Chapter 11
Water and People: Assessing Policy Priorities for Climate Change Adaptation in the Mediterranean

Ana Iglesias, Luis Garrote, Agustin Diz, Jeremy Schlickenrieder, and Marta Moneo

Abstract Water is scarce in Mediterranean countries: cities are crowded with increasing demand; food is produced with large amounts of water; ecosystems demand more water than is often available; drought affects all. As climate change impacts become more noticeable and costlier, some current water management strategies will not be useful. According to the findings of CIRCE, the areas with limited water resources will increase in the coming decades (Parts 1 and 2) with major consequences for the way we produce food and we protect ecosystems (Part 3). Based on these projections this chapter discusses water policy priorities for climate change adaptation in the Mediterranean. We first summarize the main challenges to water resources in Mediterranean countries and outline the risks and opportunities for water under climate change based on previous studies. Recognizing the difficulty to go from precipitation to water policy, we then present a framework to evaluate water availability in response to natural and management conditions, with an example of application in the Ebro basin that exemplifies other Mediterranean areas. Then we evaluate adaptive capacity to understand the ability of Mediterranean countries to face, respond and recover from climate change impacts on water resources. Social and economic factors are key drivers of inequality in the adaptive capacity across the region. Based on the assessment of impacts and

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A. Iglesias (✉) • A. Diz • J. Schlickenrieder
Department of Agricultural Economics, Universidad Politécnica de Madrid,
UPM, Madrid, Spain
e-mail: ana.iglesias@upm.es

M. Moneo
Potsdam Institute for Climate Impact Research, PIK,
Potsdam, Germany

L. Garrote
Department of Civil Engineering, Universidad Politécnica de Madrid,
UPM, Madrid, Spain

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adaptive capacity we suggest thresholds for water policy to respond to climate change and link water scarcity indicators to relevant potential adaptation strategies. Our results suggest the need to further prioritize socially and economically sensitive policies.

Keywords Adaptation policy • Water resources • Water policy • Climate change • Mediterranean

11.1 How Much Does Water Management Need to Adapt in View of Climate Change?

The geographical focus of this work is the Mediterranean countries; the aim is to provide some insight about the policy priorities for the adaptation of water resources to climate change. We think two questions are relevant: How much does water management needs to adapt in view of climate change? How able are societies to adapt to these changes? We address these questions by evaluating the impacts of climate change on water resources and their management, the adaptive capacity and the policy responses.

In this chapter we aim to answer the question of how much does water need to adapt in view of climate change. Our approach is comprised of the following steps: (1) review of climate change impacts on water resources in the Mediterranean, (2) description of a modeling tool to determine water availability under adaptive management, (3) mapping of the adaptive capacity for different countries, and (4) evaluation the policy options.

Our analysis bridges the gap between traditional impact assessment and policy formulation by directing policy attention to the causes of the water scarcity and adaptive capacity problems. Moreover we provide a platform for determining policy responses at the basin level. This evaluation helps define the sensitivity of a system to external shocks and to identify the most relevant aspects that can decrease the level of risk posed by climate change.

The assessment is based on indicators aiming to facilitate information transfer from water resource science to policy. The combined analysis of these indicators helps to diagnose the causes of water scarcity under different climatic conditions and to anticipate possible solutions. In a relatively large region composed of many systems. These indicators may also allow for comparisons between systems to establish action priorities and budget allocation policies.

11.2 Review of Impacts

11.2.1 The Challenges to Water Resources in Mediterranean Countries

Mediterranean countries are diverse from various points of view including their socio-economic development, climate, water availability, infrastructure levels, or social and ecological pressures natural resources. However, the region as a whole is undergoing rapid social and environmental changes which may harbor negative implications for current and future sustainability. This is particularly true for the Mediterranean water sector where pressures and impacts on water scarcity are projected to multiply under climate change. Water scarcity often results in conflicts among users which are compounded by complex institutional and legal structures that threaten the development of policies geared towards sustainable management (Iglesias et al. 2007a, b; Iglesias et al. 2011; Iglesias and Buono 2009).

A number of studies have shown that under climate change annual river flow is expected to decrease in Southern Europe and increase in Northern Europe; changes are also expected in the seasonality of river flows with considerable differences over the European region (Arnell 2004; Milly et al. 2005; Alcamo et al. 2007). Nevertheless many of these projections do not take into account the effects of policy. One alternative measure that has been used to include some policy aspects is the water exploitation index (WEI), which is calculated annually as the ratio of total freshwater abstraction to the total renewable resource (Raskin et al. 1997). But even though the WEI can provide additional information regarding runoff, such an analysis still struggles to fully reflect the level of available water resources.

