: **Water for Forests and People in the Mediterranean: A Challenging Balance**.

The Food and Agriculture Organization of the United Nations (FAO) has contributed to this initiative with technical input and financial support. Having played a leading role in forests and water-related issues for many years, FAO has progressively built up a conceptual and operational framework linking forest hydrology to watershed management, sustainable mountain development, disaster risk management and the mitigation and adaptation to climate change. The strong focus on forests and water issues of FAO's work is of great relevance for arid and semi-arid areas like the Mediterranean Basin.

Two other partners, CREAF and CTFC (in relation to the SYLVAMED project), have also committed resources to support EFIMED's undertaking, in particular for making the dissemination of the book to non-English speaking readers possible.

With the present volume, in the EFI series "*What Science Can Tell Us*", EFIMED has attempted to make available the most recent knowledge and the best international scientific expertise – based on contributions from forty renowned scientists – on the complex relationships, trade-offs and emerging challenges regarding the trinomial water-society-forests.

Marc Palahi
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Figure 1. The artificial lake of La Môle in a fully forested watershed dominated by cork oak, supplying water to the tourist town of Saint-Tropez, Var, France. Photo by C. Birot.

Introduction

Yves Birot and Carlos Gracia

Water is the foundation for all biological life on Earth and one of the basic links between the biosphere and atmosphere. It is equally fundamental for humans and nature as M.K. Tolba affirms: "It hydrates our body, grows our food, powers our industry and nourishes our terrestrial and aquatic ecosystems." The water cycle links human societies and ecosystems. Water is one of nature's subsystems.

The long history of the Mediterranean region, as cradle of civilisation, is dominated by the interactions and co-evolution between man and its natural environment, with the development of agriculture, including irrigated agriculture, stock farming and the emergence of urban habitats. These evolutions are still going on with different forms. The northern rim of the Mediterranean Basin has experienced over millennia a strong decrease of the forest and vegetation cover due to anthropogenic pressure; however, such a process has been reversed during the last decades due to the abandonment of rural areas and the urbanisation of society, which has led to natural plant re-colonisation dynamics. In contrast, the eastern and southern rims are characterised by a high pressure from human populations on forest and woodland ecosystems leading to over-exploitation, overgrazing and biological degradation. Such a situation is explained by a high population growth, low income per capita and a marked rural population density. Evolutions in land use, both on the northern and southern rims have affected and are affecting biological and bio-geo-chemical processes, including the **water cycle** as well as the water resources in quantity and quality.

Mediterranean countries are home to 60% the world's "water-poor" populations with less than 1,000 m³/inhabitant/year. By 2025, 63 million of Mediterranean's population will be in the need of water (with less than 500 m³/inhabitant/year).

The Mediterranean region is recurrently or permanently confronted with the scarcity of water due, for example, to climatic factors like limited and irregular rainfall, typically, heavy autumn/winter rainfall with high intensity resulting in important runoff (and soil erosion); high evaporative demand; and important social factors such as changes in land use (especially the need for more irrigated agriculture) to cope with a growing demography, especially in urban areas. The issue of **climate change** is (and will be) aggravating the situation as it is expected to: i) increase water scarcity (less rainfall and runoff) and decrease water resources; and ii) impact, through higher aridity and more frequent extreme events (heat wave, dry spells), the vitality, resilience and even survival of trees and ecosystems. This, in turn, raises the question of a loss of goods and services that ecosystems provide to human societies. The question of the water cycle and water budget, therefore, should be considered in an integrated manner by taking into account both **blue water** (water in liquid form used for the human needs or that which flows into the oceans) and **green water** (water having the vapour form resulting from evaporation and transpiration processes). Such an approach of water flows raises many scientific challenges.

Forests, woodlands, garrigues and maquis are not the only components of Mediterranean rural landscapes; they are adjacent to other ecosystems, more or less man-induced such as irrigated and rain-fed crop lands, rangelands and aquatic ecosystems. However, forests and woodlands may cover important areas, often occupying the upper part of a watershed in hilly or mountainous areas, and playing a crucial role in soil protection. Accordingly, they may influence the water regime. The interactions between forest cover and water are rather complex in regard to variables such as low flow, high flow, water yield and water quality. As they depend on many parameters, some of which have a site-specific nature, the results in the scientific literature appear contradictory. In fact, "no one size fits all". Moreover, the relationships between forests and water are characterised by many accepted opinions that Hamilton (1985) described as the four Ms: misunderstanding, myth, misinterpretation and misinformation. There is a clear need to close the gap between science and public perception.

Water, forests and people form the three vertices of a triangular relationship that should be analysed pairwise and as a whole.

Many of the water-related natural processes in the landscape are neither part of the agenda of policy-makers and politicians, nor that of the general public, who tend to see this issue as a specialist preserve. Moreover, water issues have been almost exclusively looked upon from the angle of blue water. Time has come to design innovative policies and strategies aimed at balancing water for man and nature through a real socio-eco-hydrological approach and based on an integrated land/water/ecosystem management. This requires increased efforts from the scientific community, in particular through a joint approach between hydrologists and ecologists/foresters for organising and structuring the available knowledge in a comprehensive manner, and for undertaking new scientific investigations.

With the present paper, EFIMED, the Mediterranean Regional Office of the European Forest Institute, would like to act as catalyst in the Science-Policy/Society dialogue and make available some concrete “food for thought”.

1.

Basics

Water, ecosystems and societies have been considered for a long time as different systems – and still are. However, it is now time to take a holistic approach which integrates these elements into a single yet complex hydro-eco-socio system. The complexity of the system should prevent any over-simplification or “black or white” opinion; rather it should call for a better understanding of the scientific background which underlies it. The current chapter aims at presenting the “basics” that should be known and is structured into five sections:

1.1 The water cycle at a glance: blue and green water;
1.2 Water and forest resources, and people in the Mediterranean area: the current situation;
1.3 Do forest areas influence rainfall regime?;
1.4 Water fluxes in forests; and
1.5 Role of Mediterranean forests in water and soil conservation.

Figure 2. Investigation on the global hydrologic cycle: global average precipitation in April from 1985 to 2005. Source: NASA.

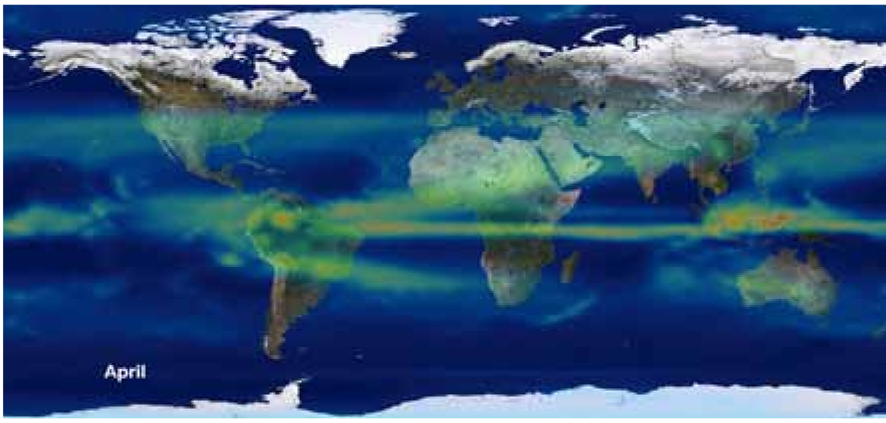

Figure 3. Reforestation on contour line terracing after a wildfire (Allègre-Les Fumades -30- France). Photo by C. Birot.

1.1.

The Hydrologic Cycle at a Glance: Blue and Green Water

Yves Birot and Carlos Gracia

At the global scale and since the origin of our planet, the same stock of water has been continuously transferred around through flows according to processes and pathways of the hydrologic cycle. This cycle creates links between the biosphere and the atmosphere, and between the ecosystems, including the anthropo-systems.

As for any cycled element or resource, water status can be characterized by **stocks** and **flows**. The total stock of water in the Earth's system has remained unchanged since its beginning; water is neither destroyed nor created. The total stock is composed of various reservoirs: oceans (by far the most important); ice (polar regions and high mountains); the atmosphere; rivers and lakes, permafrosts; soil moisture; groundwater; and the water embedded in living organisms, in particular vegetation. The stock of each of these reservoirs is influenced by ingoing and outgoing flows of water:

i) Rain falls over lands and oceans (about three times more for the latter).
ii) Water returns to oceans after runoff and percolation through surface flow and ground water flow.
iii) Water is emitted towards the atmosphere through ocean evaporation and condensation, as well as evaporation from lakes and rivers, and evapotranspiration from the vegetal cover.
iv) Some water vapour is transported from ocean to land; however, contrary to commonly accepted views, it accounts only for about 10% of the total ocean evaporation and one third of land precipitation (Figure 4).

The water cycle is solar powered; it consumes 25% of the total solar energy striking the earth during one year.

The journey of water in terrestrial ecosystems begins when rain falls, after which it follows routes (pathways) that can divide at junctions, called partitioning points, as described in Figure 5. The first partitioning point (PP) is located in the canopy, which intercepts part of the rainfall – the water being re-emitted by direct evaporation. At the second PP, rainfall is divided into surface runoff and infiltration. At the third PP, moisture is divided into evaporation from soil, transpiration from plants, and groundwater recharge.

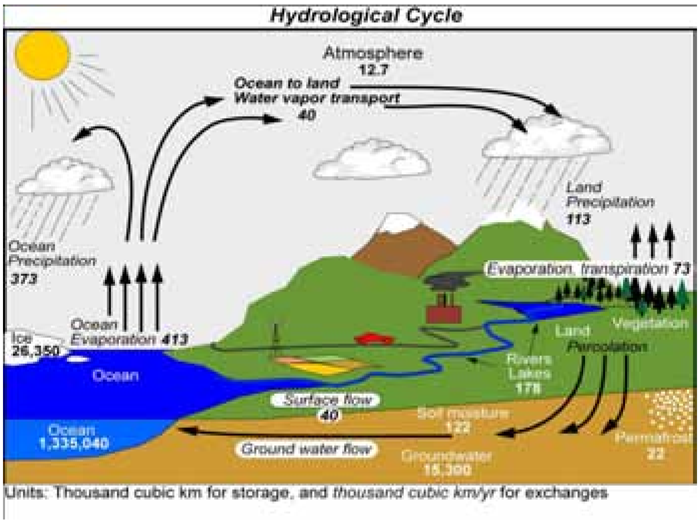

Figure 4. The global hydrological cycle: estimates of the main water reservoirs (plain font) in 10^3/km^3/yr and the flow of moisture through the system (italic font) in 10^3/km^3/yr, equivalent to exagrams (10^{18}g) per year. Source: Trenberth et al. 2007.

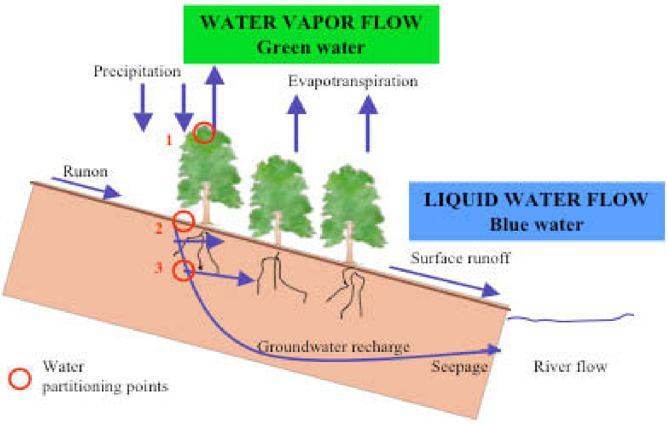

Figure 5. The hydrological cycle for an ecosystem showing the partitioning of rainfall. Source: Falkenmark and Rockström 2005.

Together, evaporation and transpiration constitute the **green flow** branch, while surface runoff and groundwater recharge constitute the **blue flow** branch. The partitioning of water flows in the hydrological cycle is determined by biophysical (e.g. water holding capacity of the soil, rainfall intensity, atmospheric demand, etc.), biological (photosynthesis pathway) and human (e.g. land use, forest management, compaction, etc.) factors.

The speed of water movement along the different routes and between reservoirs of the hydrologic cycle can vary greatly. The travel time in groundwater recharge can be very slow, whereas the peak flow following a very intense and heavy rainfall is almost immediate. However, recent studies on the isotopic composition of water show that the water collected downstream of a water catchment in such circumstances contain molecules coming from the incident rain in addition to others previously stored in the soil. The renewal of water in oceans and groundwater may take several thousands of years, while a molecule of water stays an average of only eight days in the atmosphere and only few hours in plants. Table 1 presents the residence time in some compartments of the water cycle.

Table 1. Average reservoir residence times. Source: Pidwirmy 2006.

Reservoirs	Average residence time	Reservoirs	Average residence time
Antarctica	20,000 years	Groundwater (deep)	10,000 years
Oceans	3,200 years	Lakes	50–100 years
Glaciers	20–100 years	Rivers	2–6 months
Seasonal snow cover	2–6 months	Marshes/wetlands	5 years
Soil moisture	1–2 months	Water incorporated in plants	Several hours
Groundwater (shallow)	10–200 years		

> The sound management of water resources at various geographical scales is based on a thorough analysis of the water balance. It is an accounting method, which requires assessing many hydrological data regarding water stocks and fluxes (input and output).

How can the amount of water moving from the atmosphere, across the land surface, into the ground, through plants, into the ocean and back to the atmosphere through evaporation and condensation be calculated? The most common method is a water balance or water budget – a convenient method of bookkeeping that provides a good framework for understanding hydrologic processes. It can be performed at various scales: from plot level, small and large watersheds (Figure 6), even globally. It is necessary to understand this "balance" in order to sustain the resource and its environmental and human interconnections within the considered area, for example the watershed. In its simplest form, a water budget analysis is based on a single equation that balances water input and output while accounting for changes in storage.

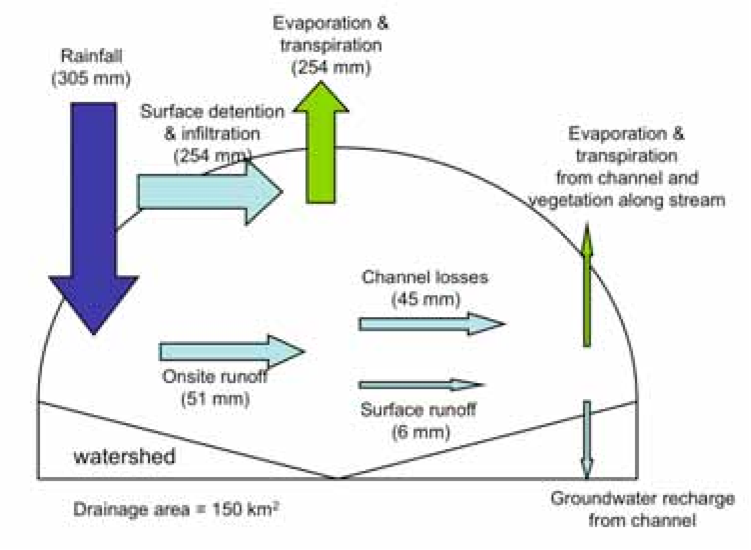

Figure 6. Water balance illustrating the water accounting within the Walnut Gulch Experimental Watershed, an ephemeral tributary watershed within the large San Pedro River Watershed, Arizona. Source: Renard et al. 1993.

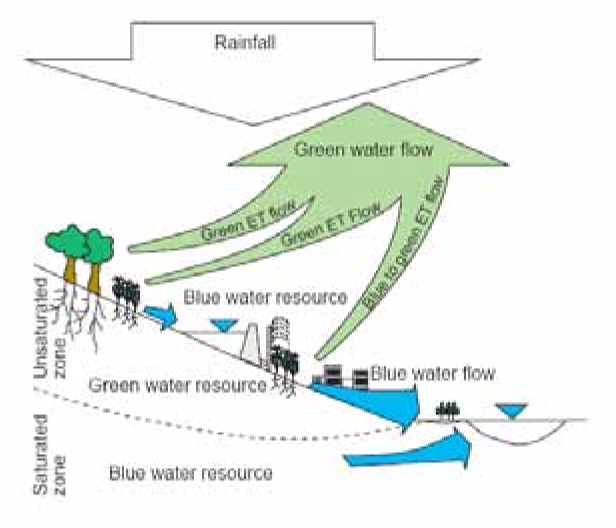

Figure 7. Green and Blue water. Source: Falkenmark and Rockström 2005.

A water balance analysis requires assessing hydrologic data such as: rainfall; interception; evaporation; evapotranspiration; percolation and infiltration; runoff (surface and groundwater); storage (surface and groundwater); and water use. Such data are not always available. This difficulty can be partly overcome by using simulation hydrologic models (empirical and process-based), which can project detailed water budget variations over several years. **Nevertheless, real data coming from long-term instrumented watersheds are always required.**

The notion of green/blue water provides a valuable conceptual framework in water management at various scales. Incoming rainfall generates two types of water resources: green water in the soil consumed in plant growth and production and returning to the atmosphere as vapour flow; and blue water in rivers and aquifers, accessible for human use, including irrigation (by which blue water is transformed into green water). This framework (Figure 7) offers an interesting approach of several issues of the analysis, such as:

- bridging ecological protection and hydrological processes
- producing food through rain-fed and/or irrigated agriculture
- integrating water management by looking at the water's movement through the landscape in relation to land use
- balancing water for humans and nature
- understanding the concept of eco-socio-hydrology

The green water approach has raised much interest in recent years, in particular in dry regions where it dominates the hydrological cycle. However, it is clear that there are limits to the concept in informing water resources management and planning.

These limits are related to some simplification of the hydrological cycle in green water-based studies; adequate spatial and temporal scales for the consideration of low flows; the uncertainty regarding water storage in the soil profile; and the generation of flows from saturated and unsaturated soil water. For this reason, it is proposed that more attention is paid to the hydrological linkages between green and blue water flows and their representation in water resources management rather than focusing on these flows.

Recommended reading

- Falkenmark, M. and Rockström, J. 2005. Balancing water for humans and nature; the new approach in Ecohydrology. Earthscan. 247 p.
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1.2.

Water and Forest Resources and People in the Mediterranean:
the Current Situation

Gaëlle Thivet and Mohammed Blinda

Home to some 470 million inhabitants, the Mediterranean region with its climate and the diversity of its territories is located at the crossroads of three continents. Its natural and cultural heritage and, of course, the common sea shared by the rim countries and territories is the locus where environmental and development issues are the most acute. In this eco-region, economies remain largely dependent on natural resources, particularly in the south. The need to satisfy the requirements of a growing population in a region where climate is uncertain and energy crises loom raises many questions on the availability and renewal of water resources, the fertility of soil, the survival of forests, natural balances and land development.

The demographic growth is considerable in the south and east, particularly in urban and coastal areas with an annual increase of 4.1 million inhabitants and an annual flow of 175 million tourists.

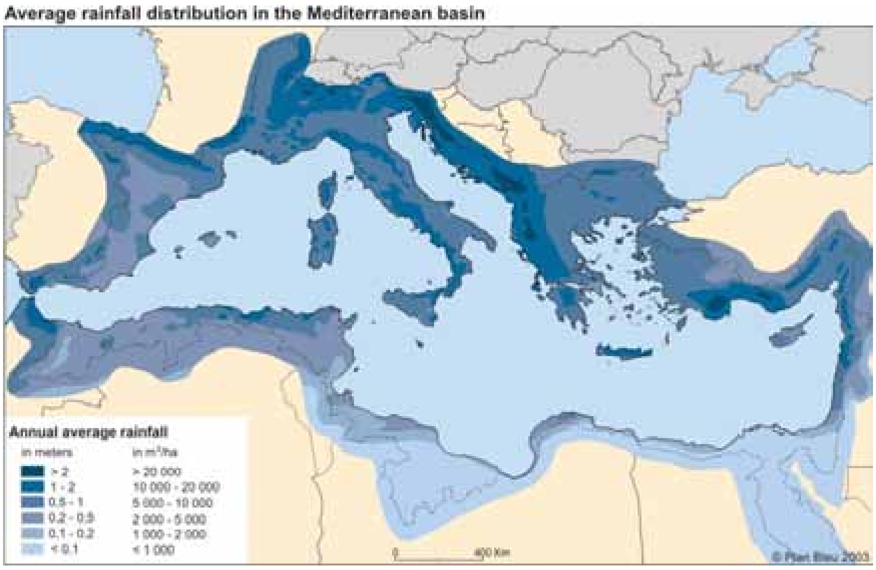

Figure 8. Average rainfall distribution in the Mediterranean basin.
Source: Plan Bleu, Margat.

Over the past 40 years, the population growth in the Mediterranean region has been considerable, increasing from 280 million in 1970 to 468 million in 2008. This is particularly true in southern and eastern Mediterranean countries (SEMC)[1] where a historical growth record of 2.21% per year was reached between 1970 and 2008, with an increase of 4.1 million inhabitants per year. This represents five times the population growth of northern Mediterranean countries over the same period, averaging at 0.5% yearly.

Although their population numbers have exceeded those of the northern Mediterranean countries since 1985, the fertility rate in the SEMCs has dropped by 2% to 3% a year in the past twenty years. However, despite the acceleration of demographic transition, it is expected that population growth will continue until 2025 and beyond (see Chapter 5.2). The increase in demographic pressure is particularly high in urban and coastal areas. One third of the Mediterranean population is concentrated on coastal zones, covering only 13% of the total available surface. In 2000, Mediterranean coasts hosted 70 million urban inhabitants, over 580 coastal towns and 175 million visitors.

Irregular rainfall in time and space imposes the construction of storage capacity amounting to a high proportion of surface water (>90% in Syria, 80% in Morocco and Tunisia).

This population growth is putting increasing pressure on already vulnerable water resources due to the irregular, scarce and fragile character of water in the Mediterranean. The Mediterranean climate is characterised by the highly uneven spread of rainfall in both space and time (Figure 8).

Estimations show that the mean quantity of renewable underground and surface fresh water resources throughout the Mediterranean averages out at approximately 1,080 km^3/year, with nearly two-thirds concentrated in northern countries. In the east and south respectively, countries enjoy one quarter and one tenth of these resources, while only 1% of the total quantity is available to the six least endowed countries and territories (Cyprus, Israel, Libya, Malta, Palestinian Territories and Tunisia). Furthermore, 16% of these resources cross borders and are therefore shared by several countries, whether

Box 1. Facts and figures

In 2008, the 22 rim countries and territories of the Mediterranean represented:

- 5.7% of the world's lands above sea level, including many deserts and mountain ranges
- 7% of the world's population (stable share) with approximately 468 million inhabitants
- 31% of international tourism with 175 million visitors
- 3% of global water resources
- 60% of the world's population living in "water-poor" countries[2]
- 12% of global GDP (declining) and 8% of CO_2 emissions (increasing)

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[1] Including all riparian countries from Morocco to Turkey.

[2] The countries where renewable natural water resources per capita (although not all exploitable) level off at 1,000 m^3/capita/year.

Table 2. Renewable natural water resources in the Mediterranean region Source: Plan Bleu, 2007.

		Sub-regions (individual countries)			Total
		North (Europe)	East (Near East)	South (North Africa)	
Renewable natural resources (blue water) (annual average) (a)	Total (km^3/yr)	740	247	95	1,083
	Total (%)	68	23	9	100
	Per capita (m^3/yr)	3,915	2,371	631	2,441
Competition index	Inhabitants/hm^3/yr	255	422	1,584	410
Exploitable renewable natural resources (annual average) (b)	Total (km^3/yr)	359	133	81	572
	Total (%)	63	23	14	100
	Per capita (m^3/yr)	1,899	1,279	536	1,289
Estimation of green water (annual average) (c)	Total (km^3/yr)	300	100	70	470
	Total (%)	64	21	15	100

(a) Internal and external resources calculated per sub-region, excluding double accounting due to riparian country exchanges.
(b) As per individual country criteria.
(c) Used and consumed rainwater (evapotranspiration) by farm irrigation and grazing lands.

Mediterranean or not. Rates on reliance on external resources are particularly high in Egypt (98%), Israel (59%), Croatia (47%) and Syria (43%).

To this irregularity of water resources in space is added further irregularity in time, both intra- and inter-year. Intra-year irregularity is characterised by rainfall concentrated over several months (50–100 days per year on average) and by summer droughts which occur during the peak season of demand (irrigation, tourism). Inter-year variability versus annual averages is characterised by frequent rainfall deficits stemming from inefficient rainfall in winter and spring, with essentially hydrological consequences and/or from aggravated summer droughts (magnitude and length) with immediate impacts on soil and land cover and with varying hydrological effects.

Such irregularity considerably constrains the use of surface water resources and has justified the construction of storage infrastructures, more favourable to intra- and inter-year stock regulation. The rate of surface water regulation is therefore high in some countries: 90% in Syria, 80% in Morocco and Tunisia, 70% in Cyprus and 40% in Israel.

Resources must, however, not be restricted to "blue water" from surface and underground flows, but must also include "green water", i.e. rainwater. In the Mediterranean countries, the annual average flow of green water is comprised between 400 and 500 km^3, but remains unevenly spread: 65% in the north, 20% in the east and 15% in the south (Table 2), which explains the high demand for irrigation water in all the southern and eastern countries.

The regional impacts of global climate change on the water cycle – although still difficult to quantify – will quite probably impoverish the water resources of the Mediterranean countries, aggravate variability and therefore jeopardise exploitability, mostly impacting the water-poor countries. Several southern countries have recently lowered their assessment of water resources used in their development plan objectives, either as an anticipatory measure or to take into account the frequent years of drought of the past decade which have lowered annual averages by 20% in Algeria and by 25% in Morocco.

The expression of average "natural" water per capita is the first indicator which serves to characterise situations of "tension" or "water poverty" (between 1,000 and 500 m^3 per capita/year) and "structural shortage" (under 500 m^3 per capita/year). It also illustrates the gaps between countries or internal regions or between catchment areas (Figure 9).

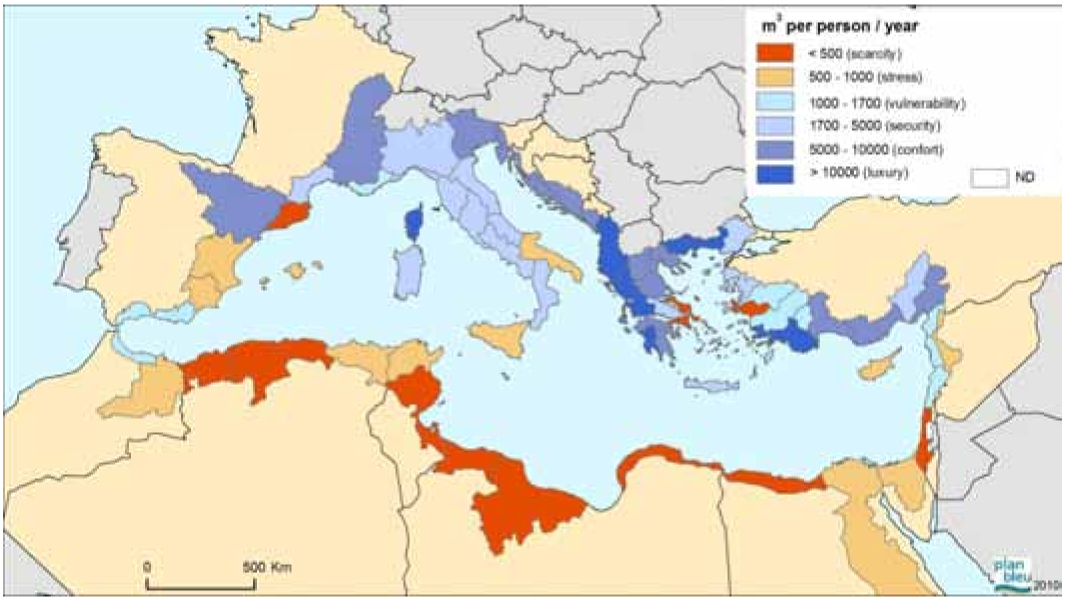

Figure 9. Renewable natural water resources (internal and external) per capita in elementary catchment basins (1995–2008). Source: Plan Bleu estimates from national sources.

In 2005, nearly 180 million Mediterranean inhabitants were water-poor and 60 million faced shortage.

Demand for water is increasing dramatically in the south and the east and is more and more satisfied through unsustainable water production

Water demands, i.e. amounts abstracted (95% of total) and unconventional production processes (desalination, reuse of treated wastewater), including losses during transport and use (estimated at nearly 40% of total water demand), **have doubled in the second half of the 20th century to reach 280 km^3/year for all riparian countries in 2007. Agriculture is the prime consumer** (180 km^3/year to irrigate 26 million hectares) accounting for 64% of the total water demand: 45% in the north, and 82% in the south and east, while it remains marginal in the eastern Adriatic countries only.

At the Mediterranean scale, the pressure of demand on resources, expressed through the exploitation index of renewable natural water resources[3], reveals strong geographical contrasts (Figure 10). Currently, in countries such as Egypt, Israel, Libya, Malta and Syria, as well as in the Gaza Strip, consumption is nearing and in some cases exceeding the availability limits of renewable resources. The situation is even more alarming when the index is computed not at the scale of individual countries but at the scale of the sole Mediterranean catchment area. Tensions on resources appear greater when only

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[3] Ratio definition: volume of annual abstraction on renewable natural water resources / annual average volume of available renewable natural water resources, expressed as a percentage.

Figure 10. Exploitation index of renewable water resources in individual countries and catchment areas (2005). Source: Plan Bleu.

Note. Indices close to or higher than 80% indicate already high tensions on water resources; ratios between 60% and 80% are signs of a high risk of medium-term structural tensions; ratios between 20% and 60% point to local or conjectural tension.

"exploitable" water resources are taken into account as they represent approximately a half or one third of renewable natural water resources.

A growing share of the demand is satisfied by unsustainable water production and is estimated at 16 km^3/year, of which 66% is from fossil water abstraction and 34% from over-exploitation of renewable resources. The unsustainable water production index[4] is particularly high in Libya (86%), the Gaza Strip (40%), Tunisia (29%), Algeria (29%) and Spain (25%).

Furthermore, tensions on natural water resources are further compounded by degradations and pollutions from human activities, which modify the water regime or quality thus limiting the possibilities of use. This results in the aggravated vulnerability of supply due to cost increases (water treatment costs in particular), public health risks, and conflicts between consumers, major sectors, regions or countries.

Water policies are still too focused on supply, inducing long-term risks.

To satisfy growing water demand, national strategies continue to focus on increasing water supply through the construction of large-scale hydrological infrastructures; the development of inter-regional and international transfers; the "mining" of non-renewable underground water reserves (in Saharan catchment areas); or such unconventional resources as the reuse of treated wastewater (Spain, Israel, Cyprus, Egypt, Tunisia), agricultural drainage water (Egypt); or sea and brackish water desalination (growing in Malta, Spain, Algeria and Israel).

The pursuit of such approaches centred on increasing supply and abstraction, exploiting and further deteriorating natural resources, may induce long-term risks, in particular: the rapid depletion of fossil resources; the destruction of coastal aquifers due to sea water intrusion; the degradation of water and aquatic ecosystem quality; the reduction of run-offs; and the regression of wetland ecosystems. Policies based on sup-

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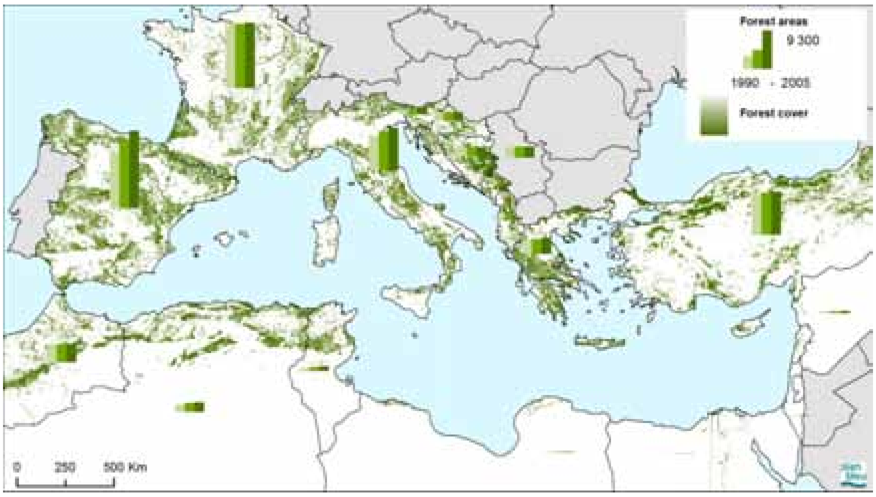
[4] Corresponding to the total volume of water abstraction from non-renewable aquifers and over-exploitation of water tables expressed as the percentage of total abstraction volume.

ply are reaching physical, socio-economic and environmental limits, as demonstrated by the state of many dams in southern and eastern countries where silting has largely decreased storage capacity.

> In spite of some common features, forest and woodland ecosystems and their dynamics show regional variations. On both rims, forests are often located in mountain areas, acting as "water towers" and main biodiversity havens, rendering crucial the interactions between forests and water upstream from catchment areas.

For centuries, human activities such as the exploitation of wood and grazing and agricultural clearing practices have submitted the natural Mediterranean ecosystems[5] to high pressure. The intensity of such practices has sometimes exceeded the forests' natural capacity for renewal, resulting in the degradation of land cover, erosion and even desertification. In periods of lesser pressure, the resilience of Mediterranean ecosystems gave rise to more or less rapid natural regeneration as forests reappeared on previously cultivated or grazed land.

The situation on both rims is currently highly contrasted (Figure 11). In the north, after the high over-use of the 18th and 19th centuries and the regression which ensued, the process of forest regeneration is observed almost everywhere, due to the gradual aban-



Note. In the north, forests currently cover nearly 50 million hectares including 20 to 25 million hectares of typically Mediterranean forest, to which are added 20 million ha of other woodlands (macchia, garrigue, matorrals). In the south and east, forests account for approximately 13 million ha and other woodlands for 15 million with over two thirds in Turkey.

Figure 11. Changes in forests surfaces from 1990–2007 (1,000 ha). Source: FAO

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[5] The natural and semi-natural Mediterranean land ecosystems under consideration here are composed of forests (territories where canopy cover by large trees exceeds 10%), other woodlands (bush, scrub, matorrals, wooded steppes) and natural grazing areas (mountain pastures, high steppes, predesert steppes, alfa grass steppes). Areas of intensive farming or aquatic ecosystems are not included. While national statistics yield useful information on the changes in forests, the knowledge regarding other woodlands and their grazing resources is much less specific.

donment of agricultural and grazing practices on most marginal surfaces made less profitable by enlarged agricultural market conditions. The increase of wooded land surfaces has further been reinforced by reforestation initiatives.

Adversely, pressure from over-use is still high on the woodlands in the south where marginal surfaces are cleared for farming, overgrazing or firewood. As the populations of the massifs fall prey to degradation, the surface of natural wooded areas is regressing; and although many higher altitude forests are turning into shrublands such as *maquis* or *garrigue* or are flecked with ever-larger clearings, they still fall under the statistical classification of "forests". However, over the past few years, improvements and even progress have been observed thanks to reforestation efforts. The situation remains intermediate in eastern Mediterranean countries.

Society's demands to the forest have evolved towards an increased multifunctionality: from wood production to social usage and environmental concerns.

In rural Mediterranean societies, woodlands and grazing lands have always been crucial for local and regional economies, providing firewood, wood for constructions on land and for sea vessels, multiple products from hunting and harvesting activities, as well as being vital grazing resources. The situation has changed for the most part in the north, but such goods still play an essential role in the south, particularly firewood and grazing. However, due to slow growth, heterogeneous production and exploitation difficulties, the modern wood industry has rarely shown an interest in Mediterranean forests.

New practices have appeared with the urban and industrial era – woodlands are used for recreation and leisure such as ecotourism and outdoor sports by both residents and tourists alike. These frequently non marketed environmental services and activities are often prevalent in the north and are now also growing in popularity in the south, although extractive activities are still predominant.

While the protective function of these ecosystems has been well-known for a long time, the focus on sustainable development now emphasises their capital value as producers of local and global public goods; in the protection of soil and water; in the combat against erosion and desertification; in the absorption of greenhouses gases; and in the conservation of flora and fauna biodiversity. This last aspect is all the more important as the Mediterranean region is one the world's biodiversity hot spots.

Traditional methods of forest management – when respecting land conservation and forest regeneration – are well-suited to wood production. However, new social usage and current concerns on the preservation of biodiversity and the combat against global climate change require major innovations in the field of woodland management.

The future of Mediterranean forests is threatened by the increased risks of drought-induced wildfires.

Forest fires are frequent during the summer season, destroying large areas – nearly 600,000 ha were destroyed by fire in 2007 in northern Mediterranean countries alone. In the north, the number of fire outbreaks is slowly growing, but the main issue relates to large fires which account for a vast majority of damage in terms of area and cost. Policies have been too focused on fire exclusion rather than on fire management, and have resulted in fuel accumulation. Rural abandonment has also lead to the encroachment of vegetation over large and uniform areas thus contributing to the increased fire risk. Another consequence of the accumulation of biomass is the accrued consumption of water – the source of growing competition between forests, cities and irrigation. In southern and eastern countries, fires are still less destructive (61,000 ha in 2005), but there are marked new outbreaks in the east, with nearly 80,000 ha burnt in 2007 (Cyprus, Slovenia, Croatia and Turkey). Although woodlands used for grazing are less prone to fire outbreaks as grazing protects against overgrowth and reduces the risk of fire, the reduction of such grazing surfaces could aggravate the risk. Furthermore, climate change may considerably increase the risk of fire hazards due to longer and more severe dry seasons, both in the north and south.

Mediterranean lands are subject to slow but steady desertification processes related to pronounced soil degradation due to unsuited management of range, rainfed and irrigated land, particularly in the south and the east of the Mediterranean.

Estimations on the amplitude and degree of irreversibility of desertification[6] are often contradictory and highly controversial. However, the seriousness of the phenomenon is today widely acknowledged in the region. According to estimations reported at the beginning of the 1990s, 80% of arid, semi-arid or dry lands are impacted by desertification in the south and east of the Mediterranean. In such zones, the impact is strongest on pasturelands and rainfed arable lands, as well as on irrigated lands due mainly to salinisation. Desertification also impacts nearly two-thirds of the arid or dry lands in Mediterranean Europe (Spain, Greece and Italy).

Although national data on the degree of soil degradation remain fragmentary and relatively unreliable, they confirm the seriousness and amplitude of the phenomenon caused in part by erosion from wind and water. The main causes of soil degradation are deforestation, intensive agricultural practices, overgrazing, the over-use of biomass, industrial activities and public works.

Figure 12 shows that in most Mediterranean countries, arable lands have been diminishing for over 20 years due to erosion, loss of fertility and urban sprawl. The values expressed are net and thus mask contrary phenomena. In the case of Egypt, the globally positive picture obscures the surfaces reclaimed from the desert on the one hand and

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[6] "Desertification" is to be understood as "*land degradation in arid, semi-arid and sub-humid zones due to several factors, which include climate variations and human activities*". Desertification is therefore a process leading to gradual loss of soil productivity and reduction of land cover essentially attributable to human activities in dry zones. Due to lesser land cover, soils are more sensitive to erosion from water and wind, which leads to their gradual destruction. The consequences of this process are decreased fertility and degraded water cycles, which have devastating effects on vegetation and production.

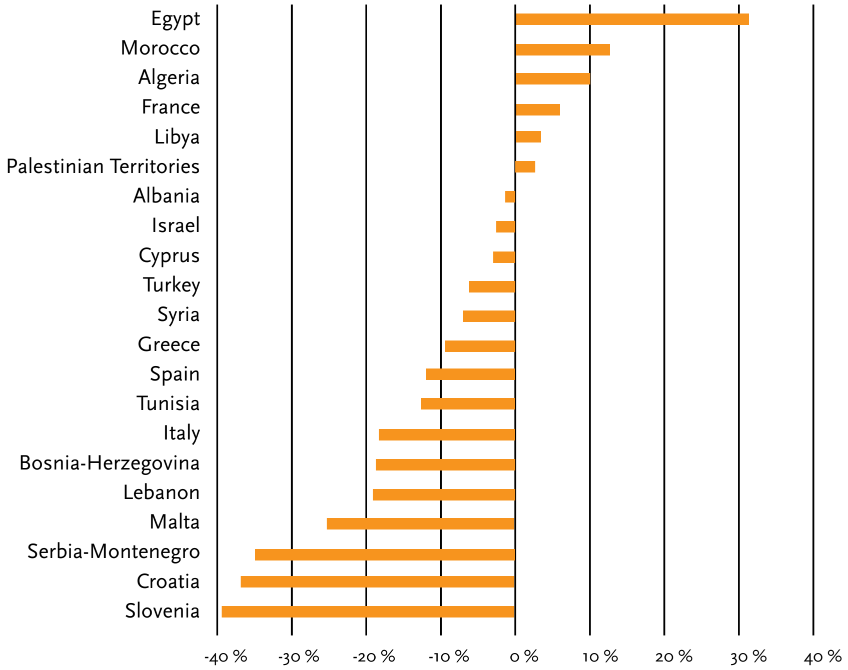

Figure 12. Net loss of arable lands between 1980 and 2005 (%). Source: FAO, Plan Bleu computation.

the loss of so-called ancient lands due to rapid urban sprawl, desertification and salinisation on the other. In the Mediterranean, arable land surfaces per capita have been reduced by 50% over 40 years.

The role of soil is fundamental to regulate run-offs, protect biodiversity, structure landscapes and absorb CO_2. Soil quality and environmental issues are dependent on how soil is used. In Italy for example, the gradual reduction over recent years of the total cultivated areas (-16.5% from 1982 to 2003) has been essentially limited to grasslands and grazing lands (-26%). Near urban centres (particularly in the plains, coastal zones and valleys), agriculture is on the contrary submitted to very strong pressures from real estate developments and has lead to the replacement of the most fertile soils to benefit non-agricultural usages, which are responsible for negative and often irreversible consequences

In many agricultural regions, particularly coastal areas and plains where agriculture is specialised, the risks of soil pollution and contamination are much higher. Excess quantities of phosphorus released by organic and mineral fertilizers are responsible for the alteration of the structural and organic balance of soils.

The risks of erosion from water and from the reduction of organic matter contents in soils are highest in mountain areas, with the exception of forests. In Italy, the average soil loss is estimated at over three tons per hectare/year and can, in some cases such as in the southern regions, be more significant and critical. Lastly, risks of water-induced erosion and fires have increased due to the stoppage of grazing and forestry activities, and to unsustainable forest management.

Stronger policies and sustainable management practices for water resources, forests and woodlands, and for soil preservation are required.

Mediterranean regions are highly vulnerable due to such handicaps as their specific landscapes and climate, and their limited land and water resources that are unevenly spread throughout the Basin. The numerous civilizations of the Mediterranean have worked relentlessly to tame these resources and conquer the land. Today, both rims are encountering difficulties in the quantitative and qualitative maintenance or renewal of these natural resources on a par with population growth, despite the measures implemented to optimise these practices and limit their impact on the environment. Ongoing population growth and the expected impacts of climate change will require stronger policies and sustainable management practices for water resources, forests and woodlands, and for soil preservation.

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1.3.

Do Forest Areas Influence Rainfall Regime?

Giorgio Matteucci, Jerry Vanclay and Javier Martin-Vide

At local to landscape scales, the role of forests in affecting microclimatic conditions, in regulating flows and availability of water downstream and in preventing erosion is generally well established. When precipitation is considered, people living in areas with large or partial forest land cover have the common believe that forests influence the local rainfall regimes. At the global scale, annual precipitation over the land is about 110,000 km^3, or 110×10^{15} kgH_2O, while evaporation and transpiration processes generate about 70×10^{15} kg of water. Terrestrial plants add 32×10^{15} kg of water vapour to the atmosphere annually, approximately two times the calculated water content of the atmosphere. This huge global flux of water vapour passes through microscopic pores on the surface of leaves (stomata) and represents a fundamental ecosystem service, contributing to the global water cycle and climate regulation by cloud formation (see sections 1.1, 1.4, 3.1).

Hence, forests sustain the hydrological cycle through evapotranspiration, which cools the climate through feedback with clouds and precipitation; large-scale model simulations have routinely demonstrated the biogeophysical regulation of climate by vegetation through albedo (reflectivity), turbulent fluxes and effects on the hydrological cycle.

Large scale tropical deforestation impacts rainfall and may create a warmer and drier climate.

When considering the role of forests in affecting rainfall regimes, the recycling of water through transpiration is a crucial and perhaps the most important process. In the Amazon, approximately 25%–30% of the rainfall is related to precipitation recycling. In this respect, observational and modelling studies indicate that tropical deforestation, changing evapotranspiration, albedo and aerodynamic roughness (which favour turbulent movements of moisture and air) impact rainfall, although at different magnitudes, while large-scale conversions of forest to pasture create a warmer, drier climate. However, forest-atmosphere interactions are complex; small-scale deforestation resulting in a heterogeneous forest cover may even produce mesoscale circulations that enhance convective clouds and precipitation.

Montane “fog” forests capture the water from wind- or convective-driven clouds.

