8-2019

Towards Conjunctive Management of Surface Water and groundwater in the Mediterranean

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31 July 2019

A capstone report submitted in partial fulfillment of the requirements for the degree of

MASTER OF NATURAL RESOURCES

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UTAH STATE UNIVERSITY Logan, Utah
2019

Table of contents

Table of Figures

Acronyms and abbreviations

CWA	Clean Water Act
DG-NEAR	Directorate-General for Neighbourhood and Enlargement Negotiations
DPSIR	Driving forces, pressures, state, impacts, response
EEA	European Environment Agency
EU	European Union
FAO	Food and Agricultural Organization of the United Nations
GDP	Gross Domestic Product
GEF	Global Environment Facility
GIS	Geographic Information Systems
GWP	Global Water Partnership
GWP Med	Global Water Partnership - Mediterranean
ICWE	International Conference on Water and the Environment
IHP	International Hydrological Programme of UNESCO
IIED	International Institute for Environment and Development
IPCC	Intergovernmental Panel on Climate Change
IWRM	Integrated Water Resources Management
MAR	Managed Aquifer Recharge
MAP	Mediterranean Action Plan
Mm^3	Millions of square meters
MEW	Ministry of Energy and Water of Lebanon
MONSTAT	Statistical Office of Montenegro
OECD	Organisation for Economic Cooperation and Development
SDG	Sustainable Development Goals
UN	United Nations
UNCED	United Nations Conference on Environment and Development
UNDESA	United Nations Department of Economic and Social Affairs
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNEP	United Nations Environment Programme
UNGA	United Nations General Assembly
USGS	United States Geological Survey
WFD	Water Framework Directive

1. Introduction

Human wellbeing is largely determined by our ability to access clean, reliable, and affordable sources of fresh water. Although water covers more than two-thirds of Earth's surface, fresh water is a relatively rare natural resource. Of the water present on the planet, only 2.5% is fresh water and of this, only about 31% is in a liquid state, the rest being frozen in glaciers and permanent snow cover (Shiklomanov and UNESCO-IHP 1998, 4). The majority of this liquid fresh water – nearly 99% – is present as groundwater (FAO 2016a, 10), with rivers, lakes and other surface water bodies accounting for the remainder.

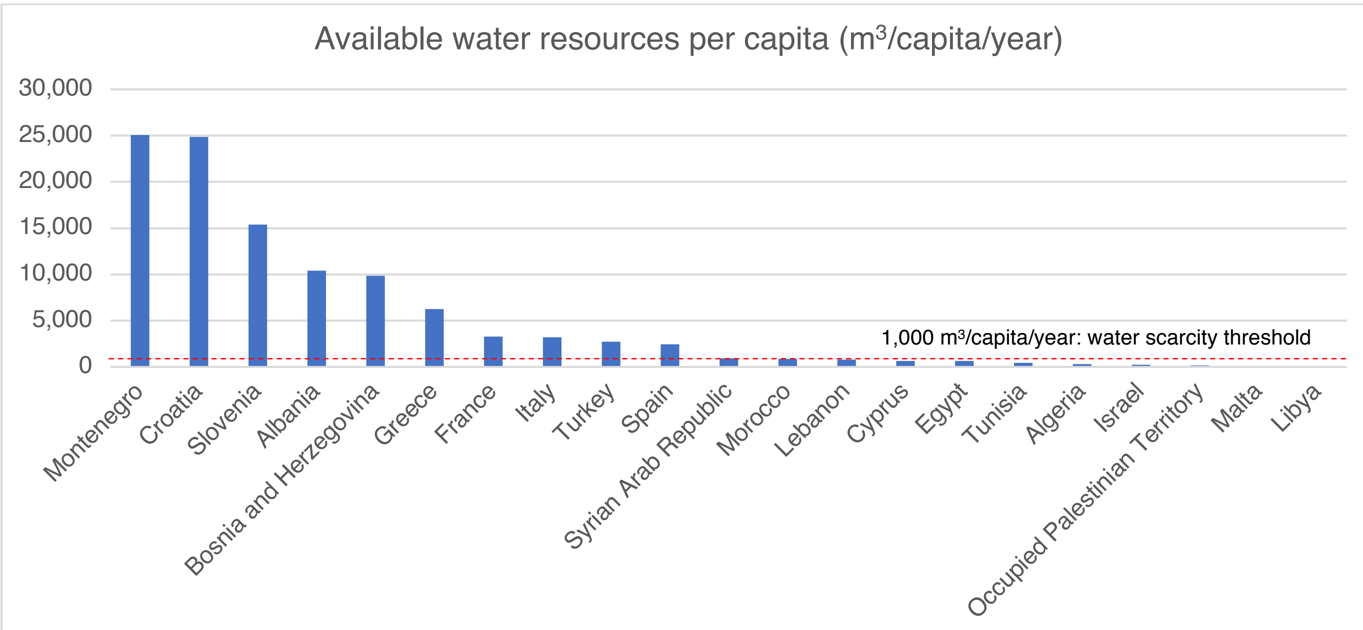
Access to fresh water for drinking and sanitation is recognized by the member states of the United Nations as a basic human right, which is essential for the realization of all other human rights (UNGA 2010). Among these is the right to adequate food, which is closely linked to the ability of governments to exploit water resources to boost food production in regions where food crops cannot be sustained solely from rainfall. Irrigated agriculture accounts for 40% of crop production worldwide on 20% of the world´s cultivated area (FAO 2014).

However, in many parts of the world the ability of people to access adequate amounts of fresh water is declining as the world population continues to increase. In 2017, there were 7.6 billion people in the world; this number is projected to reach 8.6 billion in 2030, and to increase further to 9.8 billion in 2050 and 11.2 billion by 2100 (UNDESA 2017, 2). While human populations fluctuate, the amount of available fresh water in the hydrological cycle remains relatively constant. With more people requiring access to this limited resource, some fresh water reserves are being exploited faster than natural processes can replenish them. As a result, it is estimated that by 2030, the number of people residing in areas affected by severe water stress (where withdrawals exceed safe levels) will exceed 3.9 billion (OECD 2008, 5).

One of the regions of the world most affected by water stress is the Mediterranean. Though it constitutes just 8% of the world´s population, it is home to 60% of the world´s "water poor" population; that is to say, people living in areas with less than 1,000 m^3 of water resources per capita per year, which is the definition of water scarcity (Plan Bleu 2003, 63). More than half of the countries that share the Mediterranean Sea fall below this threshold for water scarcity (Figure

1), representing nearly 162 million people, mostly in Northern Africa and the Middle East. Water stress will become even more pronounced in the coming decades: the number of people living in water scarce conditions in the Mediterranean is projected to increase to 250 million by 2030 (UNEP/MAP 2013), affecting nearly half of the region´s projected population of 572 million for that same year (UNEP/MAP 2017, 366).

Figure 1 Available water resources per capita in the Mediterranean (FAO 2016 and Margat et al. 2016)



While growing human populations will certainly reduce the amount of water available for each person in the Mediterranean, the anticipated impacts of climate change will likely further exacerbate water stress in the region by affecting the amount and seasonal timing of water in rivers, streams, lakes and aquifers. In its latest assessment report, the Intergovernmental Panel on Climate Change (IPCC) recognized the Mediterranean as one of the regions that is most vulnerable to the impacts of global climate change (IPCC 2013), indicating that by the end of the century the region will experience an overall decrease in mean annual precipitation, temperature increases between 2 to 6 ° C, and sea levels that will rise by nearly one meter (Figure 2).

Figure 2 Projected impacts of climate change in the Mediterranean (Kovats et al. 2014)

Indicator	**Projected change in indicator**
Temperature	Increase of 2 to 6 ° C by 2100, depending on the climate scenario and the season
Precipitation	*Northern Mediterranean:* overall decrease in mean annual precipitation, but with increased precipitation in cold seasons *Southern Mediterranean:* decrease in mean annual precipitation
Drought	Increase in number of hot days, with more frequent, longer and more intense heat waves
Sea level	Increase of 0.1 m to 0.3 m by 2050, and of 0.1 m to 0.9 m by 2100

Water resources managers in many Mediterranean countries are therefore facing important challenges as they attempt to supply sufficient quantities of this resource to fulfill the needs of increasing numbers of people, while taking into account the uncertainties of a changing climate and the needs of ecosystems. To meet these challenges, many of these countries have committed to aligning their water management practices with the principles of integrated water resources management (IWRM), a transdisciplinary approach that emerged in the 1990s as a means of coordinating land and water resources management while promoting human development and protecting ecosystems.

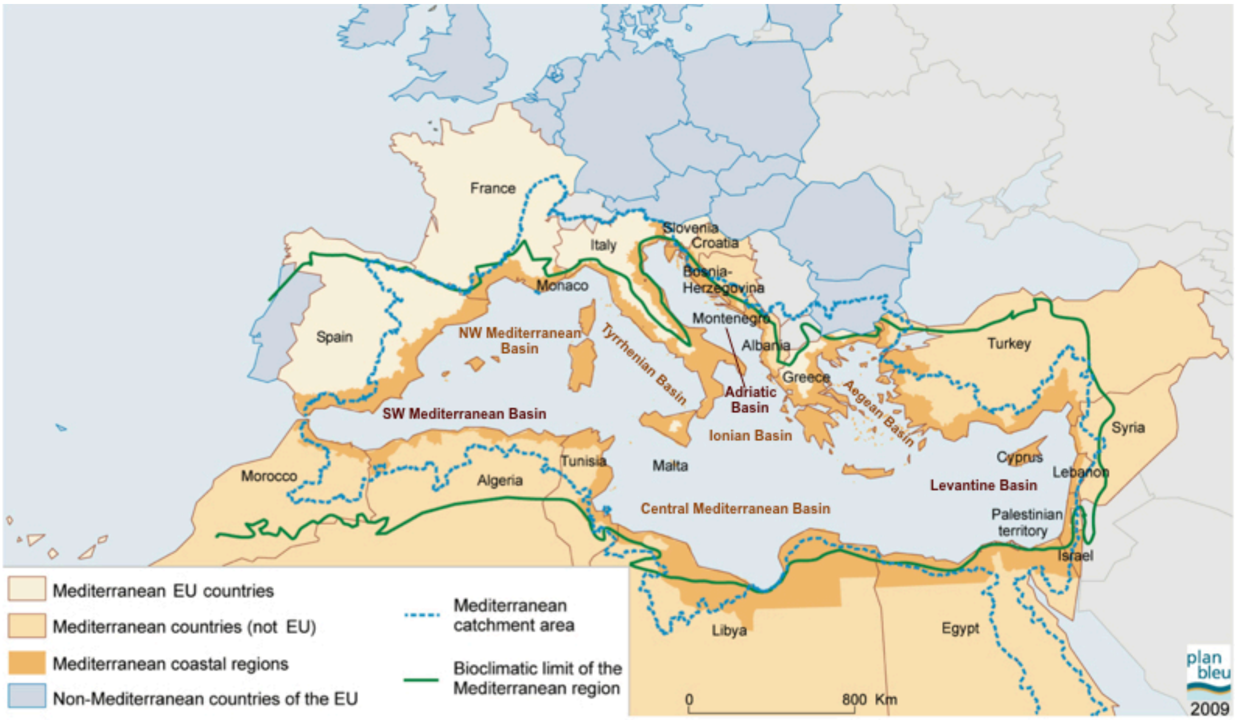
At the heart of IWRM is the integration of management approaches across the natural and human systems that affect water resources. One of the most fundamental underlying principles of integration among natural systems for IWRM is the interconnected nature of water in the hydrological cycle, including the interactions between surface water and groundwater. Although scientists have long recognized these interactions (USGS 1998, 1), in many cases they are not reflected in natural resources policies and management practices. In response, water experts have developed a body of knowledge termed "conjunctive water resources management" to promote management approaches that treat surface water, groundwater and other components of the water cycle as a single, interconnected resource. The aim of conjunctive management is to ultimately increase the supplies of fresh water that are available for human use, to maximize their economic and social benefits while minimizing risks to the environment and ecosystems.

This paper will examine the potential for application of conjunctive management approaches in the Mediterranean region. First, an overview of IWRM will provide the overarching framework

for the subsequent analysis of conjunctive management. Next, the concept of conjunctive management of surface water, groundwater and other components of the water cycle will be introduced as one aspect of IWRM, with examples to illustrate how conjunctive management approaches can provide solutions to water supply challenges and related problems. Finally, a series of case studies will document the state of water resources management in three Mediterranean countries, challenges for the implementation of conjunctive management approaches, and recommendations that could assist the countries in moving towards implementation (or expansion) of conjunctive management practices.

The three countries selected for the case studies are Lebanon, Montenegro and Morocco. These countries are representative of the three continents with catchment areas that drain into the Mediterranean Sea, namely Asia, Europe and Africa (Figure 3). Lebanon forms part of southwestern Asia and drains to the Levantine sub-basin of the Mediterranean Sea. Montenegro is located in southeastern Europe and is associated with the Adriatic sub-basin. Morocco occupies the westernmost area of the Maghreb region of northern Africa, and its Mediterranean catchment area drains to the sea's Southwestern sub-basin.

Figure 3 The Mediterranean region and location of the main Mediterranean Sea sub-basins (UNEP/MAP-Plan Bleu 2009)



2. Integrated water resources management

2.1 Origins of integrated water resources management

The international community called attention to the growing need to better manage and protect water resources at the 1977 United Nations Water Conference in Mar del Plata, Argentina. The concept of "integrated water resources management" (IWRM) was introduced at this event, which produced a set of recommendations calling for "integrated planning, development and management of water resources," "integrated basin development," "integrated water and land-use planning," and "an integrated interdisciplinary approach to the formulation of water policies" (UN 1977), amongst others. Despite their agreement on the need for a more integrated approach to the management of water and other resources having an impact on water, governments and natural resources managers were ill-equipped to actually implement the principles of IWRM on the ground. As a result, water resources management in the 1980s was marked by fragmented, mainly sectoral approaches that failed to recognize the connections between human systems and natural systems, and that were not in line with the Mar del Plata recommendations (GWP Med 2002).

2.2 The guiding principles of IWRM

It wasn't until the 1990s that the principles of IWRM were clearly articulated and began to gain traction around the world. In January 1992, an international group of water experts held the International Conference on Water and the Environment (ICWE) in Dublin, Ireland, to send a clear message about the need to heighten the importance of water on the agenda of the international community. The intent of the conference participants – which included representatives of 100 countries, as well as international, intergovernmental and nongovernmental organizations – was to inform the debates that would take place later that year in Rio de Janeiro for the United Nations Conference on Environment and Development (UNCED) (more commonly known as the Earth Summit). More precisely, they "urge(d) all governments to study carefully the specific activities and means of implementation recommended in the Conference Report, and to translate those recommendations into urgent action programmes for water and sustainable development" (IWCE 1992). The recommendations

for action on water resources management issued at the Dublin conference were based on four guiding principles of integrated water resources management, also articulated at the conference (Box 1).

> **Box 1** The four guiding principles of IWRM
>
> 1. Fresh water is a finite and vulnerable resource, essential to sustain life, development and the environment.
>
> 2. Water development and management should be based on a participatory approach, involving users, planners and policy-makers at all levels.
>
> 3. Women play a central part in the provision, management and safeguarding of water.
>
> 4. Water has an economic value in all its competing uses and should be recognized as an economic good.
>
> *(Dublin Statement on Water and Sustainable Development 1992)*

These four principles – referred to as the Dublin Principles – were well received in Rio at the Earth Summit, and IWRM was identified as one of the seven programme areas in the freshwater sector defined in Agenda 21, the ambitious programme of action issued by the United Nations at the Earth Summit to achieve sustainable development in the 21st century.

By the year 2000, a commonly agreed definition of IWRM emerged: a process that "promotes the coordinated development and management of water, land and related resources in order to maximize economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems and the environment" (GWP 2000, 22).

2.3 IWRM and the 2030 Agenda for Sustainable Development

The 2030 Agenda for Sustainable Development, adopted by UN Member States in 2015, is the international community's follow up to Agenda 21 and the Millennium Development Goals. Its 17 global objectives – known as the Sustainable Development Goals (SDGs) – address challenges related to poverty, inequality, climate, environmental degradation, prosperity, and peace and justice. SDG 6 is devoted to the availability and management of clean water and sanitation, and promotes a holistic approach to water management through target 6.5: "By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate" (UNEP 2018, 6). The United Nations Environment Programme

(UNEP) works with countries to gather information about the progress achieved on implementation of IWRM at the national level, and to facilitate assessments of global and regional trends on water resources management and water efficiency plans. It is responsible for reporting on the SDG 6 Indicator 6.5.1 dedicated to IWRM.

2.4 The four dimensions of IWRM

Following nearly three decades of exchange of best practices and collaborations among government organizations, international and regional organizations, academia, the private sector and civil society, a wide consensus in the international water community indicates that efforts to implement integrated water resources management must consider the following four dimensions (GWP 2000 and Lenton and Muller 2009):

- A strong enabling environment – policies, laws and plans that put in place 'rules of the game' for water management that use IWRM.
- A clear, robust and comprehensive institutional framework and opportunities for the participation of civil society and the private sector – for managing water using the basin as the basic unit for management while decentralizing decision making.
- Effective use of available management and technical instruments – use of assessments, data and instruments for water allocation and pollution control to help decision makers make better choices.
- Sound investments in water infrastructure with adequate financing available – to deliver progress in meeting water demand and needs for flood management, drought resilience, irrigation, energy security and ecosystem services.