In many countries throughout the region, water demand already exceeds water availability often imposing a strain on ecosystems (Iglesias et al. 2007a, b; Yang and Zehnder 2002; Hoff 2011) this indicates the need for a policy-sensitive approach. The average annual potential water availability per capita considering the total freshwater resources in southern Mediterranean countries is less than 1,000 m^3/capita and year (Table 11.1). In countries like Egypt, Israel, and Libya, demand is above the available resources, and water scarcity crises are common (Table 11.1). The difficulty in forecasting highly variable rainfall multiplies the challenges faced by water resource managers and increases the likelihood of water conflicts.

The region's overall socio-economic model places available water resources under considerable stress. In many cases, agriculture is responsible for water imbalances because it accounts for more than 50% of water use of most countries (FAOSTAT 2010). Thus, other economic uses of water – urban, energy and tourism – are imposing further challenges for meeting ecosystem services (Hoff 2011) and increasing conflicts among the affected parties. Some of the potential solutions to these problems – such as changes in infrastructure or limitations of irrigation – are not accepted by all social sectors. Water resource managers face the dilemma of ensuring future sustainability of water resources while maintaining strategic agricultural, social and environmental targets. Climate change imposes an additional challenge, and understanding its implications and policy requirements is a complex process, as we shall see.

11.3 A Survey of Previous Studies

The Mediterranean is considered to be a region that will experience large changes in climate mean and variability; that is a climate change "hot-spot" (Giorgi 2006). Scenarios of water resources availability are developed from climate projections but need to take into water management, infrastructure and demands. Our current

Table 11.1 Water resource indicators: total freshwater resources, available resources, use, and water availability in selected Mediterranean countries

Country	Total area ($\times 10^3$ km^2)	Population (million)	Rainfall (mm/year)	Internal usable water resources (km^3/year)[a]	Usable water resources (km^3/year)[b]	Internal ground-water (km^3/year)[c]	Total water use (km^3/year)	Total water use (% renewable)	Potential total usable water resources per capita (m^3/capita per year)
Algeria	2,382	32	89	13.90	14.32	1.70	5.74	40	473
Egypt	1,001	72	51	1.80	58.30	1.30	61.70	106	859
France	552	60	867	178.50	203.70	100.00	35.63	17	3,439
Greece	132	11	652	58.00	74.25	10.30	7.99	11	6,998
Israel	22	6.5	435	0.75	1.67	0.5	1.63	103	254
Italy	301	57	832	182.50	191.30	43.00	43.04	22	3,325
Libyan Arab J.	1,770	6	56	0.60	0.60	0.50	5.73	954	113
Morocco	447	31	346	29.00	29.00	10.00	12.23	42	971
Spain	506	41	636	111.20	111.50	29.90	35.90	32	2,794
Syrian Arab R.	180	18	252	7	26.26	4.2	20.6	100	1,403
Tunisia	164	10	313	4.15	4.56	1.45	2.58	57	482
Turkey	770	71	593	227	213	69	37	18	2,800

Source: Iglesias et al. (2007a, b)) and FAO (data of 2004)

[a] The values refer to both regulated and unregulated water. Real available water resources in all cases are a fraction of these values

[b] These values include transboundary water. See also Wolf et al. (2011)

[c] A proportion of these values is included in the total renewable water resources

understanding of Mediterranean climate leads to projected overall temperature increase from 2 to 4°C and precipitation changes of 10 to −50% by 2080s (RACCM Part1). The changes are not equally distributed across the regions or the seasons. The changes are likely to be more pronounced in North Africa, with temperature increase that reaches +5°C by the 2080s in some scenarios and an alarming increase of extreme temperature (hot and very hot days); drought periods may increase throughout the Mediterranean (Giorgi and Lionello 2008; Christensen and Christensen 2007). As result, evapotranspiration rates will increase, soil structure changes will result in increased rates of soil erosion. Climate change may also produce some positive changes in water resources in some areas, give an adequate adaptive management. The changes may results in risks and opportunities for the water system and the environmental and social systems that depend on water.