Montane “fog” forests are one type of ecosystem where the active role of forests on the hydrologic cycle is more prominent. In addition to normal precipitation, these forests harvest water directly from wind- (advective) or convective-driven clouds. These ecosystems are common in interior mountain ranges particularly, but not exclusively, in the tropics. For example, mountain forests are also present in coastal ranges in some Mediterranean countries and on small oceanic islands. The interception of cloud and fog water significantly affects the water availability for the forests and also downstream. In this respect, the deforestation of montane forests can seriously impact the hydrologic cycle of the surrounding landscape, as other vegetation types do not have the proper structure to intercept cloud and fog moisture. In this condition, the reforestation of montane tops and slopes can restablish this peculiar hydrological cycle. Furthermore, modelling has shown that deforestation in the lowlands can cause the elevation of the orographic clouds, leading to changes in the harvesting of cloud water by montane vegetation.

A body of evidence, both by observations and modelling studies, suggests that forests affect local climatology/weather patterns through changes in albedo, leaf area, canopy structure (roughness) and evapotranspiration.

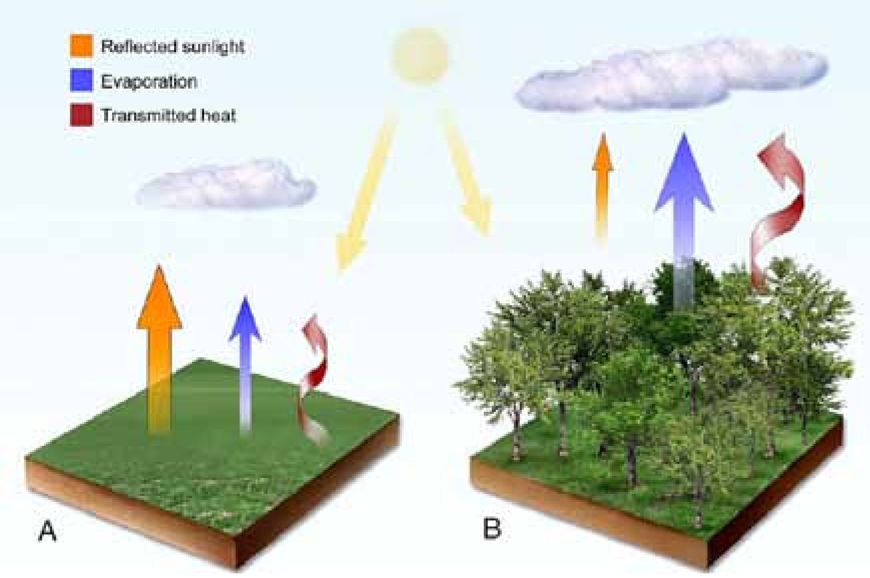

Figure 13. “Examples of various biophysical factors in a grassland or cropland (A) and a forest (B). Because of a grassland or cropland’s higher reflectivity (albedo), it typically reflects more sunlight than the forest does, cooling surface air temperatures relatively more. In contrast, the forest often evaporates more water and transmits more heat to the atmosphere (latent and sensible heat, respectively), cooling it locally compared to the grassland or unirrigated cropland. More water vapour in the atmosphere can lead to a greater number and height of clouds as well as to increased convective rainfall. In addition, the forest has a more uneven canopy (surface roughness) that increases the mixing and upwelling of air.” Source: Jackson et al. 2008

In temperate climates, the effects of forest cover on rainfall and other biophysical parameters is more uncertain. For example, in warm seasons, in areas where convective precipitation is a common process, rainfall should be expected to change in response to change in land cover since surface fluxes of moisture, heat and transpiration also change. However, the effect on cold season precipitation is much less clear. A number of climate model studies suggest that temperate forests cool the air compared to grasslands and croplands, while other studies show the opposite. The local cooling by the forest is caused by more evapotranspiration that may contribute to increased rainfall and cooling in nearby areas. In other regions where water availability is relatively scarce, such as the south-western USA, forest plantations may warm regional climate by absorbing more sunlight (decreased albedo) without substantially increasing evapotranspiration (see section 2.2).

Climatic effects of long-term land use/land cover were simulated for the USA under three difference surface vegetation distribution: pristine conditions (1700), maximum deforestation (1910) and current conditions (1990). Modellers found that changes in the land-use/land-cover pattern can lead to several degrees of warming/cooling accompanied by significant changes in precipitation patterns. However, in temperate regions, it is difficult to detect the signature of forests' land-use changes on precipitation due to the naturally high frequency large-scale meteorological system (e.g. frontal depressions) and rainfall patterns; the regional landscape variability; the nonlinear changes in the forest cover and the related effects of urbanisation; pollution loadings; and regional circulation.

Changes in land cover can trigger hydrologic changes also at the local scale. In Sahel, an initial drought, probably triggered by changes in ocean circulation and/or land use patterns, caused a substantial reduction in plant cover. As a result, with declining vegetation, albedo increased and evapotranspiration decreased; convective uplift and associated monsoon rains were also reduced in the region. Hence, positive ecosystem feedbacks apparently contributed to the magnitude and extended duration of the drought. Desertification is widespread in arid regions of the world, due to both climatic and land-use-change impacts. To what extent might these human influences contribute to enhance drought? On the reverse side, can afforestation reduce the trend towards continued drought? The importance of ecosystem feedbacks on the hydrological cycle suggests that there is space for management options that could potentially reduce the likelihood of extended droughts (see section 5.3).

Figure 14. Biotic pump of atmospheric moisture: transpiration fluxes regulated by natural forests exceed oceanic evaporation fluxes to the degree when the arising ocean-to-land fluxes of moist air become large enough to compensate losses of water to runoff in the entire river basin. Source: Sheil and Murdiyarso 2009.

Conversion from grasslands or croplands to forest leads to a decrease in albedo and increases of *Leaf Area Index**, canopy roughness and rooting depth. Changes in these parameters can modify the near-surface energy fluxes, which can influence temperature and humidity. In this respect, measurements and modelling studies agree that afforestation and reforestation generally decrease near-surface temperatures and increase evapotranspiration, while impacts on precipitation are not so clear, depending on the geographical location, extension of the plantation and other regional characteristics (see section 2.2). For example, over Sahel, modelling exercises indicate that current rainfall increases in an afforestation/reforestation scenario compared to current land cover, due to changes in vegetation structure, moisture patterns and evapotranspiration. In southwestern Australia, land-cover changes from trees to grasslands/croplands over the last 250 years could partially explain the decreases in winter precipitation and extensive reforestation may cause, in the long term, an increase in rainfall (see also sections 2.2, 5.3). On the other hand, an exercise coupling an afforestation scenario and a climate model over the USA found that changes in summer precipitation were marginal and depended on site location.

Several factors influencing water use by tree plantations can be controlled by management and there is scope to design and manage forest plantations for increased water use efficiency. Plantation design (edges, firebreaks, streamlines, use of mixed species) has the potential to modify the atmospheric coupling of forest plantations with impact on their water use. Furthermore, proper management of natural and planted forest has a relevant impact on the water that may become available downstream for agricultural and civil uses (see sections 4.3, 4.4).

Hence, the body of evidence, both by observations and modelling studies, suggests that forests affect local climate/weather patterns through changes in albedo, Leaf Area, canopy structure (roughness) and evapotranspiration.

Recent findings, referred to as the active "biotic pump" theory, suggest that in areas with extensive and continuous natural forest cover, atmospheric moisture is transported inland from ocean to forests.

Is the influence of forests on rainfall an "active" process? Recently, while analysing vegetation data from terrestrial transects of the International Geosphere Biosphere Program and precipitation fields, researchers concluded that rainfall in areas with extensive natural forests (such those of the Amazon, the Yenisey river basin in Siberia and equatorial Africa) does not decrease with increasing distance from the ocean – the same is not true over non-forested areas – and proposed the existence of an active "biotic pump" that transports atmospheric moisture inland from the ocean to forests, regulated by the continuous forest cover. Due to the features described above, natural forests maintain high evaporation fluxes, which support the ascending air motion over the forest and "suck in" moist air from the ocean. The authors of the study claimed that the replacement of the natural forest cover by other land cover may lead to an important reduction in the mean continental precipitation and so to assure the long-term stability of the terrestrial water cycle the recovery of natural, self-sustaining forests on continent-wide areas is necessary.

However, the "evaporative force" on which the "biotic pump" theory is based has been criticised by micrometeorologists and hydrologists as not being supported by basic physical principles; other researchers, on the other hand, underlined the relevance of the "biotic pump" in offering new lines of investigation in landscape ecology, hydrology, forest restoration, paleoclimates and transforming, and, if proven valid, how we view forest loss, climate change, hydrology and environmental services.

We should improve the weaknesses and uncertainties in understanding and modelling the climatic responses, including precipitation patterns, to land cover change.

Even though the theory of "forests as biotic pump" has not received enough confirming support to date, should we discard the issues raised by the authors of the theory? This is not the case! All researchers working on the role of forest and vegetation on climate agree that we should improve the weaknesses and uncertainties in modelling the climatic responses, including precipitation patterns, to land cover change. In this respect, it must be underlined that land-use/land-cover change is still not generally recognised in international climate assessments as playing a role on precipitation, at least not as significant as that caused by the radiative effect of the human addition of greenhouse gases, since forests can amplify or dampen climate change arising from anthropogenic greenhouse gas emission through albedo, evapotranspiration, the carbon cycle and other processes (see sections 5.1, 5.2, 5.5).

> *"The biophysical consequences of forest cover change and other co-effects can be large at regional scales and may sometimes reduce or even cancel the benefits of carbon sequestration. Biophysical interactions should therefore be factored into climate mitigation strategy in at least two ways: in designing carbon sequestration projects to achieve the greatest climate benefit and in comparing the costs and benefits of terrestrial carbon sequestration with those of other mitigation activities."* Jackson et al. *Environ. Res. Lett.*, 2008.

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1.4.

Water Fluxes in Forests [1]

Jorge S. David, Juan Bellot, Yves Birot and Teresa S. David

Water fluxes into and out of forests can viewed at different scales - both in space and in time. At the catchment level, the primary space scale of inputs and outputs of water are usually easy to identify and follow a simple water mass balance equation.

The simplified water mass balance (water budget) of forested catchments can be written as: $P = E + Q + IF + \;S$ (1), where P is precipitation, E is evapotranspiration, Q is streamflow at the catchment outlet, IF is deep infiltration and S is the variation in storage within the catchment (soil and groundwater). Normally, the deep infiltration (IF) is a small output extremely difficult to assess and evaluate, and in the case of an impermeable geology will be zero (see Figure 15 and Chapter 2). Also, at the annual basis, S is most often negligible, which further simplifies equation (1) at this time scale. P is the input flux of water into the catchment and E and Q are the main output fluxes. This means that when rain falls into the catchment, part of it is evaporated back to the atmosphere and the remainder of the water flows out of the catchment through the channel stream line. As equation (1) shows, if the input is greater than the outputs, the variation in storage is positive (recharge); however, if the input is smaller than the outputs the variation in storage is negative (depletion). The water balance equation (1) can be applied at any time-interval scales. To simplify our approach, the analysis will start at the simpler annual time scale, and then proceed at shorter time scales to identify processes that are difficult to assess and understand on an annual basis.

Hereafter, the main elements of the water mass balance equation (1) will be analysed in more detail.

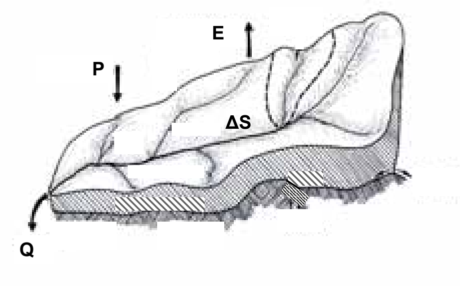

Figure 15. The water balance fluxes at the catchment level considering an impermeable geology:

P = Rainfall; E = Evapotranspiration;
Q = Streamflow; DS = Variation in storage.

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[1] See also sections 1.5, 2.1, 2.2, and 4.1

Box 2. Important definitions

- **Evapotranspiration** from a forested catchment is the sum of all fluxes of water evaporation out of the catchment surface. The evaporation fluxes, which are referred to as the **green water**, can follow different paths in the way out of the exchange surface layer, which differentiate the partial components of overall evapotranspiration: **interception loss**, **transpiration** and **soil evaporation**.
- **Interception loss** is the direct evaporation from free water surfaces retained on leaves during and immediately after rain events when the canopy is wet. In Mediterranean forest ecosystems, it may amount to 25% of the annual evapotranspiration.
- **Transpiration** is the dominant pathway of green water flow in Mediterranean forests. Water is absorbed from soil or groundwater by roots, transported by xylem sapwood of stems and branches, and finally released back to the atmosphere through leaf stomata (see Fig. 17). In Mediterranean forest ecosystems, it may amount about to 75% of total evapotranspiration.
- **Soil evaporation** is the direct evaporation of water to the atmosphere from soil surface and upper layers

Precipitation is usually the only input flux into the catchment. In Mediterranean-type climates, precipitation shows a high inter-annual variability and a strong seasonality with high intensity rainfall events in the rainy season.

Rainfall mainly concentrates in autumn, winter and early spring; the late spring and summer being usually hot and dry (seasonal summer drought). The severity of the Mediterranean seasonal summer drought has, however, a strong inter-annual variability which is connected to the irregular time distribution patterns of rainfall. Climate change scenarios for the Mediterranean region foresee an aggravation in the length and severity of the summer drought period as well as dry spells.

When rain falls onto a vegetated surface, part of it is intercepted by the canopy and evaporated directly back into the atmosphere (interception loss, I) and the remainder reaches the ground, either through gaps and dripping from the canopy (throughfall), or by running down the main stems (stemflow) (see Figure 16). The magnitude of interception loss by evaporation depends on the distribution, duration and intensity of rainfall, the canopy storage capacity (typically ~2–5 mm) and the rate of evaporation from the wet canopy. Once the canopy storage capacity is saturated, water will trickle and drip to the ground. Frequent light rainfall wetting the canopy gives much more opportunity for high interception losses than a rainfall regime dominated by large falls in a few heavy storms, where the canopy is wetted only rarely and most of the storm period rainwater can drain through the canopy to reach the ground.

Since radiation is low during rainfall, the evaporation rate under such conditions is predominantly determined by the aerodynamic roughness of the surface (aerodynamic conductance). Since the canopy of forests (tall and irregular elements) is aerodynamically much rougher than that of short vegetation (grass), and generates turbulent eddies which are crucial in vertical water transport, evaporation rates from wet canopies are 3–5 times higher from the former than from the latter under similar meteorological conditions.

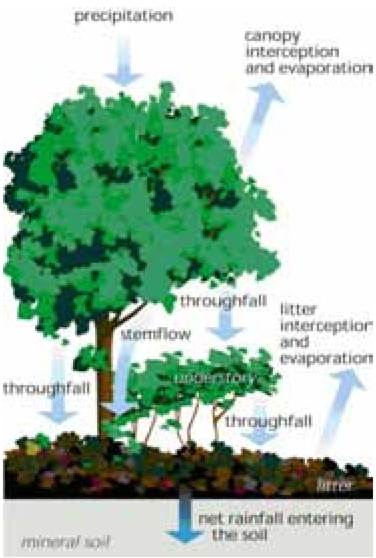

Figure 16. The rainfall interception process. Source: www.fairfaxcounty.gov/.../urbanforest.htm

Transpiration from Mediterranean forests may amount to 75% of overall forest evapotranspiration, while interceptions losses account for about 25%.

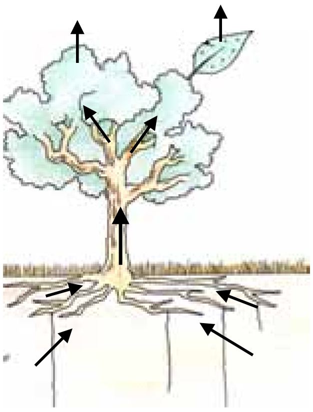

Figure 17. The transpiration process: water is absorbed by roots and released by leaf stomata – ascending flow through xylem sapwood.

On a worldwide perspective, higher interception losses occur in climates with frequent small storms (e.g. temperate climates) than in climates with a fewer larger storms (e.g. Mediterranean climates). Interception loss from forests across the world may range from 8% to 60% of rainfall and from 25% to 75% of overall forest evapotranspiration. The reported values for Mediterranean forests are in the lower range of these intervals.

Although the atmospheric drivers of transpiration and interception loss are the same (radiation and vapour pressure deficit maintained by wind), transpiration is a physiologically controlled process (stomatal aperture) whereas interception loss is a strict physically-driven evaporation process. Due to the features of the Mediterranean climate (low rainfall frequency), transpiration predominates over interception loss in the long-term water balance of Mediterranean forests. The reported values in the literature state that on an annual basis, transpiration from Mediterranean forests may amount to about three-quarters of overall forest evapotranspiration.

The supply of water to the transpiration flux totally relies on infiltrated water stored in surface and deep soil, within the range of tree root access. Tree species adapted to the Mediterranean climate need to survive the seasonal summer drought. To do so, they usually rely on a well developed root system – both horizontally and in depth – that is able to exploit a large reservoir of stored water. Evergreen Mediterranean species cope to survive the summer drought either by drought tolerance (stomatal closure and leaf shedding) or drought avoidance (deep rooting) strategies (see section 3.3). When water tables are shallow, deep roots may directly tap water from these groundwater reservoirs. These features are common to trees in all semi-arid environments. Long-term transpiration from forests is always higher than that from shrubs or herbs due to the more developed root system of the former and canopy roughness.

Box 3. Soil evaporation patterns in arid zones

Soil moisture and gas exchange studies carried out in open semi-arid ecosystems of southern Spain and Israel suggest that soil evaporation may be much higher than previously thought in some cases. Confirmation of this is given by a recent study carried out at a sparse, semi-arid pine forest in Israel, where soil evaporation was measured through gas exchange chambers: direct evaporation rates were much higher from sun-exposed than from shaded soils; annual soil evaporation was about 36% of the incoming rainfall. This high amount of soil evaporation was ascribed to the local rainfall regime, characterized by small showers that frequently re-wetted the exposed topsoil.

Both transpiration and interception loss from forests greatly depend on leaf area index (the ratio between the sum of the area of all trees leaves and the soil area of a given forest plot) and thus on stand density. Low density forests (which may be another adaptation to dryness) have lower transpiration and interception losses than denser ones.

Direct evaporation from wet shallow **soil** is frequently assumed as negligible in vegetated areas (both in forests and shrublands or grasslands). This assumption is based on two main reasons: (i) the canopy of vegetation protects the soil surface from the evaporation atmospheric drivers (radiation and wind); and (ii) the soil moisture depth involved in the process is low. However, there are some exceptions in arid conditions as explained in Box 3.

In general terms, direct soil evaporation can probably be considered negligible in most forested areas, except in some open semi-arid forests subject to frequent small rains.

Although a small component of the overall annual water balance of Mediterranean catchments, the **streamflow** output, i.e. **blue water**, plays a paramount role on the downstream water supply to urban populations, industry and irrigated agriculture.

In addition to evapotranspiration, streamflow is the other main output that must be considered from forested catchments (see equation (1)). Under Mediterranean climatic conditions, annual rainfall is usually lower than the atmospheric evaporative demand (frequently evaluated through potential evapotranspiration (PE)). Under these circumstances, the annual streamflow should be expected to be very low, compared to the annual overall evaporation. This is confirmed by data collected both at catchment and plot levels, which show that annual streamflow is normally less than 5% of rainfall in Mediterranean forested areas. In the dryer areas and/or during the dryer years, the annual streamflow declines to zero. This may also be valid for other vegetation types, since annual potential evapotranspiration will anyhow be higher than the annual rainfall in the Mediterranean.

If the annual rainfall was evenly distributed in time, there would be no streamflow at all in Mediterranean catchments, since the annual water balance is always negative (P<PE). To understand the fundaments and reasons for the occurrence of some degree of streamflow, we must look at shorter time scales when the water balance is temporary positive (P>PE), namely during the Mediterranean wet season. During this period, there

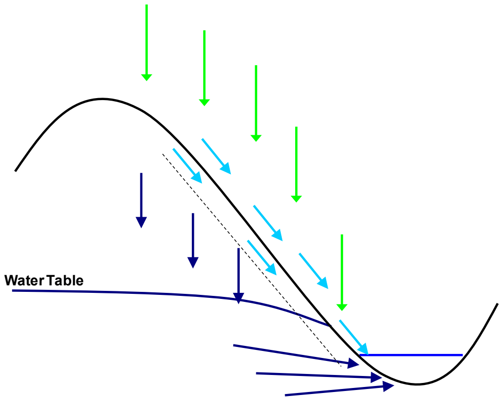

Figure 18. The flow generation processes: green arrows indicate rainfall; light blue the quick flow responses (surface and subsurface runoff); and dark blue the slow/delayed flow responses (deep drainage followed by groundwater flow).

is usually a net input of water into the soil and, when the soil water storage is full, water percolates deeper down recharging the groundwater aquifers. Typically, there are a couple of months between soil and aquifer recharge: soil water starts to recharge upon the onset of the autumn rains, whereas aquifer recharge takes place later during the winter. Water stored in groundwater reservoirs may be used the following spring and summer to supply tree deep roots (if the water table is shallow), drain slowly to the main stream channel (if the geology is impermeable), remain stored, or drain deeper out of the catchment limits (if the bedrock is permeable and the aquifer deep). Groundwater drainage (see Figure 18) and some slow subsurface flow are the most common origins of the delayed flow component that can maintain some flow in the stream channel during the Mediterranean dry season. Due to their high evapotranspiration, forests usually decrease the amount of deep drainage and delayed flow. During periods of extremely high-intensity rainfall, , and mainly when the rainfall intensity exceeds the soil infiltration capacity, some quick flow responses to the rainfall may occur, such as surface runoff. (see section 1.5). In addition to surface runoff, there are other possible pathways that may originate quick runoff responses, namely subsurface flow and saturation overland flow at the wet expanded stream banks (see Figure 18). Quick runoff responses may result in floods and soil erosion. Surface runoff only occurs in soils with a low superficial infiltration capacity. Therefore, the source area of surface runoff is not usually continuous but rather patchy in space. Since forest litter and organic matter contribute to increase soil infiltration, surface runoff is very uncommon in forests, mainly occurring in exposed and degraded soils. To some extent, forests are considered to prevent quick flow generation processes (mainly surface runoff); however, the mitigation effect of forests on floods seems to be more effective in small/medium floods than in large/extreme ones.

Both the quick and delayed flow components converge to the main stream channel forming together the streamflow catchment output.

Figure 19. Eddy flux tower for assessing gas (water vapour, CO_2) exchanges between a *Pinus pinaster* forest and atmosphere in Portugal. Photo by J. Soares David.

Vegetation type and density may affect the amount and time distribution of streamflow through its action on evapotranspiration and surface soil infiltration. The manipulation of vegetation in Mediterranean forested catchments may therefore play an important role in trying to get the more appropriate and optimised equilibrium between water balance fluxes. This requires careful consideration of multiple objectives as conflicts and trade-offs are involved.

Thinking on an annual basis, vegetation type may play some role on the amount of evapotranspiration and, in turn, on streamflow: vegetation types with higher evapotranspiration (such as forests) will produce less streamflow and vice-versa (see equation (1)). The impact of forest cover changes on hydrology, as related to major perturbations (wildfire) or deliberate management actions (clear cuttings, thinnings) is dealt with in sections 2 and 2.1.

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- Bellot, J., Bonet, A., Sanchez, J.R. and Chirino, E. 2001. Likely effects of land use changes on the runoff and aquifer recharge in a semiarid landscape using a hydrological model. Landscape and Urban Planning 55: 41–53.
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- Jewitt, G. 2005. Water and Forests. In: Encyclopedia of Hydrological Sciences. Anderson, M.G. (Ed.). Volume 5, Chapter 186. John Wiley & Sons, Ltd., Chichester. Pp. 2895–2909.
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1.5.

Role of the Mediterranean Forest in Soil and Water Conservation

Jean Albergel, Jean Collinet, Patrick Zante and Hedi Hamrouni

In the Mediterranean, soils constitute a fragile component of terrestrial ecosystems; they are susceptible to erosion as they are exposed to heavy and intense rainfall, followed by marked runoff phenomena accelerated by the hilly or mountainous topography. The issues of water and soil must therefore be considered together.

As pointed out in section 1.4, rainfall regime in the Mediterranean is characterised by intense meteorological events, with an important fraction of annual precipitation falling in a few days. These features, combined with intensive and destructive land use (forest clearing, overgrazing and fires) over millennia have resulted in marked regressive ecological evolution of the terrestrial ecosystem, in particular due to pronounced erosion phenomena. Soil erosion is still a major phenomenon today as illustrated in Figures 20, 25 and 26.

For example, two vast climatic areas of the Iberian Peninsula and Maghreb are characterised by soil parent material developed on limestone and marl of the Cretaceous and Tertiary periods. The semi-arid region is characterised by rains of 300 to 600 mm, an inter-annual variability of 25% to 50% and 4–7 dry months. The climatic conditions, which were once more humid, have allowed for the differentiation of isohumic* soils, red fersiallitic* soils more or less encrusted on limestone or, in conditions of lower drainage or on marls, vertic* and waterlogged soils. In this area, climax formations are found such as: oleaster bush, forests of Aleppo pines, cedars, junipers and cypress. The **sub-humid** region receives 600 to 800 mm annually with a variability of 10% to 25% and 3–5 dry months. Continuous moisture has produced a soil darkening. The red soils are formed on carbonated hard rocks. However it is not rare to observe, on hard limestone, soils with brown tints; this soil darkening affected the profile either totality or partially[1]. The darkening of fersiallitic soil brings an upgrade of the essential physical characteristics, the porosity, the useful reserve and the resistance of the aggregates to erosion. To the previous climatic formations, one can add sclerophyllous oaks: holm (*Q. ilex*), cork (*Q. suber*) and shrub (*Q. coccifera*) oaks.

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[1] The darkening of fersiallitic soils (distinct from the darkening by the organic matter) is possible when the climatic and land cover conditions are intermediate (sub humid climate); however, a category of brown fersiallitic soil saturated in calcium it exists (subgroup of fersiallitic soils).

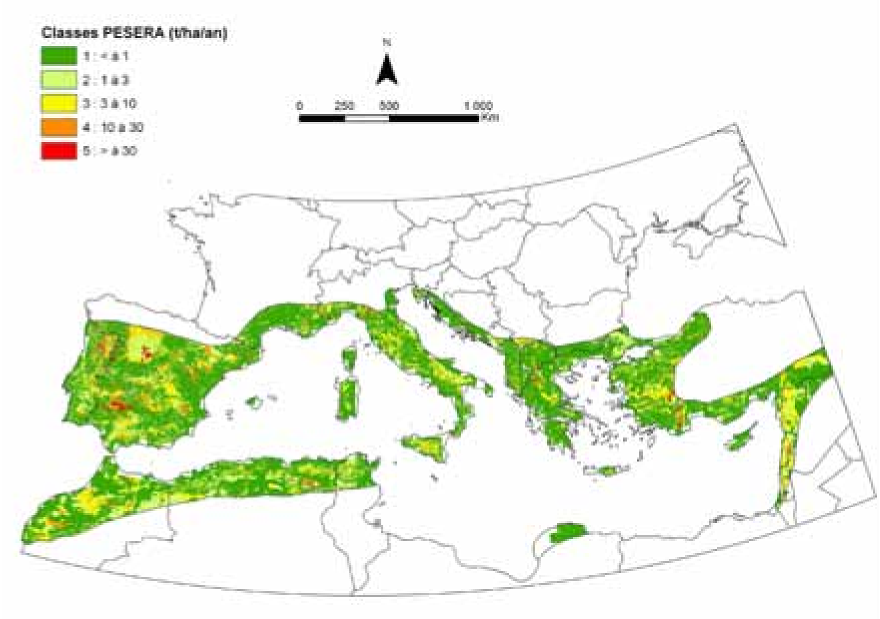


Figure 20. Map of soil erosion for the Mediterranean Basin for current conditions (PESERA Simulation). Source: Y. Le Bissonnais et al. 2010.

The original soil covers have more or less disappeared due to drier climate and concurrent geological cycles of erosion. The export of wood since the Phoenician era (1000 BC) and the increase of agriculture since the Roman era (200 BC) intensified anthropogenic erosion by leaving a landscape where rocks, regolith and continuous or fragmented calcareous encrusting are exposed. In these landscapes, the climatic vegetation has deteriorated into *maquis* (acidic soils), and *garrigues* (calcareous soils); however, some forests, usually found upstream of catchment areas of more than 50 km² where cattle breeding (sheep) is dominant, have been saved.

The balance models typically take into account various fluxes between the forest cover and the atmosphere: atmospheric carbon is fixed in vegetation by photosynthesis; it is stored in the leaves, wood, roots and the soil receiving the debris and accommodating a more or less strong biological activity. This carbon is re-emitted during plant respiration or the decomposition of organic matter. Trees, on the other hand, re-evaporate rainwater intercepted by the leaves or water taken up from the soil through transpiration. Finally, forests and soils reflect part of the solar infrared radiation. These different fluxes are mainly quantified in continuous forest cover situation and thus in more humid areas than in the Mediterranean. With smaller biomass, growth dynamics and flux intensities that are different from those of temperate and even more humid forests, Mediterranean forests should continue to play an important role in a context of the precarious subsistence of neighboring societies, and the difficult management and conservation of water and soil – although from north to south and from east to west of the “olive tree range” the situations differ. Indicators of stocks and fluxes of hydrous, organic and mineral compounds allow, within certain limits, to assess the fragility and resilience of the binomial soil and vegetation.

Raindrop energy impacting the soil can be controlled by vegetation, above a ground cover rate of 20% to 30%, with small differences between plants, shrubs and trees.

Water related soil erosion processes consist of the:

a) impact of the kinetic energy of falling rain drops resulting in the fragmentation of soil aggregates into finer particles (rain splash erosion);
b) role of runoff which acts as carrier of these particles; and
c) role of runoff as active erosion agent (sheet and/or gully erosion).

These mechanisms are, in turn, related to the characteristics of the vegetation cover since foliage intercepts part of the rain, reducing the splash effect and contributing to the re-emission of water to the atmosphere through evaporation (see section 1.4), and as the root systems limit the mobility of soil particles. Of course, erosion and runoff are also related to soil features; in particular, structural stability and hydro-dynamic characteristics.

The effects of a forest begin with the interception of rainwater before it reaches the ground. Depending on the local ecological conditions, we find different types of plant and structural organisations that strongly interfere with the **rain splash effect** and the genesis of **runoff**, and thus with the **mobilisation of erodible land.** The share of inter-

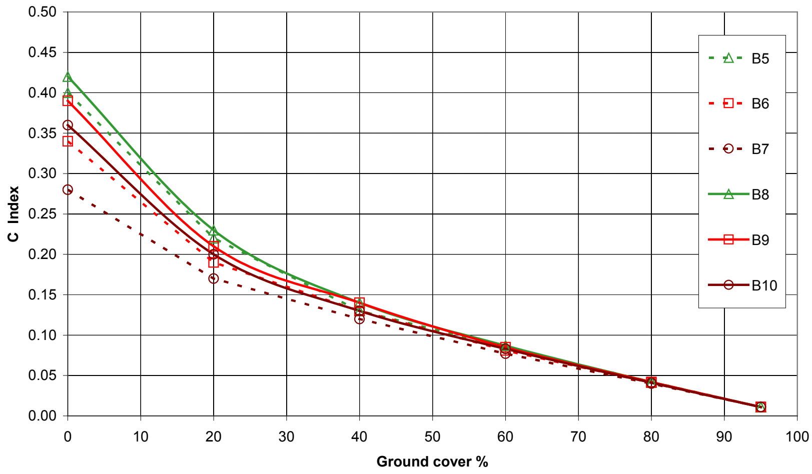


Figure 21. Role of plant cover in limiting raindrop energy: C Index for various ground cover types canopies (C = 1 in the total absence of interception on a clean tilled continuous fallow: a situation presenting maximum vulnerability)

- B5: 25% shrubby stratum with raindrop falling from 2m + herbaceous ground cover with broad leaves
- B6 : 50% shrubby stratum with raindrop falling from 2m + herbaceous ground cover with broad leaves
- B7 : 75% shrubby stratum with raindrop falling from 2m + herbaceous ground cover with broad leaves
- B8 : 25% of forested stratum with raindrop falling from 4m + herbaceous ground cover with broad leaves
- B9 : 50% of forested stratum with raindrop falling from 4m + herbaceous ground cover with broad leaves
- B10 : 75% of forested stratum with raindrop falling from 4m + herbaceous ground cover with broad leaves

ception in the water balance equation has been documented in section 1.4. Hereafter, the emphasis will be put on the **structure of vegetation layers and its role for controlling raindrop energy.** The importance of this factor has been taken into account in the development of new models for predicting water erosion, through the quantification of the interception of rainfall energy through various plant structures from the trees to the herbaceous layer. Figure 21 illustrates the values of the ground cover and management index C as related to various plant cover types, corresponding to different combinations of heights and densities of canopy and ground coverage. One can conclude that differences between plant cover types are limited above a threshold of ground cover above 20% to 30%; in other words, shrubby vegetation can be as efficient (and even better) as a forest regarding the control of splash effect. In terms of water budget, shrubby vegetation is in general less water consuming than forest.

Forest soils have a comparative advantage vis-à-vis other soil types regarding porosity and hydraulic conductivity, and reduced susceptibility to rain splash effects.

When water from stemflow, throughfall and raindrops reach the ground, several processes can take place. The **water recharge** of soil layers will start, followed by **seepage** in more or less deep levels, usually before the occurrence of **runoff**. Soil characteristics play an important part in the relative share and intensity of these processes. To a large extent, they are related to the ecosystem type which influences the **physical and biochemical transformations of upper layers**, facilitating soil water recharge and deep drainage by seepage.

In the case of forests, various studies have shown that

- In hardwood forests, structural changes of surface horizons related to polymerize humic compounds stabilising the structures of the initial horizons are to be observed. However, this action is limited in pine and teak forests and almost invalidated in eucalyptus forests, whose litter secrete antibiotic substances that limit the mineralisation and humification of litter.
- Animal and microbial biological activity promotes porosity. Worms emit 3 t/ha of castings in forests vs. 0.5 t/ha for less biologically active soil types. This activity counteracts the development of surface crusts and heavily favours the surface hydraulic conductivity as well as, unfortunately, the mobilisation and erosion of thin mountain soil.
- Increased protection of the soil top layers by litter or a herbaceous layer acts as mulch, dispersing the incoming energy in the proportions as shown in Figure 21.
- A deep porosity is favoured by the development of roots; however, this will depend on the structure of the root system, size of the roots (hairy surface, pivotal system, etc) and its health status.

The genesis of runoff depends on soil surface status, initial soil water content and, of course, on rainfall intensity. The forest cover influences runoff, only by delaying its onset and slowing the establishment of a strong runoff regime.

Box 4. Rainfall, infiltration and runoff

Under rainfall simulation, it was found that the intensity of minimum infiltration Fn (mm / h), or that the maximum intensity of runoff Rx (mm / h), varies with rainfall intensity (I mm / h). This relationship, which may seem surprising, results from the lateral variability of saturated hydraulic conductivity Ksat (mm / h) which, under constant rainfall intensity, corresponds to Fn (mm / h). This fundamental property is explained in Figure 22.

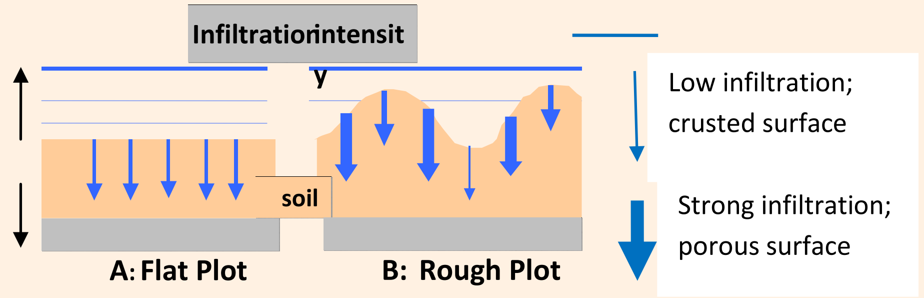


Figure 22. Relationship between soil roughness and saturated hydraulic conductivity, Ksat (mm / h).

Situation A, Flat land: On flat land, the soil is covered with a homogeneous crust; Ksat has the same value everywhere. As soon as the rain intensity (I) exceeds Ksat, runoff appears. The flow only depends on rain intensity and soil slope.

Situation B, Rough land: loamy crusts are more important in the lowest part of the plot; they are affected on the sides of the clods, which are more permeable and are more or less permeable on the summits of hillocks. Ksat varies from one point to another, the number of sites where I > Ksat increases with the height of the flowing water. This is the case of irregular land surfaces, cultivated land, land with high biological activities and with dense vegetation cover - all rough surfaces - and, as a result, irregularly submerged under a depth of run-off for increasing rainfall intensities. An illustration of these behaviors is shown in Figure 23 showing the relationship between a steady regime surfaces run off (Rx) and rainfall intensities (I).

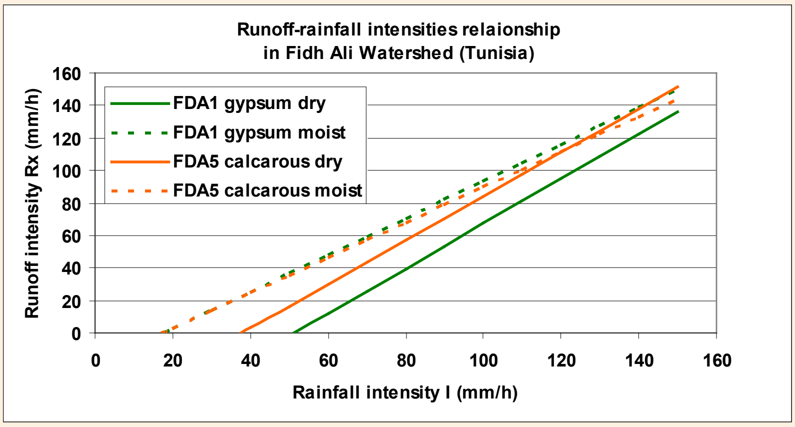


Figure 23. Relationships between runoff maximum intensity Rx and rainfall intensity (I) for gypsum (FDA 1) and limestone (FDA 5) soils with two initial soil moisture contents.
Note that the intersection of regression lines with the abscissa determines the highest intensity of rain (Ilim. mm/h) causing the initial flow. This value can be obtained experimentally by gradually reducing the intensity of simulated rain. FDA 1 is a soil derived from loam gypsum, the surfaces are rough with well-formed but unstable aggregates. With accumulated rainfall, they disperse into a silty clay material. FDA 5 is derived from limestone. The surfaces are quickly smoothed into a fine silty and sandy lining with low infiltration. On initially dry soil, behaviors are parallel but with different rainfall intensity limits: 51mm/h for FDA 1 and 37 mm/h for FDA 5. On initially humid soil, the behaviors converge on surfaces that are smoothed and clogged identically (Ilim ¹18.5mm/h).

Studies of the genesis of water flow erosion – runoff and land mobilisation – have experienced major and successful developments based on the use of **rainfall simulation techniques** in the Maghreb on soil materials of various thicknesses, as well as in dry and wet areas in sub-Saharan Africa. More than the "more or less" profound differentiation in these soils' characteristics is their **surface status** (SS), which controls much of their surface water properties. Runoff appears when rain intensity exceeds saturated hydraulic conductivity as explained in Box 4. The infiltration process also relates to soil porosity and the soil surface roughness.

Soil losses as sediment loads in the running-off water and their dynamics during rainy episodes also depend on soil surface status. Under the forest cover, compared to other plant cover types, the limitation of erosion is linked to the delay of runoff onset and to the slow establishment of a strong runoff regime as above mentioned.

Rainfall simulation techniques are also powerful for assessing the evolution of sediment loads related to the increasing intensities of runoff for different SS. Box 5 summarises the genesis of erosion and the sediment load dynamics in relation to flow and soil surface parameters.

The implication of the Mediterranean forest cover on water and soil conservation is quite different from the clichés too often suggested and accepted, considering that forests are full protection against erosion processes.

There are only few experimental forested watersheds that permit the joint study of hydrology and soil erosion in the Mediterranean area; furthermore, only few rainfall simulation studies have been undertaken under forest conditions. However, the findings of these studies can be complemented with reasonable assumptions derived from intensive study sites under agricultural conditions, selected to reflect the conditions of forest soils. As an example, data based on rainfall simulation studies in Tunisia in crop field situations comparable to the SS of forest soils, have been grouped together: low vegetative cover on aggregate and structural lining; bare land with lining; bare rough land with clods and structural lining; and land sprayed with coarse elements (see Table 3).

In the limestone areas of the Mediterranean, the localisation and extension of forests, and the depth of soils supporting them often depend on the size of the catchment area.

In small catchment areas that are strictly calcareous (<10 km^2), upstream forest soils are eroded up to the regolith as well as the rest of the basin, except at the foot of the slope where thicker soils can be differentiated on colluviums. Upstream, the forests are found on rocks or limestone crusts where the useful water reserves, deflected towards the low humidity, depend on the cracking of these materials for their existence. On the ground, this implies a succession of surface states depending on the period:

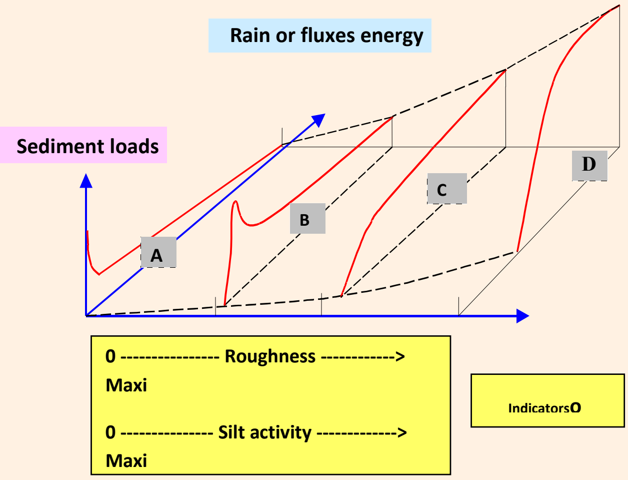
The resumption of the September-October rains on soils with bare gravel, no sprouts and some stubble, as reflected in table 1 by SMA1 result in runoff occurring quickly but lightly during rainfall with higher intensities.

Box 5. Genesis of erosion and sediment load dynamics in relation to flow and soil surface parameters

Figure 24 illustrates the behavior of four contrasted soil types regarding sediment load in relation to rain and flow energy. Curve A reflects the behavior of soil with very low structural stability. The collapse of aggregates by dissipation of rain energy smoothes the surface and forms a lining with low infiltration. The thickness of the water flow intercepts the energy streaming across the surface. The flow remains laminar and thus less abrasive; we then observe a gradual depletion of exportable soil particles. The increase of sediment load is mainly linked to a strong increase of runoff. Curve D reflects the behaviour of land with higher structural stability. The collapse of aggregates by dissipation of rain energy is much more gradual. The delay in the onset of the runoff is also explained by open pores at the surface of the soil. There is no formation of a lining apart from a fragile and porous structural lining. There is no smoothing of the surface except for a major rainfall. As the thickness of the water flow is low, the runoff does not affect the entire surface. There is little interception of energy on the surface, so the splash effect remains stable. Because the surface is rough, the flow becomes turbulent and thus abrasive. As a result, there is a rapid increase in erosion, which may seem contradictory since it is the structural stability which is at the origin of this process. Here, the limitations of erosion will only be linked to the delay of the onset of runoff and to the slow establishment of strong runoff regimes - the first thing that farmland "conservationists" or foresters must consider.

Figure 24. Sediment loads in relation to flows and surface status parameters.

Considering the above, intermediate situations illustrated by curves B and C are easy to interpret. The changes in sediment loads are also associated with different conditions of roughness, mineralogical clay activity (swelling-shrinkage), structuring or disintegrating salt load, crusts and the spreading of coarse elements which act as excellent behavioral indicators.



The start of the rainy season with a more or less significant decrease until April and the rainstorms in May; growth of a grass cover at SMA3 with lightly loaded runoff which becomes more delayed as the grass cover becomes dense and continuous.

In larger catchment areas (> 50 km²) it is not uncommon to find relics of deep red fersiallitic soil in limestone nodules upstream of these areas, unaffected by erosion cycles but can be next to rock outcrops. Forests on structured materials were maintained in these areas thanks to iron oxides and polymerized humic compounds. As these soils have good water reserves and areas with high conductivity, vegetation grows rapidly from October to May. We are getting to the following successive situations: SM1 to SM2 to SM3 with lightly loaded runoff and gradually decreasing rain intensity limits thereby replenishing the usable water reserves.

In these basins, **marls** are sometimes squeezed into the limestone beds and they give the landscape badlands. Areolar erosion on limestone (<5t/ha/year) becomes linear with peaks of about 50t/ha/year. There is no forest but low shrub vegetation with

Figure 25. The formation of badlands on marl-limestone parent material resulting from the removal of the matorral. Tleta watershed, Ibn Batouta dam, Western Rif, Morroco. Photo by P. Zante.