2.5 Integration of human and natural systems in IWRM

IWRM is ultimately a tool to reconcile human water demands with available water supplies, while protecting ecosystems. The implementation of the IWRM approach must therefore integrate resource management activities within and across human and natural systems (GWP 2000, 23). For example, effective management and protection of water resources implies a coordinated management of surface water and groundwater (integration within a natural system), as well as the removal of pollutants from wastewater generated by human activities (integration

across natural and human systems). Other examples of integration in natural and human systems that contribute to IWRM are in Figure 4. The four dimensions of IWRM provide the framework in which this integration can be planned, implemented and improved over time.

Figure 4 Integration of natural and human systems in IWRM (GWP 2000)

Natural system integration	Human system integration
• Integration of freshwater management and coastal zone management • Integration of land and water management • Integration of surface water and groundwater management • Integration of quantity and quality in water resources management • Integration of upstream and downstream water-related interests	• Cross-sectoral integration in national policy development • Macro-economic effects of water developments • Influencing economic sector decisions • Integration of all stakeholders in the planning and decision process • Integrating water and wastewater management

Each government must decide for itself the most appropriate way of moving towards more integrated approaches for natural resources planning and management. The human and natural systems that are the focus of IWRM's integration are complex and involve a vast and diverse set of stakeholders. Furthermore, integration implies sustained political will and the investment of significant human and financial resources. Naturally, most governments that commit to adopting the IWRM approach will do so in phases, starting with integration of those aspects of their natural and human systems that can yield the greatest benefits. A country facing widespread pollution of water resources from nonpoint agricultural sources may, for example, start by establishing a coordination mechanism between the government unit responsible for land management and that of water management. Alternatively, a country in an arid region facing irrigation water shortages may choose to explore how the coordinated management of surface water and groundwater could increase the amount of water available for human use, and its reliability throughout the year.

2.6 Elements of the IWRM framework

To implement IWRM on the ground, the four dimensions of its framework (enabling environment, institutions and participation, management instruments and financing) must be translated into concrete elements that promote sustainable water resources management and the

desired integration within and across the human and natural systems that affect and are affected by water resources. These elements must furthermore be elaborated at the scales appropriate to the administrative and hydrological boundaries of the water resources at hand. For most countries these include the national, subnational, basin and transboundary scales. In its 2018 assessment report of global progress on IWRM implementation, UNEP (2018) references the main elements of IWRM which are applicable to most countries (Figure 5). They represent a practical framework for applying the four guiding principles of IWRM (the Dublin Principles) to the governance of water resources in the world's diverse geographic and political settings.

Figure 5 Main elements of IWRM by category and implementation level (UNEP 2018)

	Enabling Environment	**Institutions and Participation**	**Management Instruments**	**Financing**
National level	Policy Law Plans	Authorities Cross-sectoral coordination Capacity Public participation Business participation Gender objectives	Availability monitoring Water-use management Ecosystem management Disaster management	Budget for investment Budget for recurring costs
Sub-national	Policy	Gender objectives	Data and information sharing	Subnational or basin budget for investment Revenues raised
Basin / Aquifer / Local	Basin/aquifer management plans	Basin/aquifer organizations Local public participation	Basin management instruments Aquifer management instruments	
Trans-boundary	Management arrangements	Organizational arrangements Gender objectives	Data and information sharing	Financing for cooperation
Federal countries only	Provincial water law	Provincial authorities	-	-

That being said, there is no standard framework or approach for the implementation of IWRM. Each government must decide which tools and activities are the best suited to facilitate achievement of its specific water and development goals, based on its governance approach, human and institutional capacity, financial resources, water infrastructure and hydrogeological setting, amongst other considerations.

2.7 Conjunctive management of surface water and groundwater as a starting point for IWRM

Governments looking to strengthen their IWRM framework and enhance the integration among the human and natural systems that account for water demand and supply may not know where to begin this process. A logical starting point would be to ensure that they are able to accurately estimate all components of their water budgets. Water budgets represent an accounting of the water entering and leaving a basin, and reveal how much water is available, how much water is used, where the water comes from, and the rates at which water is replenished or consumed. To estimate water budgets and how they change over time, resource managers require scientific data and models for surface water storage and stream flows, groundwater sources and recharge, evapotranspiration rates, vegetation and land cover and climatic conditions.

A particular challenge in the computation of water budgets is the interaction between surface water and groundwater, since a drop of water may pass between both surface water and groundwater bodies as it flows through a basin. Water budgets that fail to properly account for these interactions run the risk of overestimating the quantities of available water, which can lead to the unsustainable use of these resources as well as damage to water-dependent ecosystems. Indeed, according to the USGS (1998) "surface water commonly is hydraulically connected to groundwater, but the interactions are difficult to observe and measure and commonly have been ignored in water management considerations and policies." UNESCO (2019) observes that "the daily practice in most countries is characterized by a tradition of dealing with groundwater and surface water separately, without significant coordination." There are of course exceptions to these statements: the state of California, for example, recognized the importance of coordinated management of surface water and groundwater in its 2016 Water Plan (California Natural Resources Agency 2016). However, in many countries the uneven level of awareness and scientific knowledge about surface water and groundwater and their interactions represents an important barrier to the sustainable use of water resources and the ultimate goals of IWRM.

In response to this, there has been renewed focus on the coordinated management of surface water and groundwater – what is referred to as conjunctive management of these resources.

Conjunctive management holds the promise of better overall management of water resources, improved water security for people and protection of ecosystems.

3. Conjunctive management of surface water and groundwater

3.1 Conjunctive management and its context in IWRM

Conjunctive management can be defined as "an approach to water resources management in which surface water, groundwater and other components of the water cycle are considered as one single resource, and therefore are managed in closest possible coordination, in order to maximize overall benefits from water and to minimize its potential harmful impacts, both in the short and the long term" (UNESCO 2019, 5). It has the potential to increase the amount of usable water resources available by revealing new opportunities for water use and reuse (UNESCO 2019, 14). Conjunctive management is therefore a response to challenges stemming from water quantity, rather than water quality[1]. Conjunctive management also takes into account the water needs of ecosystems, or environmental flows, which are also increasingly factored into the decisions of water resources managers, as awareness grows about ecosystem services and how ecosystems are sustained by surface water and groundwater systems (USGS 2003, 1).

Conjunctive management can be classified as spontaneous – for example, when a farmer sources water from a well in addition to an irrigation delivery canal – or as planned – when a public water utility designs an irrigation or municipal water supply system to draw from surface water and groundwater sources (Foster et al 2010, 4). For the purposes of this paper, I will focus on conjunctive management that is planned by a central authority, as part of its wider strategy to implement IWRM.

To implement a conjunctive management approach, resource managers must understand how water circulates through the atmosphere, land and oceans through the hydrologic processes of precipitation, evapotranspiration, and runoff. In particular, resource managers require monitoring data, numerical models and complementary information about the movement of terrestrial freshwater between the surface and subsurface, behaviors of fresh-saline water interactions in the coastal zone, and the role of fresh water in sustaining ecosystems. With this knowledge, they can

[1] The exception to this is the case of seawater intrusion in coastal aquifers, wherein the quality of groundwater resources is degraded by saline water entering the aquifer as a result of excessive groundwater pumping (hence a quantity issue).

then make informed decisions that capitalize on the comparative advantages of surface water and groundwater while minimizing tradeoffs, includes those affecting ecosystems.

It follows then that the conjunctive management of water resources has a critical role in achieving the overarching objective of IWRM, when carried out in a manner that sustains water resources and their related ecosystems over the long term. Conjunctive management of surface water and groundwater is just one aspect of IWRM, but an important one since it promotes holistic management approaches that consider all components of the water cycle and their potential interactions. These approaches can foster greater water security, which is increasingly being threatened by growing human pressures on water resources and the uncertainties of climate change.

3.2 Conjunctive management – a response to water quantity issues

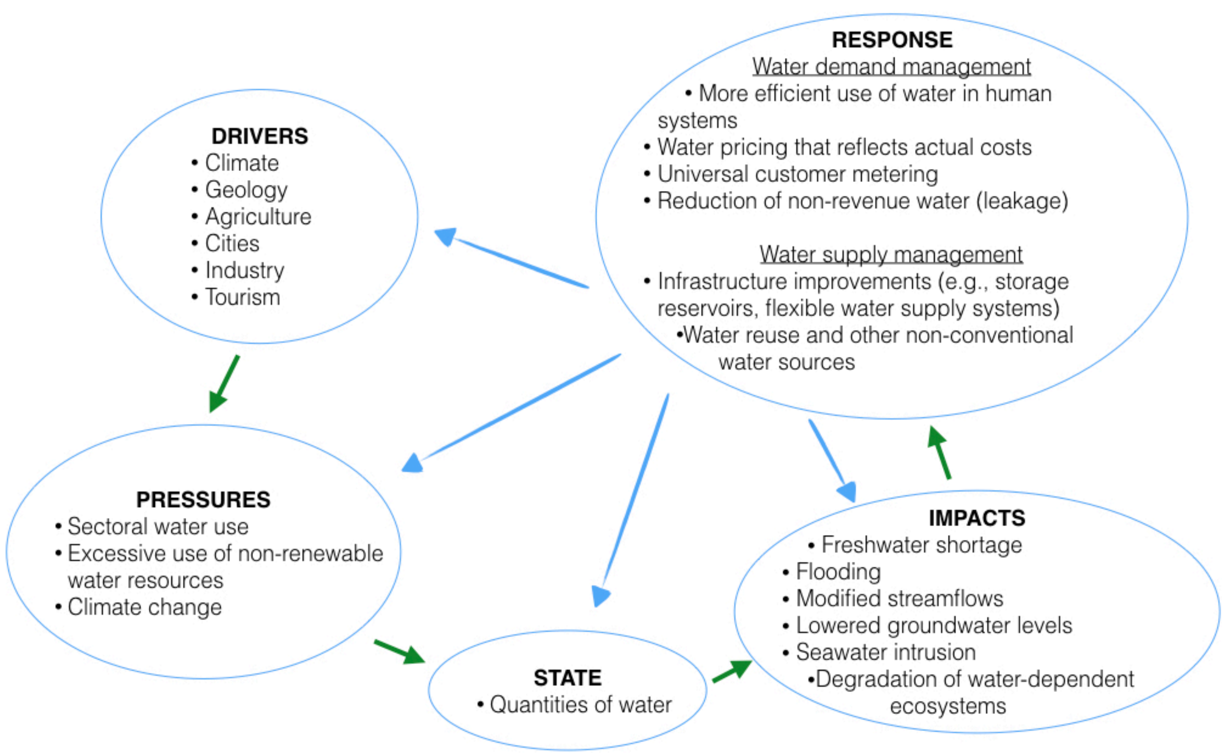
To understand how conjunctive management responses are conceived, it is first necessary to consider the links between water availability and the natural and anthropogenic factors that affect water resources. One approach that can be used to articulate these links is the DPSIR[2] framework, a causal framework for describing the interactions between society and the environment adopted by the European Environment Agency (EEA). According to the DPSIR framework there is a chain of causal links initiated by 'driving forces' (economic sectors, human activities, natural environment), which generate 'pressures' (consumption, emissions, waste) on the 'state' of the resource (physical, chemical and biological) that lead to 'impacts' on ecosystems, human health and functions, which are then the basis for 'responses' (new management approaches, target setting, indicators) (EEA 1999).

In applying the DPSIR framework to water challenges associated with water quantities (water scarcity or floods), we seek to identify responses to the impacts generated by pressures on the physical state of water, namely its availability in terms of quantity and distribution over time and space (Figure 6). The driving forces affecting the availability of water resources are both anthropogenic (human needs for water, food and development) and natural (climate, geology, and geography). These driving forces exert pressures on the availability of water resources,

[2] DPSIR: driving forces, pressures, state, impacts, response.

including water consumption for agriculture, human settlements, industry and tourism; as well as the effects of climate change (modifications to precipitation patterns and evapotranspiration rates), geology (infiltration and storage associated with different soils and rocks) and geography (the effect of topography on surface water and groundwater flows). Changes to the availability of water resources lead to impacts affecting society (insufficient quantities of water to meet human needs at a given time and place, or damages associated with flooding) and impacts on natural systems (modified stream flows, lower water tables, seawater intrusion, and degradation of water-related ecosystems, etc.). The potential responses are conceived to counteract the impacts caused by anthropogenic driving forces, while at the same time adapting to the impacts brought about by natural forces of climate, geology and geography.

Figure 6 DPSIR analysis applied to issues of water quantities



Effective responses to water availability challenges must combine approaches addressing both water demand management and water supply management. Water demand management focuses on techniques to promote wise use of the resource, to reduce waste and nonessential consumptive uses, and to bring water prices in line with actual costs of delivering water services. Water supply management addresses the management of the resource itself, through approaches to increase the water resources available for human use and to improve the likelihood that adequate water resources are available when and where they are needed. Conjunctive management is simply a water supply management approach, but one that differs from traditional approaches by emphasizing the interconnected nature of water and its occurrences in the hydrological cycle. Conjunctive management approaches include infrastructure improvements to store water for future use and exploitation of non-conventional water sources such as treated wastewater and desalinated water. Descriptions of the most common conjunctive management techniques are provided in the next section.

3.3 Description of conjunctive management techniques

Conjunctive management techniques take advantage of the inherent assets of surface water and groundwater, in an attempt to meet water demands using the sources that are the least costly to deliver or that enable the achievement of other management objectives in the given local context. Surface water bodies, for example, can supply relatively large quantities of freshwater for comparatively low development costs (UNESCO 2019, 10). However, this water may require substantial treatment to satisfy use requirements. Groundwater, meanwhile, is generally of good quality (due to the natural protection and filtering actions of its overlying layers of soil and rock) and often remains available at times of the year when surface waters are scarce (Younger 2007, 168). It may nevertheless require considerable initial development costs for drilling wells and ongoing energy costs for pumping. Where local conditions are favourable to their conjunctive use, surface water and groundwater together have the potential to offer greater amounts of water reliably at more attractive costs than either of the two resources alone. Resource managers must, however, devise their water supply strategies on the basis of adequate scientific data to ensure that water resources are not exploited beyond their renewable limits, and that water bodies maintain sufficient quantities to sustain their associated ecosystems.

The following types of techniques and activities are those most commonly associated with planned conjunctive management.

Flexible Water Supply Systems

In water supply systems that have been engineered with the flexibility to exploit both surface water and groundwater sources, resource managers are able to implement strategies that combine different water sources based on seasonal availability, cost, quality and even palatability for consumers (Younger 2009, 168). A well-documented example of this type of system can be found in Madrid, Spain, where the municipal water supply system is designed to meet 100% of the demand of the city's 6.5 million inhabitants in 96 of every 100 years by accessing water from surface reservoirs, rivers and aquifers (Sánchez, Muñoz, Iglesias, & Cabrera 2003, 2). Another example is Lima, Peru, where the municipal water supply system can shift its source from groundwater to surface water to maintain desired water table levels and prevent intrusion of salt water in the aquifer that serves the city (Foster et al 2010, 10).

Managed Aquifer Recharge

Under natural conditions, an aquifer is recharged through the infiltration of precipitation or by the inflow of water from surface watercourses that are hydraulically connected to the aquifer. Managed aquifer recharge (MAR), in contrast, is a technique that involves the deliberate introduction of water to augment the quantity of water stored in the aquifer (USGS 2003, 4). This technique takes advantage of the fact that many aquifers have a significant capacity to store additional water in their unsaturated zone. Surface water is the main source of water for MAR, however the use of nonconventional sources is growing, including desalinated seawater, treated wastewater and stormwater. The type of equipment used to introduce water into the aquifer depends on the nature of the aquifer. Deep or confined aquifers require injection wells to recharge the aquifer, while spreading methods are used to recharge unconfined aquifers.

Recharge of the aquifer may be desired to meet a number of management objectives including the following:

- to increase the quantity of subsurface water reserves to meet future water demands, or to provide an emergency supply in the event that surface watercourses become polluted or otherwise unavailable;
- to improve the quality of the water used for recharge, by utilizing the natural filtration capacity of the aquifer (in the case of spreading basins, which allow water to infiltrate unconfined aquifers);
- to compensate for the historic over-extraction of the aquifer, to raise the level of the water table;
- to create a hydraulic barrier to stop or slow the migration of polluted groundwaters or saline water (in the case of coastal aquifers);
- to mitigate the severity of floods, if the hydrogeological properties of the aquifer (or engineered structures) allow for relatively rapid infiltration of floodwaters; and
- to minimize the volume of water lost to evaporation, since evaporation losses from aquifers are significantly smaller than those of surface reservoirs (FAO 2016, 171).