Figure 26. Gully erosion on calcareous loams (south of Fahs bridge, Tunisia). Photo by P. Zante.

little grass or bare surfaces as their reserves are diverted to high humidity; continuous abrasion prevents germination. The behaviours are similar to those of SML2 then SML1 sites where the collapse of structures supplies heavy loads for runoff that was first delayed but is rapidly increasing afterward.

Further research is needed to develop a body of knowledge on water and soil conservation under forest conditions in the Mediterranean. A concerted research programme around the Mediterranean Basin could offer interesting perspectives.

Examples of in-depth studies that analyse the factors affecting the behaviour of the forest-soil pair are rare. Experimental approaches must precede modelling; they are needed to improve the models' calibration and allowing their validation pro parte. An example of a fast and easy field experiment to be implemented can be the rainfall simulation

Table 3. Rainfall simulation studies in the Siliana region, Tunisia. Average rainfall (30 years) = 430mm; rainfall erosivity: 57-130 megajoules.mm / ha.h by year
Runoff and erosion results in relation to Soil Surface status (SS) of plots whose behavior is assumed to be comparable with those of Mediterranean forest soils.

Soil and loose depth	Sites	Topo	Slope	C + S	landuse	SSF				Runoff		Erosion
1	2	3	4	5	6	7 Slaking crust	8 Struct. crust	9 Cracks	10 Gravels	11 Rx (I) r^2	12 I lim	13 Load (R) r^2
Brown limestone on marl limestone (30cm)	SM1	upstream	19	52	unploughed	45	45	4	0	$1.06I-10.1$ 0.98	9.5	$0.008R^2 - 0.086R + 11.97$ 0.98
	SM2	middle	12	50	fallow	78	18	0	1	$1.03I-11.9$ 0.97	11.6	$0.006R^2 - 0.033R + 13.26$ 0.92
	SM3	downstream	10	45	wheat + weeds	59	23	0.5	0	$1.05I-24.4$ 0.93	23.3	$0.275R+3.63$ 0.95
Brown calcium, concretioned on colluvium (70cm)	SML3	upstream	8	54	wheat seedlings	54	24	4	2	$0.95I-15.6$ 0.98	15.7	$0.004R^2 - 0.352R + 25.44$ 0.79
	SML2	middle	10	50	fresh ploughing	16	54	6	0	Rx not met	> 42	C.max.4.4g/l to I = 120mm/h
	SML1	downstream	13	48	bare fallow	72	16	5	5	$1.00I-6.4$ 0.97	6.4	$-0.004R^2 + 1.392R - 2.7$ 0.87
Scattered outcrops of fragmented calcareous crusts (0cm)	SMA1	middle	12	49	bare fallow	44	20	0	34	$0.95I-2.1$ 0.96	2.2	$0.002R^2 - 0.125R+9.99$ 0.70
	SMA3	middle	9	62	Fallow + culm	28	9	0	12	$1.09I-23.3$ 0.97	21.2	$0.016R + 0.82$ 0.82
	SMA4	middle	15	63	recent ploughing	33	12	1	7	0.911.10.0.89	12.1	$0.001R^2 + 0.015R + 2.35$ 0.69

Legend:
1 Soil classification (CPCS), parent material and depth of soft soil (<50EG).
2 Sites of rainfall simulation plots with different toposequence in the Siliana region (Tunisia).
3, 4 Topographic position on slopes from 300 to 1,000m in length and slope in %.
5 Texture of soil: clay (<2m) + fine silt (2-20) + coarse silt (20-50) in % of soil without gravels.
6 Agricultural land-use during the tests.
7, 8, 9, 10 Soil Surface Features: slaking crust, structural crust (more or less collapsed clods or aggregates surrounded by dispersion material of these structures), partially
smectic desiccation cracks in clay soils; rate of gravel (2 to 20mm) and pebbles (>20 mm) laid on the ground.
11, 12 Relationship between runoff intensity at constant speed and intensity of rainfall; minimal intensity limit I.
13 Relationship between sediment load contained in the runoff and runoff intensity R, detection of areolar or linear erosions.

on plots representative of soils, cover and soil surface features, and whose data can be easily coupled with natural rainfall occurrences. Such approaches entail respecting the phenological stages of the forest (upper and understorey) and taking into account the energy changes related to rainfall interception.

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2.

Blue Water

Blue water, the liquid form of water, is vital for human societies and has thus been the focus of managers and land-use planners in their attempt to "domesticate" water resources. It is essential to understand how blue water is generated through the various and complex hydrological processes that take place in the watersheds before, during and after rainfall episodes. Rain falls on terrestrial ecosystems, which differ in their hydrological behaviour. In the Mediterranean and in other regions, forests frequently occupy the heads of watersheds – often located in mountainous areas – and constitute a kind of "water tower" for the region. It is therefore crucial to better understand the specific hydrological features of these ecosystems.

The issue of the relationships and interactions between forests and blue water is one of the most controversial. In spite of scientific achievements based on hydrological studies, there are still many generally accepted concepts and dogmatic beliefs which have no or limited scientific background. It is absolutely necessary, therefore, to try to bridge the gap between science and public perception.

This chapter aims at presenting an overview of what science can tell us about these important subjects; it is structured into two sections:

2.1 Hydrology of Mediterranean ecosystems
2.2 Water resources depend on vegetation cover and land use

Figure 27. Weir for measuring stream flow. Copyright Hubbard Brook Experimental Forest. Source: USDA, www.hubbardbrook.org

Figure 28. The Ardèche canyon in a holm oak-dominated landscape, France. Photo by C. Birot

2.1.

Hydrology of Mediterranean Ecosystems[1]

Francesc Gallart and Pedro Berliner

Most of the water resources in the Mediterranean are generated in wet mountains, whereas lowlands and coastal areas are water consumers.

Because of its geological history, the Mediterranean basin is surrounded by many mountain ranges. The higher precipitation and lower temperature in these areas cause an excess of water balance, so they become the source of the main streams or the *recharge** areas of the underground waters.

Forests are the most natural land cover of the Mediterranean mountains, where water abundance allows their growth. Nevertheless, sunny and gentler slopes in middle-altitude mountains have been habitually used for agriculture. Yet, most of the wet higher altitude areas were deforested and managed to get extensive pastures in order to feed livestock flocks during summer.

Mediterranean lowlands have typically unfavourable water balances due to both the lower precipitation and higher temperatures. In most of the internal depressions and littoral plains there is an extensive and increasing demand of water for irrigation and urban use that is commonly supplied with resources from distant origin.

Underground water resources are of primary importance in most Mediterranean areas. A particular case occurs in areas with permeable bedrock such as limestones (Karstic areas). These areas show sinks and dry valleys in the highlands and long-lasting water springs, streams and wetlands in the foothills and depressions.

Intensive extractions of groundwater have induced the desiccation of springs and wetlands as well as the disruption of the regime of streams.

Stream flows are highly varying in time in the Mediterranean. Small basins feed characteristic ephemeral or sporadic streams (ramblas, ouadis) that convey flash floods. Large basins have seasonal or permanent streams with summer low flows sustained by underground waters.

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[1] See sections 1.4, 1.5, 2.2, 4.1 and 5.3

Stream flows are commonly separated by hydrologists between storm flow and base flow. The first is the rapid response to a given rain event, whereas the second is due to the delayed discharge of groundwater stores, usually following a seasonal fluctuation.

In dry areas and especially in small basins, base flows may be absent because of the lack or disconnection of underground waters; the stream flow response to rainstorms therefore take the form of sudden and short-lived *flash floods** whose volume usually decreases downstream because of the *transmission losses**.

Larger basins usually show a seasonal regime, with monthly or quarterly high flows during winter, or the equinoxes and low or null flows in summer. Nevertheless, the regime may be diverse if the main sources are dominated by snow melting out of the Mediterranean zone or regulated by dams.

The main processes of generation of water resource in the Mediterranean relate to percolation to deeper levels, once the soil water retention capacity is reached (as in wetter climates), but also – classically in a drier climate – to rainfall exceeding the rate of infiltration in the top soil, resulting in runoff and thus causing erosion and flooding hazards.

Box 6 Flash floods caused by heavy and intense rainfalls in the Mediterranean may result in catastrophes: the case of Vaison-la-Romaine, France, 1992

The climate of the French Mediterranean mountainous hinterland ranging from the Pyrénées to the south-western dry Alps is characterized by a predominating autumn-winter rainfall regime. Extreme events – in terms of precipitation height and intensity – and of catastrophic flash floods have been frequently recorded. On 22 September 1992, a heavy rainfall struck the “départements” (= districts) of Drôme and Vaucluse (south-western dry Alps) with precipitations amounting to 200 to 300 mm in only 4–5 hours, compared to the average of 80 mm for the whole month of September. Most of the rainfall that day fell in less than two hours with intensities reaching 200 mm/h. This rainfall affected part of the Ouvèze catchment and resulted in a sudden and brutal flash flood, which peaked in only a few hours after the beginning of the rainfall event. Upstream of Vaison-la-Romaine, the catchment (587 km^2) collected 66 million m^3 of water. At the flood peak, the flow was about 1,000 m^3/s at the roman bridge of Vaison-la-Romaine (see Figure 29) and the river carried various objects at a speed of 4 m/s (14 km/h) (Source: Cemagref-Lyon). The river flow and overflow caused huge damages in terms of human lives (40 casualties) and infrastructure – roads, several bridges and more than 100 houses were destroyed with losses estimated EUR 100 million.
www.languedocroussillon.ecologie.gouv.fr/meteocdrom/Evenements_memorables/doc/19920922_vaison.htm

Figure 29. Flash flood in Vaison-la-Romaine on 22 September 1992. This Roman bridge, built in the 1st century AD, over the Ouvèze River resisted the flood while newer bridges and buildings collapsed. Photo by M.J. Tricart

There are two main types of processes for generation of water resources. On the one hand, **saturation** processes are common in humid areas and occur when rainfall or snow melting exceeds evapotranspiration demand during a sufficient period of time to allow the wetting of entire soil profiles beyond their water retention capacity; the water in excess flows through and over the soil, feeds streams and percolates deeply to recharge underground resources. On the other hand, **rainfall excess** processes are usual in dry climates and occur when the rainfall rate exceeds the rate of water infiltration in the topsoil; the water precipitated in excess flows over the ground, feeds streams with flash floods, causes soil erosion and may recharge underground resources principally through transmission losses (see Box 6).

One of the main characteristics of the Mediterranean climate is the high seasonality and low precipitation during the summer. This means that even in humid and sub-humid areas where saturation processes are the more usual, soil moisture is depleted during summer, causing the interruption of saturation processes. Conversely, wet periods with saturation processes may occur seasonally or occasionally in semi-arid climates.

Soil cover and surface status characteristics play an important but complex role in the hydrological and erosion processes.

Usually, low cover or unprotected soils favour runoff and soil erosion, while dense grass cover causes intermediate runoff and low erosion rates; dense forest cover determines the lowest runoff and erosion rates; however, the reduction in runoff and erosion is observed only if the rainfall amount and intensity stay below certain thresholds.

Soil infiltration rates depend more on the condition of the uppermost soil horizon than on the quality of the entire soil profile. The impact of raindrops on the unprotected soil surface may lead to the formation of a nearly impervious soil crust, which limits its infiltration and enhances rainfall excess overland flow. On the other hand, biological activity (e.g. roots, worms) or ploughing break down the soil crust and enhance soil infiltration capacity.

In wet or intermediate wetness conditions, soil moisture is lower under the forest cover than in clearings because of the higher water evapotranspiration. In dry conditions, when soil water content is too low to be drained by gravity, it may be higher under tree or bush cover because of the canopy shadow effect.

There are therefore complex interactions between mechanisms that lead to trade-offs in land management for given climatic and soil conditions. A forest cover will increase infiltration and reduce runoff and soil erosion, but the overall water balance and aquifer recharge will be reduced because of the higher actual evapotranspiration rates. Conversely, a barren soil will induce the highest runoff and soil erosion rates but the water balance will be more positive since the lowest actual evapotranspiration rate and aquifer recharge will most likely be increased because of transmission losses in streams.

In dry areas, some traditional *rainwater harvesting** techniques (such as "meskat" and "tabia" in Tunisia) consist of the management of barren field-sized areas in order to produce runoff that irrigates isolated trees or small crop plots.

The preservation of the ecological quality of Mediterranean streams needs the protection of flow regime, water quality, stream morphology, riparian forest and sediment conveyance.

Excessive water abstractions, river regulations or effluents from sewage treatment plants may severely modify the natural stream regime. A typical modification in large rivers is the increase of flow regularity, which favours the spreading of invasive species, decreases the sea fertilisation role of floods and endangers sediment transportation.

Sediments are part of the fluvial system. Accelerated erosion due to land use may cause an excessive increase of sediment loads; further, sediment trapping by dams also jeopardises the sustainability of alluvial plains, deltas and beaches.

The maintenance of healthy riparian forest may represent some water loss but improves water thermal and nutrient quality (see section 5.4).

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2.2.

Water Resources Depend on Vegetation Cover and Land Use[1]

Mark Robinson and Claude Cosandey

Over the centuries, human development has led to the replacement of many natural forests by farming, including pasture and cropland, as well as by commercial plantation forests. Such changes can, and do, have major impacts upon the local hydrological cycle and on the water resources of the wider region. More recently, however, the abandonment of farmland in marginal areas has partly reversed this process.

Vegetation cover and its management can have a profound impact on the partitioning of water and energy.

The vast majority of catchment studies have found lower streamflow from forested areas compared with short crops, and this finding has been supported by process studies including measurements of soil moisture depletion and evaporation fluxes. It is now generally accepted that forestry almost inevitably leads to higher evaporation; this is due to higher interception losses of rainwater held on the forest canopies in higher rainfall areas and during the wet season. In drier conditions, this greater loss is due to higher transpiration as a direct result of the trees' deeper and more extensive rooting systems giving them greater access to soil water reserves compared to shorter vegetation.

Interception losses by evaporation are the first term in water partitioning. Contrary to the high interception losses of temperate maritime forests exposed to frequent rainfall of short duration and low intensity, Mediterranean forests usually experience short duration high intensity rainy episodes, and lose much less in proportion.

The effect of vegetation cover on transpiration rates will be moderated by soil water availability. In areas with limited storage capacity (for example thin soils), any increase in transpiration will be restricted; however, in riparian areas near to a perennial stream, the local evaporation (transpiration) rates may be greatly enhanced with resulting reductions in streamflow available to downstream river users.

In some cases, such as fast-growing deep rooted eucalyptus plantations, the consumption of water may exceed the rate of soil water replenishment, leading to long-term "mining" of the subsurface water reserves.

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[1] See also sections 1.4, 1.5, 2.1 and 4.1

The impact on dry season streamflow in particular may be masked by time lags in situations where there is an appreciable soil water store: the felling of trees may take several years to lead to a sufficient replenishment of subsurface water reserves before an increase in seen in dry weather flows.

Although *absolute* increases in evaporation (and annual streamflow reductions) are greatest in higher rainfall areas, the largest *proportional* reductions occur in dry season flows when less water is available.

Myths about forestry and water:
The beneficial effects of forests have sometimes been exaggerated by conservationists wanting to protect natural areas, and by commercial foresters wishing to justify new plantations.

Forests can sometimes increase dry weather flows, but in general they are most likely to reduce them.

The forests' ability to moderate floods is much weaker than often claimed, being restricted to small storm magnitudes and limited catchment sizes.

Forest impacts on dry season flows are likely to be very site specific. Forests may evaporate more water and, in particular, higher dry season transpiration will increase soil water deficits and reduce dry weather flows. But in situations where the infiltration properties of the soil are very low, the presence of trees may be very beneficial: protecting the soil from rainsplash and erosion; providing leaf litter and breaking up the soil and facilitating water flowpaths to deeper layers by their roots, leading to higher soil water recharge and increased dry weather flows (see section 1.5).

In terms of soil conservation and subsurface water recharge, the impact of forestry depends on the partitioning between infiltration and surface runoff. An extreme example is an overgrazed land with loss of soil structure and surface crusting under high rainfall intensities, which can lead to overland flow and minimal infiltration and recharge. This can result in a feedback loop with vegetation loss, leading to loss of soil which, in turn, leads to further loss of vegetation and more erosion.

Forests (especially natural ones) may be expected to have lower erosion than agricultural and pasture land. They protect the land from erosion by their canopy and leaf litter – sheltering the ground from direct raindrop impact as their root network binds the soil together (particularly important on steep slopes).

While erosion from natural forests is likely to be lower than from other land covers, this is not necessarily the case for plantation forests where roads, drainage channels, logging and suppression of understorey vegetation can cause higher erosion rates than from well-managed pastures or agriculture.

It is important to take account of the well-proven fact that in many cases the impact of the treatment is not stable over time. The effect of forestation is *long term* whilst that of deforestation is much shorter term. A natural forest containing a mix of species and tree ages will attain a fairly constant water use over time; in contrast, an even-aged monoculture may show pronounced changes through the plantation life cycle. In the case of eucalyptus, this may comprise a period of pronounced decreasing water yield for the

Figure 30. The Draix catchments in the French pre-Alps (Provence Alpes Côte d' Azure) are steep catchments with friable marl soils. The Draix area once had a forest cover, but over 200 years ago the trees were replaced by pasture and the land became badly eroded due to over-grazing of a fragile environment. The farmland downstream has good soils which may comprise the material washed down from these hills. This badland landscape accounts for about 2000 km^2 of land in the French pre Alps. Forest restoration to control erosion began in some parts of the area in the 1870s. The Draix research catchments were instrumented beginning in 1983.

first couple of decades after planting as the trees become established and grow. This is then followed by a longer period of a slowly decreasing impact and weakly increasing water yield as the forest becomes older and its growth slows down, so that the yield is at least partially recovered. This finding has been replicated in several studies of eucalyptus forests and is attributed to a transpiration peak in eucalyptus stands at about 10–20 years of age. It seems likely, but has not been as well documented, that a similar pattern of decrease in water use over time may also apply with the aging of other tree species.

The impact of felling a forest can result in a short-term increase in water yield, but this is very dependent upon the new land cover. Pasture may have a higher water yield, whereas if forest regeneration occurs with fast growing young forest the water use may be little different (or even higher) compared to the old forest. In contrast, if the land post-felling is overgrazed resulting in unprotected soil that is vulnerable to erosion and loss of soil water storage, there may be an increase in water yield and much more extreme flows.

The impact of forests on baseflows is well established: low flows are reduced by forestry and increased by deforestation. However, even here there are exceptions. Observations in the Draix catchments indicate that reforestation of badly eroded badlands can result in a gradual stabilisation and thickening of the soil layer, resulting over time in an increase in the magnitude of low flows (Figures 30 and 31).

The impact of vegetation on water resources is now much better understood and the sometimes conflicting observations can now be subject to scientific explanation. Deforestation studies show an immediate increase in water yield, but this may be only of short duration, especially if the new vegetation is young and fast-growing. The potential for forests to have a greater transpiration than shorter vegetation is dependent upon soil depth being sufficiently thick. Otherwise, the difference between forest and grass

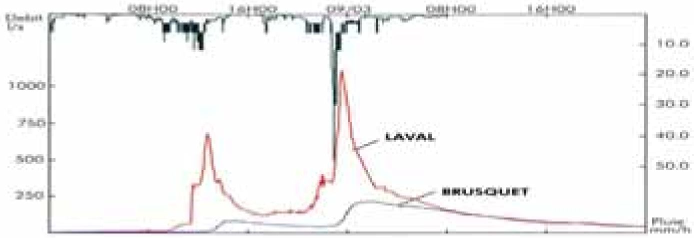

Figure 31. Streamflow response of eroded (Laval) and reforested (Brusquet) catchments to intense (max 50mm/h) storm in 8–9 March 1991 (from Lavabre and Andréassian 2000).

evaporation will be limited to differences in their interception losses. Climate is an important and related factor; if water is always plentiful then evaporation differences will be largely dependent upon the greater roughness and albedo of the forest canopy, especially where rainfall is frequent and the canopy is often wet. Where there is a strong seasonal variation in soil water availability, the ability of the deeper rooting trees to exploit the deeper soil water reserves will lead to higher evaporation losses.

The impact of forests upon floods has long been a source of controversy. In many early studies, forest management was very severe with large-scale clear-felling by heavy machinery causing much soil compaction damage, which often resulted in immediate large increases in peak flows. More recent forest management practices seek to protect the soil from compaction and result in a much less dramatic effect on flood response, showing that much of the apparent forest effect was in fact due to the felling operations involving soil damage and the building of logging roads. Furthermore, many studies were only of short duration and did not include rarer larger storms. The available evidence is that the claim that forests reduce floods is mainly true for small and medium floods hydrographs, but not for larger and hence more potentially damaging events.

Soil type is of crucial importance: where it is permeable and deep, the impact of felling on peak flows is likely to be much less evident than where it is shallow and impermeable. Similarly, where the soil is friable and easily eroded, the removal of a protective forest cover may lead to a great increase in peak floods due to the resulting loss of soil depth rather than to differences between forest and other types of vegetation.

The non-stationarity of a superficially "stable" land cover may put into doubt the validity of using a catchment as a benchmark site for climate change studies, or being a valid control against which to compare a change in land cover in a nearby experimental basin. Clearly, care must be taken in the selection of such an index catchment.

Forest cover and soils are, in general, beneficial for the quality of ground and surface waters generated in the watershed.

As forest cover limits soil erosion processes, the physical properties of surface water generated in a forested watershed, such as soil particles load and turbidity, are generally low compared to other types of cover. Some exceptions, however, can be observed in case of

Box 7. Forest soils and water quality and quantity: a US synthesis of an ideal 'natural' forest.

"The most sustainable and best quality fresh water sources in the world originate in forest ecosystems. The biological, chemical and physical characteristics of forest soils are particularly well suited to delivering high quality water to streams, moderating stream hydrology, and providing diverse aquatic habitat. Forest soils feature litter layers and high organic contents, both of which contribute to an abundant and diverse micro- and macro-fauna. Root systems under forests are extensive and relatively deep compared to agricultural lands and grasslands. Together, these biological conditions create soils with high macroporosity, low bulk density, and highly saturated hydraulic conductivities and infiltration rates. Consequently, surface runoff is rare in forest environments, and most rainfall moves to streams by subsurface flow pathways where nutrient uptake, cycling, and contaminant sorption processes are rapid. Because of the dominance of subsurface flow processes, peak flows are moderated and baseflows are prolonged. Conversion of forests to row crops, pastures, or lawns almost always results in deterioration of water quality. In North America, the majority of municipalities ultimately rely on forested watersheds to provide adequate quantities of high quality water for human use. This is particularly true in the western and eastern parts of the continent where human populations are large or growing rapidly. Forest soils provide the perfect conditions for creating high quality water supplies." Quoted from Neary D.G. et al. 2009.

heavy and intense rainfall or drastic forest operations (road construction, clearcutting).

The chemical properties of water basically depend on soil types, tree species, rain chemistry and atmospheric deposition on the canopy as well as from soil processes including weathering. It is commonly observed that the intense biological activity in most forest soils contributes to the denitrification process, although clearcuts can induce, at least temporarily, an increase in the nitrate content of surface water. Water acidity is only an issue on soils developed on acidic parent material (granite, sandstone, metamorphic rocks); it can be aggravated by acidic deposition on the canopy and excessive mineral (Ca, Mg) export related to wood harvest. In such cases, water pH can be very low.

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3.

Green Water

"Green water is what supplies terrestrial ecosystems and rain-fed crops from the soil moisture zone, and it is green water that evaporates from plants and water surfaces into the atmosphere as water vapour"(UNESCO 2006). This widely accepted definition captures the hydrological essence of the natural phenomenon. It also shows the links to other natural systems of the biosphere: altered landscapes (natural and man-made) and terrestrial ecosystems.

As the fluxes related to rain interception and soil evaporation have been described in section 1.4, this chapter will concentrate on the green water aspects associated to water relations in trees and forest ecosystems, and on how these processes influence the ecosystem functions and the derived ecosystems services. It is structured into three sections:

3.1 Green water to sustain forest ecosystems and their functions;
3.2 Water processes in trees: water uptake and transpiration and photosynthesis; and
3.3 How plant species cope with water stress.

Figure 32. Afternoon clouds over the Amazon rainforest in the dry season are believed to result from increased transpiration (Aug. 19, 2009). Source: NASA.
The clouds likely formed from water vapor released into the atmospheres from trees and other plants through transpiration linked to photosynthesis throughout the day. During the dry season, the rainforest gets more sunlight. The plants thrive, putting out extra leaves and increasing photosynthesis. In the heat of the day, the air rises and eventually condenses into clouds like those shown in this image. One can notice that there are no clouds formed over the river while they are fairly distributed over the forest, for the reasons as follows: in general, land warms faster than water and gives off more heat during the day. The hot air from the land rises, carrying evapo-transpired water vapor with it. The air cools as it rises, and the water vapor condenses into the tiny clouds seen here. But what goes up must come down. In this case, the air mass descends over the rivers, where temperatures are cooler. As the air drops, it warms, which prevents the water vapor from condensing into clouds. Caption: Holli Riebek.

Recommended reading

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3.1.

Green Water to Sustain Forest Ecosystems Processes and Their Functions

Yves Birot and Ramon Vallejo

Green water is needed not only for supporting tree's biology and life, but for keeping functional all groups constitutive of the forest biodiversity (micro-organisms, insects, animals, plants) and involved in basic ecosystem processes. Although the physiology of photosynthesis consumes little water, terrestrial plants require the transpiration of large amounts of water to allow for nutrients uptake and transport to the canopies as well as for gas exchange. Water is also essential for the circulation of chemical elements through the ecosystem.

Behind the beauty and the scenery of a forest landscape, ecosystem dynamics are at work in a series of interrelated and ongoing processes related to: i) energy input; ii) the circulation of the elements essential for life (nitrogen, carbon, mineral nutrients etc.); and iii) the circulation of water (water cycle). Although trees form the overarching component or the keystone of woodlands, many other plant, animal and microorganism communities and populations (above and below ground) constitute integral parts of this ecosystem, and interact between themselves and their physical environment. To maintain their vital functions and growth, all living organisms require an energy input. Contrary to elements which are recycled (biogeochemical cycle), energy has to be permanently renewed. The only gateway of energy into an ecosystem is plants. In plants, **photosynthesis** converts about 3% of the incident light – the rest (97%) being dissipated in the form of heat – and is the basis of biomass formation (see section 3.3). Plants are referred to as **producers** or **autotrophs**, and can be consumed, directly or indirectly by animals, insects and micro-organisms (Figure 33), which are referred to as **consumers** or **heterotrophs**. At the extremity of the food chain are the **decomposers**, i.e. the micro-organisms that break down, digest and metabolize organic wastes such as dropped fruits, dead wood, litter and animals. The three groups – **producers, consumers and decomposers –** need water as element constitutive of their tissues (made up of 70 –90% of water), and indispensable for their dynamics and for photosynthesis (producers). Every living organism that dwells in an ecosystem depends entirely on the photosynthetic process carried out by plants and thus on water. The vigour of its plants is reflected on the dynamism of an ecosystem.

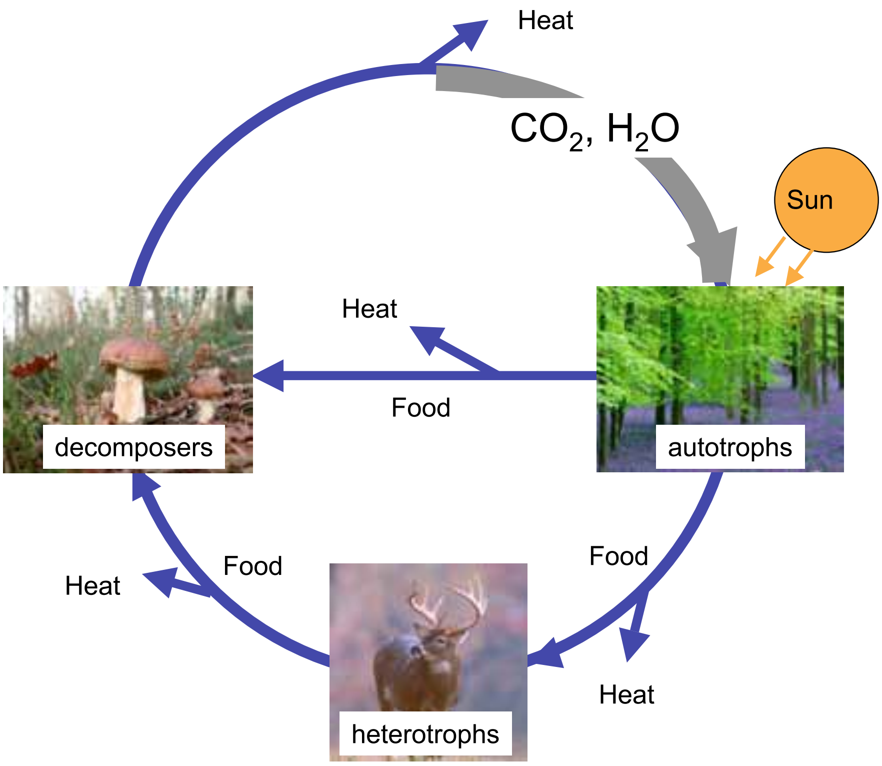

Figure 33. Basic principles of forest ecosystem functioning. Source: Canadian Forest Service. http://ecosys.cfl.scf.rncan.gc.ca/dynamique-dynamic/dynamique-dynamic-eng.asp

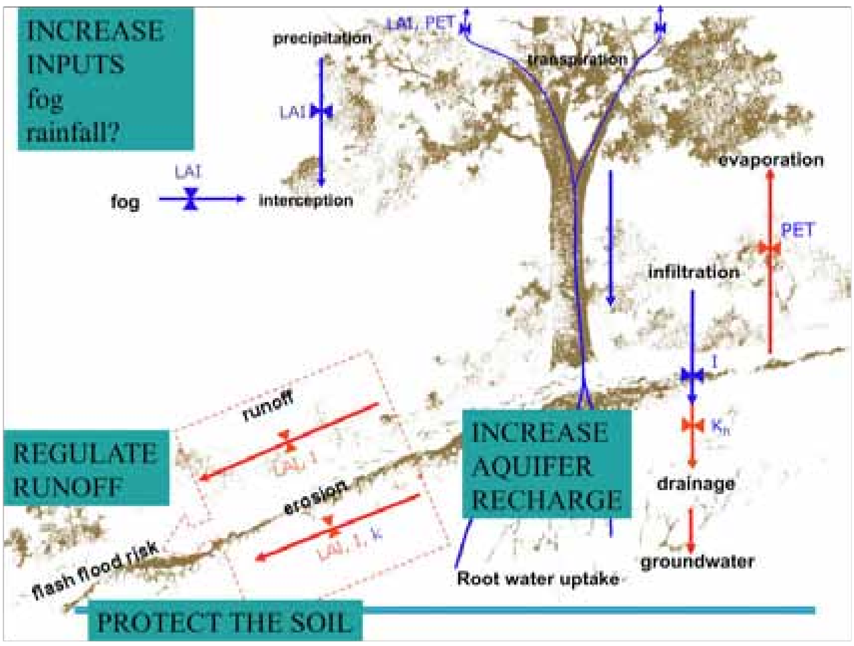

Figure 34. Role of forest cover in regulating water. LAI leaf area index; PET potential evapotranspiration, I infiltration; k permeability coefficient.

In general, the quantity of water stored in the organisms is a small part, though critical, of the amount of water circulating in the ecosystem and allowing vital processes, especially photosynthesis. On a sunny and hot day, a leaf can renew all its water content in an hour, and a plant transpires around 100 times its fresh weight throughout its life. Although only a small percent of water transpired by plants is directly used for the photosynthetic process, terrestrial plants need to consume huge amounts of water demanded by the atmosphere to allow the unavoidable trade-off of CO_2 fixation *vs* water transpiration through the stomata. Water stored in the forest trees can amount to few hundreds of tonnes per hectare, i.e. some tens of mm. For example, for Aleppo pine in one of the driest forested land in Europe (semi-arid climate, annual precipitation 270 mm), around 15 mm water was contained in the biomass for some 50 mm contained in the soil (yearly averages). Water stored in trees slightly fluctuates throughout the year, and water contained in the stem sapwood may supply transpiration demands in short drought periods for up to several days, especially in conifers. In some arid conditions, the plant water content can be relatively significant (cactus, "fountain tree" (El Hierro, Canary Islands)), especially for supplying scarce water to organisms – even mankind.

Throughout the water cycle, **water** is also a **main carrier of chemical elements and nutrients** in the ecosystem – being both a transport medium and solvent. Nutrients refer to mineral or organic substances (elements or chemical compounds) that plants

Table 4. Classification of ecosystem functions, goods and services. **Bold: direct relation to water;** *Italics: indirect relation to water.* Source: de Groot et al., 2002.

1. Regulation functions and related ecosystem services. This group of functions relates to the capacity of ecosystems to regulate essential ecological processes and life support systems through bio-geochemical cycles and other biospheric processes. In addition to maintaining the ecosystem (and biosphere) health, these regulation functions provide many services that have direct and indirect benefits to human societies (i.e., clean air, water and soil, and biological control services).	1.1. Gas regulation (**C sequestration**) *1.2. Climate regulation* 1.3 Air pollution filtering *1.4. Disturbance prevention* **1.5. Water regulation** **1.6. Water supply** **1.7. Soil conservation** **1.8. Soil formation** **1.9. Nutrient cycling** 1.10. Waste treatment 1.11. Pollination 1.12. Biological control
2. Habitat functions and related ecosystem services. Ecosystems provide refuge and a reproduction habitat to wild plants and animals and thereby contribute to the (in situ) conservation of biological and genetic diversity and the evolutionary process.	2.1. Refugium function 2.2. Nursery function
3. Production functions and related ecosystem goods and services. Photosynthesis and nutrient uptake by autotrophs converts energy, carbon dioxide, water and nutrients into a wide variety of biochemical structures, which are then used by consumers to create an even larger variety of living biomass. This broad diversity in biochemical structures provides many ecosystem goods for human needs, ranging from food and raw materials to energy resources and genetic material.	*3.1. Food* *3.2. Raw materials* *3.3 Genetic resources* *3.4. Medicinal resources* 3.5. Ornamental resources
4. Information functions and related ecosystem goods and services. As modern societies tend to be more and more urbanized, close-to-nature ecosystems provide an essential "reference function" and contribute to the maintenance of human health and well being by providing opportunities for reflection, spiritual enrichment, cognitive development, recreation and aesthetic experience.	4.1. Aesthetic information 4.2. Recreation and (eco)tourism 4.3. Cultural and artistic inspiration 4.4. Spiritual and historic information 4.5. Scientific and educational information

and animals require for normal growth and activity. Plants and trees obtain nutrients primarily from the soil by absorbing them through their roots, often in symbiosis with mycorrhizal fungi.

Rainwater chemical composition is influenced by natural (e.g. cross-Mediterranean dust wind from Sahara) and anthropogenic factors (agriculture, industry and transport) as illustrated by well-known examples (acid rain, nitrogen deposition, etc.). Other rainwater chemical modifications may also occur in relation to stem-flow and throughfall. In its transfer through the soil, water chemistry is influenced by soil organic and mineral characteristics. Water flow is a major pathway for nutrient cycling in forests, although nutrient flow *vs* water rates largely depend on the specific characteristics of each nutrient in terms of their root absorption mechanism and their interaction with the soil matrix. Water flow in soils is also a critical driver of rock weathering and soil formation, especially in forest soils where high microbial and biochemical activities enhance the weathering efficiency of water. The quality of water (blue water) is also related to these processes.

> Looking at natural ecosystem processes – to a large extent depending on water – allows understanding how they influence the ecosystem functions and, in turn, the related ecosystem services. As water is very often a limiting factor in Mediterranean forest ecosystems, water scarcity can result in a marked alteration of ecosystem functions and impact on the provision of goods and services to human societies.

An ecosystem function is the capacity of natural processes and components to provide goods and services that satisfy human needs – directly or indirectly. According to this definition, ecosystem functions can be seen as a subset of ecological processes and ecosystem structures. Each function is the result of the natural processes of the total ecological sub-system of which it is a part. Natural processes, in turn, are the result of complex interactions between biotic (living organisms) and abiotic (chemical and physical) components of ecosystems submitted to energy and matter driving forces. Ecosystem functions can be classified (Table 4) into four groups: i) regulatory functions; ii) habitat functions; iii) production functions; and iv) information functions. This grouping, valid for all ecosystems, fits particularly well to the case of forests.

Table 4 gives an insight on how water availability may influence the ecosystem functions and goods and services.

The ecosystem function approach provides a holistic view of forest-based goods and services. Focusing on ecosystem-based services allows relating to characteristics of ecosystems. In the case of the Mediterranean forest ecosystems – already subject to a recurrent water deficit – the impact that an unwise partitioning favouring too much blue water would have on societies through the alteration of ecosystem-based goods and services becomes tangible.

A major service of green water is through the role of forests in capturing blue water, regulating flows and circulating water (Figure 34). This is a critical biological mechanism in water cycle regulation and in the use of water for biological production: a forest water pathway generates productivity as opposed to the inorganic (deforested, desertified) water pathway that in many cases, especially in arid regions and in the Mediterranean, promotes erosion, land degradation, floods and damages to human beings and ecosystems. Water evaporating from bare soil does not contribute to biological production, only to physical processes on the land's surface.

Forest growth sustained by green water is one of the relevant recognised mechanisms for mitigating climate change thorough atmospheric carbon sequestration (United Nations Framework Convention on Climate Change). This service might be improved through reducing deforestation (especially in tropical rainforests), increasing afforestation, and sustainable forest management practices subject to water availability.

Green water is needed to sustain ecosystem processes, their functions and the goods and services they provide.

Ecosystems and people depend on the same water. The question of how to provide enough green water to sustain ecosystems and, at the same time, provide society with blue water is discussed in Chapter 4.

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3.2.

Water Processes in Trees: Transpiration and Photosynthesis

Santiago Sabaté and Carlos A. Gracia

Plants uptake water through fine roots, store water in their different biomass components and lose water vapour (transpiration) through their stomata. While stomata are open and transpiration takes place, plants obtain carbon dioxide from the atmosphere which will be used by photosynthesis. The ratio between both carbon gain and water loss by transpiration through plant stomata is used as a water-use efficiency measure, which could be instantaneous when obtained by gas exchange measurements, or more integrative when longer time periods of these measurements are calculated and estimated by isotopic analysis or other indirect methods.

Carbon constitutes the main component of the skeleton of plant biomass, being about half of the plant mass. Carbon is long-lived in plant tissues but water is not. Water has short life in the plant, since most of the water passes throughout the plant from soil to the atmosphere by transpiration. Water stored in plant tissues and water involved in photosynthesis and respiration processes is very little compared to the amount of water involved in transpiration. Carbon gain is thus an expensive process in terms of water requirements. Figure 35 presents the relation between instantaneous water use efficiency and the kg of water (liters) transpired per kg of carbon fixed by photosynthesis. Instantaneous water use efficiency is easily obtained by gas exchange measurements.

The large amount of water transpired to fix carbon is significant. In the case of *Quercus ilex*, values around 3–5 (mmols CO2 /mol of H2O) are typical. Once discounted the carbon returned to the atmosphere by respiration, **fixing a gram of carbon can have a resulting cost of 1,000 to 1,500 grams of water.**

Common values obtained in plants of instantaneous water use efficiency measurements can often be found between 2 and 8 (mmols CO_2 /mol of H_2O). In the case of *Quercus ilex,* values around 3 to 5 (mmols CO_2 /mol of H_2O) are typical. This value implies that between 300 and 500 kg of water are transpired per kg of carbon fixed by photosynthesis. An important fraction of this carbon (roughly 60%) is returned to the atmosphere by respiration, thus reducing up to 1/3 water use efficiency in relation to net carbon fixation. In general, it can be said that plant loss of water vapour through their stomata is far more than 1000 times higher than net carbon gain. Carbon fixation is closely related to transpiration, especially in C3 plants. But how much transpiration is possible? The total amount of transpiration by forests is related to two important environmental con-

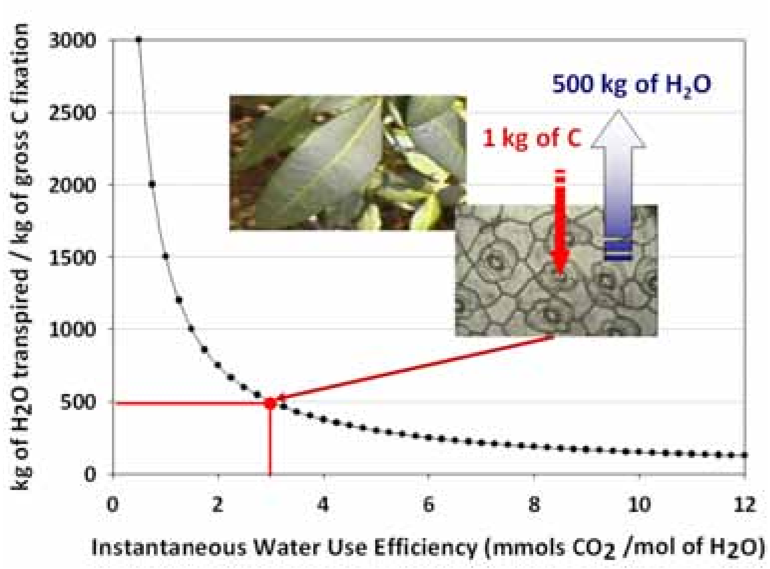

Figure 35. Water use by plants in transpiration as a function of instantaneous water use efficiency. Most Mediterranean plants have a WUE close to 3mmols CO2/mol H2O, (red dot). In these conditions, the cost of uptaking 1 g of carbon is 500 g of water. Once discounted, the carbon that goes back to the atmosphere by respiration, 1 gram of carbon stored in plants as NPP, can have a resulting cost of about 1,000 to 1,500 g of water.

straints. The first constraint is obviously the amount of water available for plants. The second is the total amount of energy available for evaporation, which gives the potential transpiration from tree leaf surfaces. The more trees have available water, the more water is transpired – but only up to an upper limit imposed by air evaporative demand, i.e. the energy available for evaporation.

Depending on the forest location, both energy-limited and water limited forests can be found. Furthermore, limitations of both energy and water can be found in the same forests depending on the season. In the Mediterranean, for instance, it is clear that forests are mostly water limited in summer periods and energy limited in winter periods, while better growing conditions are found in spring and autumn. Soil water storage plays an important role in buffering and overcoming plant water limitations in summer. Figure 36 shows the annual pattern of water in soil, evapo-transpiration and rainfall in a Prades *Quercus ilex* (holm-oak) forest (NE Spain) as an example. Soil water content in this forest is estimated to range from 96 to 0.2 mm depending on soil depth and season of the year.

In the Mediterranean, it is clear that forests are mostly water limited in summer periods and energy limited in winter periods.

When plants are water limited they control water losses by different mechanisms. The fastest response is closing the stomata that reduces stomatal conductance to water, but at the same time reduces carbon gain. In the short-term, by doing this plants solve the problem of continued tissues dehydration. Furthermore, the role of aquaporins to control

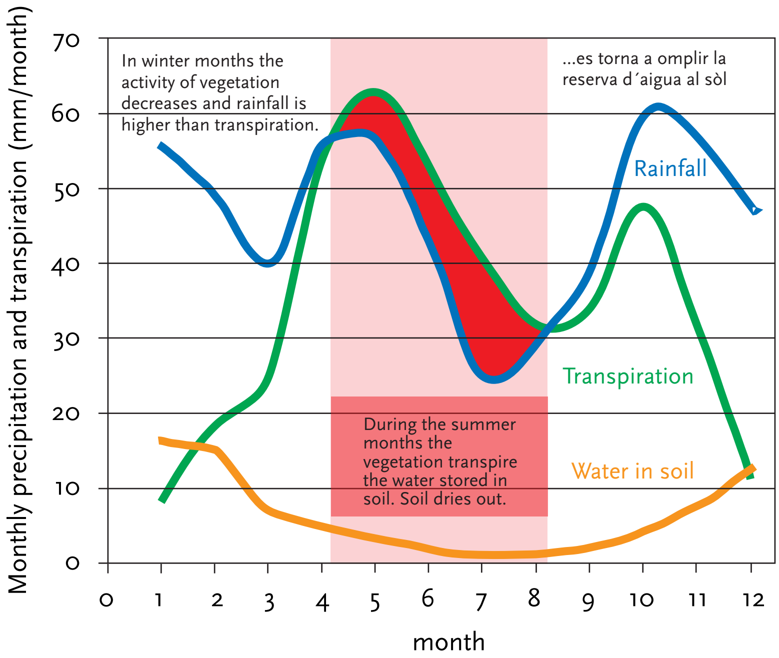

Figure 36. Annual pattern of water in soil, evapo-transpiration, and rainfall in Prades *Quercus ilex* (holm-oak) forest. The soil water content in this forest is estimated to range from 96 to 0.2 mm depending on soil depth and the season of the year.

water losses has also been emphasised, responding to variations of plant water availability from soil. Aquaporins are proteins which influence water transport in the plasma membrane; water channels in the plasma membrane can be closed when drought takes place, showing the importance of this cellular mechanism as a response to soil water supply.

Water movement through cell membranes is facilitated by proteins called Aquaporins. These proteins belong to the major intrinsic protein family, members of which are found in almost all living organisms.

Photosynthesis reduction causes problems to plants if there are not enough stored carbon reserves to maintain plant respiration needs. In addition, the lack of water may limit the functioning of phloem transport and limit long-distance carbon translocation within trees. Other problems may occur such as excessive leaf temperature promoted by the reduction of transpiration, or an excessive radiation that may cause damage to the chloroplast photosystems. When water limitation is prolonged, mid-term plant responses take place such as shedding leaves, while long-term responses include adjusting the shape of individuals or their tissues traits.

The fastest response of plants to control water losses is to close the stomata, which reduces stomatal conductance to water; **at the same time, however, this reduces carbon gain.**

Given the plasticity of certain plant species, different traits of individuals related to leaf and wood structures, as well as root/shoot ratios can be found. Furthermore, different species may show different response abilities and strategies to face drought.

A broad classification of plant response categories to soil water availability is based on how plant tissue hydration is maintained stable under fluctuating environmental conditions. Isohydry is attributed to the strong stomatal control of the transpiration rate, which results in the observed similarity in midday leaf water potential in both droughted and well-watered plants. Anisohydric plants typically exhibit less stomatal sensitivity to evaporative demand and soil moisture, allowing large fluctuations in midday leaf water potential. A third type of response is exhibited by isohydrodynamic plants, which show strong stomatal control that maintains relatively constant internal water potential gradients, but at the same time allows midday leaf water potential to fluctuate dramatically on a seasonal basis in synchrony with soil water potential.

As mentioned above, the amount of water stored in plants as well as the amount used by photosynthesis is by far lower than water transpiration amounts. For example, in the case of the *Quercus ilex* (Holm oak) forest at Prades (NE Catalonia) mentioned above, the amount of transpiration has been estimated at 463 mm/year on average, while free water in fresh tissues is in the range of 11 to 17 mm. Furthermore, in the same forest, based on gross primary production and plant respiration, the amount of water used by photosynthesis, as an electron donator to reduce carbon, is estimated to be some 2.3 mm/year and water produced by plant respiration 1.2 mm/year. These values are just to show the change in the magnitude of water use by Mediterranean forests, stressing the importance of transpiration.

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3.3.

How Plant Species Cope with Water Stress

Oliver Brendel and Hervé Cochard

A lack of water poses stressful conditions for plants. Here we will discuss adaptations to the deficit of water in the soil. Sufficient water in the soil is necessary for plant survival, as maintaining the water flux from roots to leaves insures sufficient cell turgor for growth, nutrient turnover and stomatal opening to allow gas exchange.

Plants have developed various strategies, at different time scales, to cope with reduced water availability in the soil: phenological adjustments, water status control, morphological and anatomical features which may vary between and within species.

Herbaceous plants can **escape** periods with reduced water availability during the annual cycle by completing the growth / flowering / seed production cycle entirely before the onset of a drought period. Perennial and woody plants, such as forest trees, cannot completely escape drought periods; however, the adjustment of budburst, leaf development and drought induced leaf shedding can limit the impact of drought on the growth cycle, as has been shown for different deciduous and evergreen Mediterranean oak species.

Drought resistance in forest trees is thus mainly a question of survival and competition within an ecosystem; in forestry, however, it is also a question of maintaining growth. Drought resistance strategies can be grouped into **avoidance** and **tolerance** mechanisms, where drought tolerance mechanisms can be divided into **dehydration avoidance** and **dehydration tolerance**.

Maintaining sufficient hydration of tissues is one strategy with which to **avoid** drought stress, and can be measured through the water potential of tissues. Stomatal closure with the onset of drought will conserve water in the plant (measured as water potential) and thus protect it; however, productivity decreases as less carbon can enter the plant.

Another strategy is to **tolerate** the decreasing water potential of the tissue where stomata are kept open and productivity does not decrease. This is achieved by plants either through increasing **dehydration tolerance** by osmotic adjustment in the cells, anatomical properties of the water conducting elements (e.g. loss of conductivity) allowing a higher tension on the water column; or by increasing **dehydration avoidance,** for example by reducing total leaf surface, stomatal density, increasing leaf thickness, leaf cuticular and sclerophylly of leaves as well as increasing below ground mass fraction (root/shoot ratio) and rooting depth.

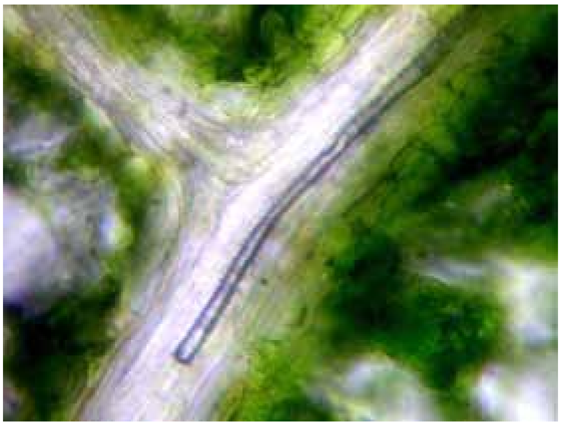

Figure 37. An air bubble trapped in a xylem vessel of a tree leaf vein. During water stress, the tension in the xylem sap increases and cavitation can occur. This provokes the entry of air in the xylem conduits which ruptures the water supply to the leaves and may eventually lead to plant death by desiccation. Mediterranean tree species are much more resistant to cavitation than other species, which partly explains why they can better cope with intense water stresses. Photo by H. Couhard.

While some of these strategies require time to develop, especially morphological and anatomical adjustments, other strategies involve rapid responses. Some of the most rapid responses of plants to acclimate to a soil water deficit are stomatal closure and osmotic adjustments. This is followed by **morphological adjustments** such as increased root growth and for continuous growing plants changes in stem and leaf morphology. The exploration of available soil moisture is especially important for Mediterranean plants and important differences between species exist. For example, it was shown that *Quercus ilex* had a deeper root system compared to Q. *suber* and that *Q. ilex* maintained root growth during a drought compared to *Q. cerris* and *Q. frainetto*. Significant differences in root biomasses were reported for four different Mediterranean pine species with different degrees of drought tolerance. However, differences do not only exist among different species – they also exist within a given species where genetic variation results in a diversity of responses. For example, significant differences have been shown for the biomass allocation to the roots compared to the shoots among *Pinus pinaster* families and among *Cedrus libani* provenances, where provenances from the dryer sites had larger root systems.

In the following, we will clarify two particularly interesting traits: species differences in embolism in water conduits during drought stress and the diversity of water use efficiency within species.

Under pronounced water stress, an **embolism in the conducting vessels** – preventing the sap to ascent from soil to leaves – may occur and lead to tree and branch dessication and mortality. Thresholds of xylem critical pressure related to embolism are highly variable between species – Mediterranean species being among the most drought resistant.

As indicated above, sap in the xylem conduits is under large negative pressure (=tension). Water is physically metastable under this condition, and may change to a more stable gaseous phase by **cavitation**. Cavitation, in turn, provokes an **embolism**, i.e. it breaks the integrity of the water columns in the xylem pipes (Figure 37) and thus impairs the mechanisms that permit sap to ascent from the soil to the leaves. The physiological consequences of cavitation are of great significance because it may eventually lead to shoot or tree mortality by desiccation. This explains why much effort over the past three decades has been devoted to the characterisation and understanding of cavi-

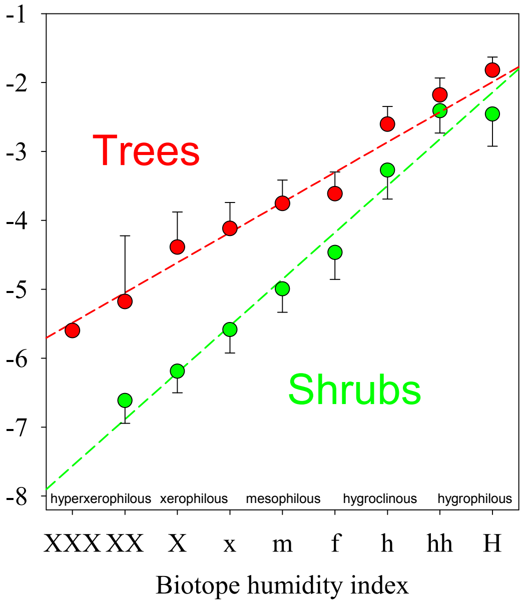

Figure 38. Correlation between the xylem vulnerability to cavitation of nearly one hundred woody species of the French flora and the humidity index of their habitat. Species cavitation resistance is estimated by the xylem pressure provoking 50% of cavitation (P50, MPa). The biotope humidity index is from Rameau et al. (1989, 1993, 2008). Species from dry habitats are clearly more resistant to cavitation. In a same habitat, shrubs are more resistant to cavitation than trees, probably reflecting a more shallow root system in the former species.

tation in trees. These studies clearly show that cavitation only develops when the xylem pressure drops below a critical value P_{cav}. P_{cav} is probably one of the most variable physiological parameters across tree species.

The most vulnerable species (like *Salix* or *Populus*) have P_{cav} values as high as -1.5MPa. In contrast, the most cavitation resistant species (like *Cupressus* or *Callitris*) have P_{cav} values below -10MPa. Such a large range has profound implications on species water relations and their responses to water stress. The xylem conduits of species with high P_{cav} are intrinsically unable to support high water stress levels. Therefore, these species have to close their stomata early during a drought to avoid deleterious embolisms from developing and are thus **drought avoiding**. In contrast, species with low P_{cav} can tolerate the presence of more intense water stress and tend to be more **drought tolerant**. In both cases, a remarkable coordination between xylem and stomatal functions can be observed: stomata close to control xylem pressure, allowing to keep its values slightly above P_{cav}.

The high drought resistance of Mediterranean tree species comes at the cost of high wood densities and low growth rates.

The behaviour of many Mediterranean species is quite surprising at first sight. As a rule, they are very resistant to cavitation (Figure 38) and tend to display the most negative P_{cav} values measured so far. Nevertheless, the behaviour of their stomata does not differ much from the behaviour of species with higher P_{cav} values. In other words, stomata close well before xylem pressures reach the critical P_{cav} values. They are both avoidant in terms of water loss and tolerant in terms of xylem function. As a result, the hydraulic safety margin of Mediterranean species is higher than in more temperate species. This strategy largely explains why Mediterranean species are highly drought resistant. However, there are costs associated with this behaviour. First, stomata can remain open only during a

Box 8. Investigations on drought adaptation related traits: some results

Traits related to drought adaptation were studied in the provenance or population trials of most of the major Mediterranean forest tree species (e.g. *Pinus halepensis, Pinus brutia, Pinus pinaster, Pinus nigra, Pinus canariensis, Pinus pinea, Juglans regia, Castanea sativa, Quercus suber, Quercus coccifera, Quercus ilex, Cedrus libani*) and concerned survival; growth; the biomass of different compartments; wood anatomy related to water conducting elements; water use efficiency; stomatal conductance and density; CO2 assimilation; plant water status; leaf osmotic adjustment; leaf anatomy; antioxidant status; hydraulic conductivity and loss of conductivity. Sometimes, trait measurements for one environmental condition are not sufficient to characterise population differences, although when a plasticity index is calculated for different environments, then differences might be determined. This was the case for *Pinus halepensis*, where saplings from a Garrigue site showed significantly higher plasticity compared to a rock site; this, however, was not the case for *Quercus coccifera*.

Genetic variation was also studied using neutral genetic markers: for *Castanea sativa*, a study detected a geographical pattern that was linked to rainfall; for *Pinus pinaster, P. nigra and P. Uncinata*, intrapopulation genetic diversity was linked to summer precipitation.

short part of the "growing" season, i.e. when water is available. This may imply that these species must maximise their carbon gain during this period, which comes at the cost of poor water use efficiency. The second drawback is that the construction cost of xylem conduits with low P_{cav} is very high. This is because conduit walls must be mechanically reinforced to cope with the high xylem tensions, requiring even more carbon resources.

Adaptive traits for drought increase the chance of survival under soil water deficit. Their variations between and within species (among populations) allow the selection of better-suited seed sources for plantation.

All these traits discussed above can be called "adaptive" for drought if they increase the chance for survival under soil water deficit conditions. Differences in adaptive traits between species are one cause for observed species distributions, for example along gradients from mesic to more xeric environments. However, also within species, diversity can exist for a given trait, resulting from differences in the genetic background. This genetic diversity provides the basis for adaptation of populations (plants within a common environment) to their local environmental conditions. The genetic background of each individual is called its genotype. Adaptation is a process that will change the composition of different genotypes within a population through natural selection over generations, thus creating differences among populations. Observing trees grown from seeds from different populations in one or several common environments (e.g. provenance trials) is a means to detect such differences and thus populations that are better adapted to certain environments than to others. This can result in direct recommendations for seed source classification and planting strategies.

Diversity has been shown within different Mediterranean plant species in their capacity to accumulate biomass through photosynthesis for a given amount of water used, referred to as **Water Use Efficiency** (WUE). This opens the way to potential applications in breeding and silviculture.

Box 9. A genetic approach to Water Use Efficiency (WUE)

Only few studies have further dissected this diversity for WUE in Mediterranean forest trees. This can be done with controlled crosses, to either estimate heritability or to dissect the observed variability within a full-sib family into Mendelian inherited components, i.e. Quantitative Trait Loci (QTL) detection. The first QTL suggesting a genetic determinism for WUE in Mediterranean forest tree species was found for *Pinus pinaster*. Another study detected 17 QTL for WUE in *Castanea sativa*, explaining a low to moderate proportion of the total phenotypic variance. QTLs were distributed throughout the whole genome. However, when comparing these QTL to QTL for WUE in *Quercus robur*, for which an oligogenic control was shown with few major QTL; however, no QTL co-localised between the two species. Although genetic maps also exist for families of *Pinus halepensis* and *Juglans regia*, no QTL detection studies have been published to date. For *Pinus pinaster*, QTL have also been detected for growth and wood properties. The QTL detection studies cited above are either based on optimal conditions or natural plantations with no published results to date on QTL detection under drought conditions. Such QTL are a starting point to characterize both functional and gene candidates. Genes related to drought stress can then be used for population genetic studies, elucidating patterns of natural selection and adaptation, which represent the major resource for a durable, adaptive silviculture.

Water use efficiency (WUE), the ratio of accumulated biomass for a given amount of water used, can be estimated for large numbers of samples by measuring the carbon isotope composition (^{13}C) of plant material (leaves, wood, wood extracted cellulose). Differences among populations in WUE have been found for *Pinus halepensis*, *Pinus pinaster*, *Juglans regia*, *Castanea sativa*, *Quercus ilex* and *Cedrus libani*. These population differences across many species suggest that WUE is a trait which has been selected in specific environments and is thus probably important for fitness and survival. However, WUE is not necessarily a trait directly linked to drought stress resistance, but needs to be interpreted within specific environmental situations. Classical examples are found for *Pinus pinaster* and *Castanea sativa* where trees from *a priori* dryer provenances showed lower water use efficiency. WUE is a composite trait whose full understanding requires deeper exploration, in particular through genetic studies (see Box 9).

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4.

Blue and/or Green Water: What Trade-Off?

Rainfall is the only naturally incoming water in a watershed, with a variable but finite amount. The partitioning of the incoming water into blue and green water flows depends to a large extent on natural processes, in which vegetation types and land-use play an important role. The development of human societies has been based on the domestication of biological (plants and animals) and physical (soil, water) resources, and on the emergence of urbanisation and industries, as exemplified long ago in the eastern Mediterranean. Basically, such a development has consisted in changing the vegetation cover, and partly **redirecting** water flows from natural to artificial ecosystems; from water courses to cities; and thus from nature to humans.

Today, as water resources become scarce in the Mediterranean, it is of paramount importance to recognise the inevitable competition and even conflicts between eventually contradictory objectives in water use. How can sound science-based strategies, integrating water management with environmental and human needs, be developed? The present chapter presents some aspects of the possible ways for redirecting water flows through biological and physical "engineering" between ecosystems components; between upstream and downstream; and between nature and society. It raises the question of the water footprint of our daily life, and also illustrates some historical undertakings on a large scale in forest hydrology and soil conservation.

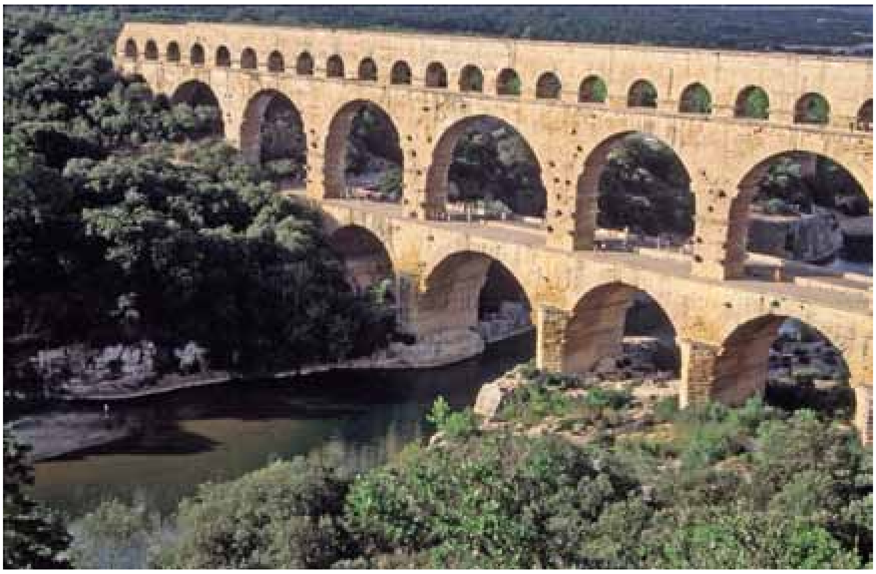


Figure 39. The famous Gard Aqueduct (2000 BP) spanning the Gardon river. Built by the Romans to supply blue water to the city of Nimes (France). Photo by C. Birot.

4.1.

Securing Water for Trees and People: Possible Avenues

**Carlos Gracia, Jerry Vanclay, Hamed Daly,
Santi Sabaté, and Javier Gyenge**

In the context of water scarcity, threats on forest survival in drier areas, and thus of inevitable trade-off between man and nature for the use of water, this section addresses three main questions of importance for foresters and land-use planners:

a) Can vegetation (upper- and understorey) management techniques in existing forest ecosystems reduce water stress for trees?
b) Can vegetation management and land-use planning increase the availability of blue water and green water for other uses than the forest?
c) To what extent and in what conditions can green water be directed to tree plantations?

Forests are needed for securing the provision to society of diverse goods and services, such as soil protection and water quality, which are both related to the canopy structure. Physiologically speaking, tree canopy and fine roots are the most active parts of trees, and thus any management regime of forest ecosystems must be based on a deep understanding of the functioning of both components and their responses to different silvicultural treatments. Sapwood is also essential as it relates roots to canopy and is highly dependent on silviculture.

In most cases, the structure of Mediterranean forests is influenced by a dense population of trees with moderate or small diameters. For centuries, exploitation has left behind stunted stems with a strong resprouting capacity in some cases. Under critical environments, this is at the origin of the very dense populations of small trees with very low growth rates due to: i) the lack of water availability combined with a high potential evapotranspiration characteristics from the Mediterranean climate; and ii) the higher respiration rates per unit of biomass or wood volume associated to the coppice structures as compared with the respiration rates of more “mature” population structures.

At the same time, it is now well accepted (see sections 2.1, 2.2) that forests are net water consumers. Most experimental studies have shown the high transpiration levels of forest ecosystems and the direct effects of forests on the reduction of water yield and stream flows. In energy limited continuous cover forests, – forests in which water availability is higher than potential evapotranspiration (PET) – the annual transpiration is very close to this PET, while in water limited forests, as it is the case in most Mediterranean forests, the annual transpiration can account for a high fraction of annual rainfall. Up to 90% has been recorded in *Quercus ilex*.

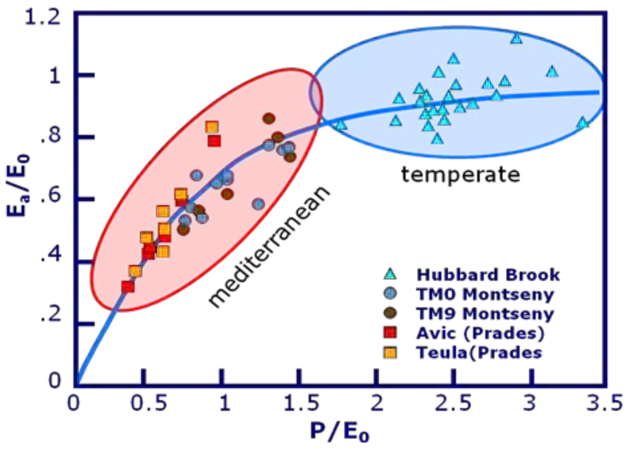


Figure 40. In Mediterranean forests with an effective rainfall lower than the potential evapotranspiration, the actual evapotranspiration is only a fraction of potential evapotranspiration; in other words, the forests grow under water-limited conditions. In boreal or temperate forests where precipitation is higher than the potential evapotranspiration, the actual evapotranspiration equals or is very close to the potential evapotranspiration. These environmental characteristics are the bases of important differences in the ecophysiological responses of water-limited and non-water limited forests. Source: Piñol, J. et al. 1999.

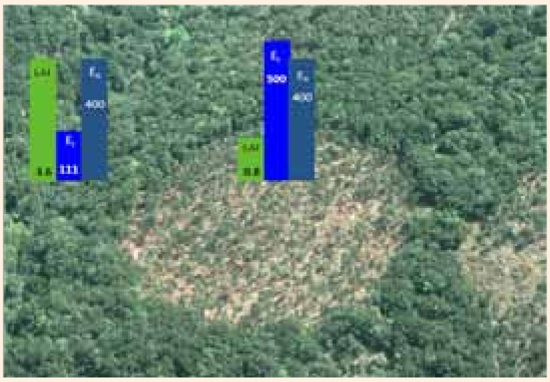
Two questions thus arise: i) Can adequate forest management and planning techniques reduce the water stress undergone by trees and contribute, at least, to the survival of forest stands? ii) Can adequate forest management and planning techniques be useful to reduce water use by forests and/or enhance water-use efficiency (less water is used to produce biomass)? Answering these questions is not an easy task. Some understanding of the water requirements of the tree for different functions and how the water limitations can affect these functions is needed. It is well known that the amount of water directly involved in photosynthesis is almost negligible and that most of the water is transpired through the stomata at the leaf level. Nevertheless, the role of this transpiration is crucial for the tree. The water transpired is the vehicle that carries nutrients on from soil, and the loss of this water through the stomata is the mechanism for up taking carbon by leaves, among other important physiological roles.

In most Mediterranean forests, potential evapotranspiration is much higher than precipitation – trees cannot achieve the potential rates of transpiration due to the lack of water (Figure 40). In these conditions, the reduction of LAI (e.g. by removing some trees) does not lead to a proportional reduction of transpiration. The remaining trees can use much of the water not used by the cut trees (see Box 10). Nevertheless, despite this lack of apparent response in the amount of water transpired, there are some positive side effects as the thinning improves the survival of the remaining trees.

In Mediterranean conditions, the reduction of LAI (e.g.: through thinning) does not reduce the total transpiration since the remaining trees use much of the water not used by the cut trees. As a consequence, the remaining trees have a better survival.

If a less dense population transpires the same amount of water, each tree transpires a higher proportion of water, which can result in less water stress experienced by trees during extreme drought conditions. The problem can be addressed as a cost-benefit analysis between the reduction of tree density and the increase of survival capacity of the remaining trees in future severe drought conditions. To carry out the correct analysis, one has to know how much water a tree of a given species uses to survive, and how this water is used by the tree.

Box 10. Experimental manipulation in the *Quercus ilex* forest of Prades, Spain. The forest has a coppice structure with a very high density of resprouts, which was reduced in different intensities in replicated experimental plots. Source: Gracia et. al. 1999.



The figure on the left shows the result of applying one of these thinning intensities on the transpiration rates (values are the average of three replicates): the leaf area index was reduced from 3.6 in the control plots to 0.8. The transpiration on a leaf area basis (EL) increased from 111 l/m2 of leaf/year to a value of 500 l/m^2 of leaf/year. Nevertheless, the transpiration on a ground area basis (EG) remained constant at a value of 400 liters/m2 of ground/year, which represents 84% of the total precipitation in that particular year.

Two years later, a very dry period of more than eleven months with less than 300 mm of cumulated rainfall caused an intense die-back of an important fraction of the trees in the control plots. The trees in the thinned plots (left) which transpired the same amount of water but distributed among a reduced number of trees, kept the water potential in better conditions than the trees in the control plots; also, no dieback was observed despite the almost total recovering of the previous values of leaf area index (see also Box 11).

The ratio between water used *per* actual or new produced biomass is easier to understand with an example related to the forest in figures in Box 10. Four years after thinning, the density of trees on the experimental plot was 2,000 trees/ha with a basal area of 36.4 m^2/ha. From the annual precipitation of 580 mm, the trees transpired 490 mm or 84% of total rainfall. The average tree in this population transpired 2,450 liters of water. Box 11 summarises the amount of carbon required to maintain the leaves in the canopy, the wood and bark from stems, coarse roots and branches, and the fine roots. This maintenance requires some carbon, which is respired to provide the energy needed to repair or replace the molecules of different compounds needed to keep the functionality of leaves, fine roots and the living cells present in the remaining tissues of the tree.

In addition, some new leaves and fine roots have to be formed to replace the losses and to grow. In the formation of new tissues and the maintenance of the previous formed, the carbon fixed in photosynthesis is involved (carbon represent the 50% of the dry weight of the plant) and this carbon is fixed at the cost of a huge amount of water transpired (see section 3.2). The data in Box 11 summarise the amount of carbon required by the mean tree in the population to maintain and form the different components of its structure, as well as the water required to fix this carbon. It is evident that

Box 11. Water used by a *Quercus ilex* tree

The table below summarises the use of water in the thinned plot of Box 1 four years after thinning. The tree density is 2000 trees/ha. LAI (3.10) was almost totally recovered (see the picture on the right in Box 10). In these conditions, from the total annual precipitation (580 mm) the trees transpired 84% or 490 mm; or 2,450 liters of water per tree on average.
The table compares the cost of maintenance and formation of leaves, fine roots and wood and bark components of branches, stem and coarse roots both in terms of carbon and in terms of transpiration needed to fix this carbon. On an annual basis, the forest transpired 301 liters of water per each gram of carbon fixed.

	Biomass	Annual production	Annual respiration (gC/tree)		
	kg/tree	kg/tree/year	Maintenance	Formation	Total Cost
			grams of Carbon /tree/year		
Leaves	2.72	1.13	3536	833	4,,369
Bark and Wood*	91.00	2.10	739	1,544	2283
Fine roots	0.40	1.30	514	956	1,469
TREE			4,789	3,332	8,121
			liters of water/tree/year		
Leaves			1,065	251	1,316
Bark and Wood*			223	465	688
Fine roots			155	288	442
TREE			1,442	1,004	2,446

*(including coarse roots)

To maintain and form leaves, the average tree (see table above) requires the leaves to transpire 1,316 liters of water to fix 4,369 grams of carbon, making foliage the most expensive water component of the tree. Bark and wood requires 688 more liters of water and the fine roots, which are renovated several times per year, 442 liters. In total, 2,446 liters of water is transpired per tree annually. The maintenance cost requires 1,442 liters of water per tree or 288 mm in total. Given that transpiration represents 84% of annual precipitation, the 288 mm of transpiration represents 343 mm or 64% of the total annual rainfall.

just to maintain the tissues present on the tree, 1,442 liters of water are required (equivalent to 68% of the annual rainfall); this maintenance does not compensate the leaves and fine roots losses which have to be replaced with the formation of new ones.

Keeping trees alive, even without biomass increment, may result in a huge cost in water, in particular for evergreen species common in the Mediterranean.

These results, however, must not be generalised. Water-use efficiency can differ among tree species (see section 3.3): different tree structures or population densities that can be modified by pruning, thinning or other silvicultural practices can modify the resulting values; however, this example shows the enormous amount of water involved in the functionalism of a forest. It also makes evident the severe risk that the reduction of precipitation projected by most Global Circulation Models in southern Europe, North Africa and other areas in the world represent a threat to the survival of some forests, at least

Box 12. Water used by a *Pinus sylvestris* tree.

The following table summarises the use of water of the average pine tree in a forest with a density of 800 trees/ha, with a basal area of 36 m2/ha and a LAI of 1.4, lower than *Q. ilex* LAI in the forest of Box 11. In these conditions, from the total annual precipitation (634 mm) the trees transpired 68% of precipitation or 430 mm; or 5,378 liters of water per tree on average (in this case the average tree is 24 cm in DBH, bigger than the holm-oak trees in Box 11). The table compares the cost of maintaining and forming leaves, fine roots as well as the wood and bark components of the branches, stem and coarse roots both in terms of carbon and in terms of transpiration needed to fix this carbon. On an annual basis, the forest transpires 350 liters of water per each gram of carbon fixed.

	Biomass	Annual production	Annual respiration (gC/tree)		
	kg/tree	kg/tree/year	Maintenance	Formation	Total Cost
			grams of Carbon /tree/year		
Leaves	3.25	1.06	2,600	781	3381
Bark and Wood*	326	2.90	9,403	2,131	11,534
Fine roots	0.13	0.45	104	328	432
TREE			**12,107**	**3,240**	**15,347**
			liters of water/tree/year		
Leaves			911	274	1185
Bark and Wood*			3,295	747	4,042
Fine roots			36	115	151
TREE			**4,243**	**1,136**	**5,378**

*(including coarse roots)

To maintain and form leaves, the average tree (see table above) requires the leaves to transpire 1,185 liters of water to fix 3,381 grams of carbon. In these trees, bark and wood are the most expensive components due to the bigger proportion of sapwood when compared to holm-oak. These tissues require 4,042 more liters of water and the fine roots – which are renovated 3.4 times per year – 151 liters. A total amount of 5,378 liters of water is transpired per tree annually. The maintenance cost requires 4,243 liters of water per tree or 339 mm. Given that transpiration represents 68% of annual precipitation, the 339 mm of transpiration represent 498 mm or 78% of the total annual rainfall.

with the structure they have at present. This threat is particularly severe for those forests living in environmental conditions, in which the annual rainfall is lower than the PET – as it is the case for Mediterranean forests previously discussed. In these water limited conditions – especially in those areas in which climate models project severe reductions of precipitation – it is crucial to analyse the cost in terms of water of the forest and evaluate the physiological benefits of reducing the density of tree populations. This task is particularly urgent in Mediterranean species with a very high density of resprouts. Some recent observations make evident the dieback of various tree species in some Mediterranean forests after just three consecutive dry years with rainfall far below the average.

Nevertheless, there is still some room to mitigate water loss from forests through silvicultural practices, although there remains a great need for research in this area. A few examples of potential applications of new research findings are given below.

Water-use patterns in natural eucalypt forests in which the canopy structure varies greatly between irregular old-growth (with “windbreak” trees) and even-aged regrowth (without windbreaks), offers some hints that water use may be reduced by modifying the canopy structure. Thus it seems possible that internal “windbreaks” within a plantation could create a water-wise forest similar to an old-growth forest. The number and

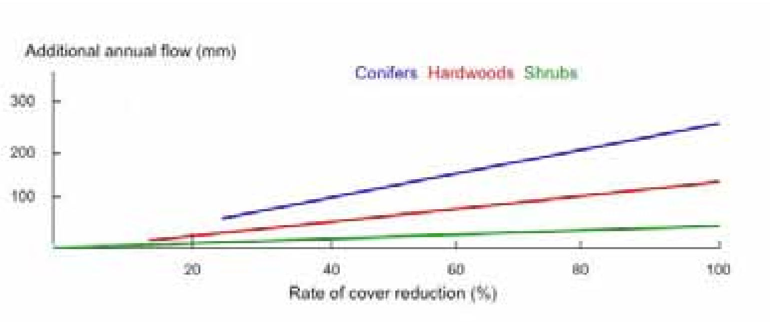


Figure 41. Impact of forest cover reduction (%) on additional annual flow (mm) within the five years following the cut. Source: Bosch and Hewlett 1982.

layout of windbreaking trees required within a plantation to quench thirsty regrowth remains an interesting research question. Careful species selection may be needed to ensure that water savings are achieved with internal windbreaks and ensure that they do not merely simply swap one problem for another. Species differ greatly in their ability to control stomata – with some species maintaining a very frugal water balance while others remain at the mercy of the elements.

One way to modify water use through the structure of the canopy is through the boundary layer that influences how the air near the trees mixes with the upper atmosphere. Even-aged plantations have a very different boundary layer than mixed-species plantations and old-growth forests, which is reflected in their water use. Canopy texture is important because it affects the aerodynamics, especially the turbulence and the boundary layer. Fortunately, it is relatively easy for forest managers to manipulate the canopy texture through species selection and thinning regimes. However, many plantations are relatively small, and edge effects are important. It is clear that unproductive transpiration can be reduced by softening plantation edges through pruning and thinning, by avoiding unnecessary breaks in the canopy and possibly with hedges to create more aerodynamic edges.

There is evidence that mixed-species stands offer hydrological as well as other benefits. Some studies report greater production efficiency (ratio of transpiration:assimilation) in mixed species plantings compared with pure stands. Pure *Acacia mearnsii* achieved 1,406 (± 302) m^3 of water/ m^3 of wood, but improved to 882 (±98) m^3 of water/ m^3 of wood when mixed with *Eucalyptus globulus*. It seems likely that the different statures exhibited by these two species helped to create this effect, as the eucalypt tends to be tall and narrow, whereas the acacia tends to be shorter and broader, offering a mutual benefit: the taller eucalypts provide shelter for the acacia, and the leguminous acacias provide nitrogen for the eucalypts.

In the Mediterranean environment constrained by water limitations, only drastic changes in the forest cover beyond the limits of classical thinnings might result in an increase in blue water.

As mentioned earlier, forests are in general net consumers of water and hence negatively influence the annual water yield, even if their cover may have a beneficial impact on flow seasonality. Hydrological studies have shown that the large watersheds are not suited for investigating the relationships between land use and water yield as well as the experimental paired watersheds because the interpretation of the results raises many problems. Our available knowledge is based on experiments, planned or carried out in small catchments. The forest cover manipulations in the catchment relate to clear or partial cut, afforestation of bare land or fire. A literature review carried out on 94 catchments has shown that the additional flow related to the rate of cover reduction can be significant, but only above a threshold of about 20% to 30%. This additional flow ranged from a few per cent up to 20% of the annual rainfall. The amount of this additional flow was also proportional to the rainfall. The relative flow increase, in regard to the annual rainfall, for different cover types: conifers, hardwoods and chaparrals was respectively in a range of 10% to 20%; 0% to 20%; and 5% (after chaparral removal). For chaparrals, whose occurrence is situated in dry areas (usually below 600 mm), the flow increase would amount only 30 mm even after a drastic modification.

These data suggest that the impact of classical silvicultural treatments like intermediate or moderate thinnings on an increase in water yield is small or non existent. This is even truer in water-constrained environments like in the Mediterranean. These results are also consistent with those discussed above, showing that the surplus of water generated by the thinning in a Holm oak coppice is entirely consumed by the remaining trees. One can conclude that only drastic modifications of the forest cover, such as its partial or full conversion to other land use, may result in a significant increase of water yield.

The question of a drastic change in forest cover, and thus of land use, in order to increase the production of blue water downstream deserves much attention and should integrate all goods and services related to the initial cover. Soil erosion, inter alia, is a major threat in the Mediterranean (see section 1.5) and should not be underestimated. Changing partially or totally the forest cover in a catchment into other land-uses can be also envisaged. It amounts to redirecting green water flow from forest trees to other plant cover: fodder in rangelands, crops in fields, agroforestry systems, etc. It also requires a thorough assessment of the pros and cons.

Box 13. Negotiating a reforestation project in Tunisia

During a 1998 participatory appraisal exercise in the poverty-stricken hilly areas of Zaghouan Governorate in Tunisia, participants from the surrounding douars (villages) expressed serious concerns about the restrictions imposed by a new mechanised reforestation project covering the hilltops of the Sidi Salem forest (410 ha). Before the project, local communities viewed the public forest as their free grazing area, where they also collected fuel wood and medicinal herbs. Reforestation involved bulldozing and replanting the whole area with Aleppo pine in fenced plots. Traditional uses of forest products were banned until the commercial wood had been sold to outside traders after a nine-year rotation period. Local communities, therefore, perceived the programme as a threat to their customary rights.

To address the issue, project staff met with local representatives and the Soil Conservation and Forestry Services. The aim was to identify possible measures that would be technically and economically acceptable to the line agencies, while answering local needs. The joint final proposal included the following measures: i) replacing Aleppo pine with fast-growing fodder and honey producing tree species on gentle slopes so as to reduce the deferred grazing period; ii) extending the firebreak network to make the upper forest zone accessible to livestock; and iii) setting aside the steeper sections for Aleppo pine and covering the rest with fodder species plots.

The agreement also mobilised community participation in the project's implementation through initiatives such as: i) contracting local interest groups to prepare and maintain plantations; ii) establishing pilot plots to test the introduction of local fodder species; iii) creating a local forestry association to be responsible for forest management as required by Tunisian law; and iv) providing microcredit for buying improved stoves that consume less fuel wood.

Following discussions and negotiations on cost-sharing and reciprocal obligations, all activities were integrated into the action plans of the concerned douars and line agencies without any increased costs for the project.

Source: FAO 1997.

Box 14. An example of a payment for environmental services (PES) in a Tunisian watershed

An illustrative example of potential PES scheme can be drawn from the management of the Barbara watershed in north-western Tunisia. Most land is privately owned and cultivated with cereals. In order to protect the downstream water infrastructure, the government gives large subsidies (80% of the investment costs) to protect gullies using acacia plantation and/or check-dams. However, these subsidies are not conditional and the landowners are not compensated for expenses and lost income from grazing resources. Consequently, the survival rate of acacia is quite low. The economic analysis of different land-use alternatives showed that all the protection measures are less profitable for farmers than producing cereals alone; only one cereal with the acacia plantation in gullies seems to be profitable from a national perspective. In order to encourage acacia plantation in gullies, farmers should be compensated for any loss of income incurred (100 TND/ha). This compensation could be covered by the reduced cost of sedimentation (200 TND/ha). The payment by water users could increase the budget available for conservation, contribute to a more efficient use of water and could increase the survival rate of acacia because payments would be conditional to success indicators.

The question of a drastic change in forest cover to increase the production of blue water downstream deserves much attention and should integrate all goods and services related to the initial cover.

Planting trees in a context of overall water scarcity should take into account not only the multitude of marketed and non marketed goods and services that could be provided, but also the large number of stakeholders at local and national levels who could be affected and who have different and divergent perceptions regarding forest plantation and the use of natural resources (Box 13).

Upstream users can benefit from the direct uses of forest plantations, while downstream users of water resources would be affected by the effects of land management change upstream on the quantity and quality of the water reaching the reservoir.

While public administration is more concerned by soil and water resources protection and economic development, the private owner is interested in the short-term private benefits of the plantation. Also, the local population who live in forest areas, especially in southern and eastern Mediterranean countries, would like to maximise its private income for the current use of natural resources in the short term. Another distinction could be made between the upstream and downstream users. Upstream users can benefit from the direct uses of forest plantation, while downstream users of water resources would be affected by the effects of land management change upstream on the quantity and quality of the water reaching the reservoir. This mixed characteristic of forest services and their scale dimension stress the critical trade off between watershed protection and the local benefits for forest owners or local users. The situation is still more complex given that some land-use changes can have non-reversible effects on the development of forests, at least in the short term.

In such circumstances of conflicts and controversies, the effects of the land-use change on water resources and their distribution among stakeholders should be analysed when establishing a plantation strategy in a water-constrained environment. For example, before the conversion of shrubs to forest plantation, we should compare the situations with and without intervention: What would be the on-site effects of direct uses in the long term (wood, fodder, fruits, etc.) and the off-site effects on water flows, groundwater recharge, sediments and water quality? What are the net returns for the forest owner, local users and what are the net benefits at the social perspective? Who are the gainers and the losers from this land use change? The plantation could be conducted only if it can be economically desirable at social perspective, i.e. the discounted net benefits of the plantation exceed those of the situation without intervention and it is financially viable. The analysis should also consider the projected effects of climate change that in some cases will severely reduce water availability. Consequently, there is a need for offsetting the potential income loss if improvements in soil fertility and water capacity were undertaken. Non-market benefits and off-site effects are not usually considered because it remains difficult to measure the land-use effects on soil erosion and water resources, especially for large basins. Usually, public intervention through subsidies, grants and compensation for income loss is needed to fill the gap between private profitability and public utility. Besides these traditional instruments, other market-based instruments were introduced, based on the payment by off-site beneficiaries for the services provided. Mostly applied for were water provision services, which were implemented through the Payment for Environmental Services scheme (PES), i.e. direct negotiations between water users and landowners (Box 14); the trade of "credits" between companies and landowners for exceeding the requirements on water use; or public payments to farmers/forest owners for management practices that protect water quality.

Investments in forest plantations induce lower direct returns compared to the current situation "business as usual" scenario, but could generate higher benefits for society when local- and national-scale externalities such as increased soil fertility and water capacity, and global-scale externalities such as biodiversity protection and carbon sequestration are included.

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4.2.

Balancing Water for Ecosystems, Goods and Services, and People

Robert Mavsar

Both water and ecosystem goods and services are fundamental for our existence.

Without doubt fresh water is essential for the survival of all non-marine life and in most cases has no substitutes. Water is therefore not just a commodity but a fundamental life support element.

Also in relation to human activities, freshwater is unique having no substitutes in most of its uses. In general, the importance of water is mostly seen through the direct withdrawal and use of blue water for irrigated agriculture, industrial production and domestic use, for example. However, this direct use of water is not sufficient to secure our existence. Water is also needed to sustain the multiple ecosystem goods and services on which we heavily depend. These goods and services represent the benefits that humans derive directly or indirectly from ecosystems (terrestrial and aquatic). As briefly explained in section 3.1, these include a wide range of different goods and services that can be divided into four main categories (see Table 5).

Provisioning services are the products people obtain from ecosystems such as food, fuel, fresh water. **Regulating services** are the benefits people obtain from the regulation of ecosystem processes, including air quality maintenance, climate regulation, erosion

Table 5. Ecosystem goods and services.

Provisioning	Regulating	Cultural
Food Fibres Genetic resources Biochemicals, natural medicines, pharmaceuticals Freshwater	Air quality regulation Climate regulation Water regulation Erosion regulation Water purification and waste treatment Disease regulation Pest regulation Pollination Natural hazard regulation	Cultural diversity Spiritual and religious values Knowledge systems Educational values Inspiration Aesthetic values Social relations Sense of place Cultural heritage values Recreation and ecotourism
Supporting		
Soil formation, Photosynthesis, Primary production, Nutrient cycling and Water cycling		

Source: Millenium Assessment Report, 2005.

control and water purification. **Cultural services** are the nonmaterial benefits people obtain from ecosystems through spiritual enrichment, recreation and aesthetic experiences. **Supporting services** are those that are necessary for the production of all other ecosystem services, such as primary production, pollination, production of oxygen and soil formation. Supporting services differ from provisioning, regulating, and cultural services because their impacts on people are indirect.

To enable the functioning of ecosystems and to sustain the production of ecosystem goods and services, water (blue and green) is needed.

> Blue water and green water are needed to sustain the provision of goods and services that we need.

When estimating the importance of water, we have to consider both the direct and indirect use of blue and green water. “Direct water use” refers to water withdrawal or use that directly benefits the society. In contrast, “indirect water use” refers to those water functions that benefit society in an indirect way like green water flows that support the development of habitats.

If we consider rainwater as the basic freshwater source, we can partition it into four main water flows (see Figure 42). **Direct blue water use** refers to the direct withdrawal of blue water for irrigated food production, industrial production, domestic use (e.g. drinking, cooking and washing) and for the provision of municipal services. **Indirect blue water use** consists of the provision of goods and services from freshwater ecosystems (e.g. wetlands, river basins and lakes). **Direct green water use** secures goods and services that can be directly consumed (e.g. food, fibres, wood and fuel) and are provided by rainfed agriculture and livestock production, forests and other ecosystems. Finally, by **indirect green water use** we refer to ecosystem goods and services that are provided by wetlands, grasslands and forests, etc, and indirectly benefit society (e.g. carbon sequestration, biodiversity and pollination).

> The majority of rainfall is naturally allocated for the provision of ecosystem goods and services.

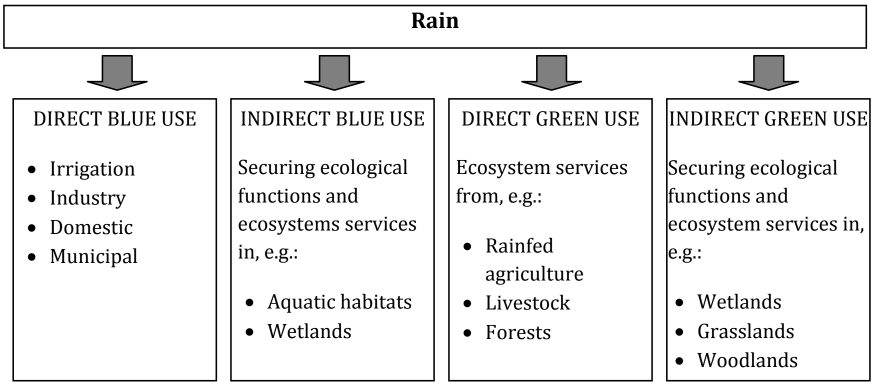

Figure 42. Partitioning of rainwater into blue and green water for direct and indirect use.