When designing MAR systems, due consideration must be given to the quality of the water that will be used to recharge the aquifer. Depending on the source of recharge water, pre-treatment may be necessary to maintain the physical, chemical and biological integrity of the aquifer. Water that is high in suspended solids can clog soil pores and reduce the recharge capacity of the aquifer. In this case, physical pre-treatment by coagulation or sand filtration can be employed to remove the solids. Recharge water that contains significant levels of chemical or pathogens can adversely impact the quality of groundwater in the aquifer. Pathogens and the associated microbial growth can also increase the risk of clogging of soil pores or infiltration wells. To remedy this problem, ultraviolet or chemical pre-treatment may be considered (Hartog and Stuyfzand 2017, 2). Therefore, effective MAR systems require water quality monitoring and, where appropriate, pre-treatment facilities to ensure proper functioning of the recharge process and to prevent the degradation of the aquifer.

<u>Reuse of Treated Wastewater</u>

The reuse of treated municipal or industrial wastewater for irrigation or aquifer recharge is another technique that conjunctive management systems employ to augment the quantity of

water available for human use. In this way, a second set of benefits is derived from water resources that have already met the water needs of municipal or industrial users, and the reuse of this water also decreases the pressures on other water sources. When applying this technique, extreme care must be given to ensure that the quality of the treated wastewater is consistent with its intended end use. Public health may be compromised, for example, if insufficiently treated wastewater is used in the cultivation of crops that are typically eaten uncooked, or if there is the potential over the long term for the accumulation of toxic elements such as mercury or boron in the soil or food chain (Foster et al 2005, 2). Water quality guidelines must be established and enforced to minimize these risks.

Desalinization

Desalinization of saline or brackish water is another means of augmenting freshwater supplies, and is an increasingly common practice in conjunctive management systems (UNESCO 2019, 19). This technique is employed primarily in arid regions where water demands are outpacing freshwater supplies, especially in the Middle East and Northern Africa, where 48% of the world's desalinated water is produced (Jones et al. 2019, 1343). The feedwaters for desalinization plants include seawater, river water, brackish surface water or groundwater, and wastewater, amongst other sources. While desalinization appears at first glance to offer an unlimited supply of freshwater, this is not the case. It is a relatively expensive process due to energy-intensive processes and the generation of considerable quantities of toxic brine discharges that must be properly treated to prevent environmental damage (Jones et al. 2019, 1349). Despite this, desalinization remains a viable option in many water-scarce countries, especially to satisfy domestic and municipal water demands.

3.4 Benefits and trade-offs of conjunctive management

As we have seen, the primary aim of conjunctive management is to increase the amount and the reliability of water resources available for human use, thereby enhancing water security. The enhanced water security associated with conjunctive management can benefit people, communities and economies in several ways. A secure, affordable access to water is recognized as a basic right for all people, and a precondition for the realization of all other human rights. Water security promotes reliable irrigation and thus food security and human livelihoods:

irrigated agriculture represents 40% of food production worldwide (FAO 2019) and provides economic opportunities to many of the world's rural population. Water security also underpins all healthy economies, especially those in which agriculture is a main contributor to economic growth (FAO 2017, 1). Water security is furthermore linked to the stability of communities and political systems.

At the same time, conjunctive management approaches recognize the potential impacts of water resources management decisions on the environment and the functioning of ecosystems. This can lead to the generation of environmental benefits which ultimately benefit human communities as well. The potential environmental benefits associated with conjunctive management include the following:

- recharge of depleted aquifers (with surface water or treated wastewater);
- flood mitigation (when flood waters are diverted to subsurface storage space in aquifers);
- control of salinity in groundwater in coastal zones (one aspect of managed aquifer recharge);
- ecosystem protection, resulting from management approaches that maintain environmental flows in water bodies; and
- reduced stress on water supplies resulting from reuse of treated wastewater for irrigation and industrial applications, or from the use of desalinated water.

Finally, conjunctive management promotes a "systems thinking" approach to the accounting of water budgets, which can prevent the double counting of water that is exchanged between surface water and groundwater. This can prevent the overallocation of water resources, which can reduce the potential for human conflicts over shared water resources, and promote the protection of ecosystems.

While conjunctive management offers the possibility to increase the human benefits derived from water resources, there are also some important potential trade-offs to consider. Since conjunctive management often results in the exploitation of greater volumes of freshwater, this can negatively impact the sustainability of these resources over the long term. Managers should therefore seek not only to increase water availability, but should also approach water challenges

with an eye to managing water demand and increasing the efficiency of delivery of water to ensure that every drop counts.

Another potential trade-off is that the functioning of ecosystems may be negatively impacted by conjunctive management approaches that underestimate the water necessary for environmental flows. These detrimental impacts can result from an insufficient understanding of the water exchanges between surface water bodies and groundwater bodies, and the links between these water bodies and related ecosystems. Managers must always seek to balance the needs of human communities with those of ecosystems and be vigilant about new information that can facilitate a better understanding of the interactions between ecosystems and managed water systems. The ultimate objective of conjunctive management approaches should therefore be a sustainable use of the water resources that balances benefits to human communities and the needs of ecosystems.

3.5 Key elements for effective conjunctive management

Let us recall that IWRM aims at the integrated management of water, land and other related resources, and that conjunctive management of surface water and groundwater is one strategy that supports IWRM. To move to the implementation of conjunctive management approaches, governments will need to develop the elements of the IWRM framework that focus primarily on the management of water resources, leaving aside temporarily those that address the management of land and other related natural resources. The goal of the exercise will be to articulate those elements of the IWRM framework in a way that reflects the government's vision for the management of surface water and groundwater as a single connected resource.

What follows is an articulation of the elements of the IWRM framework that a government may need to put in place to achieve the conjunctive management of surface water and groundwater. It is based on the four dimensions of the IWRM framework (Figure 5) and the author's experience in managing projects focusing on water resources management. The following lists represent elements that may apply to a broad cross section of countries. In practice, each country will need a unique set of tools and measures to advance its implementation of conjunctive management approaches, conceived to respond to its own governance structure and hydrological setting.

Enabling environment

The elements of the enabling environment of the IWRM framework that promote the conjunctive management of surface water and groundwater are those that define the management boundaries of water resources and that integrate the concept of an interconnected water cycle into policies, laws and plans. They include:

- Policy and legal frameworks that recognize the watershed, river basin or aquifer basin as the management unit for water resources, rather than those that focus solely on administrative boundaries.
- Policies, laws and plans for water resources management and protection that consider surface water and groundwater as two occurrences of a single natural resource. These include national water codes (laws), master water plans, permitting for the allocation of water resources (surface water flows and groundwater extraction) and for pollutant discharges.
- Policies on resource fees and enforcement.
- Management arrangements with neighbouring governments for transboundary river basins or aquifers.

Institutions and participation

The enabling environment for conjunctive management can only set the “rules of the game” - the implementation of its underlying principles is ultimately the responsibility of the institutions and stakeholders associated with the water resources at hand. The following elements of the IWRM framework related to institutions and stakeholder participation will promote the conjunctive management of surface water and groundwater:

- Institutions in charge of water resources management that have adequate technical capacities in assessment and management of both surface water and groundwater.
- Cross-sectoral coordination, including a water resources apex agency (in the event that surface water and groundwater responsibilities are not housed in a single ministry or government unit) (Foster et al. 2010, 25), and technical assistance from institutions that are able to assess the links between water resources and ecosystems.

- Basin/aquifer management organizations (river basin agencies, aquifer councils, watershed councils, etc.).
- Mechanisms to promote engagement of civil society and the private sector in decisions that impact water resources.

Management instruments

Management instruments represent the concrete tools, data and measures that allow responsible institutions and stakeholders to operationalize the principles of IWRM on the ground and take informed decisions about the use of water resources. The fundamental management instruments that underpin the conjunctive management of surface water and groundwater are:

- Monitoring networks for surface water and groundwater bodies that provide information on water quantity and quality.
- Data and information about surface water and groundwater interactions, including results of hydrogeological investigations; studies that demonstrate how these interactions change over time and as a function of precipitation, evapotranspiration and land use changes; assessments of environmental flows to determine how surface water bodies and groundwater sustain local ecosystems.
- Water balances, including interactions between surface water and groundwater bodies.
- Delineation and characterization of priority surface water and groundwater resources, and management plans for these resources.
- Conceptual and numerical conjunctive management models that bring together groundwater models and hydrologic models to account for the interactions between surface water and groundwater, and the impacts of climate change.
- Metering the consumption of water users (farmers, public institutions, individuals, the private sector, industry, etc.)
- Vulnerability maps that facilitate the identification of water pollution risks from land-based activities, to inform decisions about the siting of waste management facilities or the need for wellhead protection areas, for example.

Financing

Implementing the IWRM framework also requires adequate levels of financing to ensure that the infrastructure and institutions are in place to extract, treat and deliver water to people and businesses and to collect and treat wastewater for reuse or safe discharge into the environment. The financing sources will include government budgets as well as resource fees collected from users based on consumption and pollution discharges. In the case of conjunctive management, the following financing sources and activities should be considered as a part of the overall financing strategy for IWRM:

- Budgets at the national level to support water resources management agencies (including an apex water agency) and at the subnational level to support monitoring, assessment and management activities at the level of the river basin or aquifer.
- Collection of resource fees from water users.
- Analyses to estimate economic value of surface water and groundwater, and to assess the feasibility of implementing direct or indirect pricing of water resources if this is not current practice (Garduño et al. 2006, 6).
- Assessment of the policies and subsidies affecting water abstraction.

4. Case study design

The objective of this paper is to develop recommendations that could assist three Mediterranean countries in moving towards the implementation (or expansion) of conjunctive management approaches, as part of their wider efforts to implement an effective framework for IWRM. The chapters on IWRM and conjunctive management (Chapters 2 and 3) have provided a brief overview of the IWRM framework, the articulation between this framework and conjunctive management, and examples of the most commonly employed conjunctive management techniques. The recommendations that are the ultimate aim of this paper have been developed on the basis of the case studies in the following three chapters (Chapters 5, 6 and 7, respectively).

The three countries selected for the case studies are Lebanon, Montenegro and Morocco. As previously stated, these countries are representative of the three continents with catchment areas that drain into the Mediterranean Sea, namely Asia, Europe and Africa. More precisely:

- Lebanon forms part of southwestern Asia and drains to the Levantine sub-basin of the Mediterranean Sea.
- Montenegro is located in southeastern Europe and is associated with the Adriatic sub-basin.
- Morocco occupies the westernmost area of the Maghreb region of northern Africa, and its Mediterranean catchment area drains to the sea's Southwestern sub-basin.

Each of the case studies is built around the following six sections:

- **General information.** Includes: data on demographics as well as insights on the political setting and unique challenges faced by the country that affect natural resources management.
- **Water profile.** Includes: key information about water resources, water supply sources, water use by sector, and anticipated future water demands. Unless otherwise noted, the source of data for this section is FAO´s AQUASTAT database (http://www.fao.org/nr/water/aquastat/data/query/index.html).

- **Main issues of concern for water resources**. Includes: descriptions of the water quality and quantity issues faced by the country, along with an indication of how conjunctive management approaches could address those issues related to water quantity.
- **Overview of IWRM implementation progress and implications for conjunctive management.** Includes: an overview of progress achieved by the country in implementing the elements of the four components of the IWRM framework (enabling environment, institutions and participation, management instruments and financing), and the implications of this progress for the implementation or expansion of conjunctive management approaches. Unless otherwise noted, the sources of the information on progress on IWRM implementation are the responses provided by countries to the UNEP survey to gauge progress on SDG Indicator 6.5.1 "Degree of integrated water resources management implementation" (UNEP 2018) (see note below).
- **Key challenges to implementing conjunctive management approaches.** Includes: an indication of the challenges that must be overcome before the countries can implement or expand implementation of conjunctive management approaches, based on the gaps in the IWRM framework.
- **Recommendations.**

Note: The 2018 UNEP report "Progress on integrated water resources management: Global baseline for SDG 6 Indicator 6.5.1: degree of IWRM implementation" is a global assessment of the world´s progress towards implementation of IWRM. It is based on the responses provided by governments of 172 countries to more than 60 questions distributed across the four dimensions of the IWRM framework: enabling environment, institutions and participation, management instruments and financing (see Figure 5). For each question, countries were asked to provide evidence of their progress on a specific aspect of the IWRM framework as well as a score between 0 and 100 to quantitatively assess their performance on that aspect. An average score for each of the four dimensions of IWRM was then calculated to provide an overall indication of the progress achieved, and to highlight areas where additional efforts were needed.

The UNEP report provides a rich source of information on water resources management in the countries that contributed to the report´s preparation. However, readers should recall that

information provided by the countries was not verified by UNEP and that the assessments may reflect varying degrees of self-reporting bias. Nevertheless, in the case studies of the present report, the average scores for each of the four dimensions of the IWRM framework are provided as a starting point for the discussions on current levels of IWRM implementation (Figure 7). The scores also facilitate comparisons among the four dimensions for a given country, as well as among all three of the case study countries.

Figure 7 Assessment of IWRM progress in each of the case study countries (UNEP 2018)

	Average scores for each of the four dimensions of IWRM, as reported by the countries			
Country	Enabling environment	Institutions and participation	Management instruments	Financing
Lebanon	37/100	40/100	40/100	12/100
Montenegro	50/100	28/100	40/100	20/100
Morocco	68/100	69/100	64/100	55/100

5. Case study: Lebanon

5.1 General information

Lebanon is a small country (10,200 km^2) in the Middle East bordered on the north and east by Syria and on the south by Israel. In 2017, it had a population of 6.1 million (World Bank 2018), including an estimated 1.5 million people seeking refuge from the ongoing war in neighboring Syria. Lebanon's governance structure is deeply influenced by the country's religious sectarianism. After Lebanon gained independence from France in 1945, its communities agreed to a "national pact" that dictated that positions of power in government would be shared among the primary religious groups: the president must be a Maronite Christian, the Prime Minister a Sunni Muslim and the President of the Chamber of Deputies a Shiite Muslim. This power sharing agreement is still in effect and is also extended to the posts in the government, which in theory are allocated on the basis of affiliation with religious groups, according to their relative importance in the population (Lacoste 2009, 388). After the Second World War, Lebanon enjoyed a period of prosperity until 1975 when a 15-year civil war ensued. The country was further devasted during its 2006 war with Israel. As a result of these conflicts, the current Syrian refugee crisis and its political sectarianism, the government of Lebanon faces significant challenges to natural resources management, including fragile water management institutions and infrastructure. It is currently working with several UN agencies to address the specific challenges arising from the influx of refugees, including the need for housing, food, clean water and sanitation.

5.2 Water profile

Water resources. It is estimated that the annual net exploitable surface water and groundwater resources[3] in Lebanon are approximately 2.08 km^3, of which 1.58 km^3 of surface water and 0.50 km^3 of groundwater. The three largest river basins in Lebanon cover about 45% of the country, and there are eight major aquifers. Since its elevation is greater than that of its neighboring countries, most of Lebanon's water resources originate within the country. Although Lebanon's average annual precipitation is 823 mm and 17 of its 40 large rivers have perennial flows, it is

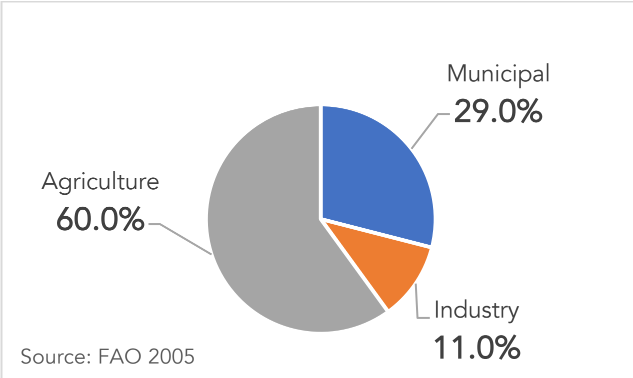
[3] The term "exploitable groundwater resources" means the amount of water that can be annually extracted from a given aquifer under current socioeconomic constraints and ecological conditions.

characterized as having high water risk (World Resource Institute 2019). This is due primarily to the country's limited capacity to capture and store water for use during the seven dry months of the year, its aging water infrastructure, widespread water pollution and the Syrian refugee crisis. According to one Lebanese hydrologist, the amount of available renewable water in the country has dropped from more than 1,000 m^3/capita/year – considered the threshold of water poverty – to around 700 m^3/capita/year since the refugees arrived (The Guardian 2016). However, it should be noted that Lebanon is relatively water-rich when compared to other Middle Eastern countries like Jordan which has only about 156 m^3/capita/year (Government of Lebanon 2010, 6); Lebanon's water scarcity is largely due to institutional and infrastructure challenges (IIED 2017), rather than actual scarcity of the resource itself. Finally, water resources in Lebanon are projected to become more vulnerable with the impacts of climate change that are expected in the region: decreased annual precipitation and longer, hotter summers (IPCC 2014, 1209 – 1210).

Water supply sources. In 2005, FAO estimated that 1.31 km^3 of freshwater was used in Lebanon, supplied in the following manner: 0.7 km^3 (53.4%) from groundwater, 0.396 km^3 (30.2%) from surface water and 0.214 km^3 (16.4%) from non-conventional water sources, most notably recycled agricultural drainage water (0.165 km^3) and desalinated water (0.0473 km^3). Groundwater supplies 80% of the country's potable water and 50% of its irrigation water (IIED 2017). The figures for 2005 show that Lebanon's groundwater extractions (0.7 km^3) were greater than the net exploitable groundwater resources (0.5 km^3), indicating that extractions were exceeding the natural recharge rates of the country's aquifers.