Table 6. Percentage of rainwater needed to sustain water dependent human activities at the global level.

Water	% of rainfall	Flow domain		Use	% of rainfall
Blue	38%	Available	Used	Food (irrigated)	2%
				Domestic and industry use	1%
			Unused	Time-stable runoff (e.g. rivers)	8%
		Unavailable		Flood runoff (non-utilizable)	27%
Green	62%	Direct		Food (rainfed)	4%
				Permanent grazing	18%
		Indirect		Grasslands	11%
				Forests and woodlands	17%
				Arid lands	5%
				Wetlands	1%
				Lake evaporation	1%
				Unaccounted green flow	5%

Source: Rockström et al. 1999.

At the global scale, the traditional use of freshwater (direct withdrawal of blue water) accounts only for about 3% of the annual rainfall (see Table 6), which is approximately one third of the available blue water.

In the past, it was considered that food production (agriculture) is the main consumer of water. According to the present accounting practices, only 2% of the rainfall is used for production of food on irrigated areas. However, this accounts only for one part of the food production, because on average almost 70% of the current food production originates from rainfed agriculture.

On the other hand, the majority of the available water is used for the maintenance of main ecosystems and the provision of ecosystem goods and services (indirect use of green and blue water). In other words, almost 90% of the global green water goes to sustain ecosystem goods and services from the main types of biomes.

A drastic reduction of the forest area might increase the availability of water, but would negatively influence the provision of ecosystem goods and services.

As explained in section 4.1, forests need water for their existence and hence in general have a negative impact on the annual water yield. However, the water consumed by forests is also needed to maintain their capacity to sustain the provision of ecosystem goods and services. This suggests that a decrease of forest cover, on one hand, could increase the available amount of water for other uses; on the other hand, however, it would reduce the capacity of forests to produce ecosystem goods and services.

To explore the economic dimension of the implementation of a policy aimed at reducing forest cover, we would have to compare the gain in and the value of water as well as the losses of environmental goods and services and their value. The issue of a forest's water consumption has already been discussed in section 4.1. In this chapter,

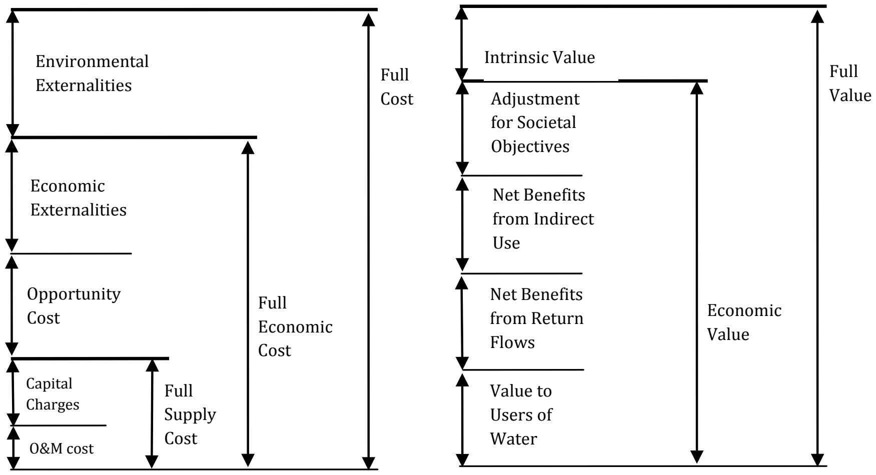

Figure 43. General components of the cost and value of water. Source: Rogers et al., 2002.

we will only consider the issues of the economic value of water and the value of ecosystem goods and services.

When taking the value of water into account, we should distinguish at least two concepts: the value and the price of water (Figure 43). According to one of the classifications, the value of water is comprised of the economic and intrinsic value. The **economic value** includes the value of water to users (e.g. value of water in industrial and agricultural use and the willingness to pay for its domestic use); net benefits of return flows (e.g. recharge of groundwater); net benefits from indirect use (e.g. benefits associated with improvements in income and in health that can accompany schemes that provide water for irrigation, domestic and livestock use); and adjustments for social objectives (e.g. poverty alleviation, employment generation and food security). The **intrinsic value** of water includes the stewardship, bequest and pure existence value.

However, the actual price of water is mainly defined based on the cost of supply. The recommended approach would be to define the water price on the basis of the full-cost of supply. This cost includes supply costs (e.g. operational and maintenance costs, and capital charges), opportunity costs, economic externalities and environmental externalities (Figure 43). Nevertheless, in most countries in the Mediterranean area, water is priced below its full cost. Table 7 gives examples of water prices for agriculture. Such a pricing system not only underestimates the price of water, it also fails to provide incentives for more efficient water use (see section 5.5).

With regard to the economic value of ecosystem goods and services, it should be noted that very few of these have established market prices or are traded in traditional markets. Nevertheless, it is recognised that these services are of utmost importance and value for society. Over the past decades, a number of studies have been conducted to estimate the economic value of different ecosystem goods and services. For example, Merlo and Croitoru (2005) estimated an average total economic value of Mediterranean forests to be in the range of EUR 133 per hectare of forests or in other words almost EUR 50 per year and capita. Only some 35% of this value can be ascribed to wood forest products (see Figure 44). However, it should be considered that the above values were obtained as an average from a number of different case studies. In practice, it means

Table 7. Structure of agricultural pricing systems and price levels. Source: Chohin-Kuper et al., 2003.

Price structure	Country	Price		Incentive to save water
		EUR/ha	EUR/m^3	
Free	Egypt			None
	Albania			
Area pricing (per ha)	France	108		Low
	Greece	75 – 175		
	Spain	32 – 200		
	Lebanon	227		
Area pricing depending on crop	Turkey (and by region)	16 – 80		Low
	Italy (and by type of soil)	24 – 200		
Volumetric uniform	Spain (rare)		0.02 – 0.06*	Low
	Morocco (part)		0.01 – 0.04	Low
	Tunisia (part)		0.07	Low
	Cyprus		0.095	Moderate
	France (ASA)		0.05 – 0.06	Moderate
	France (SAR)		0.05 – 0.23*	Moderate to high
Optional	France (SAR)	40 or 25	0.05 or 0.14	Moderate
Increasing Block pricing	Jordan		0.02	Moderate
	Israel		0.10	Moderate, High within the limits of the quota

*only the volumetric component of a two-part tariff

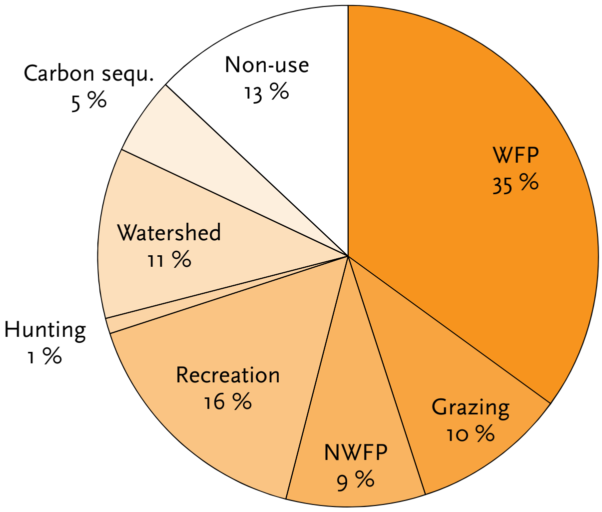

Figure 44. Composition of the Total Economic Value of Mediterranean Forests. Source: Merlo & Croitoru 2005.

that depending on the case, the economic value of ecosystem goods and services can vary significantly in magnitude and composition.

This indicates that it is difficult to make general statements about the magnitude of the social and economic effects of potential reduction of forest area in order to increase water availability for other uses (e.g. agriculture, industry and personal use). Further, such changes would most likely not only influence the social welfare, but could also have significant distributional impacts, especially on those sectors of the world's population who depend directly on the goods and services provided by forests and other ecosystems. All in all, forests should not be considered as mere net water consumers; rather, they should be seen as providers of crucial ecosystem goods and services which are essential to the very wellbeing of all humans.

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4.3.

Integrated Water Management at the Landscape Scale:

Science Backing Development – a Case Study in Tunisia

Jean Albergel, Jean Collinet, Patrick Zante and Hedi Hamrouni

Section 1.5 has shown the importance in the Mediterranean to address water and soil as interrelated issues. The integrated management of water and soil around the Mediterranean Basin is based on different approaches depending on the country. Between the "no more drop of water to the sea" and the depletion of groundwater or the start of the depletion of fossil aquifers, different choices exist. Based on the example of the national programme of watershed management in Tunisia as a case study, **the present section illustrates how recent scientific achievements can provide concrete solutions for backing and improving the integrated water management at the landscape scale.**

Strategies aimed at increasing availability of water resources as well as limiting floods and reducing the negative effects of soil erosion have evolved towards the design and implementation of a vast programme of small-scale (< 50 km^2) watershed management; a subset of which is used for parallel research aimed at improving knowledge for the further extension of the programme.

What seems to assert itself is the construction of **small dams** as facilities that are not only targeted to the mobilisation of surface water resources (hillside reservoirs), but also for controlling the high floods by protecting – and limiting the silting of – the largest structures downstream. In recent years, Tunisia and Morocco have opted for this solution. In Tunisia, within a project of 1,000 small dams, over 500 have already been built with the following objectives: i) manage the slopes to reduce the loss of agricultural land amounting to 5,200 ha / year; ii) reduce the silting of some 10 major dams downstream, silting which reaches 25 million m^3/year; iii) increase groundwater recharge; iv) mobilise the larger part of the 500 million m^3 lost in sebkrhas (i.e. salted depressions in arid zones) or in the sea; and v) create points of irrigation development.

A hillside reservoir is a lake resulting from the building of a small dam made of earth in the bed of an ephemeral or intermittent river. The dam can reach 10 meters high (always below 15 meters which is the threshold set up by the declaration of the international commission for the large dams) and is equipped with a lateral weir. This weir, slightly consolidated, is used as a fuse in case of very heavy rains. Hillside reservoirs show a high diversity and capacity, ranging from tens of thousands to several hundred thousand cubic meters, while watershed areas vary from a few hectares to several dozen square kilometres.

Table 8. Silting of small dams in 13 hydrological retention lakes with various land covers. Source: Directory – ACTA and IRD Tunis. The figures do not show or express relationships between forest cover and protection against erosion. Farmlands, protect the soils better by using soil and water conservation techniques. The percentage of bare soils in the catchment is not either a solid indicator of solid transport. Bare soils can be developed on marls, very sensitive to erosion, or on rocky material producing very little sediments.

Station	Watershed area	Year Const.	volume Silt 96	Life span	Vol. Export.	Total Erosion	Spec. Erosion	Vegetation %		
	ha		103 m^{3}	years	103 t	103 t	t/ha/ year	Forest	Cultivated lands	Bare lands
Sadine 1	384.0	1988	31.2	9	4.7	54.8	17.8	0	68	32
Fidh Ali	412.5	1991	29,6	23	0	47.4	23.0	0	12	88
M'Richet el Anse	158.0	1991	5	42	0	8	10.1	0	92	8
El Gouazine	1,810.0	1990	16.8	83	1.4	28.3	2.6	20	65	15
Hadada	469.0	1992	14	24	1.3	23.8	12.7	0	76	24
Janet	521.0	1992	36	11	3.5	61.1	29.3	0	62	38
Dekikira	307.0	1991	21	51	0	34.1	22.2	33	35	42
Es Senega	363.0	1991	12	36	0.4	19.3	10.6	0	34	66
Arara	708.0	1993	41	7	4.1	70 .1	33.0	59	41	0
Saadine	272.0	1992	27	7	6.6	50.3	46.3	30	70	0
Es Seghir	431.0	1992	2	>100	0	3.2	1.9	20	80	0
Kemech	245.5	1993	11.4	38	10	28 2	38.3	0	75	25
Brahim Zaher	464.4	1992	14.4	24	0.2	23.1	12.5	30	27	43

Since 1995, twenty-six of them have been selected and equipped to build a network of observatory sites for hydrology in order to evaluate their silting and thus their life span and overall erosion of the basin (Table 8).

Experiments (rain simulation) and modelling on runoff, water stocks and soil loss from slopes have been carried out. They allow advocating for and implementing conservation and management measures at the catchment scale, based on a sound scientific basis.

Knowledge based on the calculation of useful water soil reserves (UR) allows: i) simulating various results for annual rainfall; ii) comparing the soil water storage capacity of catchments with those of retention (dams), and iii) simulating irrigation requirements in relation to various plant covers. Finally, it provides tools for balancing between green and blue water.

The water storage capacity was first estimated from climatic parameters for soils with hydro-physical characteristics assumed to be homogeneous at a constant depth. Subsequently, a better assessment of the Total Available Water (TAW) was approached through a coefficient of utilisation of these reserves by a plant whose root system development allowed for a progressive use of 100 cm of loose soil. Using the soil depth (thickness) accessible to the roots is already a relevant step forward. However, it neither gives information on the physical characteristics of materials that can control accessibility and the volume of necessary reserves, nor on the possibilities of capillary rise from a deeper aquifer. An example of the methods used to overcome these difficulties is presented in Box 15, Table 9 and Figure 45.

Box 15. Water useful reserves computation in the Zanfour basin

Soil maps at the basin level and the implementation of a GIS were used to build and spatialize this hydro physical information. The Zanfour basin, which has an area of 42 km² and a reservoir of 710,000 m3, is part of the pilot Tunisian watershed network. It was therefore interesting to calculate the TAW, simulate various results for annual rainfall, compare the water capacity of soil in the catchments with those of retention and to simulate irrigation requirements in relation to all types of cover.
The depths, textures and coarse loads are extracted from the soil map, while critical soil moisture thresholds with potentials of 2.5 for FC (Field Capacity) and 4.2 for WP (Wilting Point) are calculated by the method of A. Bruand et al. (2002). A GIS (ArcView) was implemented to link soil units to the variations of depth, texture, coarse elements, humidity at FC and WP, and finally compute TAW isolines and draw the TAW map (Figure 42). Among all possible simulations we retain:

- **A simulation of a partial filling of TAW of soils in the basin**
  In 2001, with a rainfall of 350 mm, the rate of filling the soil reserves was obtained by cumulating annually the volumes of different classes. The partial filling of useful water reserves of all soils in the watershed provides watershed storage of 1.4 million m3 (Table 9) representing two times the capacity of the reservoir.

- **A simulation of the saturation of the whole TAW of the soil in the basin**
  The comparison of unsaturated reserves of 2001 with saturated reserves allows for the establishment of reduction coefficients in column 4 of Table 9.

The complete filling of water reserves of all soils of the basin provides storage of 2.2 million m3 representing three times the capacity of the dam's reservoir. With this stock and the results of 2001 (Annual Rainfall: P 350mm, Crop Reference Evapotranspiration ETo: 1,896 mm), it was possible to compute the theoretical annual rainfall allowing to completely fill the soils' water reserves. It should reach 553 mm, to be compared with the mean annual rainfall on Zanfour Basin: 400 mm.

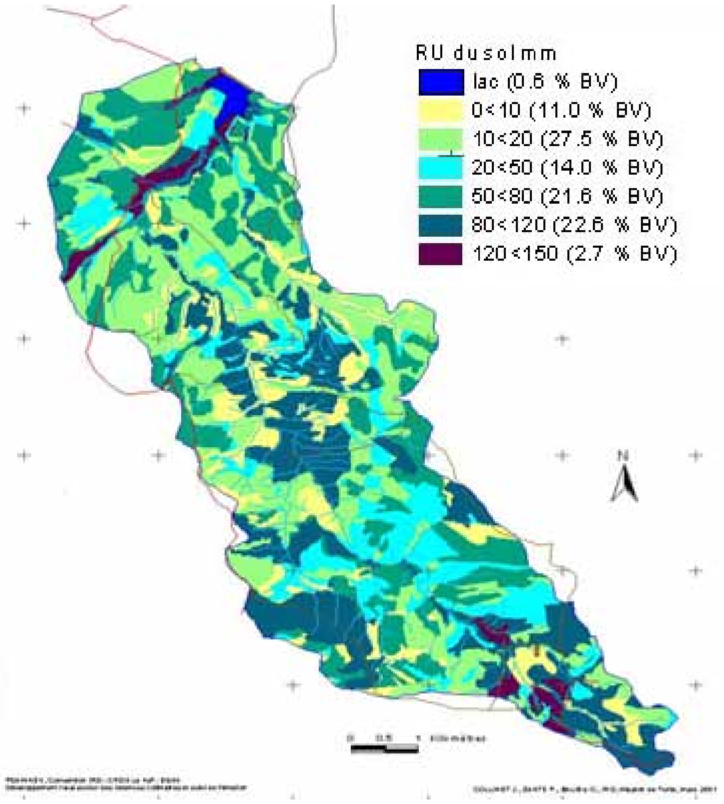

Figure 45. Map of isolines of soil usable water reserves UR. Source: Collinet et al. 2001.

Table 9. Water reserves of the basin for total and partial soil saturation.

Average UR per class (mm)	Area of each class (ha)	Total saturation UR x area (103.m^3)	Reduction Coef. Stock /P cum.	Filling 2001 UR x area x coef. (103.m^3)
5	481	24	0.29	7
15	1,202	180	0.51	92
35	609	213	0.63	134
65	943	613	0.65	398
100	988	988	0.65	642
135	117	158	0.65	103
total	4,340	2,176		1,376

The results show the usefulness of the methods which provide valuable quantitative and spatial data for water management in the watershed, in particular regarding rainfed and irrigated crops in relation to rainfall and stored water in the dam, and thus balancing between green and blue water

The effects of changing the vegetation cover, including forest, and of soil and water conservation techniques can be predicted on the basis of the calculation of sheet and gully erosion, and the use of simulation techniques.

In the following paragraphs, three examples of how scientific progresses can back watershed management in relation to soil erosion are presented. They have been obtained through research on the Abdessadok basin, which was established with the following characteristics: 307 ha, a reservoir with an initial capacity of 92,500 m^3, a current capacity (2001) of 65,000 m^3 due to specific silting of 10.6 m^3/ha/year and 50% of the basin being used for farming (low yield cereal growing + extensive sheep rearing on steep land).

a) The erosion of the slopes associated with differences in the use of the basin has been analysed and quantified either on experimental plots or at the basin scale. The large scale analysis of behaviours (plot) has allowed for the understanding of the phenomenon on a small scale (basin) and, in particular, to distinguish the transition from areolar erosion and linear erosion then to gullying. Statistical models such as RUSLE 2 (revised universal soil loss equation-version 2) of G.R. Foster, allow applications on slopes with complex geometry. They were implemented and combined with GIS on different basins of Tunisia (see Box 16). The results have been compared to the silting up of the hill reservoir. They show that the methods used for simulating soil erosion are consistent with actual observations, and can provide valuable data for further improving land-use and agricultural techniques.

b) The vegetation cover influences water and erosion processes (see chapter 1 and 2). Therefore, when designing plans for watershed management, it is important to be able to predict the consequences on erosion of using certain ground cover types in some parts of the watershed. As experimenting would be a long process (in particular, in the case of planting a new forest!), sound modelling

Box 16. Erosion calculation since the dam construction (1993 to 2001)

The model has given the following overall erosions:

a) 1.75 t / ha / year in a dry year which has been computed with a rain index Rsi = 25 MJ.mm / ha.h
b) 4.12 t / ha / year in median year with Rsi = 64 MJ.mm / ha.h,
c) 6.03 t / ha / year in wet years with Rsi = 93 MJ.mm / ha.h.

It appears that the exceptional occurrences of heavy storms (above 50 mm per day with high intensities, above 90 mm/h during 5 minutes) highly affect to these estimates calculated over long periods. It is thus that 1994–95 was a particularly aggressive year with annual rain index computed on 276 rain episodes (intensity calculated on 30 minutes) with 219 rain episodes during October 1994, a period of high soil vulnerability due to ploughing: the calculation of the overall erosion, weighted by the area and a bare soil index (C = 1) during the ploughing season, gives 22.5 t / ha / year which is enough to explain the previous silting up.

Box 17. Simulation of reforestation with Aleppo pine of upstream scrubland on stony limestone soils (lithosols)

The first simulation focused on the reforestation of the current scrubland area of the steep foothills (slope >25%) with stony and shallow soils (lithosols on soil unit 3 and regosols on soil unit 7). Instead of waiting 20 years for a forest stand to grow to observe an improved overall protection of the basin, the simulation allowed to detect an increased protection by some 12% (Figure 45). Other factors should also be considered, such as the improvement of water reserves (as observed on the Zanfour Basin), the availability of timber and firewood – essential goods for the farming community in the basin as well as benefits related to reduced erosion.

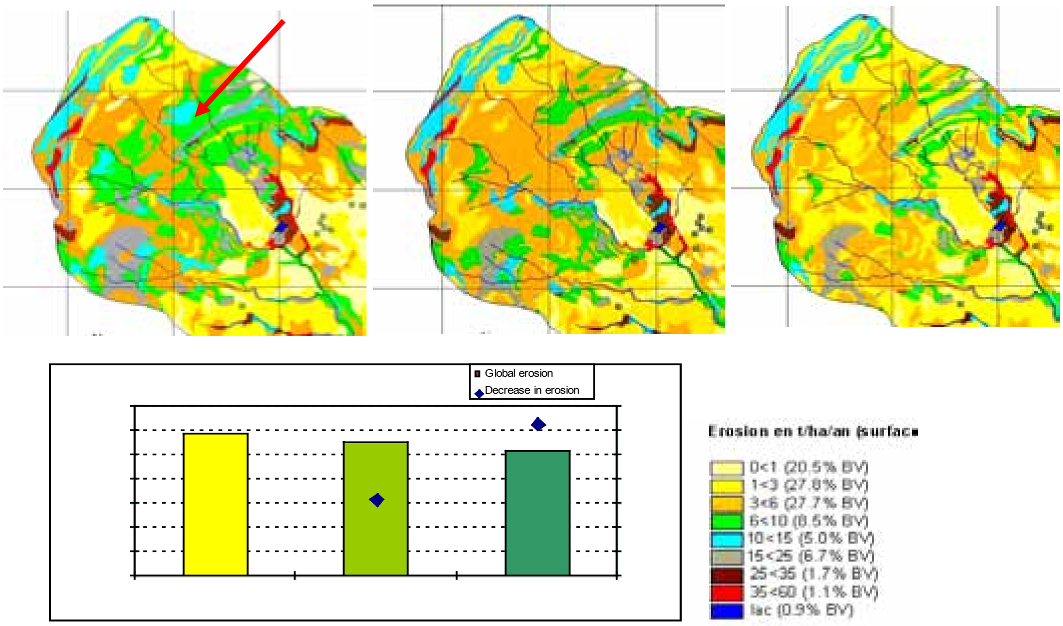

Figure 46. The Abdessadok Basin (partial), limiting erosion with the replacement of scrubland (left) on upstream lihosols by a young forest (center) becoming a mature adult (right).

Box 18. Simulation of the removal of terracing benches

This simulation analysed the effects of the total removal of the terracing benches on both sides of the river. This removal would increase by 30% the overall erosion of the basin (Figure 47). By only removing the benches on the right bank or only on the left bank, it was shown that their protective effects varied significantly depending on the banks: the right bank appeared more fragile as the bare soils occupy a greater area and slopes are steeper.

techniques can offer excellent alternatives. On the same Abdessadok basin, such methods have been successfully applied as presented in Box 17. The results show that substituting some units' shrubby vegetation with planted stands of Aleppo pine would effectively reduce soil losses and dam siltation, in addition to the provision of other goods.

c) In addition to dams, watershed management often includes bench-terracing for the retention of water and soil on both banks of the river as it flows through the cultivated glacis. Modelling techniques may simulate the absence or the removal of such equipments. Some data regarding simulations carried out in the Abdessadok basin are presented in Box 18. They show that while benches play a significant role in reducing erosion, their protective efficiency differs in relation to soil and land cover.

It is better to keep one's critical sense on a model that is more statistically than physically based. The used model presents several multiplicative terms which do not account for the non-linearity between factors, but the fact remains that the calculations of erosion resulted in four previous studies of basins of equivalent areas produce results consistent with those measured by bathymetry in the hill reservoirs. This consistency is probably due to the fact that the sediment produced on the different segments of slopes are fully transmitted to the outlet, without intermediate sedimentation – since the slopes are short and generally very steep, the water flows keep their carrying capacity, given their speed and thinness of the transported elements. Within the characteristics listed above, the estimate of overall erosion calculated by weighting is also a reasonable hypothesis. The simulations finally give a proper assessment of the effects of any proposed changes

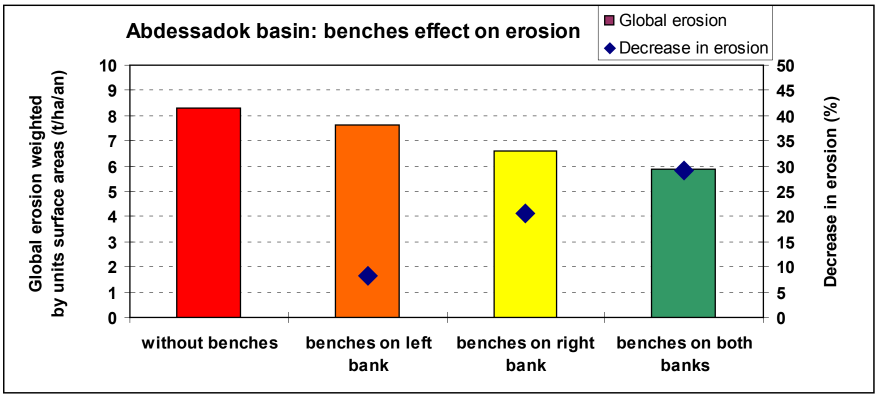

Figure 47. The Abdessadok basin: changing erosions with the partial and total removal of the terracing benches in the downstream area of the basin.

including reforestation, to be carried out when relevant in areas with proper water reserves for the successful establishment of young seedlings. One specific case not covered in the reported studies, concerns basins that are partially or wholly on marl, and that are thus particularly susceptible to gullying. In such conditions, erosion can be between 10 and 100 times heavier than sheet erosions calculated in previous models.

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4.4.

Towards Integrated Ecological, Socio-Economic and Hydrological Management

Bart Muys, Paolo Ceci, Thomas Hofer and Claudia Veith

This chapter aims at assembling the sectoral discussions in the previous sections and looks at the topic of "water for forests and people in the Mediterranean" from a holistic perspective. As the title suggests, such an approach necessarily involves hydrological, ecological and socio-economic dimensions.

Due to unsustainable water consumption patterns and the impacts of climate change, water scarcity is becoming a huge problem in the Mediterranean. Conflicts of interest between upstream and downstream and between rural and urban areas are likely to worsen as the management costs for water protection, urban sanitation and pollution control grow. Further, since forests are major users of water, the discussion about the trade-off between reduced water availability and the ecosystem services provided by them will receive increasing attention. This chapter argues that sustainable solutions require the integration of different interests and the collaboration of all stakeholders involved. Integrated ecological, socio-economic and hydrological management is needed to assure the continued provision of sufficient water resources and other environmental services.

The **blue water paradigm** is based on the evaluation of the availability of blue water resources for human purposes, as related to the effects of forests and other land uses and management; this evaluation can be achieved through both hydrological models and policy relevant indicators.

In recent years, the role of forests and forest management in the water cycle has become highly controversial. Until recently, it was a common forester's belief that forests have a beneficial effect on water flows, including erosion control and peak and base flow buffering (see sections 1.5, 2.2). This understanding was the momentum behind large-scale afforestation and forest restoration programmes in the Mediterranean area in the second half of the 20th century, and was partly based on misconceptions such as the still often taught "sponge" model. Hydrological research, particularly in experimental paired catchments, pointed to a significant decrease in baseflow after afforestation with pines or eucalypts, particularly in areas with low rainfall surplus (precipitation minus actual evapotranspiration).

These findings supported what we term the “**blue water paradigm**”, where the effect of forests and other land use on the water cycle is evaluated in terms of blue water availability for human purposes. Current environmental impact assessment methods generally have a blue water approach. Most of them need a full hydrological model calibration of the considered catchment, which is tedious and data intensive. In order to avoid this bottleneck, scientists evaluated how far it is possible to merely transfer model parameters from one catchment to another. An elegant way to extract policy-relevant **indicators for land management impact on blue water resources** – either directly from measured streamflow data or from modelled data – is the **regional water balance** approach proposed by some researchers where **flood risk** is defined as the 0.95 percentile of the ranked daily streamflow data; **drought risk** as the 0.05 percentile of the ranked monthly streamflow data; and average **water availability** as the median of the same ranked monthly streamflow data (Figure 48). In order to be able to compare indicator values of land management systems between catchments having different climate or other site factors, indicator values are normalised with a reference value, which is the indicator value for the Potential Natural Vegetation (PNV) – the terrestrial ecosystem that would develop in the catchment in the long term without human intervention.

The green water paradigm – in addition to the blue water paradigm – should receive increased attention as green water flows sustain main ecosystem functions.

Despite the high relevance of the blue water paradigm, evapotranspiration as a main driver for plant growth and internal control of the ecosystem over flows of energy and matter seems to have disappeared from view, while recent ecosystem research emphasized the key

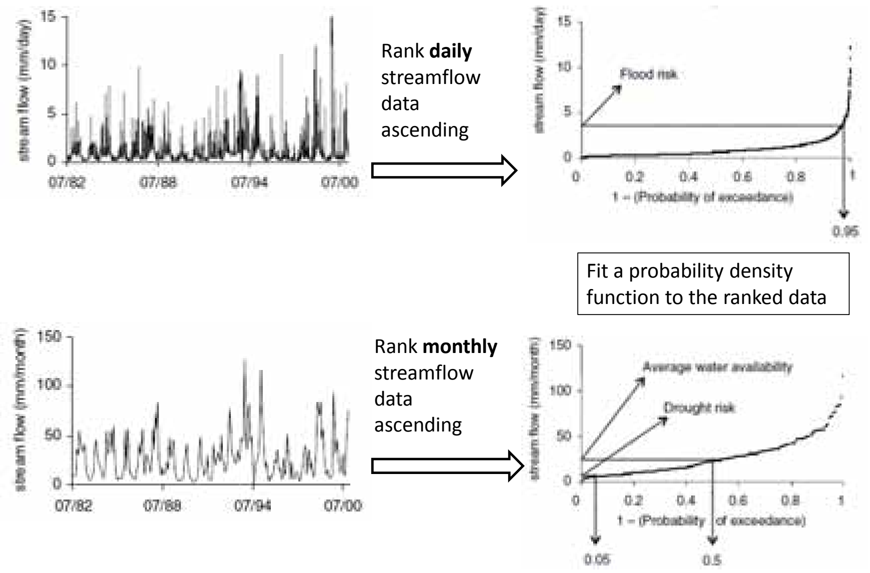
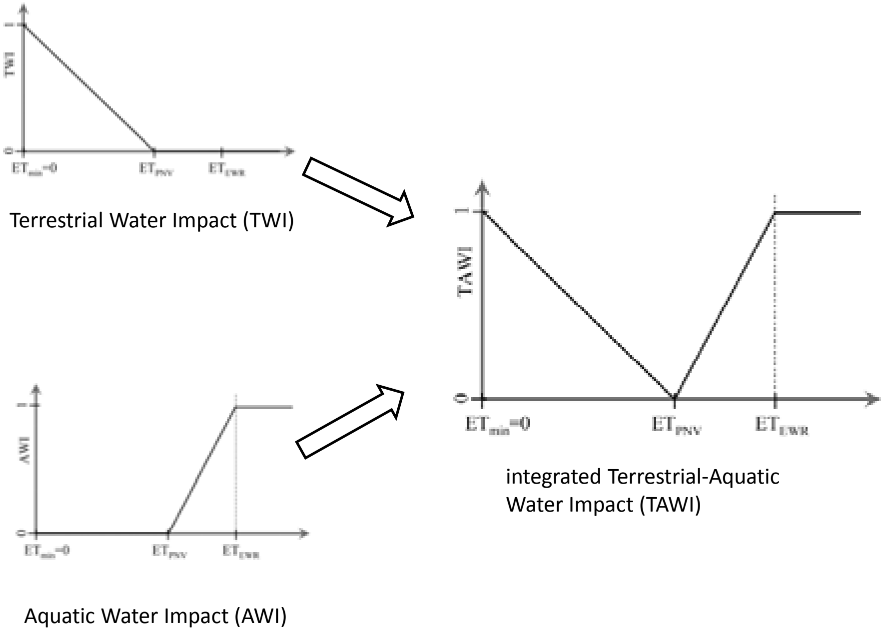


Figure 48. Calculation of simple blue water indicators to evaluate the effect of land use on flood and drought risk, and the average water availability downstream in a catchment. Source: Heuvelmans et al. 2005.

role of the green water flow for the functioning and stability of terrestrial ecosystems. In particular, forests have a larger capacity to evapotranspire than other terrestrial vegetation thanks to the deep rooting depth and bigger leaf area of trees. Deep rooting improves water availability for the entire ecosystem through uptake and hydraulic lift, while large leaf areas in multilayer canopies contributes to erosion control both through rainfall kinetic energy dissipation and interception losses (see section 1.5). The canopy structure and evapotranspiration together form a stable microclimate, necessary condition for the conservation of forest related biodiversity. These findings support a **green water paradigm**, which considers that green water flows substantially contribute to the maintenance of forests as self-organising complex systems highly resilient to disturbances.

The challenge of integrating upstream and downstream interests, including terrestrial and aquatic ecosystems, can be met through reconciling the blue and green water paradigm. This can be practically achieved by using specific methods such as the terrestrial-aquatic water impact indicator.

It has become clear that both green and blue water fractions support important ecosystem services: the green water fraction mainly upstream in the terrestrial system and the blue water fraction mainly downstream in the aquatic system. The question is how to evaluate land management in an **integrated terrestrial-aquatic approach**, taking into account both its impacts on upstream and downstream life support functions and ecosystem services. Some scientists proposed the terrestrial-aquatic water impact indicator



Terrestrial Water Impact (TWI)

integrated Terrestrial-Aquatic Water Impact (TAWI)

Aquatic Water Impact (AWI)

Figure 49. Integrated impact of land management on terrestrial and aquatic ecosystem services in a catchment (TAWI) as a function of actual evapotranspiration (ET). The threshold values are determined by the evapotranspiration of the potential natural vegetation (ETPNV) and of the ecosystem water requirement (ETEWR). Source: Maes et al. 2009.

(TAWI) method, avoiding the complex and data requiring exercise of calibrating catchment models. The impact indicator used is the actual evapotranspiration (ET) of the system. Its impact on the terrestrial ecosystem services is defined by a simple response function composed of a **terrestrial impact component**, having a linear decrease of impact between zero and the evapotranspiration of the potential natural vegetation (ET_{P-NV}), and an **aquatic impact component** having a linear increase of impact between ET_{PNV} and the evapotranspiration level that would reduce the total discharge to a critical level below the environmental water requirement (ET_{EWR}) (Figure 49). The **environmental water requirement**, or minimal flow, is a catchment-specific value for which standard calculation methods exist. The conversion of a natural dryland forest to a eucalypt plantation would, for example, lead to an increase of ET above the ET_{PNV} threshold and cause a certain impact in the aquatic TAWI component, while degradation of the same dryland forest by overgrazing or man-induced fires would lead to a decrease of ET below the ET_{PNV} threshold and might cause a similar impact, but through the terrestrial TAWI component. With more data, the calculation can be made more realistic, e.g. by defining the highest terrestrial impact at the evapotranspiration level of a sealed surface instead of zero, or by defining the evapotranspiration of the PNV rather as a range, taking into account the natural disturbance cycles in an unmanaged forest.

The integration of water with other ecosystem services should be based on a better understanding of how ecosystem services interact with each other.

Water regulation is an important but not exclusive function of forests. The Mediterranean forest is also important for many other **ecosystem services (ES)**, e.g. biodiversity conservation (supporting service); mushrooms picking and resin harvesting (provisioning services); carbon sequestration (regulating service); and recreation (cultural service) (see sections 3.1, 4.2). These services all interact in different ways in time and space. At first glance they can be either synergistic (e.g. green water flow and carbon sequestration), or negative (e.g. green water flow and aquatic recreation). Figure 50 illustrates the possible **interactions** between water and other ES in the Mediterranean forests.

In regard to integration of water with other ecosystem services, new tools are becoming available for trade-off analysis and land management optimisation.

There are different ways to evaluate relationships between ecosystem services. A simple yet solid approach to relate water with another forest function is **ratio analysis**. The ratio between transpiration and net primary productivity, for example, is a classical indicator for water productivity of agricultural crops, but equally useful in forestry (see 4.5 on water footprint). Ratios can be used to calculate the cost in terms of green water consumption for any ecosystem service of the forest, e.g. the amount of evapotranspiration in mm per ton of greenhouse gas emission reduction. A different approach is **trade-off analysis**, where forest and landscape managers specifically look for ES with antagonistic interactions, e.g. an increase in wood production at the expense of a decrease in to-

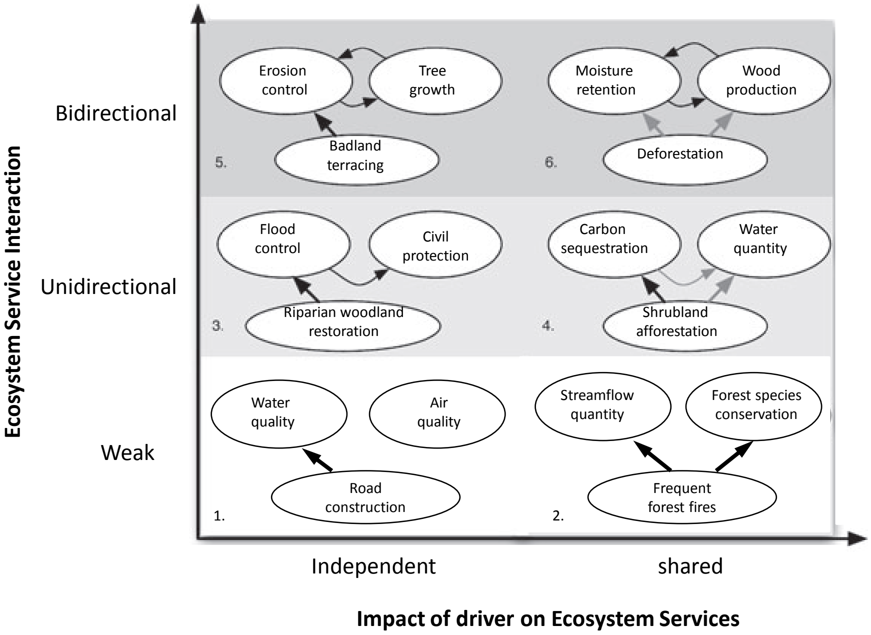


Figure 50. Examples of possible interactions between water and other ecosystem services in the Mediterranean forest, added to the conceptual scheme of Bennett et al. (2009). Water is related to other forest ecosystem services due to its (independent or shared) response to the same driver of change (climate, land management), or due to direct (weak, unidirectional or bidirectional) interactions with other services. Black arrows indicate positive effects; grey arrows negative effects.

tal discharge. In order to better understand their spatial structure such trade-offs may be mapped. Interaction of multiple forest functions has been hardly explored at all. The use of advanced **empirical modelling** techniques is promising to detect so-called **bundles of ES**, referring to sets of ES that are related to one another and repeatedly appear together in the landscape across space and time showing parallel behaviour. Detecting such bundles linked to forest water issues would facilitate the design of multipurpose management systems. Interaction between multiple ES such as groundwater recharge, groundwater quality and carbon sequestration can also be addressed using **mechanistic ecosystem models** given that the underpinning ecosystem processes of evapotranspiration, photosynthesis and nutrient cycling are all interlinked. Adding a user interface and some automation and visualisation functionalities can turn them into powerful **simulators** of ecosystem service performance and interaction.

Understanding ES trade-offs is an excellent basis for **integrated sustainable landscape management**. Any management choice made by landscape planners and forest owners and managers will have its effect on the type, magnitude and relative mix of ES provided by the forest landscape. **Management optimisation** is a complex task, as any option may sacrifice part of one ES to sustain another ES. Several **multi-objective landscape management planning techniques**, including stakeholder-weighted multi-criteria analysis, linear programming and goal programming; heuristics have also been developed for this purpose, specifically for spatial problems. They help to find optimal management solutions based on multiple decision rules. Also, an economic optimisation approach is possible to identify the highest net social benefit for the considered area. Such a cost-benefit approach assumes that methods are available to give monetary values to all con-

Box 19. Integrated environmental and socio-economic management in Italy

Two-thirds of Italy is mountainous areas. In the late 1990s, Italy developed territorial pacts (National Laws Nos. 104 of 1995 and 662 of 1996), which are legally binding social partnership contracts for planning. The pacts are public and private agreements to implement local development measures that integrate natural resource management, industry, agriculture, fisheries, public services, tourism and infrastructure. While any area can have a pact, marginal areas are priorities. Territorial pacts now involve 47% of Italy's total population and cover 53% of its land area. The pacts' use of an integrated cross-sectoral approach and their involvement of key actors make them relevant to watershed management.

The main feature of the pacts is that they harmonise different local actors without imposing external conditions: participation is voluntary and includes all sectors: administration, enterprises, banking, research and trade, etc. The objective of a territorial pact is to achieve cohesion among current and new initiatives involving natural resources, people and economic activities. Each pact concerns specific activities, such as the management of natural resources, including water resources – more than half of the pacts approved up to 2003 include natural resource and hydrology aspects. The territory covered by a pact can range from one small watershed to the 1,600 km stretch of the Apennines.

The territorial pact for the province of Rieti, for example, involves 12 municipalities, three mountain communities and 35 signatory parties. It has created 227 new full-time jobs, and used EUR 18 million for two main activities: reinforced capacity buildings in small and medium enterprises, and investment in infrastructure, tourism and environmental services, including agriculture and forestry.

The territorial pact provides a framework for action and advantages from economies of scale with human and cultural dimensions greatly influencing its implementation.

sidered benefits, including those not traded through the market. There is still a clear need to further develop and integrate such approaches in **spatial decision support systems** for sustainable forest and water resources management in the Mediterranean region.

Integrating ecological, socio-economic and hydrological management is a key approach towards sustainability.

In order to improve the balance between water supply and demand, reduce pressure on the environment and address social and economic issues, there is a need to link water to overall natural resources management. Since water is a scarce and threatened resource in the Mediterranean region, water resources management should pay particular attention to reducing losses, increasing efficiency and arbitrating in resource allocation. This means defining environmental and social objectives; allocating roles and responsibilities between the public and private sectors; decentralising management and increasing stakeholder participation; and applying appropriate and adapted technical and economic tools.

Experience has shown that purely technical measures are not sufficient to address watershed problems. Owing to the pivotal role of human population in shaping landscapes and ensuring healthy and balanced ecosystems, local livelihoods play a key role in integrated forest and water management. Where pressure on resources is too high and their use unsustainable, alternative income-generating activities should be promoted to reduce the pressure on land resources. Such socio-economic interventions require awareness raising and capacity building at different levels.

Successful integrated forest and water management necessitates the overcoming of sectoral, institutional and administrative boundaries. It requires the participation of dif-

Box 20. Recommendations for sustainable forest and water management in the Mediterranean.

- Important water supply areas and groundwater aquifer sites should be considered for forest retention with minimum disturbance. Although tree cutting (of at least 20% of the canopy) produces a temporary increase in water yield, there are trade-offs that must be considered such as reduced water quality, increased erosion and the impact on biodiversity. Any forest product removal in these areas should avoid soil compaction and bare soil exposure in order to minimise surface runoff and concomitant erosion. Drinking-water supply catchments should have legal status as protected areas or be designated as protective forests.
- In some cases, which must be carefully assessed, the water yield of municipal watersheds can be augmented when tree species with low consumptive use replace those with high consumptive use or when forest stands are periodically thinned.
- Planning authorities should identify slip-prone areas and zone them for forest retention or agroforestry/sylvopastoral use with fairly dense tree cover. Such areas may then be part of the protective forest estate.
- Riparian forests can maintain low levels of sediment delivery to rivers, lakes and reservoirs. Therefore, they should be managed to protect water quality which, in turn, can enhance the productive capacity of aquatic ecosystems and improve the health and welfare of local human populations. It is recommended that the Mediterranean countries undertake an assessment of their key riparian zones and classify them for conservation management, protection or restoration. Adequate legislation on riparian buffer zone maintenance should also be established.
- Mountainous forested watersheds in the Mediterranean region deserve special attention. Although they are the origin of freshwater, they are also the source areas for landslides, torrents and floods. Action to prevent or mitigate disasters in mountainous terrain should include the maintenance of healthy forest cover on mountainous watersheds that are subject to torrential rainfall. Disaster risk management as well as water resource and forest management should be run together under the same authority in order to ensure adequate integration. Box 21 describes the importance of sustainable mountain development for the Mediterranean region.
- A watershed perspective capturing upstream/downstream linkages should be incorporated into the management of forest and water resources as well as in the planning of agricultural and urban areas. This perspective is needed at both local and the highest government levels in order to promote sustainable solutions.
- Payments for environmental services have significant potential and should be further explored. By reducing water subsidies and treating water as a commodity rather than a free commodity, economic incentives can support better management. This is ultimately a governance issue, involving the development of the necessary institutional arrangements. Site-specific assessment requires both research and institutional adjustments.
- There is a need for expanded educational and training programmes on integrated ecological, socio-economic and hydrological management that are directed to all relevant stakeholders - from local watershed inhabitants to the highest-level policy makers.

ferent stakeholders, such as foresters, water users, farmers, landholders, local government and line agencies. As natural resource management always has economic and social costs, consensus on the sharing of these costs should be reached. Negotiation, mediation and compromise within the local political arena are essential elements of integrated management practice. They are best addressed through a collaborative approach, in which technical resource people, high-level decision makers, local administrators and local stakeholders share the responsibility of assessing the local situation and undertaking the necessary action, entailing clear management functions and entitlements for a given set of natural resources.

Box 21. The importance of mountains

Mountains are the water towers of the world. By influencing climate and precipitation patterns and modulating runoff regimes, they play a key role in the water cycle. In arid and semi-arid regions such as the Mediterranean, the proportion of water generated in the mountains can comprise up to 95% of the total freshwater available in a watershed. Since half of the countries in the Mediterranean region have at least 50% of their land classified as mountain areas, sustainable mountain development and balanced upstream/downstream linkages deserve particular attention.

Extreme climatic conditions and environmental constraints such as fragile soils and steep slopes are major obstacles to the welfare of mountain communities. Additionally, the high demand for mountain resources by lowland dwellers, and lowland-focused policies ignoring the vulnerability and disadvantaged character of mountains, often exacerbate human pressures and environmental disturbances. Degradation of mountain ecosystems not only destroys the life-support base for local inhabitants but also heavily impacts the situation further downstream. These factors have led to a growing concern for developing comprehensive national policies and strategies for the sustainable development and protection of mountain ecosystems and their inhabitants. In order to manage mountain resources in a sustainable way, balanced upstream/downstream linkages and equitable opportunities for development and conservation are required over large territories that may spread from the top of the mountain chain to the coast, and over complete water catchments that can also cross international borders.

One of the main goals of collaborative management is to ensure balanced and sustainable upstream/downstream linkages at the watershed and landscape scales. For instance, upland forest use must be made compatible with the need for the continued provision of essential environmental services such as ensuring water quality, reducing sediment load in rivers and recreation. Experience suggests that balanced upstream/downstream linkages in watersheds are achieved when policies and mechanisms are in place to buffer the socio-economic disadvantages with which upland people are generally confronted, and when lowland stakeholders are willing to pay for upstream environmental services and thus to contribute to the improvement of the livelihood situation in upland areas. The collaborative management of forest and water resources needs to be strengthened through appropriate policy, legislation and economic incentives.

To address all these challenges, enhanced synergy is needed between the forest and water communities through institutional mechanisms aimed at implementing action programmes at the local, national and regional levels. Similarly, there is an urgent need for an even better and sub-regionally differentiated understanding of the interactions between forests and water, particularly in the context of climate change, and for embedding the research findings into policies. There is a need for strengthened partnerships among research, educational, financial and political institutions. For a concrete example of integrated environmental and socio-economic management see Box 19.

Providing water in adequate quantities and quality to meet human needs is essential and a particular challenge in the Mediterranean area. As forests play an important role in this regard, forest and water management must go hand in hand. The implementation of integrated approaches requires adequate policies and institutions to promote inter-sectoral dialogue and cooperation. Forest, water and land-use programmes should be based on sound science rather than misperception. Managers of forests and water resources as well as decision makers in the forest and water sectors should consider and adopt a set of recommendations for protecting and maintaining the Mediterranean's precious water, as detailed in Box 20.

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4.5.

Water Footprint and our Daily Life:
How Much Water do we Use?

Yves Birot

Water for people and nature requires management that focuses on multiple needs of the anthropoecosystems. **Water Footprint** analysis allows the tracing, supplying and identifying of impacts, and gives clear directions on risks and responsibility.

Balancing water between humans and nature implies that we, as human beings and citizens, are aware and conscious of how much water we use from a resource, which has a finite nature and requires that it be shared with all ecosystems – be they terrestrial or aquatic. Such an issue has a temporal dimension (within and between years), a spatial dimension (from watershed to countries and global scale), and also an economic dimension (trade). Recently, and with some similarities (and discrepancies) with the Ecological footprint, Carbon footprint and Life Cycle assessment (LCA) concepts, the concept **of water footprint** has recently emerged as a way of addressing these complex issues.

The water footprint can be assessed at the **product** level, the value chain or **business** level and the **nation** level (relation between national consumption, trade and water). In the following, we will mainly address the first two levels. We, as c**onsumers**, have also a water footprint.

The water **footprint of a product** can be defined as the total volume of fresh water used to make a product throughout the various steps of its production chain. It also mentions when and where the water was used (temporal and spatial dimension), as well as the type of water which used, namely green (volume of rainwater evaporated), blue (volume of surface or groundwater evaporated) or grey water (volume of polluted water during the production process[1]). In comparison with traditional statistics on water use, which refer to water withdrawal, the water footprint concept provides a more comprehensive way of looking at water use (see Figure 51).

The water footprint is an indicator of water use that looks at both direct and indirect water use of a consumer or producer. Direct water use refers to that used by the con-

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[1] Grey water is quantified as the volume of freshwater necessary to dilute the polluted water below an acceptable threshold for the ambient water.

Box 22. The Water footprint concept has a broader scope than the virtual water content.

The water footprint is a term that refers to the water used to make a product. In this context, we can also speak about the 'virtual water content' of a product instead of its 'water footprint'. The water footprint concept, however, has a wider application. For example, we can speak about the water footprint of a consumer by looking at the water footprints of the goods and services consumed; or about the water footprint of a producer (business, manufacturer, service provider) by looking at the water footprint of the goods and services produced by them. Furthermore, the water footprint concept does not simply refer to a volume of water as in the case of the term 'virtual water content' of a product. The water footprint is a multidimensional indicator that refers both to a volume of water used, as well as identifying where the water footprint is located, what source of water is used and when it is used. This additional information is crucial in order to assess the impacts of the water footprint of a product.
Source: Water Footprint: www.waterfootprint.org/?page=files/FAQ_Technical_questions

sumer or producer himself. Indirect water use refers to the water used in the production chain of products bought by a consumer or producer.

In the case of **agriculture**, which has by far the largest water footprint (70%) among human activities worldwide, the water footprint can be assessed for **crops** as crop water use (m^3/ha) / crop yield (ton/ha), and for **animals** as the sum of water for feed, drinking and servicing. For crop or animal **products**, the approach is to distribute the water footprint of the root product over its derived products. Various models, based on climate data and crop characteristics, are available to estimate crop water requirements; a complementary approach should be used in case of irrigation the green water (i.e. the volume of rainwater that evaporates from a crop field during the growing period) and blue water (i.e. the volume of irrigation water (withdrawn from surface or ground water) that evaporates from the field during the same period.

> The assessment of a water footprint by commodity, sectoral activities or value chains provides new insights on water issues at various scales (local, regional, national and global), and opens the way to many applications regarding, economics, trade, environment, policies and industry, etc.

As an example, Figure 52 shows the water footprint for Spain of various crops using blue and green water, and also the economic productivity of the water used. Although this is a simplification since blue and green water do not have the same value, this example illustrates how useful this is approach for selecting policies.

Another example is related to spatial aspects. The water footprint has a spatial dimension so it can be mapped. A water footprint map shows the volumes of water used at various locations, for example the water used worldwide to make the products consumed by a given community (see Figure 53). Related to this, the water footprint allows links to be made between consumption in one place and impacts on water systems elsewhere. Moreover, water footprint assessment allows the identification of "water footprint hotspots" (in space and time), for example when the water footprint (of a product, consumer or producer) is important in a given area and period of the year, and when water becomes scarce for that area during the period.

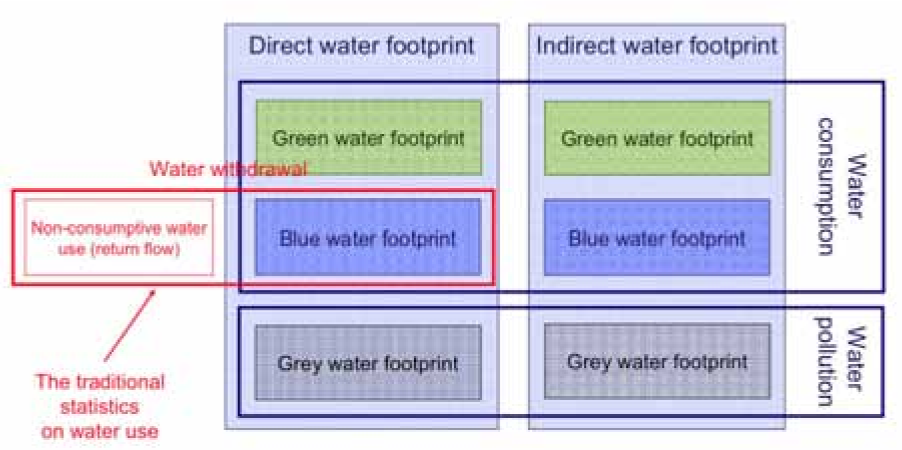

Figure 51. Components of a water footprint. Source: Hoekstra 2008.

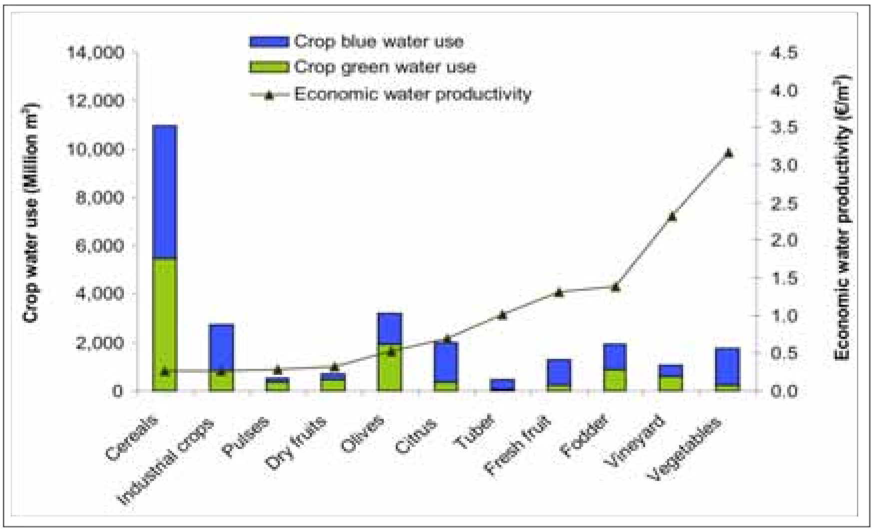

Figure 52. Economic water productivity (EUR/m³) and blue and green crop water use in Spanish agriculture during 2006. Source: Garrido et al. 2009.

Agriculture has the largest share in world's water footprint. At the global level on average, food production requires 70 times more water than a household needs (50 l/person/day). To produce a diet of 3,000 kcal/person/day (including 20% animal proteins), some 3,500 l of water are needed compared to 50 l/person/day for household use.

Figure 54 gives the water footprints of some common food products and shows how food preferences, such as a diet rich in meat and related to income, may have a strong impact on water resources, and why certain crops (e.g. maize) may be inappropriate in a water scarcity situation.

As discussed above, the water footprint of food products varies according to local conditions such as cultural systems and their efficiency regarding water and potential evap-

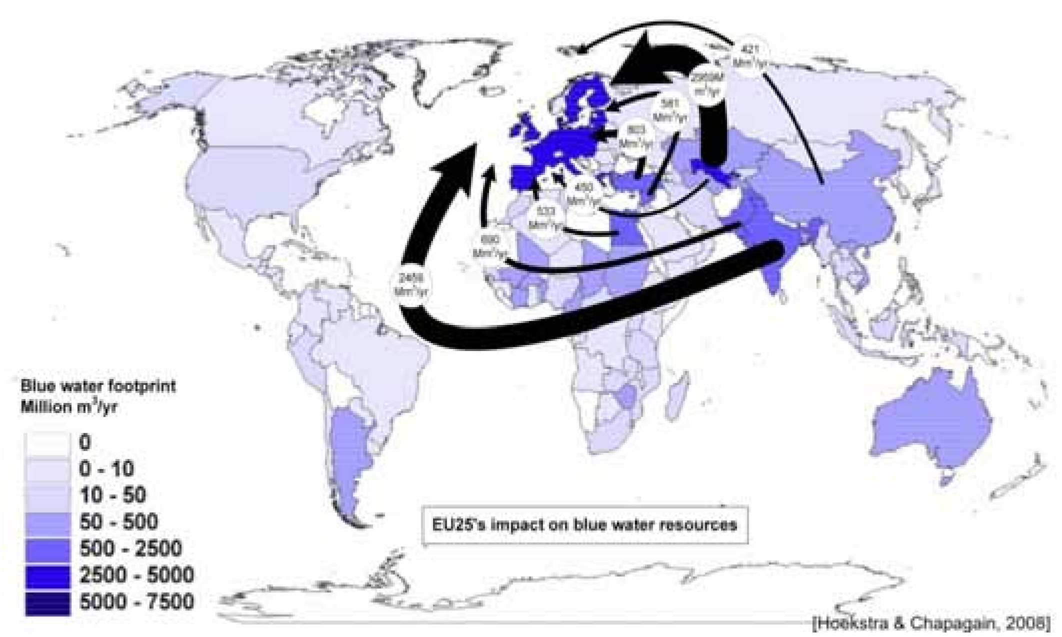

Figure 53. The impact of consumption of cotton products by citizens in EU25 on the World's water resources (million m^3/y) for 1997–2001. The map shows the blue water footprint, i.e. the volume of irrigation water evaporated. Source: Hoekstra and Chapagain 2008.

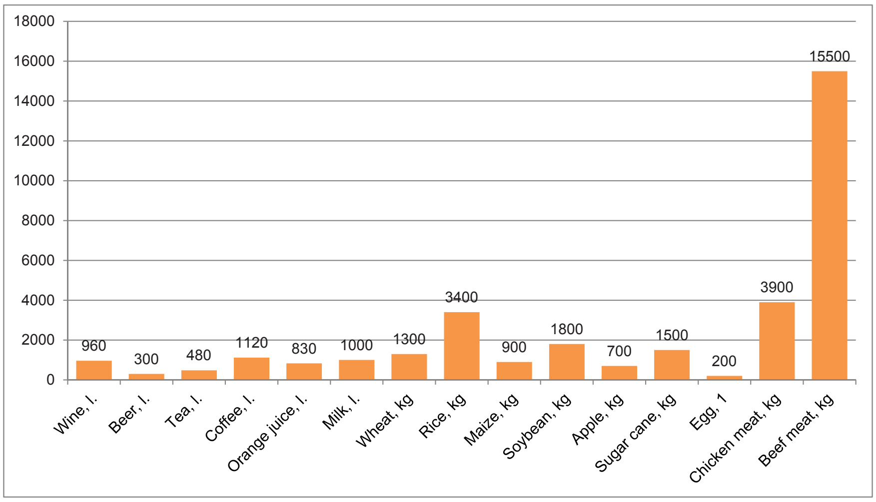

Figure 54. Water footprint (in litres) of common food products. Source: Water Footprint.

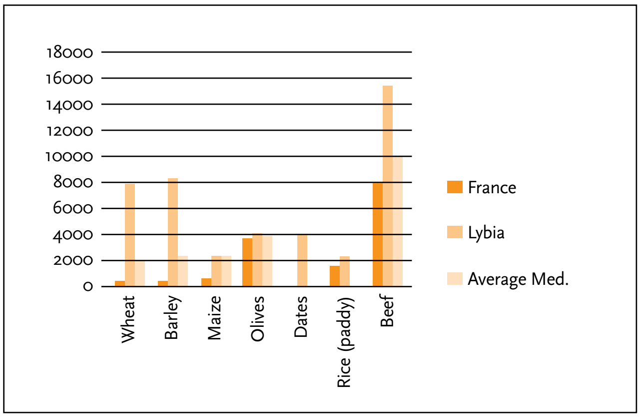

Figure 55. Virtual water content per product in l/kg in France, Lybia and on average for the Mediterranean. Source: FAO, Hoekstra

otranspiration. Figure 55 gives some figures for two contrasting situations (France and Lybia) and for the Mediterranean on average. It shows that for some crops there are minor differences, while for others there are huge differences.

Water is not only embedded in food but in various products in common use – sometimes in large quantities (Table 10).

Table 10. Water footprint of some industrial products (in litres).

Products	Water footprint (l)
Paper A4 sheet	10
Leather (1kg)	16,600
Shirt cotton (250g)	2,700
Jeans (1000g)	10,800
Diaper (75g)	800
Bed Sheet (900g)	9,700
Car (1.1t)	400,000–1,000,000
House (construction)	6,000,000

It is relevant to look at the total **water footprint of both countries and their citizens**. A study conducted for the period 1997–2001 shows that the **USA** appears to have an average water footprint of 2,480 m^3/person/year **(6.8 m^3/person/day)**, while **China** has an average footprint of 700 m^3/person/year **(1.9 m^3/person/day)**. The global average water footprint is 1,240 m^3/person/year (**3.4 m^3/person/day**). The four major direct factors determining the water footprint of a country are: volume of consumption (related to the gross national income); consumption pattern (e.g. high versus low meat consumption); climate (growth conditions); and agricultural practices (water use efficiency of the cultural techniques).

Planting trees for C sequestration in the Mediterranean is highly questionable because of the huge cost of water.

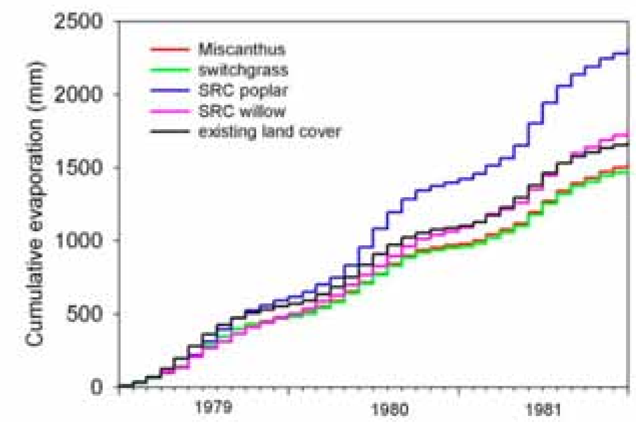

Figure 56. Cumulated evapotranspiration of biofuel short-rotation coppice. Source: Finch, 2008.

Table 11. Estimations of water footprint of wood based on the growth rates in the Mediterranean region. The water footprint is expressed in m^3 of water required to produce 1 m^3 of wood. Note that the growth rate of *Pinus radiata* can be 15–20 times more than that of *Q. ilex*, which means that the water consumption/ha is in proportion. Source: Gracia et al. 2000–2004, IEFC (Ecological Forest Inventory of Catalonia).

Species	water footprint m^3 water/m^3 wood
Pinus radiata	332
Pinus pinaster	698
Abies alba	762
Pinus sylvestris	1,443
Pinus nigra	1,458
Pinus pinea	1,642
Pinus uncinata	1,708
Pinus halepensis	2,073
Castanea sativa	675
Fagus sylvatica	698
Quercus ilex	2,842
Quercus suber	2,981

Water footprinting has not been applied to the forestry sector much apart from industry (pulp & paper) and some simple types of plantation like intensive tree culture for chemicals, fibres or bio-energy (Figure 56); compared to agriculture they are short-term and use green and blue water. However, some data regarding the amount of water needed for producing wood are available (Table 11). This raises the issue of the cost in water (predominantly green) of carbon sequestration in forests. Through photosynthesis, carbon and water are tightly interrelated, and the cost of water for carbon fixation is high (see Chapter 3). In water scarcity conditions such as the Mediterranean, planting "carbon sink" forest is thus very questionable.

Water footprint: an interesting concept and tool that should be combined with other approaches.

The concept of the water footprint offers an interesting perspective on water issues. In the context of a trend for moving from a supply-oriented to a demand-oriented management of water resources, it opens up new areas of governance and eases the differentiation and tradeoffs between different perspectives, conditions or interests. This concept also allows a distinction to be made between scales – local, regional and even global – and their linkages. It is also coherent with the approach of Integrated Water Resources Management (IWRM) (see section 4.3). However, the implicit assumption that the green water surplus generated by changing a water demanding activity related to a certain vegetation type into a less demanding water activity available for that alternative is neither true nor economically feasible.

The water footprint is a tool that should be combined to others in an analysis to integrate all factors. In the case of forests, these ecosystems are usually net consumers of water. In an integrated approach, other factors should also be take into account such as: i) the limitation by forest cover of soil erosion, which contributes to dam siltation and maintains the availability of blue water; ii) the infiltration and percolation of water facilitated by stem-flow, increased soil organic matter and soil permeability due to the tree root system, which contributes to groundwater recharge; and iii) the positive impact on water quality.

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4.6.

Lessons Drawn from the Past:
an Historical Perspective on Forest Hydrology and Soil Conservation in the North and South of the Mediterranean Basin

Pietro Piussi, Yves Birot, Éric Roose and Mohamed Sabir

Problems of soil conservation and forest hydrology are strictly linked to the process of deforestation. In the Mediterranean area, the destruction of forest cover started in prehistoric times due, in part, to the result of a planned transformation of forests into agricultural land – by terracing, organising water flow and drainage, cultivating herbaceous and tree crops – or the irrational use of forests for grazing or various systems of shifting cultivation. From the hydrological point of view, these activities resulted in frequent floods that caused heavy damages to communities living in the valleys and in the plains. Negative consequences of human activities were exacerbated by some adverse environmental conditions specific to the Mediterranean area: the climate, the rough topography and the wide distribution of limestone. Locally, temporary declines in population sometimes led to land abandonment and a secondary succession re-established a woodland cover; however, the prevailing trend has been, at least in some parts of the northern rim of the Mediterranean, intense land exploitation until the mid-19th or mid-20th century. This is the situation that countries on the eastern and southern rims are currently facing with perhaps additional aspects related to water resources management (dam siltation).

In response to major hydrological catastrophes, large-scale watershed management programmes, based on biological and civil engineering and implemented in Europe since the second half of the 19th century, have been largely successful in spite of limited knowledge in forest hydrology and insufficient consideration of social factors. Today, the challenge is how to maintain the protective functions through the renewal of planted areas and equipment in totally different social and economic contexts.

Watershed management work was usually realised by the central state in the middle of the 19th century (a few decades earlier in Austria) in response to the need to control floods and reduce soil erosion, which frequently caused loss of life and major damag-

Box 23. From 1860 to present: the French Programme on the Restoration of Mountainous Terrains (RTM)

Following catastrophic floods in the mid 1800s affecting the lower parts of river catchments, arguably due to forest removal caused by excessive pressure by man (demography, overgrazing and cultivation), an active political debate emerged at the national level. It resulted in a series of acts and laws – the most well-known is that of 1882 on the "restoration and conservation of mountainous terrains". This legal and judicial framework coupled to a substantial public funding, allowed the development of an ambitious State policy resulting in the purchase of 380,000 ha of land, on which biological and civil engineering works were carried out to prevent and control runoff and erosion and limit their impacts on both people and the infrastructure. This took place in an overall context of a booming industrialisation and of the undertaking of major national programmes such as developing the railways, land-use planning and rehabilitation through drainage and afforestation (Landes, Sologne and Champagne) at a time when the ideology of technology-based progress was flourishing.

In addition to the emergence of a real ideology built around the RTM concepts and goals, the Forest Administration, given the task to implement this policy, was able to successfully set up a corpus of methods and technologies, based on the pioneering theoretical and applied works of Surrel and Demontzey. The operations, concentrated in the heads of watershed and/or in the vulnerable areas, were based on a combination of: i) re-vegetation or vegetation encroachment with trees (local species and *Pinus nigra*) on slopes and shrubs and grass along the banks and in the gullies completed by some terracing; and ii) civil engineering, which consisted of building staircase-like dams in the torrent-bed to reduce erosion and that of the banks and to limit the transport of materials. Looking back to the conditions that prevailed some 150 years ago, there is no doubt that this policy, pursued decade after decade, has been rather successful. This success story, or RTM saga, was presented as a panacea and used as background for a "copy and paste" transfer of RTM concepts and principles to European and other countries, and to Maghreb during the colonial period. In the latter case, the underestimation of a different ecological, socioeconomic and cultural context sometimes resulted in failure (see Box 25).

Some figures on RTM's achievements
Reforestation >260,000 ha
Number of municipalities concerned: 950 in 25 "départements" in middle or high mountain areas;
1,100 torrents "treated"; 100,000 small dams built; work on 115 landslides and 100 avalanche corridors.

However, seen from a social angle, it must be stressed that the RTM has been mainly a top-down process which has, in some cases, resulted in conflicts with local rural populations (farmers were forced to sell their land) or accelerated their migration to cities or other areas. This must also be put in the context of the 19th century, characterised by a marked centralisation and the conviction that such a public interest driven policy, balancing the needs of up-stream and down-stream areas (even broader areas) and addressing long-term objectives should be centrally designed and implemented.

The "golden age" of RTM was between 1882 and World War I. In 1909, more than two-thirds of designated RTM areas were already treated. The period from 1914–1940 was characterised by the maintenance and management of existing work due to the economic and demographic impact of the War. The decline came after World War II as a result of less funding and the increasing weight of maintenance costs (in particular labour costs). In 1980, however, the RTM was deeply reformed and re-established within the National Forestry Board (ONF).

Today, the main challenges, in a context of limited financial resources, are to find tradeoffs between the maintenance/renewal of forest stands and equipment, and how to address the security needs (acceptable, accepted risks) in relation to various natural hazards in mountainous areas. Moreover, the articulation of the State policy with the local authorities and competencies is of primary importance today. The RTM policy in the 19th century was a response to catastrophic events through new legislation and considerable financial means. Will updating the RTM be strong and efficient enough without waiting for next ecological or human catastrophes?

Box 24. River catchment, runoff, dam, sediments: the Italian story

During the past 150 years, afforestation and hydraulic engineering works have developed side by side in the Italian mountains. Mountains and hills dominate the Italian landscape, while plains occupy only 20% of the country. At the end of the 19th century, after many centuries of over-exploitation of mountainous area – resulting in high population density and irrational land use practices – the Italian territory was characterised by a dramatically reduced forest cover and extremely active torrential erosion, while the plains between the mountains and the sea were frequently occupied by swamps.

Some afforestation and torrent control work was carried out already at the end of the 19th century. However, a new integrated land use policy launched in 1933 addressed the bonifica integrale (comprehensive reclamation) of watersheds by means of drainage, road constructions and new settlements in the plains, together with engineering and forestry works in the mountains. In the same period, the development of hydro-electricity required erosion control measures to limit sediment accumulation in artificial reservoirs. Between 1867 and 1950, the planted areas totalled 194,000 ha. The swamp reclamation work was pursued for a longer time.

In the 1950s, a new wave of afforestation was undertaken to mitigate the high unemployment rate in rural areas. Between 1950 and 1959, 159,000 ha of plantations were established, mainly in the southern part of the country. The most common technique employed in steep terrain was the use of gradoni – small terraces built on contour lines in which young plants could have enough soil and moisture to survive during the dry season. On the Apennines and on the lower part of the Alps, degraded site conditions required the almost exclusive use of Black pine (*Pinus nigra*) seedlings, even if occasionally hardwood was seeded between the young pines, quite unsuccessfully. Plantations carried out since the 1960s frequently used better soils, hence Silver fir (*Abies alba*) and Douglas fir (*Pseudotsuga menziesii*) have been employed. A different feature was the afforestation -mainly done with stone pine (*Pinus pinea*) - on the sandy soils along the coast, aimed at stopping wind erosion and dune movements, as well as protecting agricultural crops, settlements and infrastructures.

From a social point of view, it is true that afforestation programmes in the mountainous areas created many job opportunities. There was, however, at least at the beginning and especially in southern Italy, a marked opposition to plantations from shepherds and large landowners renting their land to small tenants. As a consequence, young plantations were quite often destroyed by fire and illegal grazing.

Watershed management by means of civil engineering and afforestation, usually done on private land, was always hindered by lack of public financial resources. This lack of funds did not allow understorey control and thinning in the plantations as well as maintenance works on dams in recent years. Over the last few decades, the value of timber has dropped heavily while new forests are now being appreciated for their recreational and aesthetic values; for these reasons, the social importance of forest maintenance has grown, but with no advantage for land owners. Today, most plantations are excessively dense and dry summer periods cause heavy mortality, which increases fuel accumulation on the ground leading to fire risk. Natural regeneration of introduced species is usually absent, and the establishment of other species (renaturalisation) is not common. Foresters are currently facing new economical, technical, social and political problems.

es to settlements and infrastructures in the lower parts of the valleys and on the plains (Box 23 and 24). Work carried out during the 20th century was also aimed at protecting mountain slopes surrounding artificial water reservoirs built for the electricity industry. In most cases, this work – the construction of dams and reforestation – was also a precious support to employment in mountain regions where depopulation was already a widespread phenomenon. Plantations were usually done with pioneer tree species. Civil engineering techniques implemented for mountain torrents and reforestation techniques were largely discussed and became university courses; in addition, local experiences stimulated international contacts and visits.

However, some of the factors (agriculture and pastoralism) which caused deforestation and soil erosion also acted, at least locally, as barriers to the formation of a new for-

Box 25. Soil conservation programmes in the Maghreb with a particular emphasis on the DRS "Défense & Restauration des Sols" Programme in Algeria from 1940 to 1980

Following the silting up of Oran harbour and various spectacular phenomena linked to water-related erosion in the mountain range of northern Algeria, the French colonial Forest Administration consulted an American specialist of soil conservation, W.C. Lowdermilk, and then undertook an ambitious programme on soil and water conservation called DRS. This programme was based on contour lines terracing work on cultivated lands (called absorption and diversion "banquettes"), complemented by RTM-like work (see Box 23) of torrent and gully control, and the afforestation of degraded and overgrazed lands mainly in the upstream of watersheds. Such works were based on empirical knowledge with practically no research to validate them. Between 1940 and 1980, about one million hectares in the Maghreb region were treated by the DRS Specialised Service under the auspices of various Ministries. Considerable funding and means were allocated by the colonial administration and then by the State for counteracting spectacular erosion phenomena through the development of huge work sites for terracing in the watersheds including dams, reforesting the upper parts of watersheds (more than 800,000 ha for Algeria only), correcting gullies and stabilising temporary water courses (oueds), and for protecting large threatened constructions such as dams.

In the 1980s and beyond, assessments of these water and soil conservation programmes have been carried out in Algeria as well as in Tunisia and Morocco. They have shown in general a limited positive impact of these huge investments. Floods, dam siltation and the low production of wood and crops still prevail today. In Algeria, an enquiry has shown that among the 350,000 ha treated, 20% of banquettes have been intentionally destroyed by ploughing, 60% are subject to gullying – they have never been maintained and are no more operational, while only 20% are in good status but are located in non-erosion prone areas. In Morocco, studies have shown that most of banquettes built on certain soil types and parent material (argillite, soft schist, marl) on steep slopes (25%) have actually contributed to landslides and gullying, worse than the previous sheet erosion.

Since 1985, a new method has been employed in Algeria, based on a participatory approach of integrated rural development that is proposed, discussed and tested. This incorporates new research results (limited level of sheet erosion, detrimental effect of some tillage practices) and new criteria such as a better exploitation of land producing crops for local people and forage for domestic animals while reducing the risk of erosion at the same time. In Morocco, recent studies on traditional management techniques of surface water and soil fertility have shown the use of a broad range of techniques in relation to local agro-ecological and human conditions. Improvements are proposed to enhance their cost-effectiveness and their efficiency for controlling soil losses, C sequestration and biodiversity.

est cover since plantations were reducing grazing areas and inhibiting traditional land use practices deeply rooted in remote rural areas. Reforestation, not always strictly linked to watershed management work, was not just a technical problem dealing with ecology and civil engineering. Watershed management was aimed at improving living condition for the most important sectors of the population and economy, modern agriculture on the plains, cities, industries, roads and railways, etc. In some cases, they were also an occasion to mark the activity of the political power: the "new" landscape was a permanent signature of the ruling power. Undoubtedly, it was also a relief to unemployment – at least temporary. Very little has been said about the local traditional societies living in mountain territories; eroded land and poor vegetation were still supporting a rural economy. Afforestation, especially when implemented on common land (as on the baldios in Portugal) or large private ownership rented to small farmers was sharpening already existing economic difficulties and stimulating social unrest. Illegal grazing and fires were the obvious answers.

The very large programmes of soil and water conservation undertaken on the southern rim of the Mediterranean with a more integrated approach addressing together pastoralism, agriculture and forestry, have produced somewhat contrasting results, much below expectations. This is due to insufficient scientific knowledge and an excessively top-down approach.

Forest hydrology and soil conservation measures developed much later on the southern rim (Morocco, Algeria and Tunisia) of the Mediterranean. This has been undertaken on a very large scale by the French colonial administration since 1940 through ambitious programmes on watershed management, by restoring degraded land through afforestation and constructing terraces (banquettes), and agroforestry management. The RTM model (see Box 23) inspired the whole enterprise but in a different context, in particular because it was implemented in densely populated areas and with a more integrative approach of rural activities and development at the landscape level. To a large extent, it was also combining biological engineering and civil engineering – for the latter, the technological developments made possible the use of heavy machinery (tractors, dozers, etc.).

This work, extending over one million hectares in Algeria, Tunisia and Morocco, was aimed at creating a forest cover, reinforcing slopes and protecting large settlements, developing sustainable agricultural and pastoral practices as well as protecting human infrastructures. These programmes were pursued after the countries regained their independence but with variable levels of investments (Figure 57). Box 25 gives an overview of these programmes and their results, which were carried out, with limited knowledge of erosion processes, and a marked top-down, centrally driven policy in its design and implementation (the “participatory approach” was not at that time “fashionable”).

Figure 57. Reforestation operations in Italy in 1895.

Figure 58. Torrent control equipments in Morocco. Photos by Mohamed Sabir.

The main reasons for the general failure of these programmes are due to both technical and social problems which can be summarized as follows: i) poor knowledge of local geology and soil dynamics; ii) the overestimation of sheet erosion; iii) in general, the overestimation of runoff on an average, even if it can be important in case of heavy and intense rainfall; iv) poor tree planting material and tendency to large scale mono-specific plantations; v) the reluctance of local population to change their practices such as cultural and pastoral techniques; and vi) legal aspects regarding land property, etc.

> Updating and adjusting policies of water and soil conservation as related to tree and forests should be rethought in today's context. This should be undertaken as soon as possible without waiting for new catastrophes to occur, by using latest knowledge, and by integrating all aspects related to sustainable development.

The lessons to be drawn from these past undertakings for controlling water disorders and soil losses are manifold:

a) It is clearly apparent that environmental problems and solutions are not only technical but also socio-economical and cultural. To be efficient and long lasting, any project should be developed without deep involvement of the local people. Local administrations should be more responsible for both new urban development and traditional rural activities.
b) The environmental problems are complex and cover inter alia the water budget, soil fertility loss through erosion, and rural economic development. The solution must therefore integrate all the aspects of sustainable development.
c) It is crucial to define acceptable risks and tradeoffs between different and/or interrelated hazards.

Looking at the present context, it becomes obvious that a holistic approach of landscapes and territories management and planning is needed. Recent events in southern Italy have shown how conservation problems involve not only traditional watershed management and afforestation but also inappropriate land use for buildings and infrastructures on geologically frail ground. Sheet erosion has in fact decreased over recent decades due to forest area increase (mainly through secondary succession) and careful soil tillage; however, forest fires can cause sudden and serious damage to surface soil layers. Landslides and gully erosion are the most important contributors to debris transportation. The climate and its vagaries – like the 2003 summer drought and the heavy precipitations of winter 2010 – remind us that natural phenomena cannot be underestimated. Since the beginning of the watershed management policy, many changes took place and new problems emerged: the regeneration of the oldest plantations, the lack of thinnings and the increased fire danger, the impact of wildlife (ungulates), the new role of forests for recreation, CO_2 fixation and biodiversity. These issues must be jointly addressed.

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5.

Key Challenges

The current and future sustainability of Mediterranean socio-eco-hydrosystems depends on our collective capacity to meet some significant challenges. Without professing to be exhaustive, this chapter identifies some major challenges, explains their scientific background, and proposes ways on how to cope with them. Five challenges have been selected, as listed below:

1. Climate change implications on forests and hydrology
2. Land use changes and increasing demography
3. Afforestation to combat desertification
4. Riparian and aquatic ecosystems
5. Economics of water and forests

Figure 59. Drought affecting vegetation in the Iberian Peninsula in spring 2005. Between November 2004 and March 2005, Spain and Portugal experienced their driest winter respectively since 1943 and 1980. The impact of the drought on vegetation is shown in this vegetation anomaly image, created using data collected by the Moderate Resolution Imaging Spectroradiometer between April 7 and April 22, 2005. Compared to the average vegetation density (a good indication of plant health) for the same period in the five preceding years, vegetation was clearly stressed. Brown represents those regions where vegetation was thin and less dense than average, while tiny flecks of green show where vegetation is healthier than average. The dark reddish-brown streak shows the most severely affected regions. Note the importance of the network of dams, for which water refilling has also been affected by the winter drought. In a context of climate change, such droughts could become more frequent. Source: NASA.

5.1.

Climate Change Implications for Forests and Hydrology: an Overview

Javier Martin-Vide, Francesc Gallart and Joan-Albert Lopez-Bustins

The Mediterranean basin is a climatically complex region with a varied mosaic of climate subtypes and consequently of highly contrasted ecological environments.

The Mediterranean basin is geographically a unique region in the world. It comprises (i) a large sea measuring 2.5 million km^2, with a volume of 3.7 million km^3, and is located between three continents with almost no connection with oceanic waters; and (ii) the surrounding territory presents significant mountain ranges. It stretches 3,800 kilometres from the eastern coasts to the Atlantic through the straits of Gibraltar – a "sea between lands" as its name indicates. At their narrowest point, the Gibraltar straits are a mere 15 kilometres wide which reinforces the paradox for a sea – its "continental" nature.

The variety and complexity of its geographic factors and its "isolation from the outside" provide its climate with a specific personality and unique features, and yet while this climate is Mediterranean by definition, in much of the surrounding territory it presents so many nuances that the terms "climates" or "climatic mosaic" are far better suited.

The Mediterranean has lent its name to one of the planet's main climatic types, the Mediterranean climate, which in the collective subconscious is associated with benign atmospheric conditions, with the idea of sun-soaked beaches, constant sunshine, mild winters, long summers, little rainfall and landscapes that, arguably, have been secularly humanised for millennia with little plant cover. The adjective "Mediterranean" has been exported from the climatic point of view to regions of other continents at similar latitudes in a western location and with the ocean to the west.

In general terms, Mediterranean climates, or dry-summer subtropical climates (lying between about 30/32° and 41/45° latitude and all near the coast on the western edge of continents), are influenced by the polar front in winter and thus present moderate temperatures and rainy weather; and by the subtropical anticyclones in summer when the weather is hot and dry (*Csa Köppen*'s subtype) except in some coastal areas where there can be milder conditions, and even fog due to the presence of cold ocean currents (*Csb Köppen*'s subtype) (Table 12).

Table 12. Main characteristics of Mediterranean climates

- All regions are located between 30/32° and 41/45° N/S and, except large areas of the Mediterranean basin, are on the western coasts.
- The typical seasonal precipitation regime is wet winters and dry summers.
- Summers are warm to hot and winters are cool to mild; temperatures below 0°C are not frequent at sea level.
- Annual rainfall is relatively low, with a high percentage falling in the winter half of the year. The common annual mean precipitation is from 250 to 900 mm.
- Solar radiation is high, especially in inland areas due to clear, cloudless skies and low humidity. Evapotranspiration is high in inland areas. Cold marine currents give rise to mild and foggy summers in some coastal areas.
- Mountains, frequently parallel to the coastline, influence and modify climatic patterns, forming distinct rain shadows, rainy "islands" and microclimates.

The complex geographical factors of the Mediterranean basin produce a "puzzle' of seasonal rainfall regimes. In regions facing the east (e.g. the eastern fringe of the Iberian Peninsula) the rainiest season is autumn and not winter. In other areas, the rainiest season is spring and even summer in some northern mountainous areas.

With regard to atmospheric dynamics, the Mediterranean basin is a unique place, in which the signal of *teleconnections** and of external variability patterns is generally quite weak. Certain internal mechanisms have a greater influence on rainfall than the main hemispheric patterns. Thus, the *Mediterranean Oscillation*,* which connects the western and eastern basins by means of the good fit of the wavelengths of the upper circulation *(Rossby waves*)*, give rise to an opposed, but synchronised, behaviour pattern between both extremes, so that when it is rainy on the Iberian Peninsula, it tends to be dry on the Balkans Peninsula and vice versa. Something similar occurs with temperature.

The Mediterranean basin has been undergoing a warming process since the 1970s similar to what the planet has been experiencing, although presenting a higher warming rate than the global rate. The climate models coincide in an evident and generalised temperature rise throughout the 21st century.

The best series of temperatures at ground level, available for the Mediterranean basin show, almost without exceptions, a temperature increase since the 1970s parallel to what has been taking place on the planet as a whole. One can appreciate the same phases in temperature evolution, i.e. the values below those of the international reference period (1961–1990) throughout the second half of the 19th century; an increase during the initial decades of the 20th century; a decrease towards the 1960s of last century; and an evident final increase from the 1970s to the present.

It should be pointed out, however, that in many cases the temperature increase in the Mediterranean basin over the last century (1906-2005) surpasses the value of 0.74°C corresponding to the global temperature rise, according to the Fourth IPCC Report (2007). That is, the century warming rate in the Mediterranean is somewhat higher than the global rate and can be estimated at approximately 1°C.

According to the Fourth IPCC Report (IPCC, 2007), a temperature rise in the Mediterranean basin is, as in the global context, highly likely (90%) for the 21st century. If at the global scale the range of temperature increases for the 2090–2099 period is be-

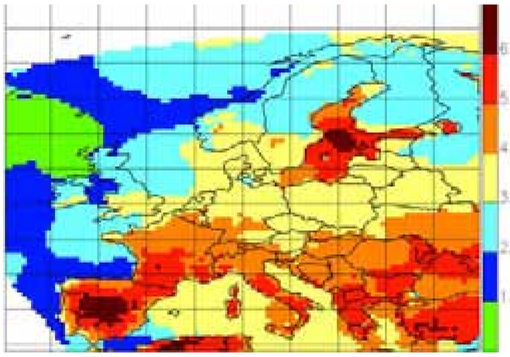

Figure 60. Annual temperature increases for 2071-2100 for Europe in relation to the last two decades of the 20th century. Source: http://prudence.dmi.dk/.

tween 1.8°C and 4.0°C, depending upon the emissions scenario in relation to the last two decades of the of the 20th century, greater increases can be expected in the areas surrounding the Mediterranean. As it constitutes a marine area, however, a substantial part of the basin's temperatures are moderated by the effect of the waters – i.e. the thermo-regulating influence of the sea. More moderate increases can therefore be expected in the maritime areas and the coastal zones under their influence than in the inland and mountainous continental environments. In particular, the climate models indicate that on the inland Italian, Balkans, Anatolian and Iberian peninsulas, especially the latter, the temperature will rise by between 1°C and 2°C more than in the nearby coastal areas (Figure 60).

The global predictions in relation to sea level point to a notable rise caused by the thermal expansion of water bodies and glacial melt. For the Mediterranean basin, the regional models forecast increases in sea level of approximately 35 cm for the end of the century, although these may be more moderate along the coast. This rise in sea level could favour the entry of saltwater into aquifers close to the sea and threaten coastal ecotones such as deltas and marshes.

There is uncertainty regarding future rainfall pattern evolution in the Mediterranean basin, although rainfall totals are very likely to decrease and may show higher temporal variability than in the present.

The increase in temperature on the planet is likely to reinforce the water cycle due to the logical increases in evaporation, with the resulting return of water from the air to the Earth's surface as more rainfall. Nonetheless, the global models predict that this phenomenon will not be generalised as they identify subtropical zones, like in the Mediterranean, and many tropical zones that will receive less rainfall in the future. This is what is most likely to occur, although it should be mentioned that in this sense, there is greater uncertainty than in the predictions for temperature increases.

Regardless, if both phenomena are combined – warming and reduced rainfall – we can expect a future scenario in southern Europe with fewer water resources, which will exacerbate the differences from the rest of the continent.