Water use by sector. Difficulties arise in reliably estimating the sectoral use of water in Lebanon since illegal wells are widespread (IIED 2017) and leakage from water distribution systems is on the order of 35 to 50%. That being said, FAO estimates that agriculture (irrigation and livestock) accounts for 60% of all water use, followed by municipalities (29%) and industry (11%) (Figure 8). Water supply service in the country is unreliable due to frequent power outages in hot, dry months that prevent pumping and delivery of water. Many homes in the Beirut area, for example, have only three hours of water service per day; as a result, people of all socio-economic groups supplement municipal supplies with other water sources (bottled water, illegal wells, etc.) (IIED 2017).

Figure 8 Estimated freshwater use in Lebanon in %, by sector[4] (FAO 2005)



Water pollution. Lebanon's water resources experience widespread pollution from untreated municipal and industrial wastewaters: it is estimated that only 3% of the country's wastewater receives secondary treatment before it is discharged into the environment (IIED 2017). Pesticides and fertilizers from agricultural activities also leach into both surface water and groundwater bodies. While public utilities treat water prior to distribution (mainly groundwater), many thousands of illegal wells exist from which people extract and use groundwater directly from aquifers without treatment; this is alarming considering that the contamination and depletion of groundwater have reached "catastrophic" levels (Foreign Policy 2019). In coastal areas, many aquifers also experience intrusion of seawater as a result of over-extraction of groundwater (UNESCO 2015b, 27).

Anticipated future water demands. By 2100, Lebanon's domestic water demands are projected to decrease by 28% with respect to the 2020 baseline (UNDESA 2017, 24 and Neverre and Dumas 2015, 10). This estimate assumes that the future population levels in Lebanon will eventually return to the 2010 levels, prior to the influx of refugees from Syria (Figure 9). No reliable data was available to estimate the future water demand of industry or agriculture, although these can be expected to vary directly with human population levels.

[4] These estimates are from 2005, the latest year for which reliable estimates are available. They do not fully reflect current water use, especially considering the additional pressure on the resource exerted by the 1.5 million Syrian refugees that are estimated to have entered the country since 2011.

Figure 9 Projected population and domestic water demands in Lebanon, 2020 to 2100 (UNDESA 2017 [population] and Neverre and Dumas 2015 [water demand])

Year	Population (thousands)	Municipal water demand[5] (Mm^3)
2020	6,020	571.90
2025	5,606	532.57
2030	5,369	510.06
2040	5,392	512.24
2050	5,412	514.14
2060	5,368	509.96
2070	5,200	494.00
2080	4,904	465.88
2090	4,594	436.43
2100	4,350	413.25

5.3 Main issues of concern for water resources

The main issues of concern for water resources in Lebanon are the following:

- Insufficient quantities of water to meet the needs of municipalities (the country is now below the water poverty threshold of 1,000 m^3/capita/year) and those of the country's 1.5 million refugees, many of which reside in informal settlements.
- Frequent interruption of water supply service due to electricity outages during the country's seven dry months.
- Widespread pollution of surface water and groundwater resulting from discharge of untreated wastewater. People relying on illegal wells run the risk of consuming polluted groundwater.
- Seawater intrusion in coastal aquifers that supply drinking water to municipalities.
- Insufficient data on the quantity and quality of the country's surface water and groundwater resources, their links to ecosystems and the potential impacts of climate change.

Conjunctive management approaches could be employed to alleviate some of the issues of concern associated with water quantity. To combat water scarcity, river water could be captured before its discharge to the sea and stored in the subsurface space of aquifers to be used during the

[5] The projected demands do not account for the losses that occur in Lebanon's pubic water distribution network, which are on the order of 35 to 50%.

country's seven dry months. Non-conventional sources of water such as desalinated seawater could provide an additional source of safe drinking water. Managed aquifer recharge could be used to prevent further intrusion of seawater in coastal aquifers. Finally, the implementation of integrated monitoring networks for surface water and groundwater would increase the data that could be used in hydrological models to better plan water use and protect ecosystems affected by water extractions.

5.4 Overview of IWRM implementation progress and implications for conjunctive management

This section describes the current state of IWRM implementation in Lebanon, and its implications for the initiation of conjunctive management approaches. It is based primarily on data provided by the government of Lebanon to UNEP for a 2018 report titled "Progress on integrated water resources management: Global baseline for SDG 6 Indicator 6.5.1: degree of IWRM implementation" and on complementary information from the government, the literature and the press. In the 2018 UNEP report, the government of Lebanon assessed its own progress towards implementation of the elements of the IWRM framework as follows:

- Enabling environment: 37/100
- Institutions and participation: 40/100
- Management instruments: 40/100
- Financing: 12/100

These scores provide a means of gauging Lebanon's overall progress on the four dimensions of the IWRM framework, and for benchmarking with other countries that contributed to the UNEP report. In the proceeding discussion, evidence is provided to demonstrate the progress achieved in each of the four dimensions of the IWRM framework in Lebanon, followed by observations about how the current state of IWRM implementation may impact the country's ability to move forward with conjunctive management approaches.

Enabling environment (Score: 37/100). Lebanon has a moderately strong enabling environment for IWRM, although many of the plans and policies supporting this approach remain largely unimplemented. Lebanon's 2010 Water Strategy, for example, provides a detailed

roadmap for improving water management in the country and documents several actions to promote integrated management of water resources, including implementation of IWRM among the state water authorities, strengthening of legal frameworks for water and wastewater services, better engagement of water users in the management process, and water tariffs based on metered consumption rather than flat fees (Government of Lebanon 2010, 58). Furthermore, Lebanon's water laws clearly define responsibilities for water management authorities and provide a robust legal framework for the allocation of permits for water exploitation, requirements for wastewater treatment, and penalties for noncompliance. In terms of transboundary water cooperation, Lebanon has established an agreement with Syria for the Orontes and Al-Kabir rivers which are shared between the two countries.

Implications for conjunctive management: Lebanon has an enabling environment that is favorable to conjunctive management. Its Water Strategy recognizes that groundwater resources are being used excessively and that there is a need to further develop surface water sources and water storage options (Government of Lebanon 2010, 42). It furthermore calls for the development of master water plans, legislation on groundwater protection zones, and requirements for integrated monitoring of surface water and groundwater (Government of Lebanon 210, 101), all of which (when implemented) would contribute to a strong enabling environment for the implementation of conjunctive management approaches.

Institutions and participation (Score: 40/100). Lebanon's water institutions have well-defined mandates with responsibilities for implementation of many of the elements of the IWRM framework. However, these institutions lack much of the capacity to carry out their responsibilities (both in terms of technical capacity and financing), and each institution tends to work in its own silo: there is little coordination among them regarding water resources policy, planning and management. The Ministry of Energy and Water (MEW) is responsible for water resources, with duties including the setting of overarching policies, monitoring of water availability and quality; setting water quality standards; allocation of water for potable uses and irrigation at the national level; issuing water permits; and decisions about water infrastructure (dams, river flow correction, etc.), amongst others. The Ministry of Agriculture oversees the irrigation projects approved by the MEW. The country's four regional water authorities and the Litani River Authority – which all operate as autonomous entities – are responsible for the

extraction, treatment and distribution of potable water and irrigation water, as well as for the collection and disposal of wastewater. Management decisions at the level of the river basin or aquifer are taken by the regional water authorities; there are no river basin or aquifer organizations. The government states that there is no long-term strategy for capacity building for IWRM: capacity is built solely through short-term projects with regional and international partners. In terms of participation, NGOs frequently partner with the government on water resources projects, and opportunities exist for the participation of the private sector in the country's water and sanitation sectors.

Implications for conjunctive management: The limited coordination among Lebanon's water institutions and the independence of its regional water authorities do not promote a unified approach to water resources management, or for the joint management of surface water and groundwater. While Lebanon's Ministry of Environment and Water functions as a kind of "apex" water institution setting water policy and allocating extraction rights for surface water and groundwater, it is the five autonomous regional water authorities that are responsible for the extraction, treatment and distribution of water. While these authorities are exploiting both surface water and groundwater, it is unlikely that they are doing so in a manner that considers them a single, connected resource, given the near absence of monitoring data and the limited understanding of the interactions between them.

In terms of participation of civil society and the private sector in the management of water resources at the local level, there is evidence that there is political will to scale up this type of participation. In its 2010 Water Strategy, the Ministry of Water and Environment calls for the engagement of farmers in water user associations and the private sector in the water and wastewater sectors. This type of participation at the local level will feed into dialogues about competing uses for surface water and groundwater, and provide water authorities with additional perspectives on the benefits and trade-offs associated with their management decisions.

Management instruments (Score: 40/100). Despite clear institutional mandates for the use of management tools and techniques (monitoring, management plans, financial incentives, etc.), it appears that very few management instruments are in place or used effectively. Water availability is not monitored regularly by the government; much of the data is generated through

academic research and case studies. Potable water quality in public distribution networks is monitored by the regional water authorities, but there is no water quality monitoring for private wells, legal or illegal, which are widespread and used across the country as a source of drinking water and water for non-potable purposes. Water use management is difficult to implement since water metering is almost non-existent: most municipal water users pay a flat rate, and farmers pay for water based on the irrigated land area, not actual consumption. The exception to this is within the city limits of Beirut, where smart water meters were installed in 2018 to incentivize residents to reduce water consumption by paying only for the volume of water actually consumed, rather than a flat fee (Lebanon Daily Star 2018). Finally, there are no specific management plans for river basins or aquifers (i.e., development, use, and protection plans) that integrate the principles of IWRM.

Implications for conjunctive management: There are few management instruments in place to promote the conjunctive management of surface water and groundwater. Those that exist include studies on the delineation and hydrological characterization of the country's main rivers and aquifers, national water balances, and water meters to assess tariffs based on consumption (in Beirut only). Without fundamental management instruments such as better pollution control systems, monitoring systems for water quantity and quality, and numerical models to further the understanding of interactions between various elements of the hydrological cycle, it will be difficult to implement conjunctive management approaches among the water authorities.

Financing (Score: 12/100). Financing is the weakest component of the IWRM framework in Lebanon, with the government declaring that there are insufficient national budgets for most water resources infrastructure needs and for the majority of IWRM elements. Rates of revenue collection among the regional water authorities vary widely and explain a part of this budget shortfall. The Beirut and Mount Lebanon Authority recovers 80% of its costs through collected revenues, but the other three achieve only modest recovery rates: South Lebanon (65%), North Lebanon (58%) and Bekaa Valley (37%) (IIED 2017). That said, a major underlying cause of the lack of financing for the water sector (and for all government services) is the Syrian refugee crisis, which has deeply affected the country's economy and social support system. It is estimated that Lebanon has sustained more than US$ 13.1 billion in losses since 2012 as a result of this humanitarian crisis (Government of Lebanon and the United Nations 2017, 101) and is

currently more than US$ 80 billion in debt (Foreign Policy 2019). However, there is some positive news: since 2013, the international donor community has mobilized more than US$ 6.4 billion in aid to Lebanon to respond to the crisis, including support to Lebanese infrastructure such as roads, water and waste management (Government of Lebanon and the United Nations 2017, 8).

Implications for conjunctive management: Given the financial crisis in Lebanon, any investment to promote conjunctive management would have to demonstrate a low cost/high benefit to compete with the country's other pressing concerns.

5.5 Key challenges to implementing conjunctive management approaches

As we have seen, conjunctive management approaches could potentially alleviate some of the water quantity issues of concern in Lebanon. However, the country's IWRM framework at present is not sufficiently developed to implement these approaches. The key challenges to moving towards conjunctive management are set forth in Figure 10, articulated for each of the four dimensions of the IWRM framework.

Figure 10 Key challenges to implementing conjunctive management approaches in Lebanon

IWRM dimension	**Challenges for the implementation of conjunctive management approaches**
Enabling environment	• Weak implementation of policy framework that already includes references to IWRM and many principles of conjunctive management.
Institutions and participation	• Lack of institutional and human capacity for the implementation of the elements of the IWRM framework in general, and conjunctive management approaches in particular. • Limited coordination among government ministries that set water policy and regional water authorities that manage water supplies and provide water services.
Management instruments	• Limited knowledge of the impacts of current water management practices on water resources availability and ecosystems, due to absence of monitoring systems for surface water and groundwater.
Financing	• Insufficient public financing and water revenues for the operation of public water authorities and for the improvement of the country's water and wastewater infrastructure.

5.6 Recommendations

While conjunctive management approaches hold great potential for alleviating some of Lebanon's water supply challenges, including water scarcity and seawater intrusion in coastal aquifers, they can only be effective when implemented within a stronger IWRM framework. The recommendations therefore encompass actions that, on the one hand, will strengthen the current IWRM framework and, on the other hand, build knowledge about water resources that can later be used to inform decisions about water supply management, including decisions to implement conjunctive management approaches.

The recommendations for Lebanon are set forth below, organized according to the four dimensions of the IWRM framework.

Enabling environment

- **Prepare a national master water plan that incorporates the principles of IWRM - including conjunctive management - and translate it into regional plans for the five regional water authorities.** In addition to provisions for infrastructure investments, pollution prevention and water demand measures, the master plan should include water supply management objectives that promote the conjunctive management of surface water and groundwater. These objectives should make reference to (i) maximizing the potential of surface water resources (which are underexploited in Lebanon); (ii) improving the management of groundwater, by reversing the current trends of over-extraction; (iii) promoting the storage of water in surface reservoirs or in the subsurface space of aquifers; and (iv) protecting ecosystems that rely on exploited water resources. The preparation of the regional plans should be undertaken jointly by the Ministry of Environment and Water, the Ministry of Agriculture and the five regional water authorities that will ultimately implement the plans on the ground. The regional plans should also make reference to the needs of the country's refugee population which has in many cases been relegated to areas underserved by water and wastewater infrastructure.

Institutions and participation

- **Design and implement a capacity-building programme on integrated water resources management for water and natural resource managers at the Ministry of Energy and Water, the Ministry of Agriculture and the five regional water authorities.** The focus of the capacity-building programme should be on the elements of the IWRM framework that pose particular challenges to water resources management in Lebanon, namely management instruments and financing. With respect to management instruments, training materials could be developed on the use of integrated monitoring networks for surface water and groundwater quantity and quality, hydrological models to inform decisions about allocation of water resources, groundwater protection zones, and the licensing of illegal wells, for example. The application of these instruments to conjunctive management approaches should be stressed, especially managed aquifer recharge as a means of storing excess surface water and combatting seawater intrusion, as well as the quantification of environmental flows in planning water allocations at the level of the river basin. In terms of financing mechanisms, capacity-building should be oriented towards methodologies for establishing water tariffs that promote financial autonomy among the regional water authorities, and strategies to increase recovery of revenues from users of water services.
- **Establish a formal coordination mechanism among the government ministries that set water policy and law, and the regional water authorities that provide water and wastewater services.** The objective of the mechanism is to ensure coherency between water policies, regulations and plans established by the Ministry of Water and Environment and the Ministry of Agriculture and the water and wastewater services delivered to customers by the five regional water authorities. It would also represent a practical platform for the sharing of experience and data on water resources, making joint decisions on the establishment of water tariffs, and reporting on progress towards water supply management objectives. This coordination mechanism could build on the example of Lebanon's Inter-sector Working Group and its water sub-group established for the UN's Lebanon Crisis Response Plan (Government of Lebanon and the United Nations 2017, 22). The joint development of the regional master water plans would represent an ideal opportunity for the initiation of such a coordination mechanism.

Management instruments

- **Design and implement a pilot monitoring network for the country's priority surface watercourses and groundwater bodies.** The objective of the pilot monitoring network is to build the scientific knowledge base that is used to make water supply management decisions. The monitoring network should gather data on water quantity and quality trends associated with climatic conditions and water extractions; salinization (in the case of coastal aquifers); and status of water-related ecosystems. It should make use of modern technologies including wireless instrumentation and geographic information systems (GIS). A training programme on the monitoring protocols should be delivered to the operators of the network and field technicians well in advance of the network's launch. Data generated by the monitoring network can then be used as inputs to numerical hydrological models to enable water managers to make more informed, strategic decisions about where and when to extract or store water throughout the year.

- **Assess the country's main aquifer systems to determine their suitability for managed aquifer recharge as a means of (1) augmenting water reserves or (2) combatting seawater intrusion.** As a first step, the priority aquifers for assessment should be identified, including (1) aquifers in proximity to existing water supply infrastructure and surface watercourses with exploitation potential; and (2) all major coastal aquifers exploited for drinking water or irrigation water where seawater intrusion is impacting water quality. Then, through a combination of existing data and new field investigations (as needed), the following information should be gathered to determine each aquifer's recharge process: aquifer occurrence (confined or unconfined), hydrogeology, topography, soil type, land-use and proximity to pollution sources, and climate. For those aquifers considered as potential sites for subsurface water storage, additional considerations should include local capacity of electrical networks for groundwater pumping, in view of the weakness of the country's electrical grids. Finally, all priority aquifers should be further evaluated to determine storage potential and costs for injection wells or spreading basins, depending on the aquifer type.

- **Expand the use of smart water meters and volumetric water tariffs to additional cities and to the agricultural sector.** With the exception of households in Beirut, there is no

metering of individual consumption of water in Lebanon. Users are charged a flat rate, which discourages conservation and transparency in water pricing. Expanding smart water meters to other large cities and to the agricultural sector is an important first step towards full cost recovery for water services provided by the country's five regional water authorities. It also represents a potentially effective mechanism to manage water demand (by incentivizing people to use water wisely) through volumetric tariffs and therefore to reduce pressures on surface water and groundwater supplies.

Financing

- **Develop a strategy for the five regional water authorities to increase recovery of revenues from water users (water supply, wastewater and irrigation).** Cost recovery rates for the country's regional water authorities range from 37% to 80%; the uncollected revenues are preventing the water authorities from attaining financial autonomy and diminishing their ability to maintain treatment and distribution infrastructure. The government of Lebanon could establish a partnership with private sector companies that excel at billing and payment recovery, and undertake an assessment of barriers to cost recovery in coordination with one of the water authorities, with the aim of testing solutions that could later form the basis of a nationwide strategy. The rollout of the network of smart meters would be an opportunity to engage customers on new contract terms and payment modalities, in the context of implementation of this proposed nationwide cost recovery strategy for water and wastewater services.

6. Case study: Montenegro

6.1 General information

Montenegro is a small Balkan country occupying 13,800 km^2 in southeastern Europe with a population of approximately 620,000 (World Bank Group 2018). It was part of the Federal Republic of Yugoslavia (1992 – 2002), and then the joint state of Serbia and Montenegro (2002 – 2006), before declaring its independence from Serbia in 2006. Since 2012, it has been working towards admission to the European Union, and harmonization with the EU's Environmental Acquis including the EU Water Framework Directive[6] and other directives aimed at strengthening environmental governance.

6.2 Water profile

Water resources. Montenegro has ample water resources, but they are unevenly distributed across the country: karst areas in the central and western parts are arid, whereas the northern mountainous areas are richer in water (World Bank 2015, 2). The land area of the country is divided roughly equally between the Adriatic and the Danube catchments, with 95% of watercourses originating within the country. The quality of surface water and groundwater is generally good. According to the Aqueduct Water Risk Atlas (World Resources Institute 2015), Montenegro has a low baseline water stress, meaning that the total annual withdrawals of freshwater for municipal, industrial and agricultural activities are small in comparison to the total annual available blue water resources. Water resources in Montenegro, as in all Mediterranean countries, are projected to become more vulnerable with the impacts of climate change that are expected in the region: decreased annual precipitation and longer, hotter summers (IPCC 2014, 1209 – 1210). As a result, the country could experience intermittent flows of some surface

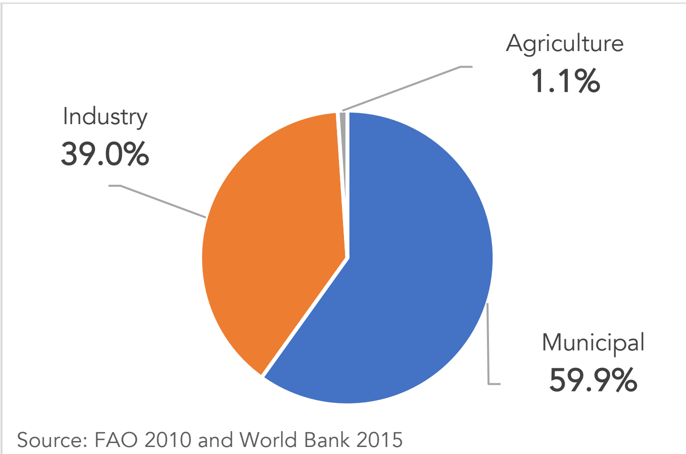
[6] The EU Water Framework Directive (WFD) can be roughly compared to the US Clean Water Act. Both laws aim to improve the management of water resources and the health of water bodies, although they differ in their respective degrees of comprehensiveness and enforceability (Council for European Studies 2018). First, the EU WFD represents a more comprehensive approach to water resources management, since its addresses surface water, groundwater and coastal zones. This is in contrast to the CWA, which is primarily focused on navigable (surface) waters. Second, the EU WFD employs a holistic approach to water resources management, seeking to achieve good environmental status of water bodies. This differs from the approach of the CWA which concentrates on the reduction of sources of surface water pollution. And finally, the WFD has proven more challenging to enforce than the CWA, since the obligations of EU member countries under the WFD are more complicated than the CWA's comparatively straightforward pollution permitting system.

watercourses and decreased groundwater reserves. At the same time, the research gathered by the IPCC indicates that the northern Mediterranean (including Montenegro) will experience more of its precipitation in the wet winter months. This has important implications for water management in Montenegro, which has experienced significant floods in the past, and currently has 24,500 hectares of farmland and urban areas in high flood risk zones (World Bank 2015, 2), including the capital city of Podgorica.

Water supply sources. Montenegro relies heavily on groundwater to meet its water needs: nearly two-thirds of Montenegro's annual withdrawals of freshwater come from groundwater reserves (World Bank 2015, 3). In 2010, public water utilities in Montenegro extracted about 94 Mm^3 of freshwater to supply municipalities (FAO 2010), of which 90% from groundwater reserves (World Bank 2015, 3). Industries in Montenegro rely primarily on water they extract themselves, not on water from public utilities. In 2010, industries withdrew about 62 Mm^3 of freshwater, of which two-thirds from surface watercourses and the remainder from groundwater reserves (FAO 2010). Groundwater supplies virtually all of the fresh water used in the country's irrigated agriculture.

Water use by sector. Municipalities are the primary users of water resources in Montenegro, consuming nearly 60% of the total annual freshwater withdrawals (Figure 11). It should be noted that the losses from the public utility distribution system are significant: in 2017, nearly 60% of the water extracted and treated by public utilities was lost from the distribution system due to leakage (MONSTAT 2017a). Industries account for 39% of total annual freshwater withdrawals, used primarily by industries in the electricity, gas and steam supply sector (MONSTAT 2017b). Agriculture is a minor user of water resources, accounting for just 1% of total annual freshwater withdrawals.

Figure 11 Estimated freshwater use in Montenegro in %, by sector (FAO 2010 and World Bank 2015)



Water pollution. The pollution of fresh water resources in Montenegro is attributed primarily to point sources: discharge of untreated communal wastewaters and industrial wastewaters (World Bank 2015, 3 and UNESCO 2015a, 19). In coastal areas, the intrusion of saline waters in aquifers has also been observed in summer months when water withdrawals by public utilities (mainly from groundwater) increase significantly to meet the needs of tourists (UNESCO 2015b, 21). The intrusion of seawater in coastal aquifers may increase the risk of other forms of pollution in coastal aquifers as well, since Montenegro's coastal municipalities discharge their wastewaters directly to the sea without any treatment (World Bank 2015, 3).

Anticipated future water demands. By 2100, Montenegro's domestic water demands are projected to decrease by 28% with respect to the 2020 baseline (UNDESA 2017, 24 and Neverre and Dumas 2015, 10). This is due to the anticipated net decrease in the country's population, which is expected to peak at 629,000 in 2020 and then decrease to 449,000 by 2100 (Figure 12). No reliable data was available to estimate the future water demand of industry or agriculture; however, these can be expected to vary directly with human population levels.

Figure 12 Projected population and domestic water demands in Montenegro, 2020 to 2100 (UNDESA 2017 [population] and Neverre and Dumas 2015 [water demand])

Year	Population (thousands)	Water demand[7] (Mm^3)
2020	629	59.76
2025	628	59.66
2030	625	59.38
2040	610	57.95
2050	588	55.86
2060	563	53.49
2070	535	50.83
2080	505	47.98
2090	475	45.13
2100	449	42.66

6.3 Main issues of concern for water resources

The main issues of concern for water resources in Montenegro are the following:

- Pollution of surface water and groundwater due to discharges of untreated domestic and industrial wastewater.
- Seawater intrusion in coastal aquifers resulting from over-extraction of groundwater in summer months.
- Extremely high losses of water from municipal water supply systems.
- Important flood risks to farmland and urban areas (previous floods have damaged wastewater and water infrastructure, leading to water shortages).
- Insufficient data on the quantity and quality of the country's surface water and groundwater resources, their links to ecosystems and the potential impacts of climate change.

Conjunctive management approaches could be employed to alleviate some of the issues of concern associated with water quantity. Most notably, managed aquifer recharge represents a solution to the issues of seawater intrusion and flooding. In coastal aquifers, the injection or infiltration of surface water can be used to reverse the encroachment of saline waters into the

[7] The projected demands do not account for the sizeable losses that occur in the pubic water distribution network: in 2017, Montenegrin public utilities estimated that nearly 60% of water extracted for municipal use was lost to leakage.

freshwater stored in the aquifer. In other areas, the unsaturated zones of aquifers can be adapted to intercept overland or surface flows, thereby reducing downstream flood risks. Finally, the implementation of integrated monitoring networks for surface water and groundwater would increase the data that could be used in hydrological models to better plan water use and protect ecosystems affected by water extractions, and to better anticipate the impacts of climate change on water resources.

6.4 Overview of IWRM framework and implications for conjunctive management

This section describes the current state of IWRM implementation in Montenegro, and its implications for the initiation of conjunctive management approaches. It is based primarily on data provided by the government of Montenegro to UNEP for a 2018 report titled "Progress on integrated water resources management: Global baseline for SDG 6 Indicator 6.5.1: degree of IWRM implementation" and on complementary information from the government and the literature. In the 2018 UNEP report, the government of Montenegro assessed its own progress towards implementation of the elements of the IWRM framework as follows:

- Enabling environment: 50/100
- Institutions and participation: 28/100
- Management instruments: 40/100
- Financing: 20/100

These scores provide a means of gauging Montenegro's overall progress on the four dimensions of the IWRM framework, and for benchmarking with other countries that contributed to the UNEP report. In the proceeding discussion, evidence is provided to demonstrate the progress achieved in each of the four dimensions of the IWRM framework in Montenegro, followed by observations about how the current state of IWRM implementation may impact the country's ability to move forward with conjunctive management approaches.

Enabling environment (Score: 50/100). Of the four components of the IWRM framework implemented thus far in Montenegro, it is the enabling environment of laws, policies and plans that is the strongest component. Montenegro's Law on Waters (2007) governs the legal status of

water resources and promotes the integrated management of waters, river basin land and riparian land and water facilities. In Article 6 of this law, water is designated as state property and an asset of common interest. The country's long-term national water management objectives are set forth in the Water Management Strategy. In terms of planning for the use and conservation of water resources, river basin management plans are currently under development but not yet approved for the Danube and Adriatic Basins (the two basins in which Montenegro is located). Montenegro shares these basins with its neighboring countries and has accordingly developed (and partially implemented) arrangements for transboundary water management with Croatia, Bosnia and Herzegovina, Slovenia and Albania.

Implications for conjunctive management: Montenegro has established the foundations of a strong enabling environment for the implementation of conjunctive management approaches by promoting the integrated management of waters, river basin land and riparian land and water facilities in its Law on Waters. Furthermore, it has adopted the river basin as the appropriate management unit for water resources. That said, it has yet to finalize and implement any river basin management plans.

Institutions and participation (Score: 28/100). Montenegro has clearly defined institutional responsibility for the various aspects of integrated water resources management; however, it lacks the capacity to translate many of IWRM's principles into practice. The Ministry of Agriculture and Rural Development is responsible for the management of water resources, and it implements policies through its Water Administration. Other institutions with mandates related to water include the Geological Survey of Montenegro (assessment and protection of groundwater resources), the Ministry of Sustainable Development and Tourism (advising on law related to water quality and sanitary protection), the Environmental Protection Agency (monitoring of water quality) and the Ministry of Economy (decisions about hydropower concessions) (UNESCO 2015a, 43 – 44). A Water Working Group has been established to improve communication and cooperation between these institutions, which represents an important asset. That said, the government of Montenegro has declared that it lacks capacity for the implementation of many elements of the IWRM framework, and that the limited capacity development for IWRM happens primarily through short-term, project-based activities. Furthermore, there are not yet any dedicated basin authorities to lead the implementation of river

basin/aquifer management plans. In terms of the engagement of non-government stakeholders in decisions related to water resources, there are provisions in Montenegro's Law on Waters for public participation in the preparation and adoption of river basin management plans and flood risk management plans; however, there is not currently a mechanism for engagement of the private sector in these activities.

Implications for conjunctive management: Montenegro's institutions are structurally well prepared to facilitate the conjunctive management of surface water and groundwater. Montenegro has a single ministry designated with overall responsibility for water resources (the Ministry of Agriculture and Rural Development) and also regularly convenes a Water Working Group to bring together the other government institutions responsible for water and water-related issues. In theory, this Working Group represents a valuable platform for the exchange of information and the joint planning of surface and groundwater resources. However, without the human and institutional capacity for IWRM and conjunctive management approaches, there is limited potential for their implementation. Furthermore, no management bodies exist at the sub-national or local levels to manage water resources (i.e., river basin management organizations or aquifer councils) or to engage civil society or private sector stakeholders in decision-making processes. This is another important gap in the IWRM framework that would otherwise support conjunctive management approaches by bringing together the users of surface water and groundwater and addressing issues emerging from the interactions between this single, connected resource.

Management instruments (Score: 40/100). Montenegro has implemented some management instruments to promote IWRM, but is not yet prepared to implement the full range of management instruments that underpin integrated water resources management. The management instruments in place at the national level are those for pollution control, sustainable water management and reduction of risks from water-related disasters. At present, there are no river basin/aquifer management instruments or instruments to manage water-related ecosystems. Furthermore, there is very limited national monitoring of the quantity and quality of the country's surface water and groundwater. Finally, Montenegro has reported adequate levels of water data and information sharing within the country as well as with neighboring countries on transboundary water resources.

Implications for conjunctive management: While the existing management instruments provide valuable information to prepare water budgets and to limit the discharge of untreated wastewaters, they do not generate the scientific data required to manage surface water and groundwater in a holistic manner. Furthermore, few hydrogeological investigations have been conducted to determine interactions between surface water and groundwater, and to assess the extent of seawater intrusion in coastal aquifers. Finally, there is no metering of the water consumption of non-commercial facilities such as schools, hospitals, agricultural producers, or of individual wells; this will impede future efforts to recover additional water tariffs from consumers to finance necessary operation, maintenance and investment for the country's water infrastructure. The insufficient monitoring data for water resources do not enable management authorities to effectively detect problems or plan to take preventive actions to avoid threats such as seawater intrusion in coastal aquifers or flooding.

Financing (Score: 20/100). Financing emerges as the weakest component of Montenegro's IWRM framework, with insufficient national budgets to implement many of the elements of the IWRM framework. The situation is further complicated by the fact that Montenegro must secure €640 million for infrastructure investments for water and sanitation to comply with EU directives by 2030 (World Bank 2015, 2), although these investments will directly support the implementation of many of the missing elements of the IWRM framework in Montenegro. The country reports that national budgets for water resources infrastructure and have been allocated for the recurrent costs of about half of the required IWRM framework elements. Processes have been formulated to capture local revenues for water at the level of the river basin or aquifer, but these have not yet been fully implemented. At present, only 35% of the required financing for the country's water and wastewater services is generated from water tariffs, the rest from taxes and transfers from the budgets of other government bodies (World Bank 2015, 8). This situation is likely to change in the near future, since according to the World Bank (2015) "a significant increase in water tariffs is expected in the coming years." Finally, there is limited financing to support transboundary cooperation for shared water resources.

Implications for conjunctive management: Without a self-sustaining financing mechanism for water and wastewater services, Montenegro will struggle to implement additional elements of the

IWRM framework, including those that underpin conjunctive management approaches. That said, the country must eventually finance the fundamental management instruments required under the Water Framework Directive, including monitoring networks for surface water, groundwater and protected areas (European Commission 2003). Once implemented, these instruments will generate valuable data that can be used to design better water supply management strategies that may include conjunctive management approaches.

6.5 Key challenges for the implementation of conjunctive management approaches

While conjunctive management approaches represent viable solutions to the issues of seawater intrusion and flooding in Montenegro, the current IWRM framework must evolve before these can be implemented. The key challenges to moving towards conjunctive management are set forth in Figure 13, articulated for each of the four dimensions of the IWRM framework.

Figure 13 Key challenges to implementing conjunctive management approaches in Montenegro

IWRM dimension	Challenges for the implementation of conjunctive management approaches
Enabling environment	• Slow progress on finalization and implementation of river basin management plans.
Institutions and participation	• Lack of human and institutional capacity for integrated water resources management, including conjunctive management approaches. • Total absence of management institutions at the level of the river basin or aquifer.
Management instruments	• Near absence of monitoring data on the quantity and quality of surface water and groundwater. • Lack of water metering for noncommercial facilities, which represent a potentially significant category of water consumption.
Financing	• Insufficient financing/revenues to implement improvements to water and wastewater infrastructure.