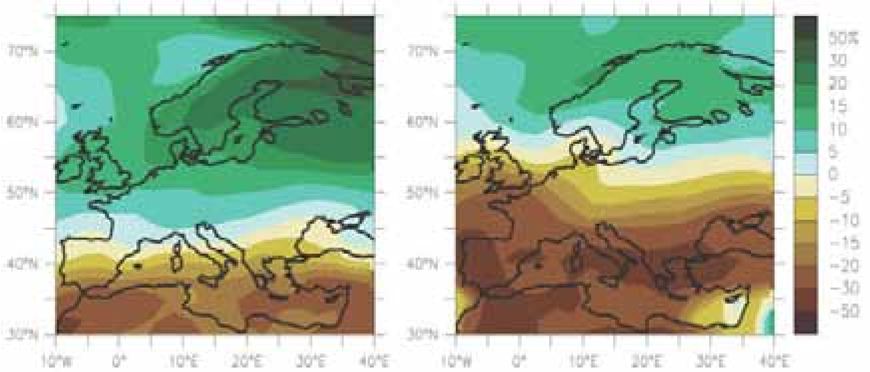

Figure 61. Precipitation change over Europe from the Multi-Model Data – A1B scenario simulations between 1980–99 and 2080–99, and averaged over 21 models. Left: December, January and February; right: June, July and August. Source: Christensen et al. 2007.

For the cold half of the year, the rainfall predictions by the climate models show a northern Mediterranean belt presenting some increases, and a southern belt with decreases. In summer, however, the models predict a generalised decrease in rainfall.

The rainfall predictions for Europe by the global climate models presented in the Fourth IPCC project increased winter rainfall in the northern extreme of the Mediterranean basin; a decrease in the remaining area; and a general reduction of rainfall throughout the Mediterranean basin in summer (Figure 61). Thus, the basin will experience a notable and general decrease in summer rainfall, between 20% and 50% (June, July and August) whereas in winter (December, January and February), a sharp gradient is expected between a northern belt with increasing precipitation and a southern one with decreasing precipitation.

The regional climate models, with greater spatial detail, confirm this projection for Europe. In particular, the most substantial results of the PRUDENCE project, which involved one of the biggest efforts with regard to research and calculation in climate science, could be summarised very succinctly and textually in the following way: ‘Future climate in Europe: warmer and dryer summers in the south, milder and wetter winters in the north.’ (prudence.dmi.dk/public/raisanen_et_al.html).

Consequently, the Mediterranean basin, a part of which comprises the whole southern zone of Europe, will most likely be (90%) warmer than in past decades and possibly (66%) less rainy. This supports the hypothesis, already verified for some areas, of the progressive replacement of forests with shrub formations, which have a lower water demand and are better adapted to the summertime characteristic water deficits of the Mediterranean climate.

The temperature rise will increase evapotranspiration demand and, even with no decrease in rainfall, there will be less soil moisture, more vegetation water stress and a drop in the water resources generated in rainy areas.

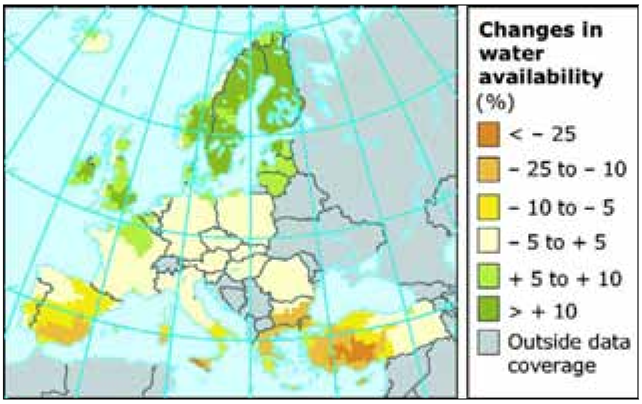

Figure 62. Changes in mean annual soil water availability up to 2030. Source: EEA 2005.

The expected change in climatic conditions will primarily cause a generalised decrease in soil moisture, whereas absolute decreases in aquifer recharge and runoff production will be more marked in wet areas (where evapotranspiration is limited by the available energy) than in drier areas (where evapotranspiration is limited by water).

Most of the land surrounding the Mediterranean basin will experience decreases in mean annual soil water availability of over 10% by 2030 (Figure 62). In particular, the south and southeast of the Iberian Peninsula, Sicily as well as the Balkans and Anatolian Peninsulas on the northern shore of the basin will undergo the biggest decreases.

In summer, the likely increase in temperature and the possible decrease in precipitation will likely result in the increase of vegetation water stress, with a low absolute decrease in the already low runoff and aquifer recharge. During the colder part of the year, even in the case of "no change in rainfall", aquifer recharge and runoff will significantly decrease in the mountains and wet areas – the sources of water resources – due to the increase in evapotranspiration demand. Changes will be lower in the drier areas, however, where evapotranspiration is not limited by energy but by water availability. Furthermore, the increase in temperature will reduce the regulating effect of the snow blanket in mountain areas.

In the southern shore of the Mediterranean, the combined effect of increasing temperature and decreasing precipitation will have severe effects on both soil moisture and water resources generation.

The Mediterranean basin will likely experience greater frequency and intensity of droughts and heat waves leading to more forest fires. Torrential rainfall could also increase although this prediction involves a high level of uncertainty.

Although future projections of the evolution of climate-related hazards are uncertain, the rise in temperature can be expected to cause more frequent and intense heat waves and drought in the Mediterranean basin. This prediction reinforces the hypothesis of more frequent forest fires.

The more typical subtropical atmospheric dynamics in the future, (quasi-tropical in the south of the basin) could involve convective processes that might be more vigorous as a result of surface warming. It can account for a possible increase in high-intensity rainfall. If it is reinforced, the binomial "drought-torrential rainfall" will necessitate very careful management of Mediterranean forests in order to avoid erosion and desertification processes, along with irreversible biophysical imbalances.

Forests can undergo major changes in area due to global change which can also condition the future availability of water resources.

In the last few decades, different land use maps of the Mediterranean area, particularly of the northern shore, have shown an increase in forested areas in detriment to croplands. These are mainly found in mid-mountain zones where the abandonment of croplands and pastures has enabled a sustained increase in forest cover. The decreasing trends observed in flow records of several streams in northern Spain have been attributed to the higher water consumption by forests, though partly shaded by climatic variability and changes in irrigated areas. This recent tendency in forests will augment the risk of forest fires in the immediate future due to increased amounts of fuel and the increase in forest continuity.

Nonetheless, the current forest expansion might be curbed by the new environmental conditions of the 21st century. The ecological models predict a generalised mortality of forests currently at their water balance threshold by the middle of the century, while the rise in temperature will favour the spread of forests in the mid- and high-mountain areas.

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5.2.

Coping with Increased Population and Land Use Changes

Gaëlle Thivet

The Mediterranean region is characterized by high demographic growth, rapid land use changes and extensive visible environmental degradations. In some cases, such degradations are observed on both rims while others are more specific to one rim or sub-region due to socio-economic, demographic and environmental conditions.

The strong population growth in the south and east will greatly increase the need for food, water, soil and energy, and will accrue pressure on natural resources. Natural and social risks are expected to be highest on Mediterranean coasts where quality and integrity are under threat.

In the Mediterranean Basin countries, resident population numbers increased from 207 to 473 million between 1950 and 2010. In the south and east the population almost doubled to reach 280 million inhabitants in 2010 over a thirty year period. Nonetheless, the main observation over the past 20 years has been the drop in fertility rates in southern and eastern countries (SEMCs) (Figure 63), and there is a high probability that this demographic transition will continue until 2050. Despite the convergence of fertility indices, the demographic swing between the rims is expected to continue. The populations on the southern and eastern rims could further increase by 57 million by 2025 and by 117 million by 2050. In the north, population growth should not exceed 3.8 million inhabitants by 2025 and should decrease by some 3 million between 2025 and 2050 (Figure 64).

Demographic pressure is expected to be highest in urban and coastal areas. By 2025, the number of urban inhabitants should further increase by 20 million and tourist flows should almost double (+140 million tourists/year) on the Mediterranean coasts. This scenario is valid for urban and coastal areas, but does not signify the reduction of the rural populations in the south and east, which are expected to remain large at least until 2025.

Land use changes will affect spatial dynamics and cause environmental degradations.

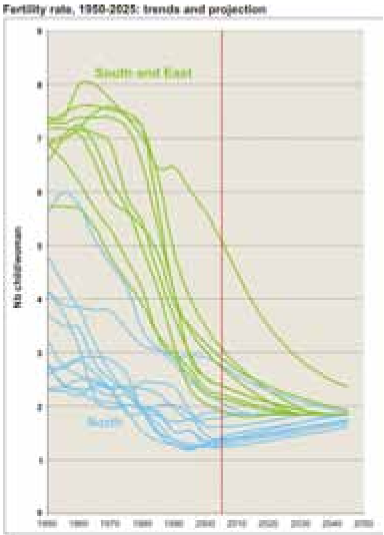

Figure 63. Synthetic fertility indices: evolution since 1950 and forecasts for 2050. Source: United Nations Population Division, World Population Prospects: The 2006 revision.

In the south and east, the number of cultivated surfaces has been multiplied by the "hunger for land" phenomenon. The impact is most severe in the five North African countries (+40% in Morocco and +28% in Egypt between 1960 and 2000), where land has been reclaimed with difficulty from pasturelands, forests and deserts. Although there has been a slowdown in the occurrence of this phenomenon in recent years, the pressure is expected to remain high in several SEMCs at least until 2020, increasing deforestation and desertification and aggravating resource degradation. Soil degradation and erosion are especially alarming in very poor mountain areas where there have been less conservation and reforestation initiatives. The increase in irrigated lands, estimated at some 38% in the south and 58% in the east by 2030 (FAO), can only intensify pressures on water resources and ecosystems, and increase soil salinization risks.

In the north, the rapid pace of the expansion of forests and shrublands should be maintained until 2025, in view of the announced decline in the number of farmers and due to changes in agricultural practices. The impact of forest biomass reclaiming rural lands is contrasted in so far as there are both positive economic and ecological results as well as negative effects such as the closure of landscapes or lessened flora differentiation in the underwood. However, it is essentially the accrued risk of large fires which has and will continue to have the most significant ecological, economic and human impacts.

Land development spells the irreversible loss of the most arable lands in the SEMCs and this trend is particularly heavy in the north. The trend is expected to endure in coastal plains mainly where it will accrue soil impermeability by limiting water penetration and thus contribute to increasing the risk of floods. Nearly 50% of the coastal zones could be built-up by 2025 (40% in 2000).

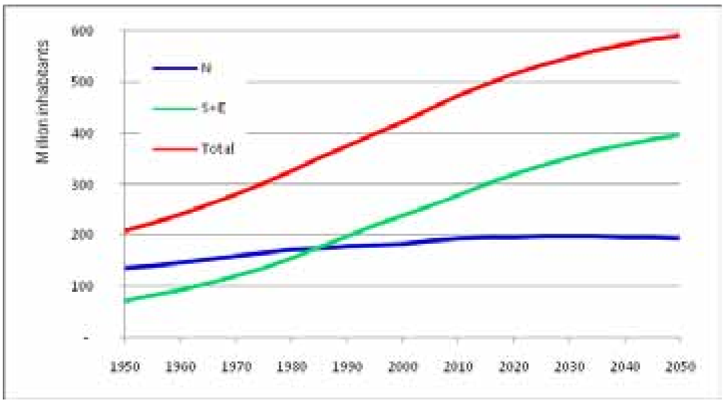

Figure 64. Evolution of northern, southern and eastern Mediterranean populations by 2050. Source: United Nations World Population Prospects, 2008.

Should current changes in rural, agricultural, grazing and wooded areas continue, they would induce or aggravate several major risks of unsustainability:

- desertification and rural poverty in the SEMCs
- direct and indirect impacts: accrued pressure on cities, heightened rural emigration, silting of dams and biodiversity loss
- loss of quality farmlands due to urban sprawl and infrastructures (estimated at over 1.5 million hectares by 2025)
- degraded water resources and increased vulnerability to fires and floods

Risks from global climate change and the economic risks associated with the rising prices of energy, raw materials and agricultural products must be added to these impacts.

Increased water demand, whether for agriculture, industry or households, is aggravating the pressure on the resource.

According to the Plan Bleu's 2009 forecasts, demographic growth and economic development will increase the demand for water in the Mediterranean, mainly in the SEMCs, by another 50 km^3 (18%) by 2025 to reach 330 km^3/year,.

Agriculture is expected to remain the prime water consumer in the volumes required to satisfy irrigation needs. The demand for drinking water should also continue to increase to meet the needs of the permanent population – more and more concentrated in very large cities – and of visiting tourists. Although the additional water demand induced by tourism may remain modest on an annual scale, it is nonetheless problematic in that it coincides with increased demand for irrigation water during a period when resources are at their lowest.

This pressure on water resources, expressed with the renewable natural water exploitation index, highlights geographical contrasts that are in some cases pessimistic as regards the "future of water" (Figure 65).

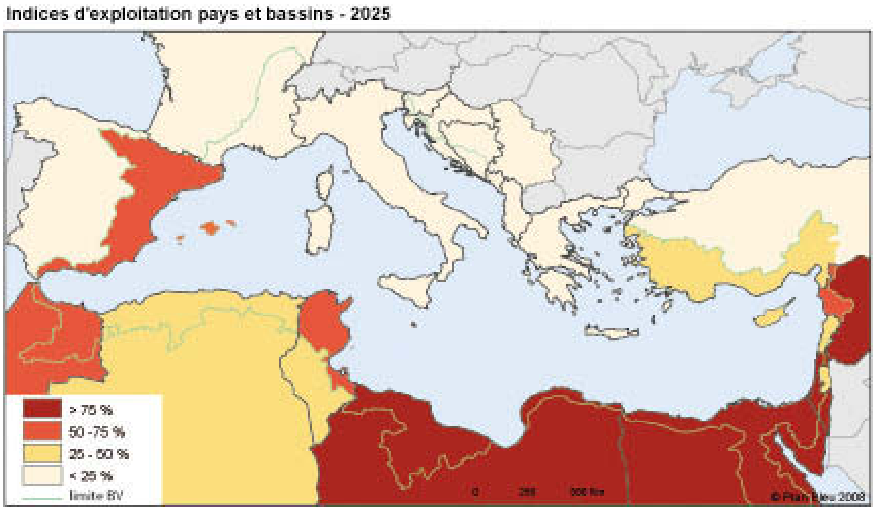

Figure 65. Exploitation indices of renewable water resources in individual countries and catchment areas in 2025. Source: Plan Bleu.

Pressure levels on resources can furthermore multiply and amplify conflicts between users, starting with the competition between cities and irrigated agriculture. This also applies to conflicts on the share of the resource between regions or countries, in particular between the upstream and downstream of transboundary catchment areas (the Euphrates, Jordan and Nile). More generally, this may induce conflicts between population needs and nature conservation requirements, by accruing threats to ecosystems and limiting conservation possibilities.

The changes in temperature and rainfall described in climate models will aggravate these trends further. The Mediterranean region, already submitted to significant hydric stress, will be more exposed to a reduction in its water resources. In SEMCs, nearly 290 million people could be facing a water shortage by 2050 (Figure 66).

New policies offer options for progress through improved water demand and supply management.

If the growing water demand is to be satisfied in the current context of resource insufficiency, rarefaction, overuse and deteriorated quality further aggravated by the impact of climate change, it is both desirable and necessary to implement deterministic policies targeted at restoring the balance between supply-based approaches and improved water demand management. Such policies must put the emphasis on:

- Efficient use of water for different needs[1] through the implementation of technical, economic, regulatory or social instruments.
- Increased exploitable potential of renewable water resources through the artificial recharging of water tables, the fractioning of regulatory works (dams) upstream of catchment areas as well as initiatives to promote water and soil conservation (re-vegetation, cultivation practices, infrastructures, biological processes). These measures will limit silting in dams, facilitate water penetration and storage in aerated soil and in aquifers, and reduce losses from evaporation.
- Recourse to unconventional water resources (reuse of treated wastewater for irrigation, desalination of sea or brackish water to produce drinking water) or to virtual water imports[2] in order to limit the pressures on natural resources.

Potential for progress is considerable as improved demand management would allow saving one quarter of the demands, or 85 km^3/year in 2025 (Figure 67). Irrigated agriculture represents the largest potential for savings in volume, with nearly 65% of total water savings identified in the Mediterranean.

In this optimistic perspective, assumed as generally applicable to all Mediterranean countries, the total water demand could approximate 105 km^3/year in the north and 140 km^3/year in the south and Near East, globally equivalent to a reduction of 40 km^3/year

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[1] The current yields of water use are far from satisfactory. Losses, leaks and wastage are estimated at approximately 40% of total water demand throughout the Mediterranean region. Losses are significant due to the obsolescence and poor maintenance of water networks and to wastage from different uses (households, industry and agriculture due to unsuitable irrigation techniques).

[2] Development of imports or reduction in exports. Virtual water contents in imported/exported goods correspond to the quantity of water consumed for their production.

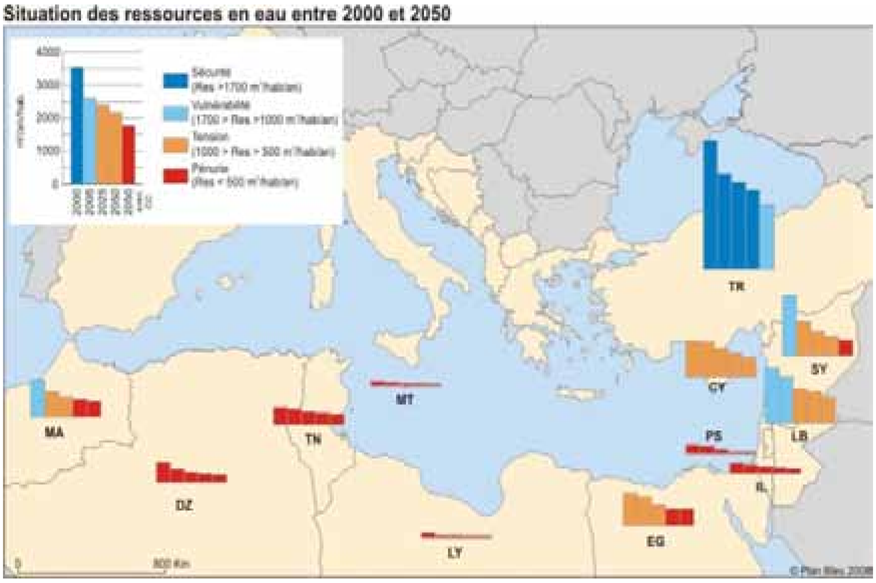


Figure 66. Evolution of water resources per capita in the SEMCs between 2000 and 2050. Source: Plan Bleu.

of the current total demand. Such water savings would also lead to greater energy efficiency and financial savings. These overall estimations, based on concrete experiments conducted in several countries, show that such a change of course is possible (Box 26).

Measures to increase the exploitable potential of renewable natural resources at lower energy, economic and environmental costs would help restore the balance of the spread of water resources in the region.

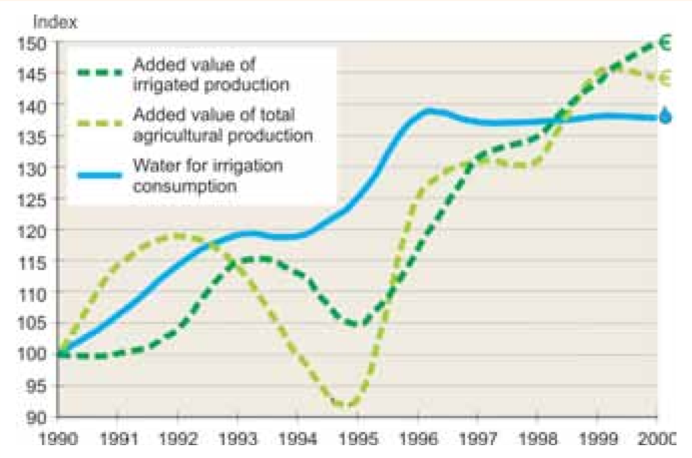
The sustainable management of water resources and demand must above all be based on an integrated approach at the catchment-area level, and on the upstream-downstream solidarity principle between hinterlands and coastal zones.

Policies should take into account the wealth of heritage in the Mediterranean's rural areas and the diversity of their functions as major assets and opportunities for the future and adapt them to changes. The sustainable management of such areas should address their multiple functions and be geared towards the prevention of natural risks such as forest fires and floods.

The new social uses of the natural Mediterranean ecosystems, the preoccupations with biodiversity conservation and the combat against climate change require strong innovations in the management of rural areas and woodlands. Working towards more sustainable processes implies the need for deep-rooted changes to the "vision" of possible and desirable roles and futures of rural areas, and to the corresponding national management policies.

Box 26. The national strategy for irrigation water savings in Tunisia.

Tunisia has implemented a national strategy for irrigation water savings based on the creation of user associations, a pricing system which has lead to gradual recovery of costs, and specific financial instruments to endow farms with water-saving technologies and to support farmer income. Since 1996, this policy has stabilized the demand for irrigation water despite the significant development of the farming sector and has secured the needs of the tourism industry – source of currency – and cities.



Water consumption and added value of irrigation in Tunisia
Source: Plan Bleu, Hamdane, Fiuggi, 2002.

In addition to their role as biomass producers, rural areas, including woodlands, fill many environmental and social functions that are essential for all Mediterranean populations:

- The ecological role of these areas ensures the quality of the rural environment and of peri-urban and urban zones, and beyond of the downstream coastal ecological balances; their function covers the regulation and conservation of water resources, soil and biodiversity, and the “production” of water and sedimentary deposits in the coastal ecosystems.
- Mediterranean woodland ecosystems contribute to offsetting greenhouse gas emissions, despite their relatively low carbon absorption capacity. They can also supply energy and renewable materials.
- Rural areas are also central to the balance of rural and urban populations. If the speed of population concentrations in cities and on coastal zones increases, it could lead to risks of social unrest and to high costs from congestion and pollution. The issue of rural employment then becomes a determining factor in the quest for viable social and spatial balance.
- Rural areas, used increasingly for residential purposes and leisure activities, help to diversify the offer of the tourism industry.

The multiple functions of rural areas, which should be considered essential in decision-making processes, are still insufficiently recognized. Woodlands in particular provide significant non-merchant services, which are not reflected in market mechanisms.

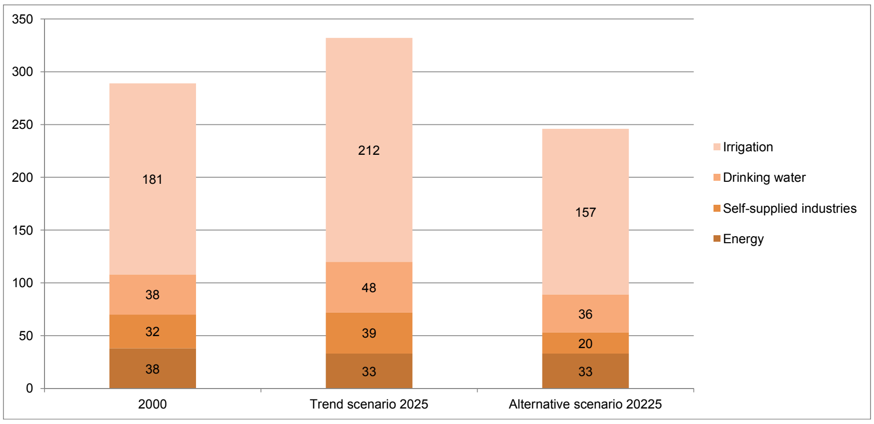


Figure 67. Water demand per sector of use (km³/year), trend and alternative scenarios (2025). Source: Plan Bleu.

Thus, current major issues include the sustainable management, funding and remuneration of the environmental goods and services provided by Mediterranean ecosystems. Environmental economists are seeking to measure the total environmental and ecological values of such areas as forests, stressing the need to recognize their social and environmental contributions, indispensable for sustainable development.

Territorial approaches are particularly necessary to ensure the sustainable management of natural resources, including forests.

All sustainable rural development strategies must be based on the following paradigms: integration, territoriality, subsidiarity, participation and partnerships. They must necessarily include rural areas and woodlands set within larger scopes which include small towns and rural villages.

Master and management plans help define development objectives and the rules and scope of the use of resources to protect the long-term balance of ecosystems, while taking into account the risks and evolutions resulting from the impacts of climate change and hydric stress in the Mediterranean region.

A large number of countries, in particular highly decentralized countries such as Spain and Italy, are working on such territorial approaches that require close cooperation between all stakeholders involved, such as economic agents, associations and local authorities. The involvement of all stakeholders allows the identification of potential conflicts of interest; helps redefine priorities and set rules for collective use; and to better allocate the funding required for sustainable resource management.

The inclusion of forest policies in all territorial development policies seems all the more important when, as shown above, the high heritage value of Mediterranean woodlands stems from their multiple functions. The sustainable integrated management of woodlands can curtail linear urban planning through the creation of green patches, contribute to the diversification of tourism through the promotion of the hinterlands and partake in abating poverty and desertification. The integration of water and forest policies is indispensable to the sustainable management of natural resources at the catchment-area scale. And lastly, the implementation of efficient fire prevention strategies requires the full integration of all current policies relating to fires: urban development, agricultural development (including breeding practices), and issues of use and property rights, etc.

The sustainable management of water resources and demands, and of rural areas and woodlands must above all be built on an integrated approach at the catchment level and on the upstream-downstream solidarity principle between hinterlands and coastal regions. It must also be in harmony with all sectoral policies: agriculture, energy, tourism, environment and land development to facilitate arbitration as regards the water and soil resources allocated to all uses.

The responses required to deal with future challenges in the management of Mediterranean water resources and woodlands which stem in particular from population growth and changes in land use, thus largely exceed the sole scope of water and forest policies.

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5.3.

Afforestation to Combat Desertification in Arid Zones Requires a Concerted Endeavor[1]

Orna Riesman-Berman, Leopoldo Rojo and Pedro Berliner

Biophysical processes leading to desertification mainly consist of increased runoff and soil erosion resulting from significant reduction of the canopy. They can be prevented or reversed through afforestation, if properly designed, with due attention to the water balance in the watershed.

Throughout the modern history of afforestation in the Mediterranean Basin, this activity has taken place in deteriorated and degraded lands, such as overgrazed natural areas, burnt forests and shrublands, abandoned agricultural fields or areas in which heavy clear-cutting has been carried out. In such lands, there is a significant threat of the destruction of the soil structure, the loss of soil fertility, loss of productivity and biodiversity, and the development of desertification processes. In this chapter, we discuss the sustainability of afforestation in severe drought-prone ecosystems, concentrating on the dry Mediterranean and semi-arid areas around the Mediterranean Basin.

In arid areas, over-grazing, fires and all anthropogenic activities that remove the vegetation cover and strip the land bare perilously expose the soil surface to erosion by wind and water. The above activities also destroy the biological soil crust which, in arid zones, stabilizes and protects the soil from erosion, diverts runoff and contributes nitrogen and carbon to the soil. Storms beating down on degraded lands accelerate the process of soil structure destruction and thus accelerate desertification processes. Rain drops hitting the bare soil destroy soil surface aggregates and, as a result, a dense physical crust is formed and runoff is increased. The unrestrained flow of water on sloping terrain may become turbulent and entrain the detached soil surface particles. In large crust-covered areas, floods tend to develop. When the flood waters subside, the eroded material will cover the fertile upper layers of the soil, contributing to the further destruction of the soil structure thus impairing agricultural activities in cultivated areas. In such degraded lands, the loss of soil fertility is accompanied by a dramatic decrease in water availability, thereby limiting the regeneration of annual herbaceous species as well as trees and shrubs. The accelerated decrease in water availability and the on-going

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[1] See also section 1.5 and 4.3

Box 27. Defining desertification.

- "'Desertification' means land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities."
- "'Combating desertification' includes activities which are part of the integrated development of land in arid, semi-arid and dry sub-humid areas for sustainable development..." Source: UN Convention to Combat Desertification – http://www.unccd.int/convention/text/convention.php?annexNo=-1.

loss of vegetation cover constitute a vicious circle, so that once fertile and vegetated areas turn into bleak landscapes crisscrossed by deep gullies. Figure 68 illustrates the sensitivity to desertification in the northern Mediterranean.

It may thus be said that a reduction in vegetation cover is the main cause of the chain of events that leads to desertification Preventing and combating desertification rely, therefore, on maintaining a stable canopy cover at least during the rainy season or on forming the canopy cover in lands at risk for desertification. Leaves absorb the energy of rain drops upon impact with the leaf surface and thereby decrease the energy of the drops before they reach the soil surface. Therefore, the canopy dramatically reduces destruction of surface aggregates and prevents the formation of a physical crust on the soil and the consequent flooding. The retention of rain drops on forest canopy leaves and the reduction in rain infiltration into the soil is of particular importance during the severe storms that frequently occur in the Mediterranean area during spring and autumn, when the annual vegetative cover is sparse. Thus, afforestation with evergreen or semi-evergreen species would ideally provide the essential canopy cover during the crucial seasons.

Large-scale afforestation of desertified areas may affect water balances in the watershed. Large-scale field experiments (12 km^2) conducted in a 30-year-old Aleppo plantation, planted in the transition area between the Mediterranean and semi-arid zones (285 mm annual rainfall), demonstrated that runoff was negligible, even during high-intensity storms. The increase in the water stored in the soil profile did not, however, result in water percolation below the root zone, and thus there was no recharging of the aquifer. The water was efficiently used by the trees and the ephemeral understory. The efficient use of available water by the trees increases the use of energy and decreases temperature at surface level. This process is determinant to reverse desertification. The presence of trees can, therefore, reduce the generation of water flows and hence reduce erosion. It thus follows that afforestation is an efficient tool in both preventing desertification and reversing it in disused agricultural lands and disturbed natural areas.

Afforestation in arid and semi-arid zones requires water harvesting techniques such as the formation of contour-terrace structures or low-lying dammed catchments.

It is, however, not an easy task to establish sustainable forests in the drylands of the Mediterranean Basin, which are characterized by low rainfall and a high potential for evapotranspiration, even in winter. As long ago as the mid-nineteenth century, foresters were aware both of the degradation of the Mediterranean forest ecosystems – and its ramifications for soil erosion – and of the increase in catastrophic floods. Ecosystem rehabilitation activities were thus instituted to promote afforestation, in particular on the headwaters of the torrential watersheds. As a result, extensive afforestation plans were developed in the 20th century in most of the Mediterranean countries. In Spain, for example, more than four million hectares were afforested or some 9% of the total national territory and 18% of the potential forest land. Initiating positive feedbacks between soil and water through afforestation entails improving water availability for the plants introduced into the degraded land. This can be achieved by several complementary means:

i) Soil preparation before planting to increase water infiltration and soil water-holding capacity, especially with techniques of runoff harvesting.
ii) Careful selection of woody species and ecotypes that can tolerate the stressful conditions of degraded lands.
iii) The acclimation of saplings in the nursery for withstanding drought conditions.
iv) The use of microclimatic conditioners such as tree-shelters.

As long ago as the ancient times of the Nabateans (100 BCE–50 CE) and Byzantines (324 CE–640 CE), techniques had been developed to overcome the intrinsic imbalance between the agricultural demand for a stable water supply and evaporation by turning the potential curse flooding into a blessing. Water harvesting, flood diversion, and runoff collection are various terms used to describe the collection of runoff water in structures that are tailored to the geomorphology of the land. The principle of this ingenious system is extremely simple: naturally generated runoff is concentrated from a large area into smaller areas and trapped there. As a result, the depth of water in the catchment areas will be much higher than the “rainfall depth”; more importantly, however, sufficient water can be stored to allow the normal development of a crop, albeit on a reduced area. In these micro-sites, water availability is thus much higher than that in the surroundings. An example of a modern implementation of such an approach for large-scale afforestation is that practiced in the transition area between the Mediterranean and the semi-arid Negev desert of Israel (annual precipitation 50–300 mm). In this approach, tree saplings are planted along a low, terrace-like mound of earth, built along the contours of a slope (Figure 69 A, B). Runoff is produced on the area in-between two neighboring contour terraces, which is the “source area”, and is collected in the lower contour terrace, “the sink”, where the saplings are planted. The distance between the contour terraces and the soil type determine the amount of runoff produced; for example, rocky surfaces produce more runoff. Similarly, in lands where a biological crust is present, crusted surfaces produce more runoff in-between terraces than degraded soil surfaces. In areas with contour terraces, tree survival is considerably enhanced and erosion is controlled. It is possible to construct the contour terraces with only minimal disturbance to the land by using a small trencher for digging the ditches and forming the soil mounds along the contours. In this way, the area between the contour terraces remains almost intact. This type of afforestation is known as “savanization”, a term describing a comparatively sparse planting design, where space is left between contour terraces and between trees along a contour. The contour-terrace technique is thus an effective management technology for the watershed as a whole. An additional advantage is its impact on forest biodiversity and productivity. The high soil moisture under the terraces improves the establishment of annual herbaceous species, and there is a considerable increase in biomass on the terraces. Similarly, species biodiversity on terrace mounds is greater than that in the crusted-soil areas between terraces. Therefore, in terraced drylands, increasing the number of terrace contours may increase vegetative biomass and species biodiversity. Hence, ecosystem services are maintained and grazing can be integrated into the forest ecosystem. Another type of construction used in the Negev desert to collect runoff is the liman (limen and limne meaning respectively port and lake in Greek; Fig. 69 C, D), which is a man-made, low-lying water-catchment area dammed by embankments that trap runoff water from wadis.

Tree-shelters, which are vinyl cylinders that are individually constructed around the planted saplings, form a shaded microenvironment around the sapling reducing evapotranspiration and promoting sapling survival. Sapling height also increases because of the effects of the shade. Protected saplings of *Quercus ilex*, for example, may reach twice the height of unprotected saplings after as little as two years. In warm climates, it is recommended to use ventilated tree-shelters to reduce the temperature inside the cylinder. Similarly, the extant canopy cover may facilitate the establishment of both introduced and regenerating woody species under stressful environmental conditions. The effect of the shade will be discussed at the end of this chapter with regard to spontaneous regeneration.

Agroforestry can increase the productivity of afforestations in drylands.

In afforested areas where the soil is sufficiently deep (abandoned agricultural fields, for example), the area between the contour terraces can be used for small-scale cultivation, a practice known as agroforestry. The technique is common in the more humid areas of the Mediterranean and is based on intercropping between the rows of trees or thinning forest trees to create an open woodland savanna that can support crops. Known examples are the *dehesa* in Spain or *montado* in Portugal, which are agroforestry systems in man-made open oak woodlands. Agroforesty is not commonly practised in drier areas. However, even in drier areas, concentrating runoff into a relatively large plot of land can increase soil water availability such that in the early summer the soil water content is similar to that in humid zones. This system is termed a runoff agroforestry system (RAS). The area of the runoff-contributing surface is planned in such a way that the run-

Figure 68. Sensitivity to desertification in the northern Mediterranean, 2005. Source EEA.

off generated spreads over the cropped area and wets the soil to a predetermined depth. The optimum size of a runoff-receiving plot is approximately one hectare, which is the maximum area that can be satisfactorily leveled by hand (to ensure homogeneous water spreading) and enables its feasible cultivation.

Regeneration of overstory and understory within dryland afforestations is a major hindrance to forest sustainability. However, encouraging the regeneration of native species within dryland forests may enhance species and structural diversity as well as ecosystem services.

Afforestation activities in drylands are designed to support multiple ecosystem services for man and the environment. These ecosystem services include recreation; maintenance of a cool micro-climate; soil conservation; soil regeneration; water conservation; groundwater recharge; dust and flood prevention; forage production; and the conservation of biodiversity. Given the few available dryland resources, it is crucial to design afforestations to maximize the provision of ecosystem services, despite the inherent difficulties of establishing sustainable forests in drylands. The forest understory, an important component of the forest that contributes to forest species diversity and its structural complexity, may provide many of the ecosystem services, including forage for livestock and honey bees as well as cultural and aesthetic services. In drylands, however, it is a difficult task to design a forest that supports an understory. In principle, afforestation in arid ecosystems creates a novel ecosystem, which drastically alters the original natural or degraded grassland or shrubland or disused agricultural land. This type of novel forest ecosystem forms an environment that differs from the surrounding open natural or cultivated lands in that the planted trees change the microclimate, soil cover, soil surface structure, soil properties and hence the overall resource availability and habitat for many animals and plants. In dryland areas, the regional species pool does not comprise a well-adapted suite of natural forest understory species but is composed of grassland or shrubland species from the surrounding areas: Therefore, the development of understory vegetation in an afforested area contributes to landscape connectiv-

Figure 69. A, B. (left) Contour-terrace afforestation in the Negev, Israel. Saplings are planted along low mounds that are constructed along the contours of a slope. C, D. (right) A liman is a planted water-catchment area. Photos by B. Bookend and http://desert.bgu.ac.il/desert/.

ity and thus mitigates the effects of both landscape fragmentation resulting from the afforestation itself and of any prior land degradation. Forming a forest that supports an understory may require a special endeavor, since forest tree species are selected mainly for drought tolerance and rapid growth and establishment and not necessarily to support the establishment of the understory. Thus, some of the best drought-tolerant species, such as species of *Eucalyptus,* inhibit plant establishment under their canopy (for example, because of allelophaty). A possible solution to this problem lies in "savanization", being an afforestation practice that allows the establishment of an understory because of the sparse design of tree planting and the formation of canopy openings that fulfill the light requirements of the native species. It is thus recommended that in order to encourage the regeneration and establishment of native species within afforestations of drylands, tree species should be selected according to their interaction with the native species and that the design of the forest stand should be comparatively sparse.

Nevertheless, one of the major hindrances to the afforestation of drylands is the limited regeneration of the overstory and native tree species within the plantations; for example, in the Aleppo plantation in the transition area between Mediterranean and semi-arid zones (285 mm rainfall), the overstory pines are not regenerating. Studies conducted to date have failed to elucidate the causes or to develop the tools to overcome the problem. In the dry Mediterranean zone (400 mm rainfall), pine overstory species have regenerated successfully; however, the regeneration of native broad-leaved woodland species within the pine plantations is very limited. Studies have found that overstory canopy shade benefits the establishment of common oak seedling in the initial stages and moderate shade (50–70%) is very efficient in promoting the oak seedlings' survival. Nonetheless, further development of young oak saplings is much more vigorous in forest gaps. In drought-prone ecosystems, as shade may improve plant water relations, the stress ensuing from the shortage of light becomes less important. Thus, a practical way to regenerate woody species would be to form a shaded environment during the initial stages of establishment of under- or overstory species and to expose the young saplings to sunlight at later stages by creating gaps in the forest.

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5.4.

Keeping Healthy Riparian and Aquatic Ecosystems in the Mediterranean:

Challenges and Solutions Through Riparian Forest Management

Francesc Sabater and Susana Bernal

Riparian forests play a major role in maintaining biodiversity, regulating energy and nutrient fluxes between terrestrial and aquatic environments, and in keeping healthy adjacent aquatic ecosystems and water resources. In the Mediterranean, their future is endangered by increasing droughts, overuse of water and pollution.

Riparian zones constitute ecological boundaries between terrestrial and aquatic ecosystems (such interfaces are defined by ecologists as true ecotones), and as such they encompass sharp gradients of environmental conditions, ecological processes and plant communities. In headwater streams, riparian zones are often constituted by narrow strips of vegetation adjacent to the channel, while in lowland areas, they are characterised by extensive floodplains covered with forests.

Because of their critical role in maintaining biodiversity and on regulating energy and nutrient fluxes between terrestrial and aquatic environments, riparian forests have become a subject of great interest for many scientists and environmental managers over the several last decades. Here we identify a group of key ecosystem functions to take into account when designing codes for the good management of these highly valued ecosystems, with emphasis on their role in arid and semiarid Mediterranean regions.

Riparian forests play a fundamental role in keeping healthy adjacent aquatic ecosystems. First, shading of the stream channel by the forest canopy regulates the stream's primary productivity and buffers the stream water's temperature, which is of particular importance in semiarid areas to ensure the survival of some fish species such as salmonids. Second, they supply large amounts of high-quality leaf litter – an important food source for aquatic insects – and coarse woody debris that increase channel roughness and reduces energy flow enhancing in-stream nutrient and sediment retention, stream habitat diversity and productivity.

It is well known that the root complex and the understory layer of riparian forests effectively prevent against soil erosion and contributes to stream bank stabilisation. Ripar-

Figure 70. Riparian forest dominated by alders (*Alnus glutinosa*) in the headwaters of a Mediterranean catchment, La Tordera, N.E. Spain). Photo by F.Sabater.

ian forests act as a barrier to soil disturbance caused by agricultural practices on nearby crop fields, and effectively remove sediments from drainage waters. Such a mitigation effect is of particular importance in Mediterranean regions where flash floods are common and have a highly destructive power. Certainly, erosion control by riparian ecosystems contributes to protect stream water quality, prevents siltation, and maintains a deep channel suitable for aquatic communities, especially fish.

The proximity of riparian forests to surface and subsurface water sources allows for the establishment of unique plant communities that cannot be found elsewhere in the catchment (Figure 70). The access to water resources allows for the continuous evapotranspiration by riparian tress during the vegetative period, keeping levels of relative air humidity high. Environmental conditions in Mediterranean riparian ecosystems are typically the wettest and freshest of the whole landscape, and the pronounced gradient of temperature and humidity allows for an array of wildlife habitats. Riparian zones are also hot spots for fauna because they offer three essential resources simultaneously: water – a scarce good in Mediterranean areas – food and hides. Moreover, the lineal configuration of riparian forests facilitates their role as biological corridors, or as preferential ways for diffusion, dispersion and migration of animal and plant species.

Riparian forests affect the annual water budget by reducing water discharge.

Riparian trees, known as **drought avoiders**, are typically deciduous and facultative phreatophitic species, opposite to those sclerophyllous species used to cope with hydric stress that predominate in the Mediterranean landscape. Evapotranspiration in riparian forests can be a major component of the water annual budget in arid and semiarid catchments. For example, a forested riparian strip in New Mexico depleted from 20% to 33% of the annual water budget in an arid watershed with an annual precipitation of 200–300 mm. In a densely forested Mediterranean catchment in north-east Spain (annual precipitation about 600 mm), however, the contribution of evapotranspiration from the riparian forest to the total annual water budget was modest (<5%). Nonetheless, actual evapotranspiration from the riparian forest was on average 510 mm (between 2 and 5 mm/day), that was 70% of potential evapotranspiration during the vegetative period (from April to October). This figure indicates that riparian trees in Mediterranean regions can have a disproportionate impact on catchment water budgets, in particular during spring and summer when water resources are more limited.

Figure 71 shows that transpiration by riparian trees exerted a dramatic influence on the groundwater table during the period of maximum evapotranspiration – when the riparian canopy was fully developed. During a two-week period, the level of riparian groundwater suffered an abrupt decline of 54 cm at a rate of 3.5 cm/day, or about 4.6 mm/day, coinciding with measured values for riparian tree transpiration. Note that the impact of evapotranspiration on the groundwater level was especially notable for leaf area indexes above 3.5 m^2 (Figure 71 inset), and that the riparian trees started losing leaves after the groundwater droped below 120 cm from the soil surface and the root system was disconnected from the groundwater level. These observations suggest that dense riparian canopies can provoke hydrological stress, which could cause decreased stream discharge or even promote streamflow intermittency in semiarid catchment during the drought period. Despite the influence of riparian forests on water discharge, this compartment has been largely ignored on catchment hydrological models. Most models are developed for humid catchments, but they fail in simulating stream flow when applied to semiarid catchments. Novel modelling approaches, including a riparian groundwater tank, conclude that the riparian aquifer is key in simulating stream discharges during drought periods in Mediterranean catchments.

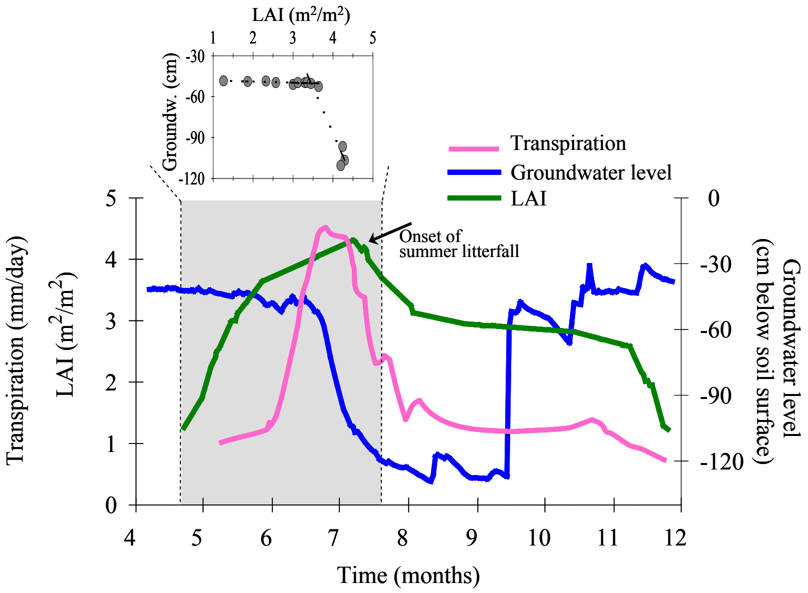

Figure 71. Riparian groundwater level from a piezometer located 5 m from the Fuirosos stream channel and average transpiration from two species of riparian trees (*Alnus glutinosa* and *Platanus acerifolia*) located nearby during the 1998–1999 vegetative period. The leaf area index (LAI) at the Fuirosos riparian plot is also shown. The inset shows the relationship between the riparian groundwater table and LAI during the period of canopy development. The black arrow indicates the onset of summer litterfall, which occurred a little after the abrupt drop of the groundwater table. The Fuirosos stream is located in the Montnegre-Corredor Natural Park (NE Spain) where average annual precipitation is ~ 600 mm. Modified from: Ester Nin, Master Thesis, 2000, University of Barcelona.