6.6 Recommendations

For a small country that has existed as an independent state only since 2006, Montenegro has made a respectable effort towards establishing solid foundations for IWRM, most notably through a well-developed legal and policy framework in this domain. Nevertheless, the country must scale up efforts in all dimensions of its IWRM framework to translate the principles of

integrated water resources management into management actions on the ground. The proposed recommendations are designed to promote river basin planning, build institutional capacity, implement fundamental water resources management instruments, and increase revenues for water authorities. Together, these actions can assist the country in fulfilling its commitments under the EU Water Framework Directive, while strengthening its IWRM framework and consequently its ability to implement conjunctive management approaches.

The recommendations for Montenegro are set forth below, organized according to the four dimensions of the IWRM framework.

Enabling environment

- **Finalize and approve the river basin management plan for the portion of the Adriatic river basin district within Montenegro.** Montenegro has initiated, but has not completed, a river basin management plan for its portion of the Adriatic river basin district, a transboundary river basin district that it shares with Bosnia and Herzegovina, Croatia and Slovenia. As a candidate country for admission to the EU, Montenegro should ensure that its management plan is designed in accordance with the EU Water Framework Directive. The development of the river basin management plan should proceed in two phases. First, Montenegro should consult with the other countries of the Adriatic river basin district to gather information about the management plans that have already been established for the river basin district outside of Montenegro. Of particular value will be the discussions with Croatia and Slovenia, both EU member states, which have adopted plans for their portions of the Adriatic and the Danube river basin districts that meet the EU's legal requirements (European Commission 2015, 5). Next, Montenegro should devise a river basin management plan to cover those parts of the Adriatic river basin district within its territory, ensuring that it is harmonized with the plans already established by its neighbors. If possible, all countries sharing the Adriatic river basin district should adopt and implement a single international river basin management plan, as this is the ultimate goal of the Water Framework Directive.

Institutions and participation

- **Design and implement a capacity-building programme on integrated water resources management for water and natural resource managers at the relevant ministries and those working at the level of municipalities, where many of the water management decisions are taken.** The capacity-building programme should focus on the weaker elements of the IWRM framework in Montenegro, including the engagement of local stakeholders in water governance and management, the use of management instruments (including monitoring systems and numerical hydrological models), and principles of cost recovery for water and wastewater services. It should also include modules on conjunctive management approaches and their application to Montenegro's water resources issues (including seawater intrusion and flooding), and on the requirements of the EU Water Framework Directive.

- **Establish a river basin management organization for the Montenegrin portion of the Adriatic river basin district.** In parallel with the development of a river basin management plan for the Adriatic river basin district, Montenegro should establish a river basin organization and involve this body in the development of the plan and its future implementation. A first step would be to secure the engagement of stakeholders in local governments, civil society and the private sector that are involved in the use or governance of land or water resources in the Adriatic river basin district. In this way, the stakeholders can be involved in setting the environmental, social and economic objectives for the river basin, and contribute to the development of the river basin management plan. Guidance on establishing river basin organizations and transboundary cooperation can be sought from the International Network of Basin Organizations, the World Bank, the Global Water Partnership and UNESCO's International Hydrological Programme.

Management instruments

- **Design and implement a pilot monitoring network for the country's priority surface watercourses and groundwater bodies.** The objective of the pilot monitoring network is to build the scientific knowledge base that is used to make water supply management decisions. The monitoring network should gather data on water quantity and quality trends associated with climatic conditions and water extractions; salinization (in the case of coastal aquifers);

and status of water-related ecosystems. It should make use of modern technologies including wireless instrumentation and geographic information systems (GIS). The monitoring parameters and protocols should be established to conform with those set forth in the Water Framework Directive. A training programme on the monitoring protocols should be delivered to the operators of the network and field technicians well in advance of the network's launch. Data generated by the monitoring network can then be used as inputs to numerical hydrological models to enable water managers to make more informed, strategic decisions about where and when to extract water throughout the year.

- **Develop hydrological models of the country's priority surface watercourses and groundwater bodies, including their interactions and behaviors at the fresh water/seawater interface.** Once adequate monitoring data are available, it will be possible to develop and test models to predict the behaviors of surface water and groundwater under different scenarios taking into account changes in precipitation, evaporation, sea level rise, water demand, and land use. These models may then serve as a starting point for the development of strategies for the conjunctive use of surface water and groundwater, including managed aquifer recharge for the prevention of seawater intrusion and for flood management. Considering that the Mediterranean will be a climate change "hotspot" according to the IPCC (2014), it will be important to integrate considerations for climate change in these models to identify strategies to optimize the conjunctive use of surface water and groundwater (see Mani et al 2016).

- **Expand the requirement for water permits and meters to the non-commercial sector (hospitals, schools), the agricultural sector and private well users to improve knowledge about sectoral water use and to increase cost recovery for the water utilities.** Given the additional investments that Montenegro will need to comply with the water and wastewater infrastructure requirements of the Water Framework Directive, it is crucial to ensure that all water users are paying their fair share for the services they receive. Currently, the non-commercial sector, the agricultural sector and private well users are not required to obtain water permits or pay for water they use from municipal water supply systems or privately-owned wells. By expanding the requirement for water permits and volumetric metering,

Montenegro will be able to improve water demand management by incentivizing people to use water wisely (and therefore to reduce pressures on surface water and groundwater supplies), and also increase cost recovery for water utilities that are not able to keep pace with needed improvements to the country's aging water and wastewater infrastructure.

Financing

- **Undertake a review of the country's cost recovery strategy for water and wastewater services and determine priority actions to increase revenues or identify cost savings that will enable water utilities to move towards a self-sustaining financing model.** At a minimum, the country should consider increasing its water tariffs, which are extremely low for the region. In addition, the expansion of the use of water permits and meters to sectors that currently do not pay for water services represents a logical step towards generating additional revenues. Cost saving strategies that should be explored include the reduction of staff at the utilities (the World Bank [2015] found that the water sector in Montenegro was overstaffed compared to other Balkan countries) and the minimization of water leakage from the distribution system, which is currently estimated at 60% of the volume treated and distributed.

7. Case study: Morocco

7.1 General information

Morocco is a country with mountain ranges and extensive deserts located in the Maghreb region of northern Africa, with coasts on both the Mediterranean Sea and the Atlantic Ocean. It covers an area of 706,000 km^2 (including the Moroccan-administered zone of Western Sahara) and in 2017 had a population of 35,739,580 (World Bank 2019). Morocco was a protectorate of France from 1912 to 1956 and, unlike Algeria, maintained strong ties with the French government and economic sector after independence (Lacoste 2009, 240). Water and wastewater management was privatized in Morocco in the 1990s and in many large urban areas these services are provided through public-private partnerships with French companies such as Suez, which manages drinking water, sanitation and electricity distribution networks for the capital city of Rabat (Suez 2019). Morocco ranks as the fifth wealthiest African nation according to its gross domestic product (GDP) (IMF 2019).

7.2 Water profile

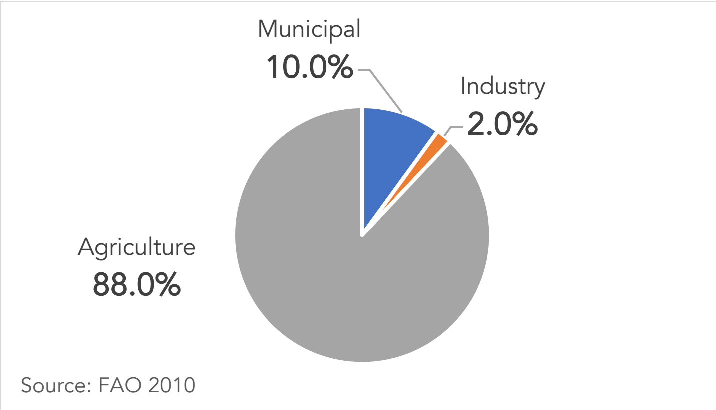
Water resources. Morocco's renewable water resources are estimated at 22 km^3/yr for surface water and 10 km^3/yr for groundwater. The volumes of water that are exploitable under technical and economic constraints, however, are smaller: 18 km^3/yr for surface water and 4 km^3/yr for groundwater. In 2014, Morocco's renewable internal freshwater resources were estimated at 845 m^3/capita/year, well below the threshold of water scarcity (1,000 m^3/capita/year). Morocco's surface water resources are unevenly distributed across the country, with 72% of surface water resources occurring within just three of the country's drainage basins. The country's main aquifers cover approximately 10% of the country's land area. Desalinated seawater is an important source of non-conventional water and one that is increasing; in 2011, the country had the capacity to desalinate 13 Mm^3 and this is projected to increase to 400 Mm^3 by 2030. Municipal wastewater, on the other hand, represents a largely untapped source of non-conventional water; in 2010 more than 640 Mm^3 were produced, of which 90% was discharged to the natural environment without any form of treatment or reuse. There are no measurable flows of water entering Morocco from its neighboring countries. Water resources in Morocco,

like in all Mediterranean countries, are projected to become more vulnerable with the impacts of climate change that are expected in the region: decreased annual precipitation and longer, hotter summers (IPCC 2014, 1209 – 1210). Finally, although Morocco is a water scarce country, the occurrence of severe flooding is increasing. Floods bring yet another challenge to water resources management, since they pose significant threats to human welfare and infrastructure, and also represent water resources that could otherwise be captured to reduce the deficit between water supply and water demand.

Water supply sources. In 2010, Morocco's water supply systems delivered a total of 10.58 km^3 of water to users: 0.007 km^3 of desalinated water, 2.32 km^3 of groundwater and 8.25 km^3 of surface water (6.80 km^3 of water from reservoirs and 1.45 km^3 from rivers). That same year, about 0.07 km^3 of treated wastewater were also used for irrigation. Water resources are mobilized to a large extent through the country's 135 major dams with a collective capacity of 17,500 Mm^3. Inter-basin water transfers are conveyed through a system of pipelines and canals.

Water use by sector. In 2010, the agricultural sector consumed 88% (9.305 km^3) of water supplied by public utilities, followed by municipalities at 10% (1.063 km^3) and industries at 2% (0.212 km^3) (Figure 14). However, in that year, water demand exceeded renewable water supplies by 4 km^3, which led to the over-exploitation of groundwater by an estimated 1 km^3, for irrigated agriculture. The over-exploitation of the country's aquifers is an ongoing problem, resulting in an average drop in groundwater levels of 2 meters per year. Irrigated agriculture is extremely important to the Moroccan economy; though practiced on only 16% of cultivated land areas, irrigated agriculture contributes about 14% to the country's GDP, represents 75% of exports and accounts for 25% of all employment. Morocco reports high losses of water in distribution networks, especially those for irrigated agriculture, which are estimated at 30%.

Figure 14 Water use in Morocco by sector (FAO 2010)



Water pollution. The most prevalent water pollution concern for irrigation water is elevated salinity levels, which result from the contact between water supplies and soil with high salt content, as well as from seawater intrusion in coastal aquifers that are used as a source for irrigation and/or drinking water. Agricultural activities themselves also represent a source of pollution; in 2015 it was estimated that agricultural producers introduced 15 tons of pesticides and 8,500 tons of fertilizers into the country's watercourses (about 1% of the total amounts applied to land areas) (Government of Morocco 2015, 55). The discharge of untreated wastewater to the natural environment represents another major source of pollution for the country's surface water and groundwater resources.

Anticipated future water demands. By 2100, Morocco's domestic water demands are projected to increase by 18% with respect to the 2020 baseline (UNDESA 2017, 24 and Neverre and Dumas 2015, 10). This is due to the anticipated net increase in the country's population, which is expected to peak at 46.8 million in 2070 and then decrease to 43.8 million by 2100 (Figure 15). No reliable data were available to estimate the future water demand of agriculture or industry; however, these can be expected to vary directly with human population levels.

Figure 15 Projected population and domestic water demands in Morocco, 2020 to 2100 (UNDESA 2017 [population] and Neverre and Dumas 2015 [water demand])

Year	Population (thousands)	Water demand (Mm^3)
2020	37,071	3,521.75
2025	39,101	3,714.60
2030	40,874	3,883.03
2040	43,714	4,152.83
2050	45,660	4,337.70
2060	46,710	4,437.45
2070	46,843	4,450.09
2080	46,226	4,391.47
2090	45,175	4,291.63
2100	43,840	4,164.80

7.3 Main issues of concern for water resources

The main issues of concern for water resources in Morocco are the following:

- Water demands that exceed present supplies and limited mobilization of non-conventional water resources, resulting in groundwater mining.
- Important water losses from irrigation networks, on the order of 30%.
- Uncertainty concerning future water availability, due to decreased mean annual precipitation, higher temperatures and droughts of greater durations that are projected to occur in the Mediterranean as a result of climate change.
- Elevated salinity levels in irrigation water (largely due to soils with high salt content) and seawater intrusion in coastal aquifers due to over-extraction of groundwater.
- Pollution of surface water and groundwater by agrochemicals and discharges of untreated domestic wastewater.

Conjunctive management approaches represent a means of addressing many of the concerns related to water quantities in Morocco, namely the over-exploitation of groundwater resources and the limited mobilization of non-conventional water resources. For example, additional surface water and non-conventional water sources could be mobilized to reduce pressure on groundwater in places where groundwater mining is occurring. Managed aquifer recharge with surface water or treated wastewater could be employed to halt seawater intrusion in coastal

aquifers. That said, the water scarcity in the country and the uneven distribution of surface water resources in particular represent important challenges to the implementation of these approaches.

7.4 Overview of IWRM implementation progress and implications for conjunctive management

This section describes the current state of IWRM implementation in Morocco, and its implications for the expansion of conjunctive management approaches. It is based primarily on data provided by the government of Morocco to UNEP for a 2018 report titled "Progress on integrated water resources management: Global baseline for SDG 6 Indicator 6.5.1: degree of IWRM implementation" and on complementary information from the government and the literature. In the 2018 UNEP report, the government of Morocco assessed its own progress towards implementation of the elements of the IWRM framework as follows:

- Enabling environment: 68/100
- Institutions and participation: 69/100
- Management instruments: 64/100
- Financing: 55/100

These scores provide a means of gauging Morocco's overall progress on the four dimensions of the IWRM framework, and for benchmarking with other countries that contributed to the UNEP report. In the proceeding discussion, evidence is provided to demonstrate the progress achieved in each of the four dimensions of the IWRM framework in Morocco, followed by observations about how the current state of IWRM implementation may impact the country's ability to scale up its use of conjunctive management approaches.

Enabling environment (68/100). Morocco has a strong enabling environment for IWRM. The National Water Strategy (2009) sets forth the country's policies and development priorities for water infrastructure, access to drinking water, the water needs of industries and the tourism sector and expansion of irrigated agriculture. Water issues are also reflected prominently in economic policies, in view of the country's water scarcity and the importance of irrigated agriculture to the national economy. IWRM was referred to explicitly in the 1995 Water Law

(Law 10-95) which described the country's requirements for decentralized management of water resources and the engagement of local authorities, water users and elected officials, amongst others. The 2015 Water Law (Law 35-15) provided necessary updates on issues related to water governance and the participatory management approach in the water sector, and also established a legal basis for the reuse of treated wastewater, rainwater harvesting and desalinization of seawater. The principles of the Water Law have also been translated into a National Water Strategy – a legal document prepared through an extensive public consultation process – which sets forth priority actions for managing water demand and water supplies, further developing non-conventional water sources, and protecting aquatic ecosystems, amongst other actions. The Water Law also requires the preparation of master water plans in line with the principles of IWRM and their articulation at the level of the river basin, in addition to local water management plans. Finally, due to its hydrological setting, Morocco shares no major water resources with its neighboring countries; hence, there are no transboundary water management agreements in place.

Implications for conjunctive management: The principles of conjunctive management are well integrated in its enabling environment. Namely, in the Water Law there is reference to the need to develop all available water resources – including surface water, groundwater, rainwater, non-conventional water resources and desalinated seawater – to meet the needs of the country while also protecting aquatic ecosystems. The concept of national water solidarity is also referenced in the Water Law, which makes provisions for inter-basin water transfers to provide additional volumes of water to people in particularly dry basins.

Institutions and participation (69/100). Overall, Morocco's institutions are well qualified to lead the implementation of national IWRM initiatives, although there are some important areas where institutional and human capacities must be strengthened in this domain. In 1995, Morocco adopted the river basin approach to water resources management and delegated these responsibilities to nine basin agencies. To ensure local stakeholder participation in management decisions, each basin agency consults with a basin council composed of water users, elected officials and other groups with a stake in the basin´s natural resources. The country builds capacity on IWRM among its institutions through short- and medium-term training programs and exchange of experience in the context of international development projects. A High Council on

Water and Climate orients water policies and water resources planning, and is composed of state representatives, water users, professional associations and the scientific research community. The overall responsibility for water resources lies within the Ministry of Equipment, Transport, Logistics and Water, and two additional ministries play leading roles on water issues: the Ministry of Agriculture, Fisheries, Rural Development and Forestry, and the Ministry of Energy, Mining and Sustainable Development. An Inter-Ministerial Committee on Water was created with the aim of ensuring coordination of water policies and actions across the various ministries and government agencies that are responsible for activities that affect the resource; however, the Committee has been inactive in recent years. Another important gap in the institutional framework for IWRM is the lack of an operational regulation organ in the water sector to enforce regulations (Government of Morocco 2014, 35).