Riparian forests act as filters of pollutants and improve groundwater quality.

The ability of riparian zones to retain nutrients, pesticides and other pollutants from groundwater arriving from areas nearby is well recognised. In particular, there is a wide body of knowledge on the ability of riparian forest to buffer groundwater nitrate loads arriving from adjacent agricultural areas. In annual terms, riparian areas in temperate regions can reduce at least 30% of groundwater nitrate loads. Similar results have been found for Mediterranean regions; for instance, a 10% decrease in groundwater nitrate by meter has been reported across a riparian forest. The removal of nitrate from groundwater mainly occurs via uptake by riparian vegetation and microbial denitrification – the reduction of nitrate to gas in anaerobic conditions. In Mediterranean riparian areas, however, soils are not usually water saturated and denitrification rates are very low (<20 mg N_2O-N/m^2/year; i.e. on average, one order of magnitude lower than values reported for temperate riparian zones). Consequently, this microbial process accounts for a very small proportion (< 1%) of the annual removal of nitrogen from Mediterranean riparian systems; this implies that assimilation by riparian vegetation – riparian trees in particular – is the main reason for the removal of nitrogen from groundwater.

Box 28. Recommendations for managing riparian forests

- If the aim is to maintain high biodiversity and riparian wildlife habitats, preserving mature riparian forests can be done by prohibiting all harvesting or only allowing selective cutting along the stream banks. Keep a good number of old trees standing since they supply coarse woody debris to the stream's environment and enhance stream nutrient retention and the quality of aquatic habitats. Always leave a convenient number of trees standing along riparian-stream edges to ensure good shading over the stream channel.
- Try to keep the herbaceous and shrub layers vigorous because they enhance the soil bank's stabilization of sediment interception during floods. Use fences to avoid livestock wandering onto riparian landscapes.
- To enhance the ability of riparian trees to retain nutrients from groundwater arriving from adjacent lands, keep a high demand for nutrients and prevent nutrient saturation by maintaining early-middle aged successional forests with a proactive coppicing programme. This is especially important when handling Mediterranean riparian zones near agricultural fields subjected to large fertiliser operations. It is important to note that the buffering capacity of riparian forests depends upon geomorphology, topography, species composition and strip width, among other factors. Regarding riparian strip width, a minimum of 5–30 m is needed to reduce at least 50% of nutrient groundwater inputs.
- When selective cutting is recommended, minimize soil disturbance as much as possible during silvicultural practices. Keep twigs and boughs in the riparian area. Avoid using forest machinery whenever possible; use horses for timber extraction instead. Traditional methods of riparian woodland management that enhance wildlife habitat diversification such as selective thinning are preferred.
- Allow the natural regeneration of riparian forests, preferably with appropriate native species according to the local climate and water regime. Avoid opportunistic species and control widespread invasion of exotic species by cutting or spraying them with herbicides as early as possible.
- In general, riparian forests and wetlands are valuable ecosystems of the local landscape and as such, a careful management of their structure and composition is required to maintain, or even improve, their visual amenity and to keep them aesthetically pleasing.

Managing riparian forests is a tool for improving water quality and protecting stream/riparian habitats – a necessity in Mediterranean vulnerable environments but an overlooked policy issue.

Overall, research performed in semiarid regions highlights that riparian trees can substantially improve groundwater quality, yet their evapotranspirative demand can potentially lower water availability and reduce discharge from catchments. Ecologists found that in Mediterranean riparian forests, there is critical trade-off between water use and water quality that must be evaluated when managing these ecosystems. We suggest the proactive management of riparian forests when dealing with the improvement of water quality and/or protection of stream/riparian wildlife habitats, mainly in Mediterranean countries where riparian and aquatic environments are extremely vulnerable to anthropogenic disturbances. Box 25 provides a brief list of recommendations for the good management of Mediterranean riparian forest ecosystems.

Many water managers and environmentalists already acknowledge that riparian forests are beneficial for improving water quality and freshwater ecosystems. However, and despite of all the aforementioned services offered by riparian ecosystems, they are hardly considered in the European Water Framework Directive (WFD) (2000/960/EC). No mention of whether these areas may contribute to the WFD implementation is made, and no recommendation about their protection and restoration is given. We believe that wetlands in general and riparian forests in particular are areas of especial interest mostly in Mediterranean regions where human pressure on water resources is extremely high.

Acknowledgments

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5.5.

The Economics of Water and Forests: Issues and Policy Recommendations

Lelia Croitoru and Mike Young

In the Mediterranean region, scarce water resources are often allocated to low value uses, mainly linked to agriculture. Why? Efficient water management requires consideration of both water supply and demand. Appropriate water pricing, improved allocation policies and regulations can be used to decrease excessive demand and promote better water use. Mechanisms to finance water providers, such as forest ecosystems, can maintain or improve water supply. This chapter briefly presents some challenges faced by water resources in the Mediterranean and discusses how some of these mechanisms work in practice. Lessons and observations from Australia are included, as this country has a Mediterranean climate and faces similar problems with water scarcity.

In a context of water resources scarcity, predominantly supply-driven policies have led to misuse and overuse of water in the Mediterranean region. Reversing these trends is possible by acting on both the demand and the supply side through adequate economic instruments.

Water in the Mediterranean region is scarce compared to other regions in the world. Scarcity is particularly acute in North African and Middle Eastern countries, where water availability is 1,100 m^3 per capita, or just 12% of the global average. Population growth will further decrease water availability, to 550 m^3 per capita in 2050 (only 9% of the projected global average for the same year) (see sections 1.2 and 4.5). Moreover, climate change is predicted to bring more frequent and severe droughts and floods. In many parts of the Mediterranean region, climate change is expected to produce a significant decline in water availability.

The region has made impressive progress in improving opportunities to manage scarce water resources through major capital investments in dams and reservoirs, and the expansion of water supply and sanitation services. However, these investments have been supply-driven and have led to the emergence of widespread management issues: governments are unable to control the use of aquifers; untreated wastewater is often discharged in streams affecting their quality; water for urban communities is generally highly subsidised, exacerbating the demand and accelerating the need for additional finance for the rehabilitation of water systems.

In many areas, these problems have led to water overuse and misuse, further degrading water supplies and threatening the population's welfare. Inappropriate irrigation practices may increase water salinity and reduce agricultural productivity. Inadequate access to clean water and sanitation results in waterborne diseases, particularly among children. Dam sedimentation and groundwater overexploitation threaten future water availability for drinking and irrigation[1]. A series of studies of the cost of environmental degradation conducted over the past decade by the World Bank estimated the annual cost associated with water degradation, inadequate water supply, and poor sanitation as ranging from 0.6% of gross domestic product (GDP) in Tunisia to as much as 2.8% in Iran.

Finding appropriate measures to conserve and share access to the region's already scarce water is essential. Many countries in the Middle East and North Africa have started to manage their water resources in a more integrated fashion. This management approach recognises the importance of economic instruments to complement technical solutions and the importance of managing demand for water as well as supply. On the demand side, measures such as greater use of pricing, robust allocation procedures and the development of water markets have been used to influence water use. One of the remaining challenges with this approach is to find ways to use these measures to protect the ecosystems that provide water supply and quality. For example, many forest and shrub ecosystems play an important role in regulating water flows and reducing the flood risk[2] (see sections 1.5, 2.1 and 2.2). As these services are usually externalities, there is often little incentive to conserve the ecosystems that provide them. Mechanisms to finance the conservation of these ecosystems, such as Payments for Environmental Services (PES), can sustainably help improve water supply, as shown by their successful implementation in several Latin America countries.

Appropriate water pricing and trading can help reduce water overuse.

On the demand side, it is necessary to distinguish clearly between pricing (charging) to reflect the cost of the service provided and pricing to reflect scarcity[3]. As a general rule, governments are reluctant to use pricing as a means to manage scarcity. One explanation of this may be the simple fact that politicians do not like increasing charges and prices in times of financial hardship like a drought. In Australia, however, and to a lesser extent in Spain, governments have allowed the development of water markets as a means to reveal scarcity prices and facilitate adjustment. The main advantage of this market-

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[1] Using data from Jordan, Yemen, Egypt, Tunisia, and Morocco, a study estimated that the value of groundwater depletion can be as much as 2% of GDP. In Tunisia for example, the annual cost of overextracting ground water is 0.1% of GDP, or about 20% of the total cost of water degradation in the country.

[2] A growing body of literature shows that the biophysical relationships between forests and water are highly variable from one location to another, depending on climate, soils and vegetation types. While forests do tend to improve water quality, their impact on dry season water flows varies depending on local conditions and their impact on total annual flow is generally negative. Forests also help to reduce downstream flood risk, but have little role to play in reducing the most damaging of floods which occur once-in-a-lifetime.

[3] In most resource allocation systems, efficiency can be achieved by charging at marginal cost. When water supplies are abundant and supplied via a single distribution system, the marginal cost is less than the average cost and tends to decrease as use increases. As a result and if a water supply utility wishes to recover its operating and maintenance costs, the supply price needs to be set at the average cost. When water supplies are scarce, however, the marginal cost of supply typically rises as more and more water is used. Thus, as a general guiding rule the efficient pricing regime is to charge the greater of average and marginal cost.

Box 29. The development of water markets in Australia's Murray Darling Basin.

In the Murray-Darling Basin, permission to extract water for irrigation was originally granted on an area basis. Between 1960 and 1980, the system moved to a regime in which all use was metered and irrigators charged for use in proportion to the volume of water diverted. In some systems, a distinction was also made between water needed to maintain perennial trees and vines and which could be used to grow grass and or annual crops. All involved understood that allocation priority would go to the irrigation of perennial crops. At the same time, the maximum area that could be irrigated was redefined as a maximum volume of water that could be diverted.

In the late 1980s, it became clear that the Basin's water resources were either fully or over developed. As a result, a limit was placed in 1993 on the amount of water that could be diverted. Quite quickly and encouraged by the emergence of a national competition policy – which amongst other things required the development of water markets so that water could be moved to places where it could be used more profitably – a market for water allocations and entitlements emerged. Today, most irrigators in the Basin buy and sell water from one another on a regular basis.

Formal water entitlement registers were established and the maximum volume that could be diverted was re-defined as an entitlement to a share of any water that was allocated for use, rather than an absolute amount. Markets and accounting systems were then established so that irrigators could decide to sell entitlements and/or allocations when this was the most profitable option for them. As markets developed further, entitlement, allocation and land-use control and development systems were formally unbundled. Today, entitlements can be transferred from a holder's water account to a neighbour's account using theInternet in a process similar to that used to move money from one account to another or buy shares over the Internet. Similar processes are used to facilitate the trade of entitlements.

Land use, development, and works approvals are issued separately and it is possible to obtain these approvals without holding a water entitlement. Compliance with the accounting system is strictly enforced. Attempts to tamper with meters can result in prosecution and penalties so steep that buying a water allocation on the market is always cheaper than paying fines for over-use.

The result has been widespread innovation and investment coupled with a new set of allocation problems caused by a failure to set in place robust allocation procedures. In order to resolve these problems, governments have collectively agreed to appoint an independent group of experts to prepare a new Murray-Darling Basin Plan so that allocations can be kept within sustainable limits. Under the new system, the role of the government is to set absolute limits on the amount of water that can be diverted from a river and the market to determine where this water is used. Water is allocated to shareholders in proportion to the number of shares they hold. Shareholders are then free to determine whether to use, sell or leave this water in storage for use in a subsequent year. Source: Young 2010.

based approach is that water users negotiate the price to pay without the need to involve a government agency. Typically, those willing to sell water do so at a price that is greater than its value to them. Those buying the water pay a price that is less than its value to them. As a result, both the buyer and seller are better off and all other water users are not affected by the transaction. This is very different from the situation where a government sets a scarcity price, collects it and then has to decide what to do with the revenue.

In Australia's southern connected River Murray System, for example, rapid growth in water trading has been encouraged through the establishment of water entitlement registers and accounts and the unbundling of water rights into shares, allocations, use approvals and works approvals (See Box 29 and Figure 72).

The use of water entitlement and allocation systems as a means to send scarcity signals and reveal opportunity costs has proved to be extremely effective in the irrigation sector, and has driven significant improvements in the irrigation efficiency and innovation such as the replacement of flood irrigation with fully automated drip irrigation sys-

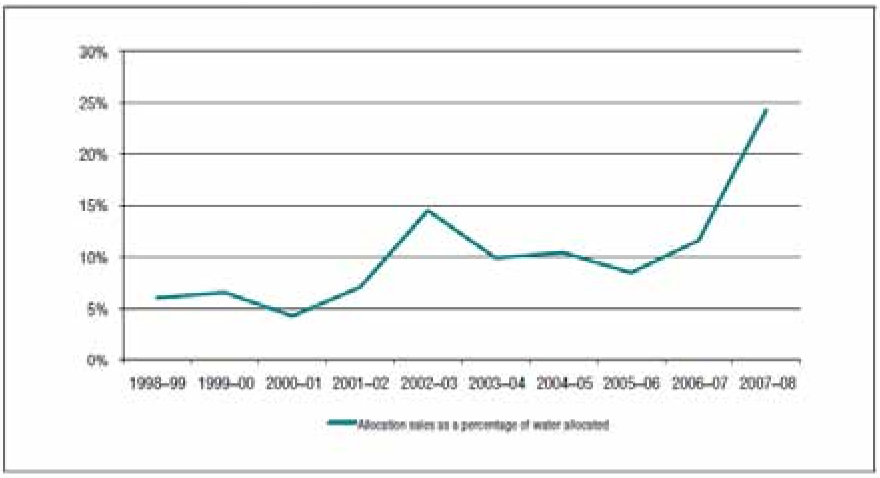

Figure 72. Percentage of water allocations sold to another water user in the Southern Connected River Murray System, Australia. Source: NWC 2010,

tems and the development of total channel control systems. Significantly, water trading has dramatically reduced the adverse impact of drought on regional economies and businesses. The Government is now turning its attention to the development of institutional arrangements that will extend the market to include the impact of unmetered water uses like increases in plantation forestry, the construction of farm dams and the capture of unregulated overland flows. Arrangements are also being put in place to take account of the fact that increases in water use efficiency tend to reduce return flows and deal with significant over-allocation problems. A new allocation plan is being prepared for the Murray-Darling Basin. Among other things, it is being designed to take account of the connectivity between ground and surface water resources and climate change.

One of the implications of this more robust approach to water accounting is the requirement for every impact of forestry on water supplies to be offset by requiring any person wishing to establish a new plantation to first acquire a water entitlement of sufficient size to offset the plantation's effects on other water users. Options for doing this include from the simple purchase of a water entitlement equivalent to the expected long-term impact of the plantation on other users to a requirement to offset impacts on an annual basis.

From the perspective of Mediterranean countries, the most important insight that can be drawn from the Australian experience is that reforms take time and that the sequence of reforms requires careful attention. The development of a market for seasonal water allocations was, for example, critically dependent upon the prior introduction of metering and the development of a culture that ensured that irrigators would only use the amount of water allocated to them.

Improving the conservation of forest ecosystems as water providers is possible through the payment by downstream users of clean water to upstream land users, and can allow internalising what would otherwise be an externality.

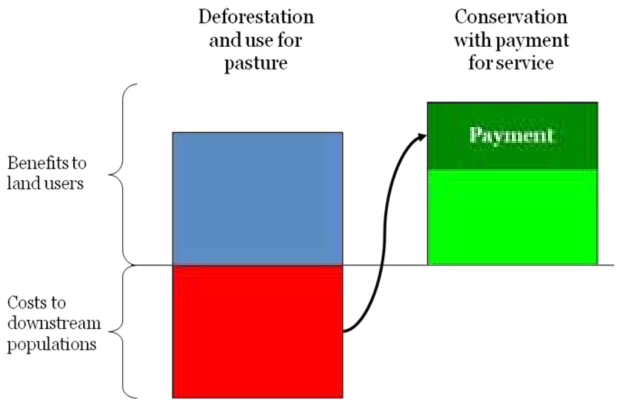

Figure 73. Payment for Environmental Services.

While water pricing and different water allocation systems help reduce water demand and overuse, they do not contribute to conserving the ecosystems that provide water services. Other mechanisms need to be devised to support the conservation of ecosystems such as forests and shrubs. These mechanisms include Payments for Environmental Services (PES), trading schemes and others. This section focuses mostly on the use of PES, as it has been successfully implemented in many countries.

PES is based on the twin principles that those who benefit from environmental services (such as users of clean water) should pay for them, and that those who contribute to generating these services (such as upstream land users) should be compensated for providing them, as illustrated in Figure 73. The approach thus seeks to create mechanisms to arrange for transactions between service users and service providers that are in both parties' interests thus internalising what would otherwise be an externality. The PES approach is attractive in that it: i) generates new financing, which would not otherwise be available for conservation; ii) is likely to be sustainable, as it depends on the mutual self-interest of service users and providers and not on the whims of the government or donor financing[4]; and iii) is likely to be efficient, in that it conserves services whose benefits exceed the cost of providing them, and does not conserve services when the opposite is true.

Two main types of PES programmes can be identified. The ideal case is that of **user-financed** programmes, in which payments to service providers depend on payments made by service users. Such PES programmes are most likely to be efficient, as service users provide not only financing but also information on what services are most valuable, and have a strong incentive to ensure that payments are used effectively. Conversely, **government-financed** PES programmes depend on financing from a third party, usually the national government, and as they typically cover much larger areas they are less likely to be efficient.

Most examples of successful PES implementation are found in Latin America. Water users participating in user-financed PES programmes include domestic water supply systems, ranging in size from that of Quito in Ecuador, to midsize towns such as Heredia in Costa Rica, to many small towns such as San Francisco de Menéndez, El Salva-

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[4] This applies to the user-financed programmes, as defined below. In this case, there is no external funding, and there is no reason to expect that the interest of the buyer will «drain out» as they are receiving concrete benefits in return for their payments. In Costa Rica for example, users who have been paying for conservation have renewed their agreements to do so when their initial agreement expired.

dor, and Jesús de Otoro in Honduras; public and private hydroelectric power producers; and irrigation systems. The programmes all seek to protect the specific watersheds from which the users draw their water. National government-financed programmes have been established in Costa Rica, Mexico and Ecuador, and are being planned in several Brazilian states. These programmes have also tended to focus primarily on water services.

Whether user-financed or government-financed, PES programmes offer the potential of inducing a much more sustainable adoption of land uses that preserve water supplies by allowing long-term payments to be made to land users who adopt such practices. The conditionality of payments that is a major feature of PES programmes also gives more control over results. In the past, watershed management projects have tended to offer only short-term support, and their impact on land use has often ceased once the projects ended. A study in a Tunisian watershed showed that implementing a government-financed PES in lieu of the current subsidy system could result in the adoption of the most sustainable land uses in areas at high risk of erosion. The primary challenges in implementing PES programmes are: i) having a clear understanding of how land uses affect downstream water services; and ii) developing appropriate institutional structures that are capable of managing PES effectively over long time periods.

New approaches promise to significantly improve water use by helping to better manage demand and protect supplies. Although these approaches have to be adapted to individual situations, there are working examples around the world which can be used for guidance. One favourable aspect of water problems is that they tend to be watershed-specific. New approaches can thus be piloted in individual watersheds, and need not be adopted countrywide from the beginning. Processes can also advance at different speeds in different watersheds, depending on local needs and capabilities.

Acknowledgements

Special thanks are given to Stefano Pagiola for his constructive comments on this chapter.

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Figure 74. Weighing of the heart (1300 B.C.). Source: Eternal Egypt: Masterworks of Ancient Art from the British Museum by Edna R. Russmann.

Water for Forests and People in the Mediterranean:
A Challenging Balance

Compilation of Key Messages

Chapter 1. The Basics

1.1 The Water Cycle at a Glance: Blue and Green Water

At the global scale, and since the origin of our planet, the same stock of water has been continuously transferred around through flows according to processes and pathways of the hydrologic cycle. This cycle links the biosphere to the atmosphere, the ecosystems themselves, including the anthropo-systems.

The sound management of water resources at various geographical scales is based on a thorough analysis of the water balance. It is an accounting method, which requires assessing many hydrological data regarding water stocks and fluxes (input and output).

The green water approach has raised much interest in recent years, in particular in dry regions where it dominates the hydrological cycle. However, it is clear that there are limits to the concept in informing water resources management and planning.

1.2 Water, Forest Resources and People in the Mediterranean:
the current situation

The demographic growth is spectacular in the south and east, more so in urban and coastal areas with an annual increase of 4.1 million inhabitants and an annual flow of 175 million tourists.

Irregular rainfall in time imposes the construction of storage capacity for a high proportion of surface water (>90% in Syria; 80% in Morocco and Tunisia).

In 2005, nearly 180 million Mediterranean inhabitants were water-poor and 60 million faced a shortage.

The demand for water is increasing dramatically in the south and east, and is more and more satisfied through unsustainable water production.

Water policies are still too focused on supply, which can induce long-term risks.

In spite of some common features, forest and woodland ecosystems and their dynamics show regional variations. On both rims, forests are often located in mountain areas, acting as “water towers” and main biodiversity havens, rendering the interactions between forests and water that is upstream from catchment areas crucial.

Society’s demands on the forest have evolved towards increased multifunctionality: from wood production to recreational use and environmental concerns.

The future of Mediterranean forests is threatened by the increased risks of drought-induced wildfires.

Mediterranean lands are subject to slow but steady desertification processes related to pronounced soil degradation due to unsuited management of range, rain-fed and irrigated land, particularly in the south and the east of the Mediterranean

Stronger policies and sustainable management practices for water resources, forests and woodlands, and for soil preservation are required.

1.3 Do Forests Influence the Rainfall Regime?

Large scale tropical deforestation impacts rainfall and may create a warmer and drier climate.

Montane “fog” forests capture the water from wind- or convective-driven clouds.

A body of evidence, both by observations and modelling studies, suggests that forests affect local climatology/weather patterns through changes in albedo, Leaf Area, canopy structure (roughness) and evapotranspiration.

Recent findings, referred to as the active “biotic pump” theory, suggest that in areas with extensive and continuous natural forest cover, atmospheric moisture is transported inland from ocean to forests.

We should improve the weaknesses and uncertainties in understanding and modelling the climatic responses, including precipitation patterns, to land cover change.

1.4 Water Fluxes in Forests

Water fluxes into and out of forests can be considered from both space and time scales. At the catchment level's primary space scale, inputs and outputs of water are usually easy to identify and follow a simple water mass balance equation.

Precipitation is usually the only input flux into the catchment. In Mediterranean-type climates, precipitation shows a high inter-annual variability and a strong seasonality with high intensity rainfall events in the rainy season.

Transpiration from Mediterranean forests may amount to 75% of overall forest evapotranspiration, while interceptions losses account for about 25%.

Although being a small component of the overall annual water balance of Mediterranean catchments, the streamflow output – the blue water – plays a paramount role on the downstream water supply to urban populations, industry and irrigated agriculture.

Vegetation type and density may affect the amount and time distribution of streamflow through its action on evapotranspiration and surface soil infiltration. The manipulation of vegetation in Mediterranean-forested catchments may thus play an important role in trying to get the more appropriate and optimized equilibrium between water balance fluxes. This requires careful consideration of multiple objectives since conflicts and trade-offs are involved.

1.5 The Role of Mediterranean Forests in Water and Soil Conservation

Soils in the Mediterranean constitute a fragile component of terrestrial ecosystems being susceptible to erosion since they are exposed to heavy and intense rainfall, followed by marked runoff phenomena accelerated by the hilly or mountainous topography. The issues of water and soil must thus be considered together.

Raindrop energy impacting the soil can be controlled by vegetation above a ground cover rate of 20–30%, with small differences between plants, shrubs and trees.

Forest soils have a comparative advantage vis-à-vis other soil types regarding porosity and hydraulic conductivity, and reduced susceptibility to rain splash effects.

The genesis of runoff depends on soil surface status, initial soil water content and on rainfall intensity. The forest cover influences runoff by delaying its onset and slowing the establishment of a strong runoff regime.

Soil losses as sediment loads in the running off water and their dynamics during rainy episodes also depend on soil surface status. Under the forest cover, compared to other plant cover types, the limitation of erosion is linked to the delay of runoff onset and to the slow establishment of strong runoff regime as mentioned above.

The implication of the Mediterranean forest cover on water and soil conservation is rather different from the clichés too often suggested and accepted, considering that forests are a full protection against erosion processes.

Further research is needed to develop a body of knowledge on water and soil conservation under forest conditions in the Mediterranean. A concerted research programme around the Mediterranean Basin, based on rainfall simulation techniques, could offer interesting perspectives.

Chapter 2. Blue Water

2.1 Hydrology of Mediterranean Ecosystems

Most of the water resources in the Mediterranean are generated in wet mountains, whereas lowlands and coastal areas are water consumers.

Stream flows vary much in time in the Mediterranean. Small basins feed characteristic ephemeral or sporadic streams (ramblas and ouadis) that convey flash floods. Large basins have seasonal or permanent streams with summer low flows sustained by underground waters.

The main processes of the generation of water resources in the Mediterranean relate to percolation to deeper levels once the soil water retention capacity is reached (as in wetter climates) as well as to rainfall, classically in drier climates, that exceeds the rate of infiltration in the top soil, resulting in runoff that causes erosion and flooding hazards.

Soil cover and surface status characteristics play an important yet complex role in the hydrological and erosion processes.

The preservation of the ecological quality of Mediterranean streams needs the protection of the flow regime, water quality, stream morphology, riparian forest and sediment conveyance.

2.2 Water Resources Depend on Vegetation Cover and Land Use

Vegetation cover and its management can have a profound impact on the partitioning of water and energy.

Forest cover and soils are, in general, beneficial for the quality of ground and surface waters generated in the watershed.

Three Myths about forestry and water:

a) The beneficial effects of forests have sometimes been exaggerated by conservationists who want to protect natural areas and by commercial foresters who wish to justify new plantations.

b) Forests can sometimes increase dry weather flows but, in general, they are most likely to reduce them.

c) Forests' ability to moderate floods is much weaker than often claimed, being restricted to small storm magnitudes and limited catchment sizes.

Chapter 3. Green Water

3.1 Green Water Sustains Forest Ecosystem Processes and Their Functions

Green water is needed to both support a tree's biology and life and to keep functional all groups constitutive of the forest biodiversity (micro-organisms, insects, animals, plants) and involved in basic ecosystem processes. Although the physiology of photosynthesis consumes little water, terrestrial plants require the transpiration of large amounts of water to allow for nutrient uptake and transport to the canopies as well as for gas exchange. Water is also essential for the circulation of elements through the ecosystem.

Looking at natural ecosystem processes - to a large extent dependent on water - allows us to understand how they influence the ecosystem functions and, in turn, related ecosystem services. As water is very often a limiting factor in Mediterranean forest ecosystems, water scarcity can result in a marked alteration of ecosystem functions and impact on the provision of goods and services to human societies.

Green water is needed to sustain ecosystem processes, their functions and the goods and services they provide.

3.2 Water Processes in Trees: Water Uptake, Transpiration/Photosynthesis

The large amount of water transpired to fix carbon is remarkable. In the case of Quercus ilex, values around 3–5 (mmols CO_2 /mol of H_2O) are typical. Once discounted the carbon returning to the atmosphere by respiration, fixing 1 gram of carbon in the tree requires 1,000 to 1,500 grams of water.

In the Mediterranean, it is clear that forests are mostly water limited in summer and energy limited in winter.

Water movement through cell membranes is facilitated by proteins called Aquaporins. These proteins belong to the major intrinsic protein family, members of which are found in almost all living organism.

The fastest response of plants to control water losses is closing the stomata that reduces stomatal conductance to water but at the same time reduces carbon gain.

3.3 How Plant Species Cope with Water Stress

Plants have developed various strategies, at different time scales, to cope with reduced water availability in the soil: phenological adjustments, water status control, morphological and anatomical features, which may vary between and within species.

Under pronounced water stress, an embolism in the conducting vessels that prevents the sap from ascending from soil to leaves, may occur and lead to tree and branch desiccation and mortality. Thresholds of xylem critical pressure related to embolism are highly variable between species, Mediterranean species being among the most drought resistant.

The high drought resistance of Mediterranean tree species comes at the cost of high wood densities and low growth rates.

Adaptive traits for drought increase the chance of survival under soil water deficit. Their variations between and within species (among populations) allow the selection of better-suited seed sources for plantation.

Diversity has been shown within different Mediterranean plant species in their capacity to accumulate biomass through photosynthesis for a given amount of water used, referred to as Water Use Efficiency (WUE). This opens the way to potential applications in breeding and silviculture.

Chapter 4. Blue and/or Green Water: What Trade-Off?

4.1 Securing Water for Trees and People: Possible Avenues

In Mediterranean conditions, the reduction of LAI (e.g. through thinning) does not reduce the total transpiration since the remaining trees use much of the water not used by the cut trees and consequently have a better survival rate.

Keeping trees alive, even without biomass increment, may have a huge cost in water, in particular for evergreen species common in the Mediterranean.

In the Mediterranean environment, constrained by water limitations, only drastic changes in forest cover, thus beyond the limits of classical thinning, might result in an increase in blue water.

The question of a drastic change in forest cover to increase the production of blue water downstream and integrate all the goods and services related to the initial cover deserves much attention.

Upstream users can benefit from the direct uses of forest plantation while the downstream users of water resources would be affected by the effects of land management change upstream on the quantity and quality of the water reaching the reservoir.

Investments in forest plantations induce lower direct returns compared to the current situation "business as usual scenario"; however, this could generate higher benefits for the society when local- and national-scale externalities, such as increased soil fertility and water capacity, as well as global-scale externalities like biodiversity protection and carbon sequestration are included.

4.2 Balancing Water for Ecosystems, Goods and Services and People

Both water and ecosystem goods and services are fundamental for our existence.

Blue water and green water are needed to sustain the provision of goods and services that we need.

The majority of rainfall is naturally allocated for the provision of the ecosystem's goods and services.

While a drastic reduction of the forest area might increase the availability of water, it would negatively influence the provision of the ecosystem's goods and services.

4.3 Integrated Water Management at the Landscape Scale: Science Backing Development; Case Tunisia

Knowledge based on the calculation of useful water soil reserves (UR) enables:

i) the simulation of various results for annual rainfalls;

ii) the comparison of the soil water storage capacity of catchments with those of retention (dams);

iii) the simulation of irrigation requirements in relation to various plant covers; and
iv) the provision of tools for balancing between green and blue water.

The effects of changing the vegetation cover, including forest, and of soil and water conservation techniques can be predicted on the basis of calculating sheet and gully erosion and the use of simulation techniques.

4.4 Towards Integrated Ecological-Socioeconomic-Hydrological Management

The blue water paradigm is based on the evaluation of the availability of blue water resources for human purposes, as related to the effects of forests and other land uses and management. This evaluation can be achieved through both hydrological models and relevant policy indicators.

The green water paradigm – in addition to the blue water paradigm – should receive increased attention since green water flows sustain the main ecosystem's functions.

The challenge of integrating upstream and downstream interests, including terrestrial and aquatic ecosystems, can be met through reconciling the blue and green water paradigm. This can be practically achieved by using specific methods, such as the terrestrial-aquatic water impact indicator.

The integration of water with other ecosystem services should be based on a better understanding of how ecosystem services interact with each other.

In regard to the integration of water with other ecosystem services, new tools for tradeoff analysis and land management optimization are becoming available.

Integrating ecological, socio-economic and hydrological management is a key approach towards sustainability.

4.5 Water Footprint of Our Daily Life: How Much Water do we Use?

Water for people and nature requires management that focuses on multiple needs of the anthropo-eco-systems. Water Footprint analysis allows tracing, supplying and identifying impacts. It gives clear steer on risk and responsibility.

The assessment of the water footprint by commodity, sectoral activities or value chains provides new insights on water issues at various scales (local, national regional and global), and opens the way to many applications regarding, economics, trade, environment, policies, industry, etc.

Agriculture has the largest share in world's water footprint. On average at the global level, food production requires 70 times more water than a household needs: 50 l /person/day. For producing a diet of 3,000kcal/person/day (including 20% of animal proteins), 3,500 l of water are needed vs. 50 l/person/day for household use.

Planting trees for C sequestration in the Mediterranean is highly questionable because of the huge cost for water.

Water footprint: an interesting concept and tool… to be combined with other approaches.

4.6 Lessons Drawn from the Past: an Historical Perspective on Forest Hydrology and Soil Conservation in the North and South of the Mediterranean Basin

In response to major hydrological catastrophes, the large-scale watershed management programmes – based on biological and civil engineering and implemented in Europe since the second half of the 19th century – have been largely successful in spite of the limited knowledge in forest hydrology and the insufficient consideration of social factors. Today, the challenge is how to maintain the protective functions through the renewal of planted areas and equipment in a totally different social and economic context.

The very large programmes of soil and water conservation undertaken on the southern rim of the Mediterranean with a more integrated approach addressing pastoralism, agriculture and forestry, have produced somewhat contrasted results, much below the expectations. This is due to insufficient scientific knowledge and an excessively top-down approach.

Updating and adjusting policies of water and soil conservation as related to tree and forests should be rethought in today's context. This should be undertaken as soon as possible by using latest knowledge and by integrating all aspects related to sustainable development without waiting for new catastrophes to occur.

Chapter 5. Key Challenges

5.1 Climate Change Implications on Forests and Hydrology: an Overview

The Mediterranean basin is a climatically complex region, with a varied mosaic of climate subtypes and of highly contrasting ecological environments.

The Mediterranean basin has been undergoing a warming process since the 1970s, similar to what the planet has been experiencing although presenting a warming rate higher than the global one. The climate models will coincide in an evident and generalised temperature rise throughout the 21st century.

There is uncertainty regarding the future rainfall pattern's evolution in the Mediterranean basin, although rainfall totals are very likely to decrease and possibly show higher temporal variability than the present.

For the cold half of the year, rainfall predictions by the climate models show a northern Mediterranean belt presenting some increases and a southern one with decreases. In summer, however, the models predict a generalised decrease in rainfall.

The temperature rise will increase evapotranspiration demand and, even with no decrease in rainfall, there will be less soil moisture, more vegetation water stress and a drop in the water resources generated in rainy areas.

The Mediterranean basin will likely experience greater frequency and intensity of droughts and heat waves leading to more forest fires. Torrential rainfall could also increase although this prediction involves a high level of uncertainty.

Forests can undergo major changes in area due to global change, which can also condition the future availability of water resources.

5.2 Coping with Land-Use Changes and Increased Demography

The strong population growth in the south and east will greatly increase the need for food, water, soil and energy, and will accrue pressure on natural resources. Natural and social risks are expected to be highest along Mediterranean coasts where quality and integrity are under threat.

Land-use changes will affect spatial dynamics and cause environmental degradations.

Should current changes in rural, agricultural, grazing and wooded areas continue, they would induce or aggravate several major risks of unsustainability:

- desertification and rural poverty in the SEMCs
- direct and indirect impacts: accrued pressure on cities, heightened rural emigration, silting of dams and biodiversity loss
- loss of quality farmlands due to urban sprawl and infrastructures (estimated at over 1.5 million hectares by 2025)
- degraded water resources and increased vulnerability to fires and floods

Increased water demand, whether for agriculture, industry or households, is aggravating the pressure on the resource.

New policies offer options for progress through improved water demand and supply management.

The sustainable management of water resources and demand must above all be based on an integrated approach at the level of catchment areas, and on the upstream-downstream solidarity principle between hinterlands and coastal zones.

Policies should take into account the wealth of heritage in the Mediterranean's rural areas, the diversity of their functions as major assets and opportunities for the future, and adapt them to changes. The sustainable management of such areas should address their multiple functions and be geared towards the prevention of natural risks (forest fires, floods).

Territorial approaches are particularly necessary to ensure the sustainable management of natural resources, including forests.

The sustainable management of water resources and demands, and of rural areas and woodlands, must above all be built on an integrated approach at the catchment level and on the upstream-downstream solidarity principle between hinterlands and coastal regions. It must also be in harmony with all sectoral policies: agriculture, energy, tourism, environment and land development, to facilitate arbitration as regards the water and soil resources allocated to all uses.

5.3 Afforestation to Combat Desertification in Arid Zones Requires a Concerted Endeavor

Biophysical processes leading to desertification mainly consist of increased runoff and soil erosion resulting from a significant reduction of the canopy cover. They can be prevented or reversed through afforestation if properly designed and with due attention to the water balance in the watershed.

Afforestation in arid and semi-arid zones requires water harvesting techniques such as the formation of contour-terrace structures or low-lying dammed catchments.

Agroforestry can increase the productivity of afforestations in drylands.

Regeneration of overstorey and understorey vegetation within dryland afforestations is a major hindrance to forest sustainability. However, encouraging the regeneration of native species within dryland forests may enhance species and structural diversity as well as ecosystem services.

5.4 Keeping Healthy Riparian and Aquatic Ecosystems in the Mediterranean: Challenges, and Solutions Through Riparian Forest Management

Riparian forests play a major role in maintaining biodiversity, regulating energy and nutrient fluxes between terrestrial and aquatic environments, and in keeping healthy adjacent aquatic ecosystems and water resources. In the Mediterranean, their future is endangered by increasing droughts, the overuse of water and pollution.

Riparian forests affect the annual water budget by reducing water discharge

Riparian forests act as filters of pollutants and do improve groundwater quality.

Managing riparian forests: a tool for improving water quality and protecting stream/riparian habitats. This is a necessity in Mediterranean vulnerable environments but an overlooked policy issue.

5.5 The Economics of Water and Forests: Issues and Policy Recommendations

In a context of water resources scarcity, predominantly supply-driven policies have led to the misuse and overuse of water in the Mediterranean region. Reversing these trends is possible by acting on both the demand and the supply side through adequate economic instruments.

Appropriate water pricing and trading can help reduce water overuse.

Improving the conservation of forest ecosystems as water providers is possible through the payment by downstream users of clean water to upstream land users thus allowing to internalise what would otherwise be an externality.

Glossary

This glossary has been compiled from various sources: Bank-Netherlands 2001; Water partnership programme AO 2004 – Glossary of water terms from the US Geol. Survey wwww.ga.water.usgs.gov/edu/dictionary.html

Aquifer
A geologic water-bearing formation(s) or structure that stores and/or transmits water to wells and springs, for example. The use of the term is usually restricted to those water-bearing formations capable of yielding water in sufficient quantity to constitute a usable supply for people's uses.

Base flow
Sustained flow of a stream in the absence of direct runoff. It includes natural and human-induced streamflows. A natural base flow is sustained largely by ground-water discharges.

Basin (or river basin)
Most often used to describe a region drained by a large river system (implies a very large watershed or catchment).

Bedrock
The solid rock beneath the soil and superficial rock; a general term for solid rock that lies beneath soil, loose sediments or other unconsolidated material.

Catchment
A natural drainage area within the boundary defined by the watershed divide. From a watershed management point of view, the terms watershed and catchments are essentially interchangeable. The scale of a catchment (or watershed) can vary in area from a few hectares to thousands of square kilometres.

Discharge
The volume of water that passes a given location within a given period of time.

Environmental services (ES)
Generic term for the positive externalities or off-site benefits that are generated by a particular land use. Typically, there are limited markets for ES and no compensation is paid for providing them. As a result, land users tend not to take ES into account when making land-use decisions.

Fersiallitic soil
Red soil developed in Mediterranean and subtropical regions.

Flash floods
Short-lived (less than six hours) runoff events in small and mid-sized streams that feed aquifers through transmission losses but provide a significant hazard for life and properties.

Flood
An overflow of water onto lands that are used or usable by man and not normally covered by water. Floods have two essential characteristics: the inundation of land is temporary; and the land is adjacent to and inundated by overflow from a river, stream, lake or ocean.

Ground water
1) Water that flows or seeps downward and saturates soil or rock, supplying springs and wells. The upper surface of the saturate zone is called the water table. 2) Water stored underground in rock crevices and in the pores of geologic materials that make up the Earth's crust.

Ground-water recharge
The inflow of water to a ground-water reservoir from the surface. The infiltration of precipitation and its movement to the water table is one form of natural recharge. Also, the volume of water added by this process.

Hydrologic cycle
The cyclic transfer of water vapour from the Earth's surface via evapotranspiration into the atmosphere; from the atmosphere via precipitation back to earth; and through runoff into streams, rivers, and lakes, and ultimately into the oceans.

Infiltration
Flow of water from the land surface into the subsurface.

IPCC
Intergovernmental Panel on Climate Change.

Isohumic soil
Clay dominated soil, with deep incorporation through biological process of organic matter stabilized by an extended climatic maturation phase.

Köppen climate types
The Köppen climate classification system is more used worldwide. Climate type boundaries have been selected bearing native vegetation distribution in mind. It combines average annual and monthly temperatures and precipitation, as well as the seasonality of precipitation.

Leaching
The process by which soluble materials in the soil, such as salts, nutrients, pesticide chemicals or contaminants, are washed into a lower layer of soil or are dissolved and carried away by water.

Leaf area index
The ratio of total upper leaf surface of vegetation divided by the area of the land on which the vegetation grows.

Mediterranean oscillation
A teleconnection existing between western (Alger) and eastern (Cairo) Mediterranean atmospheric conditions that is related to temperature and rainfall time series.

Peak flow
The maximum instantaneous discharge of a stream or river at a given location. It usually occurs at or near the time of maximum stage.

Percolation
1) The movement of water through the openings in rock or soil. 2) The entrance of a portion of the streamflow into the channel materials to contribute to ground water replenishment.

Porosity
A measure of the water-bearing capacity of subsurface rock. With respect to water movement, it is not just the total magnitude of porosity that is important, but the size of the voids and the extent to which they are interconnected, as the pores in a formation may be open or interconnected; or closed and isolated. For example, clay may have a very high porosity with respect to potential water content, but it constitutes a poor medium as an aquifer because the pores are usually so small.

Rainwater harvesting
The gathering of rainwater from roofs or prepared land areas to provide water for irrigation, drinking or aquifer recharge.

Recharge
The feeding of underground (well and spring) waters by deep effective percolation of water.

Return flow
1) That part of a diverted flow that is not consumptively used and returned to its original source or another body of water. 2) (Irrigation) Drainage water from irrigated farmlands that re-enters the water system to be used further downstream.

Rossby wave
Rossby (or planetary) waves are giant meanders in high-altitude winds that play a major influence on the spatial distribution of the weather, causing positive or negative spatial correlations of the weather.

Runoff
That part of the precipitation, snow melt, or irrigation water that appears in uncontrolled surface streams, rivers, drains or sewers.

Seepage
1) The slow movement of water through small cracks, pores, interstices, etc., of a material into or out of a body of surface or subsurface water. 2) The loss of water by infiltration into the soil from canals, ditches, laterals, watercourses, reservoirs, storage facilities or other bodies of water, or from a field.

Stomatal conductance
Stomatal conductance is the speed at which water evaporates from pores in a plant, and is directly related to the relative size of the stomatal aperture. Basically, the higher the evaporation rate, the higher the conductance of the leaf. It must also be noted that humidity, the hydration status of the plant and light intensity are also factors that affect stomatal conductance.

Stream
A general term for a body of flowing water; a natural watercourse containing water for at least part of the year. In hydrology, it is generally applied to the water flowing in a natural channel as distinct from a canal.

Streamflow
The water discharge that occurs in a natural channel. A more general term than runoff, streamflow may be applied to discharge whether or not it is affected by diversion or regulation.

Surface water
Water on the Earth's surface such as in a stream, river, lake or reservoir.

Teleconnection
Teleconnection in atmospheric science refers to climate anomalies being related to each other at long distances (typically thousands of kilometres).

Transmission losses
Loss of water flow along streams due to the deep infiltration in the alluvium or permeable bedrock. This is the commonly the first mechanism of aquifer recharge in dry climates.

Turbidity
The amount of solid particles that are suspended in water and that cause light rays shining through the water to scatter.

Unsaturated zone
The zone immediately below the land surface where the pores contain both water and air, but are not totally saturated with water. These zones differ from an aquifer, where the pores are saturated with water.

Vertic soil
Clay soils with shrink/swell properties that display strong cracks when dry and have slickensides and/or lenticular structural aggregates at depth.

Water quality
A term used to describe the chemical, physical and biological characteristics of water, usually in respect to its suitability for a particular purpose.

Water table
The top of the water surface in the saturated part of an aquifer.

Watershed
The divide between two areas that are drained by different river systems. The common usage of this term refers both to the divide itself as well as the natural drainage area within that boundary.

Watershed management
Watershed management is both a technical and social undertaking. 1) Technical: reducing soil erosion, promoting vegetative cover and managing the water cycle. 2) Social: promoting negotiation processes among all stakeholders within a watershed (harmonising the activities of numerous land-users that have multiple and conflicting objectives). The aim is to ensure that environmental objectives are well integrated with local economic, social and cultural goals.

What Science Can Tell Us

We live in an intricate and changing environment with interrelated feedback between ecosystems, society, economy and the environment. EFI's 'What Science Can Tell Us' series is based on collective scientific expert reviews providing interdisciplinary background information on key and complex forest-related issues for policy and decision makers, citizens and society in general.

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