Implications for conjunctive management: Morocco's institutions have gained considerable experience in the management of both surface water and groundwater; however, the government states that there are insufficient human and institutional capacities to manage the additional non-conventional water resources that it will need to meet its future water needs. The lack of an operational coordinating mechanism for the various government organizations responsible for water resources management also raises questions about the allocations of water at the national level, especially inter-basin transfers. Finally, in the absence of a regulation organ in the water sector, there is no mechanism for enforcement of laws intended to limit water extractions and curb the drilling of illegal wells, both factors in the general trend of groundwater mining in the country.

Management instruments (64/100). Morocco has established management instruments at the national, subnational and local levels to support the implementation of IWRM approaches at the appropriate scale. At the national level, a monitoring mechanism centralizes data from the basin agencies on water quantities, climate, geophysical surveys, isotopic investigations and groundwater drilling. A national programme for the treatment of solid and liquid waste is operational and making progress on the prevention of water pollution from cities, industries and the mining sector, amongst others. In terms of sub-national instruments, there are nine basin agencies in the country, each one a financially autonomous public entity with the responsibility for the long-term integrated management of water resources in its respective watershed. At the

local level, water resources are managed in a participatory manner, through the use of ´water agreements´ established among the users of the water resource (surface water or groundwater). Finally, the Water Law requires each basin agency to maintain an information system to share relevant water data with the public, and to consolidate data at the national level.

Implications for conjunctive management: The management instruments in place in Morocco provide a sound foundation for the conjunctive management of surface water and groundwater. Estimations of the availability of water resources at the level of the watershed and data are consolidated to serve as the basis for regular assessments that provide feedback on the effectiveness of management approaches and coherency with strategic plans for the nation's collective water resources. The basin agencies are responsible for all water resources within their respective watersheds, and user agreements are established at the level of individual surface watercourses or aquifers to govern the actions of users of the water resources. That said, there are a number of important gaps, including the lack of systematic monitoring of water quantity, unregulated consumption of water in the agricultural sector (which accounts for nearly 90% of water use in the country), and the limited use of hydrological models at the level of the watershed (Fadil et al 2011, 280).

Financing (55/100). Morocco recognizes water resources as essential to the economic and social development of the country and has accordingly allocated significant investments for hydraulic infrastructure and the mobilization of water supplies to meet needs for drinking water and irrigated agriculture. Furthermore, national budgets are regularly earmarked for the ongoing costs associated with IWRM. However, despite these investments, Morocco reports that it cannot finance all the projects it needs to maintain and expand the country´s water and wastewater infrastructure. Furthermore, water tariffs vary by region and are generally set according to the type of user and thresholds for consumption, but they do not reflect the full cost of water provision. Moreover, the autonomous basin agencies are not able to recover sufficient revenues to fulfill their mandated duties, since the volume-based water tariff structure and pollution fines foreseen in the Water Law have not been fully enforced to date (Government of Morocco 2014, 13). For these reasons, financing represents the weakest component of the IWRM framework in Morocco.

Implications for conjunctive management: Conjunctive management principles are at the heart of Morocco's water supply management strategy, and the country has committed to financing large-scale initiatives to support the implementation of conjunctive management approaches. These initiatives include the construction of new wastewater treatment plants to treat 50% of the county's wastewater to tertiary standards for reuse in irrigated agriculture by 2030, as well as new desalinization plants in three additional cities that will increase desalinization capacity by 110,000 m^3 per day (Government of Morocco 2014, 30, 60). At the sub-national level, the basin agencies also allocate their operating budgets to smaller-scale projects that support conjunctive management including the reuse of treated wastewater and rainwater harvesting. Though the government of Morocco is allocating substantial financing to mobilize water resources through conjunctive management approaches, the budget shortfall for water resources management in general may limit the potential to expand or improve existing conjunctive management actions in the country.

7.5 Key challenges for the implementation of conjunctive management approaches

Morocco´s enabling environment of policies, regulations and plans for IWRM is generally strong and the country has considerable experience in the conjunctive management of its surface water and groundwater resources. However, there is a noticeable lack of monitoring of water resources and no functional coordination among the various government agencies responsible for water. Institutional and human capacities are also limited in the domains of managed aquifer recharge and technologies for the production and use of non-conventional water resources. Furthermore, the water sector remains heavily subsidized by the government, which limits the effectiveness of the basin agencies. These and other challenges that Morocco must overcome to improve its ability to implement conjunctive management approaches are in Figure 16, articulated for three of the four dimensions of the IWRM framework[8].

[8] Challenges are identified for three of the four IWRM framework dimensions: Institutions and participation, management instruments and financing. The author considers that Morocco´s enabling environment does not pose significant challenges to the further implementation of IWRM or conjunctive management approaches.

Figure 16 Key challenges to implementing conjunctive management approaches in Morocco

IWRM dimension	**Challenges for the implementation of conjunctive management approaches**
Institutions and participation	• Lack of a functional coordination mechanism for the government entities responsible for the integrated management of water resources. • Lack of an operational regulation organ in the water sector to enforce established limits on water extractions and pollution levels in discharged wastewater. • Limited technical capacity for the implementation of technologies for managed aquifer recharge, reuse of treated wastewater in irrigated agriculture, and desalinization.
Management instruments	• Lack of systematic monitoring of water quantities in surface watercourses and aquifers. • Absence of metering for water consumption by agricultural producers. • Limited use of hydrological models at the level of the watershed for water resources planning and management.
Financing	• Insufficient cost recovery from water tariffs to maintain and expand water, wastewater and desalinization facilities.

7.6 Recommendations

To overcome these challenges to the expanded implementation of conjunctive management approaches, Morocco must focus on building knowledge on water resources, strengthening the capacities and coordination of its institutions, measuring water use, and improving the fiscal sustainability of the water sector, amongst other actions. The recommendations for Morocco are set forth below, organized according to the corresponding dimensions of the IWRM framework elements.

Institutions and participation

- **Institutionalize and make operational once more the Inter-Ministerial Committee on Water.** An Inter-Ministerial Committee on Water was convened as part of the preparatory activities for the development of the Water Laws of 1995 and 2015, however it has remained largely ineffective in its intended role as a coordination organ among the ministries that share

responsibility for the integrated management of water resources. This Committee should be reactivated and formally institutionalized to ensure the coordination and convergence of policies, projects and investments in the water sector and to take decisions about priorities for the allocation of water across the country´s watersheds. Once the Committee is operational, it should evaluate the costs and benefits of water transfers from water-rich basins to those lacking sufficient water resources. These inter-basin transfers hold the potential to mobilize more than 800 Mm^3 of water per year which are currently discharged directly to the sea (Government of Morocco 2014, 58).

- **Follow through with plans to establish the water police, an enforcement body for the water sector foreseen in the 1995 Water Law.** While Morocco has an extensive legal framework to control water extractions, to license irrigation wells and to establish permissible pollution levels in wastewater discharges, there has been little enforcement of these regulations due to the lack of a dedicated enforcement body in the water sector. In the 1995 Water Law, an enforcement body was foreseen – referred to as the water police – however, due to lack of financial resources it was never made operational. The water police should be established and charged with inspecting the country´s water resources and determining compliance with water regulations, particularly those pertaining to water extractions in the agricultural sector and pollution from discharge of industrial wastewaters. Water police should be associated to each of the country´s nine basin agencies.

- **Design and implement a capacity-building programme for basin agencies on managed aquifer recharge and the mobilization of non-conventional water resources.** Morocco has recognized that it must step up efforts to restore groundwater levels through the practice of managed aquifer recharge. At the same time, it has committed to investing in new infrastructure for wastewater treatment and desalinization. That said, the country reports that the basin agencies may not be prepared for the deployment of these technologies or for the use of the water resources they will mobilize. There is therefore an immediate need to reinforce human capacities at the basin agencies for managed aquifer recharge and the use and management of non-conventional water resources.

Management instruments

- **Establish a pilot monitoring network for the country's priority surface watercourses and groundwater bodies.** The objective of the pilot monitoring network is to build the scientific knowledge base that is used to make water supply management decisions. The monitoring network should gather data on water quantity and quality trends associated with climatic conditions and water extractions, salinization (in the case of coastal aquifers) and status of water-related ecosystems. It should make use of modern technologies including wireless instrumentation and geographic information systems (GIS). A training programme on the monitoring protocols should be delivered to the operators of the network and field technicians well in advance of the network's launch. Data generated by the monitoring network can then be used as inputs to numerical hydrological models to enable water managers to make more informed, strategic decisions about where and when to extract and store water throughout the year.

- **Implement a pilot programme for the introduction of water meters in the agricultural sector.** Water for irrigated agriculture accounts for nearly 90% of Morocco´s water consumption, yet there is no measurement of water use among the country´s agricultural producers. This prevents the assessment of volume-based tariffs and encourages wasteful practices among producers, including the selection of water-intensive crops with relatively low added-value for the agricultural sector (Government of Morocco 2014, 27). The implementation of a pilot programme for water metering in the agricultural sector would generate multiple benefits, including encouraging water conservation, detecting leaks and incentivizing farmers to choose crops that yield the greatest value per unit of water consumed. The experiences from the pilot programme could be used to design a strategy for the launch of a sector-wide metering programme for agricultural producers.

- **Design and deliver a capacity-building programme on the use of numerical hydrological models for water resources planning and management.** Hydrological models enable resource managers to simulate the behavior of water in the hydrological cycle and to predict how much water will be available for human use and its distribution over space and time. In water scarce countries such as Morocco, this kind of tool holds significant potential as an aid

in the planning and management of water resources. Morocco´s water resources are mobilized from a combination of conventional and non-conventional sources, including its increasingly large network of surface reservoirs. Therefore, decisions about the source, volume and timing of water extractions are complex. Surprisingly, it does not appear that the use of numerical hydrological models is common practice among the basin agencies in Morocco. A capacity-building programme on the use of these models would enable managers at the basin agencies to better anticipate the availability of water and aid in its allocation and management. The use of these models could furthermore assist the basin agencies in avoiding some commonly reported problems such as the overestimation of the availability of water in surface reservoirs due to insufficient considerations of silting and evaporation, and evaluating the time-lag between irrigation schedules and the storage of water in reservoirs (Government of Morocco 2014, 13).

Financing

- **Review the cost recovery strategy for the water sector and identify priority actions that will enable Morocco to move towards a more sustainable economic model for water services.** At present, the revenues generated from water and wastewater tariffs and fees are not sufficient to finance the infrastructure, operation and maintenance activities and human resources that are required to maintain the country´s water and wastewater services. As a result, the central government must provide substantial subsidies to ensure the delivery of domestic and irrigation water and the collection and disposal of wastewater. Morocco, like most countries, needs to identify measures that can render the water sector more fiscally sustainable. Indeed, this is necessary if the country wishes to continue reinforcing its IWRM framework and expanding its use of conjunctive management approaches such as managed aquifer recharge and the mobilization of non-conventional water resources. For this, Morocco should undertake an evaluation of its cost recovery strategy and practices to determine priority actions to save costs and increase revenues while ensuring fair, affordable access to water and wastewater services. A natural starting point would be an analysis of the actual costs of extracting, treating and disposing of water in each of the nine basins and a determination of the portion of these costs that the different water users are able to pay. The establishment of the water police and the use of water metering in the agricultural sector

could reveal additional opportunities for revenue generation through recovery of water tariffs from illegal wells, and the assessment of fees for water polluters, for example. Finally, public-private partnerships could be explored in the domain of hydroelectricity as an additional means of generating revenues for the water sector, since the country has considerable untapped hydropower potential.

8. Closing remarks

The conjunctive management of surface water, groundwater and other components of the water cycle represents an effective means of increasing water security as it reveals a more complete set of water supply options than traditional approaches to water supply management. Since the ultimate goal of conjunctive management is to increase the quantity of water available for human use (while protecting the sustainability of water resources and ecosystems), water-scarce countries are most apt to prioritize its adoption. Conjunctive management is, however, applicable to countries in all hydrological settings, since its management solutions address not only water scarcity but also problems such as floods and seawater intrusion in coastal aquifers. Furthermore, the management practices that underpin conjunctive management approaches – including the use of monitoring networks and numerical models, inter-sectoral coordination mechanisms and accounting for environmental flows in water resources planning – build the scientific knowledge base on water resources, which enables countries to better cope with the uncertainties that climate change is bringing to the planning and management of water resources.

These two challenges to water resources management – water scarcity and climate change – are particularly relevant to the Mediterranean, a climate change hotspot where nearly half of the population is projected to be living in water scarcity by 2030. Conjunctive management approaches can serve as one set of tools that can assist countries in meeting their water resources management objectives in the context of these challenges, as part of wider efforts to implement the IWRM framework.

The three countries examined in the case studies of this paper represent vastly different contexts for water resources management, in terms of hydrological setting, water infrastructure, demographics, water demand and use, governance, and human and institutional capacity, amongst other aspects. While it was demonstrated that conjunctive management approaches were appropriate solutions to many of the water quantity issues faced by the three countries, each country will prioritize the implementation of conjunctive management approaches differently.

Lebanon, for example, is facing water scarcity that is largely due to institutional and infrastructure challenges, rather than the scarcity of the resource itself. The situation is further complicated by extensive pollution from the discharge of untreated wastewater, the 30% increase in population that resulted from the influx of Syrian refugees in the past eight years and the massive debt that the country has incurred as a result. Although conjunctive management approaches such as managed aquifer recharge and reuse of treated wastewater could increase the availability of water resources, Lebanon does not have the institutional, technical or financial capacity to implement these management solutions at present. For this reason, it is reasonable to expect the country to prioritize other actions in the near term that strengthen its institutions and improve water quality through investments in treatment facilities for water and wastewater. These actions would subsequently enhance the country´s IWRM framework and support the future implementation of conjunctive management approaches that would alleviate pressures on water resources and contribute to improving overall water security.

Montenegro – the Mediterranean country with the greatest availability of per capita water resources – is not facing water scarcity, but rather other water-related challenges such as seawater intrusion and flooding. The conjunctive management technique of managed aquifer recharge could be applied to address both challenges, and indeed Montenegro may be able to implement this solution in the medium term. However, the strengthening of the IWRM framework that must first occur – including monitoring of water resources and the building of technical capacity among government institutions – will likely proceed according to the order of priorities of the government with respect to the requirements of the EU Water Framework Directive. While the management instruments that are required under this Directive will greatly enhance the country´s IWRM framework and its ability to implement conjunctive management approaches, the source of financing that is required to implement these instruments remains uncertain, as does the corresponding timeframe for implementation.

Among the three countries studied, Morocco stands out as the country that has most actively prioritized the implementation and expansion of conjunctive management approaches. As a water-scarce country that will experience a net increase in population by 2100, Morocco has sought to maximize its traditional water resources primarily through the capture of water in

surface reservoirs, and is stepping up efforts to mobilize significant quantities of treated wastewater and desalinated seawater in an attempt to keep pace with the country´s increasing water demands. Morocco´s strategy to exploit multiple components of the water cycle will effectively increase water security in the country, which is important especially in consideration of the decrease in mean annual precipitation that is anticipated in the southern Mediterranean in the coming century. That said, Morocco still faces significant challenges that complicate the expansion of conjunctive management approaches. The uneven distribution of surface water and groundwater resources may limit the options for mobilization of water resources in some basins; in this case, the most feasible solution may be water transfers from other basins where water is more plentiful. While new wastewater facilities and desalinization plants are in the pipeline for construction, there is still limited capacity among the basin agencies that will ultimately be responsible for their operation and management. The water and wastewater sectors remain heavily subsidized by the government since cost recovery from users of these services remains relatively low. Nevertheless, the government has placed a high priority on the continued development of its framework for integrated water resources management, and the country seems well-positioned to expand its implementation of conjunctive management approaches.

Although Lebanon, Montenegro and Morocco have documented their commitment to strengthening their IWRM frameworks, it is difficult to predict whether they would prioritize implementation of the recommendations detailed in the case studies. However, since financing was identified by all three countries as the weakest dimension of their IWRM frameworks, it is reasonable to hypothesize that many of these recommendations would be implemented if additional financial resources were available. From where could this financing come? While the ideal solution would be sustainable financing mechanisms in the countries' water and wastewater sectors, this option remains elusive in the near term. Another alternative would be to leverage the develop assistance (grants and loans) that these countries receive from the international community. The European Union, for instance, regularly contributes grant funding to Lebanon, Montenegro and Morocco through its Directorate-General for Neighbourhood and Enlargement Negotiations (DG-NEAR) for a variety of initiatives, including those aimed at improving environmental governance and building national capacities with respect to environmental protection and adaptation to climate change (EU 2019). All three countries are also eligible to

receive funds from the Global Environment Facility (GEF), the world's leading government-financed mechanism for projects to improve the global environment. The countries have collaborated in the past on GEF projects in the Mediterranean, and in a forthcoming regional project financed by the GEF, it appears that some financing will be made available to improve water resources monitoring at the national level (GEF 2019). In the case of Lebanon, the UN and the EU have stepped up efforts to provide monetary and logistic support to the assist the country in managing the Syrian refugee crisis, including improvements to the country's water supply systems. Furthermore, the European Investment Bank recently approved more than 800 million USD in loans to Lebanon for large-scale infrastructure improvements including wastewater treatment facilities, following Lebanon's demonstrated progress on governance reforms (EIB 2018). Taken together, these external aid sources could significantly boost the ability of the three case study countries to accelerate progress towards their integrated water resources management objectives, including the potential implementation of conjunctive management approaches.

As the number of people living in water scarce conditions in the Mediterranean continues to increase, it is likely that more countries in the region will prioritize actions that support the implementation of conjunctive management approaches, to make the best possible use of their limited water resources. These countries may face challenges similar to those identified in the three countries studied here, including complicated cross-sectoral coordination, inadequate technical and institutional capacities, insufficient scientific data on water resources and limited financial resources. However, as the body of knowledge on conjunctive management grows in the region and around the world, there will be increased opportunities for exchanges of best practices, technology transfers and innovative financing mechanisms that can be leveraged to overcome these challenges.

References

California Natural Resources Agency. (2016). *Conjunctive Management and Groundwater Storage: A Resource Management Strategy of the California Water Plan.* Accessed 23 April 2019 at https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/California-Water-Plan/Docs/RMS/2016/08_ConjMgt_GW_Storage_July2016.pdf.

Council for European Studies (CES). (2018). *Water Quality Law in the US and EU: A Comparison of the Clean Water Act and Water Framework Directive.* Accessed 7 May 2019 at https://www.europenowjournal.org/2018/12/10/water-quality-law-in-the-us-and-eu-a-comparison-of-the-clean-water-act-and-water-framework-directive/.

European Commission. (2003). *Guidance Document No 7 – Monitoring under the Water Framework Directive.* Accessed 31 May 2019 at https://circabc.europa.eu/sd/a/63f7715f-0f45-4955-b7cb-58ca305e42a8/Guidance%20No%207%20-%20Monitoring%20(WG%202.7).pdf.

European Commission. (2015). *Report on the implementation of the Water Framework Directive River Basin Management Plans: Croatia.* Accessed 19 July 2019 at http://ec.europa.eu/environment/water/water-framework/pdf/4th_report/MS%20annex%20-%20Croatia.pdf.

European Environment Agency (EEA). (1999). *Environmental indicators: Typology and overview*. Accessed 27 May 2019 at https://www.eea.europa.eu/publications/TEC25.

European Investment Bank (EIB). (2018). *CEDRE Conference: EIB pledges EUR 800 million to support public investments in Lebanon.* Accessed 11 July 2019 at https://www.eib.org/en/press/all/2018-083-cedre-conference-eib-pledges-eur-800-million-to-support-public-investments-in-lebanon.htm.

European Union (EU). 2019. Website of the Directorate-General for European Neighbourhood Policy And Enlargement Negotiations. Accessed 9 July 2019 at https://ec.europa.eu/neighbourhood-enlargement/node_en.

Food and Agricultural Organization of the United Nations (FAO). (2014). *Irrigated crops – Infographic from AQUASTAT, FAO's global water information system.* Accessed 8 July 2018 at http://www.fao.org/nr/water/aquastat/infographics/Irrigated_eng.pdf.

FAO. (2016a). *Thematic Papers on Groundwater – Groundwater Governance, a Global Framework for Action*. Accessed 14 June 2019 at http://www.fao.org/3/a-i6040e.pdf.

FAO. (2016b). *Global Diagnostic on Groundwater Governance.* Accessed 9 April 2019 at http://www.fao.org/3/a-i5706e.pdf.

FAO. (2017). *Statistical Yearbook of the Food and Agricultural Organization – 2017*. Accessed 8 April 2019 at http://www.fao.org/3/i3107e/i3107e01.pdf.

FAO. (2018). *FAO Stat (online library of statistics generated by FAO).* Accessed 21 July 2018 at http://www.fao.org/faostat/en/.

Fadil, Abdelhamid. Rhinane, Hassan. Kaoukay, Abdelhadi. Kharchaf, Youness. (2011). *Hydrologic Modeling of the Bouregreg Watershed (Morocco) Using GIS and SWAT Model.* Journal of Geographic Information System, 2011, 3, 279-289. Accessed 11 June 2019 at https://www.researchgate.net/publication/220549201_Hydrologic_Modeling_of_the_Bouregreg_Watershed_Morocco_Using_GIS_and_SWAT_Model.

Foreign Policy. (2019). *Lebanon Is Facing an Economic and Environmental Disaster.* Accessed 23 May 2019 at https://foreignpolicy.com/2019/02/20/lebanon-is-facing-an-environmental-and-economic-disaster-hezbollah-hariri-aoun/.

Foster, Stephen. van Steenbergen, Frank. Zuleta, Javier. Garduño, Héctor. (2010). *Conjunctive Use of Groundwater and Surface Water: from spontaneous coping strategy to adaptive resource management. Technical Report for the World Bank's Water Partnership Program.* Accessed 8 April 2019 at https://www.researchgate.net/publication/284452288_Conjunctive_Use_of_Groundwater_and_Surface_Water-From_Spontaneous_Coping_Strategy_to_Adaptive_Resource_Management.

Garduño, Héctor. Foster, Stephen. Nanni, Marcella, Kemper, Karin. Tuinhof, Albert. Koundouri, Phoebe. (2006). *Groundwater Dimensions of National Water Resource and River Basin Planning - Promoting an integrated strategy. Technical Report for the World Bank's Water Partnership Program.* Accessed 24 April 2019 at https://www.gwp.org/globalassets/global/toolbox/references/groundwater-dimensions-of-national-water-resource-and-river-basin-planning-gw-mate-2006-english.pdf.

Global Environment Facility (GEF). 2019. GEF Project Database. Accessed 9 July 2019 at https://www.thegef.org/project/mediterranean-sea-programme-medprogramme-enhancing-environmental-security.

Global Water Partnership. (2000). *Integrated Water Resources Management. TAC Background Paper No. 4.* Global Water Partnership, Stockholm. Accessed 13 March 2019 at https://www.gwp.org/globalassets/global/toolbox/publications/background-papers/04-integrated-water-resources-management-2000-english.pdf.

Global Water Partnership. (2018). What is IWRM? Accessed 21 July 2018 at https://www.gwp.org/en/GWP-CEE/about/why/what-is-iwrm/.

Global Water Partnership. (2019). Corporate website accessed 13 March 2019 at https://www.gwp.org/en/About/who/What-is-the-network/.

Global Water Partnership – Mediterranean (GWP Med). (2002). *Integrated Water Resources Management in the Mediterranean.* Accessed 19 June 2019 at

https://www.gwp.org/globalassets/documents/the-library/gwp-med-publications/iwrm/iwrmen.pdf.

Government of Lebanon. (2010). *National Water Sector Strategy.* Accessed 24 May 2019 at http://extwprlegs1.fao.org/docs/pdf/leb166572E.pdf.

Government of Lebanon and the United Nations. (2017). *Lebanon Crisis Response Plan*. Accessed 22 May 2019 at https://reliefweb.int/sites/reliefweb.int/files/resources/2017_2020_LCRP_ENG-1.pdf.

Government of Morocco. (2014). *La gouvernance par la gestion intégrée des ressources en eau au Maroc : Levier fondamental de développement durable.* Accessed 6 June 2019 at http://www.ces.ma/Documents/PDF/Auto-saisines/AS_15_2014-Gouvernance-par-la-gestion-integree-des-ressources-en-eau-au-Maroc-Levier-fondamental-de-developpement-durable/Rapport-Gouvernance-Eau-VF-16042014.pdf.

Government of Morocco. (2015). *3éme Rapport sur l'état de l'environnement du Maroc.* Accessed 3 June 2019 at http://www.environnement.gov.ma/PDFs/Rapport-reem.pdf.

Hartog, Niels and Stuyfzand, Pieter. (2017). *Water Quality Considerations on the Rise as the Use of Managed Aquifer Recharge Systems Widens.* Water (2017), Volume 9. Accessed 18 July 2019 at www.mdpi.com/journal/water.

Intergovernmental Panel on Climate Change (IPCC). (2013). *Climate Change 2013 – the Physical Science Basis.* Accessed 13 June 2019 at https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_all_final.pdf.

Intergovernmental Panel on Climate Change (IPCC). (2014). *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Chapter 21.5.1.2. Hotspots.* Accessed 9 May 2019 at https://www.ipcc.ch/site/assets/uploads/2018/02/WGIIAR5-PartB_FINAL.pdf

International Conference on Water and the Environment (IWCE). (1992). *The Dublin Statement on Water and Sustainable Development.* Accessed 19 June 2019 at http://www.wmo.int/pages/prog/hwrp/documents/english/icwedece.html.

International Institute for Environment and Development (IIED). (2017). *Five fundamentals to keep Lebanon's water flowing.* Accessed 21 May 2019 at https://www.iied.org/five-fundamentals-keep-lebanon-water-flowing.

International Monetary Fund (IMF). (2019). *World Economic Outlook Database*. Accessed 3 June 2019 at https://www.imf.org/external/pubs/ft/weo/2019/01/weodata/index.aspx.

Jones, Edward. Qadir, Manzoor. van Vliet, Michelle. Smakhtin, Vladimir. Kang, Seong-mu. (2019). *The state of desalination and brine production: A global outlook*. Science of the Total Environment 657 (2019) 1343–1356. Accessed 11 April 2019 at https://reader.elsevier.com/reader/sd/pii/S0048969718349167?token=C61409DE7CC3FFF049D

6DA7EF20B9ACCAD9B87C47E2BE70FD23EBB503A30DD868DD75D26B50DED31DED79 53FE30D5EF0.

Kovats, R.S., R. Valentini, L.M. Bouwer, E. Georgopoulou, D. Jacob, E. Martin, M. Rounsevell, and J.-F. Soussana. (2014). *In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1267-1326.

Lacoste, Yves. (2009). *Géopolitique de la Méditerrannée.* Armand Colin: Paris.

Lebanon Daily Star. (2018). *New water meters to reduce consumption in Beirut – Report from 4 April 2018.* Accessed 22 May 2019 at https://www.dailystar.com.lb/News/Lebanon-News/2018/Apr-04/444061-new-water-meters-to-reduce-consumption.ashx.

Lenton R, Muller M. (2009). *Integrated Water Resources Management in Practice: Better Water Management for Development*. Earthscan, London.

Mani, A., Tsai, F. T.-C., Kao, S.-C., Naz, B.S., Ashfaq, M., Rastogi, D. (2016). *Conjunctive management of surface and groundwater resources under projected future climate change scenarios*. Journal of Hydrology 540 (2016) 397–411. Accessed 5 May 2018 at http://dx.doi.org/10.1016/j.jhydrol.2016.06.021.

Margat, Jean. Burak, Selmin. (2016). *Water Management in the Mediterranean Region: Concepts and Policies.* Water Resources Management 30 (2016) 1 - 21. Accessed 13 June 2019 at https://doi.org/10.1007/s11269-016-1389-4.

Neverre, Noémie. Dumas, Patrice. (2015). *Projecting and valuing domestic water use at regional scale: A generic method applied to the Mediterranean at the 2060 horizon.* Water Resources and Economics. Volume 11, July 2015, Pages 33-46. Accessed 15 May 2019 at http://www.sciencedirect.com/science/article/pii/S2212428415300013.

Organisation for Economic Cooperation and Development (OECD). (2008). *OECD Environmental Outlook to 2030.* Accessed 14 June 2019 at https://www.oecd.org/environment/indicators-modelling-outlooks/40200582.pdf.

Plan Bleu. (2003). *Chapter 6 of the proceedings of the conference on ´Water Resources for the Future´ (Sassari, Sardinia, Italy 22-24 October 2003)*. Accessed 14 June 2019 at http://www.fao.org/3/a-a0438e.pdf.

Sánchez, E., Muñoz, A., Iglesias, J. A., & Cabrera, E. (2003). *Explotación de los acuíferos para el abastecimiento urbano de la Comunidad de Madrid: situación actual y futura [The exploitation of the aquifers for urban supply in the Madrid region: Present and future situation]*.

El agua y la ciudad sostenible: hidrogeología urbana. Madrid: Instituto Geológico y Minero de España. Serie: Hidrogeología y aguas subterráneas, 11.

Shiklomanov, Igor and UNESCO-IHP. (1998). *World Water Resources – A New Appraisal and Assessment for the 21st Century.* Accessed 13 June 2019 at http://documentos.dga.cl/PHI710.pdf.

Statistical Office of Montenegro (MONSTAT). (2017a). *Public water supply and water protection 2017*. Accessed 9 May 2019 at https://www.monstat.org/eng/page.php?id=1038&pageid=64.

Statistical Office of Montenegro (MONSTAT). (2017b). *Industrial water supply and water protection 2017*. Accessed 9 May 2019 at https://www.monstat.org/eng/page.php?id=1038&pageid=64.

Statistical Office of Montenegro (MONSTAT). (2019). *Water Statistics.* Data accessed 13 February 2019 at https://www.monstat.org/eng/page.php?id=1008&pageid=64.

Suez. (2019). *Setting up water and electricity services in Casablanca, Morocco, in line with its future economic and demographic growth.* Accessed 3 June 2019 at https://www.suez.com/en/our-offering/success-stories/our-references/casablanca-drinking-water-sanitation-and-electricity-distribution-networks.

United Nations. (1977). *Report of the United Nations Water Conference: Mar del Plata, 14 -25 March 1977.* Accessed 19 March 2019 at https://www.ircwash.org/sites/default/files/71UN77-161.6.pdf.

United Nations Department of Economic and Social Affairs (UNDESA). (2017). *World Population Prospects – Key findings and advance tables (2017 Revision).* UNDESA Population Division. Accessed 15 May 2019 at https://population.un.org/wpp/Publications/Files/WPP2017_Volume-I_Comprehensive-Tables.pdf.

United Nations Educational, Scientific and Cultural Organization (UNESCO). (2012). *Conjunctive use and management of groundwater and surface water within existing irrigation commands*. Accessed 27 March 2019 at http://www.groundwatergovernance.org/fileadmin/user_upload/groundwatergovernance/docs/Thematic_papers/GWG_Thematic_Paper_2_01.pdf.

UNESCO. (2019). *Conjunctive Management – An Introduction.* Forthcoming publication of the International Hydrological Programme (as yet unpublished).

UNESCO-IHP. (2015a). *Legal, institutional and policy aspects of coastal aquifer management. Strategic Partnership for the Mediterranean Sea Large Marine Ecosystem (MedPartnership)*. Accessed 7 May 2019 at https://groundwaterportal.net/sites/default/files/MedPartnership_L%26I.pdf.

UNESCO-IHP. (2015b). *Final report on Mediterranean coastal aquifers and groundwater including the coastal aquifer supplement to the TDA-MED and the sub-regional action plans. Strategic Partnership for the Mediterranean Sea Large Marine Ecosystem (MedPartnership*). Accessed 7 May 2019 at https://unesdoc.unesco.org/ark:/48223/pf0000235306.

United Nations General Assembly (UNGA). (2010). *General Assembly resolution 64/292. The human right to water and sanitation (28 July 2010).* Accessed 8 July 2018 at http://www.un.org/es/comun/docs/?symbol=A/RES/64/292&lang=E.

United Nations Environment Programme (UNEP). (2018). *Progress on Integrated Water Resources Management – Global Baseline for SDG 6 Indicator 6.5.1 Degree of IWRM Implementation.* Accessed 28 March 2019 at http://www.unwater.org/publications/progress-on-integrated-water-resources-management-651/.

UNEP – Mediterranean Action Plan (UNEP/MAP). (2013). *State of the Mediterranean Marine and Coastal Environment, UNEP/MAP — Barcelona Convention, Athens.* Accessed 14 June 2019 at https://wedocs.unep.org/bitstream/handle/20.500.11822/364/sommcer_eng.pdf?sequence=4&isAllowed=y.

UNEP/MAP. (2017). *Quality Status Report of the Mediterranean Sea.* Accessed 14 June 2019 at https://www.medqsr.org/sites/default/files/inline-files/2017MedQSR_Online_0.pdf.

UNEP/MAP – Plan Bleu. (2009). State of the Environment and Development in the Mediterranean, United Nations Environment Programme/Mediterranean Action Plan – Plan Bleu, Athens, 2009. Accessed 4 July 2019 at https://wedocs.unep.org/bitstream/handle/20.500.11822/386/soed2009_eng.pdf?sequence=3&isAllowed=y.

United States Geological Survey (USGS). (1998). *Ground Water and Surface Water A Single Resource - U.S. Geological Survey Circular 1139*. Accessed 26 March 2019 at https://pubs.usgs.gov/circ/circ1139/pdf/circ1139.pdf.

USGS. (2003). *Evolving Issues and Practices in Managing Ground-Water Resources – U.S. Geological Survey Circular 1247.* Accessed 5 April 2019 at https://pubs.usgs.gov/circ/2003/circ1247/.

World Bank Group. (2015). *Water and Wastewater Services in the Danube Region*. Accessed 4 March 2019 at http://documents.worldbank.org/curated/en/859881468178184081/pdf/97241-WP-P146139-PUBLIC-Box391472B-SoS-Montenegro.pdf.

World Resources Institute. (2015). *Aqueduct Water Risk Atlas.* Accessed 9 May 2019 at https://www.wri.org/publication/aqueduct-country-and-river-basin-rankings.

Younger, Paul L. (2007). *Groundwater in the Environment: An Introduction.* Malden, MA: Blackwell Publishing.