Scenarios of water resources availability rely first on climate projections. Our current understanding of Mediterranean climate leads to projected temperature increase from 2 to 4°C and precipitation changes of 10 to −50% by 2080s with large implications for water resources (RACCM Part 2, Alpert et al. 2011). These projections may result in reductions of average annual runoff up to 50% challenging the whole socioeconomic model which is based largely on water demanding activities: recreation, tourism, and food production. The solution to those problems will imply social changes, a progressive increase of water demand management and a consensus reallocation of water availability to essential users. The agreement on essential uses remains a controversial issue across the region. In this process, policies regulating water usage, water accessibility and hydraulic infrastructure, will play a critical role in making water available to users by overcoming the spatial and temporal irregularities of natural regimes.

Protecting the world's freshwater resources requires diagnosing threats over a broad range of scales (Vorosmarty et al. 2010) and sectors (Table 11.2). In the Mediterranean, climate change impacts on water will have a large impact on human water security and biodiversity (Vorosmarty et al. 2010). There are several hundred studies on the potential impacts of climate change on water resources in the Mediterranean which apply many different approaches (European Environment Agency 2009). According to Gleick and Palaniappan (2010), more and more watersheds appear to have passed the point of "peak water", a concept related to the sustainability of water management. These studies have different focus – from ecosystems to water pricing to recreational water–, a wide range of time-frames, different scenarios and spatial scales that vary from the local to the global analysis. Although the results are diverse and sometimes contradictory, a common element is that one of the primary impacts of climate change will be a reduction of water availability in the Mediterranean (European Environment 2007, 2009).

11.4 How Able Are People to Adapt to These Changes?

The ability of societies to anticipate and face an external shock is often called their adaptive capacity. When the external shock is climate change, this adaptive capacity is estimated by environmental, social and economic factors. At the same time these

Table 11.2 Climate change induced risks and opportunities and degree of expected impacts on different sectors

Description	Ecosystems	Urban areas	Agriculture	Health	Economic activities (excluding agriculture)
Risks					
Expansion of area with water deficit	High	Low	High	High	Medium
Increase in water demand (irrigation)	High	Low	High	High	Low
Increased drought and water scarcity	High	Medium	High	High	Medium
Increased floods	Medium	High	Medium	High	Medium
Water quality deterioration	High	Medium	Medium	High	Low
Increased soil erosion, salinity and desertification	High	Low	High	Medium	Low
Loss of snow and glaciers (natural reservoirs)	High	Low	High	Medium	Low
Sea level rise	High	High	Medium	High	Low
Opportunities					
Increased water availability	High	Medium	High	Low	Medium
Increased potential for hydroelectric power	n.a.	High	Medium	Low	High
Increased potential to produce food and bio-fuels	n.a.	n.a.	High	n.a.	High

Sources: Alcamo et al. (2007), Arnell (2004), Barnett et al. (2005), Blanco-Canqui et al. (2010), Copetti et al. (2011), EEA (2009), Iglesias et al. (2009), IPCC (2007), Milly et al. (2005), Parry et al. (2004), Plan Bleu (2010), Rosenzweig et al. (2004), Vorosmarty et al. (2010), Wolf et al. (2011)

factors are essential components of a country's development status and of the sustainability of its socio-economic model. In other words, adaptive capacity and development are closely linked processes that feed and rely on each other. In the case of water the synergies between the two are particularly noticeable.

The linkages between development and the water sector are widely recognized. According to the 2006 Human Development Report, over a billion people in developing countries have inadequate access to water primarily due to poor institutional and political choices (UNDP 2006). Access to water has often been considered a human right in itself (Gleick 1999), but water also has crucial implications for production and the environment (Rijsberman 2003). It therefore comes as no surprise that water is essential to achieving all of the Millennium Development Goals (UNDP 2006). The overarching importance of the water sector is best exemplified by its central role in two of the main development approaches – namely pro-poor growth and human capacity development.

The poor disproportionately bear the brunt of a weak water sector. Pro-poor growth policies seek to reduce overall poverty levels by enhancing the ability of poor people to participate in, contribute to, and benefit from growth (OECD 2006). Given the predominance of rural livelihoods in most low-income countries, problems in water availability, quality and management are likely to have a greater impact on poorer and more marginalized social sectors. For this reason water management has tangible pro-poor enhanced rights effects. Rights based policies are concerned with water accessibility. This involves the duties of providers and the rights of beneficiaries and their ability to supply and access water respectively. It also brings up issues of water quality and water conflicts all of which impinge upon a people's ability to access water.

Water is also an essential component of what Amartya Sen called "development as freedom" since water is essential as part of "a process of expanding the real freedoms that people enjoy" (Sen 1999). In that sense, poverty can best be understood as the deprivation of capabilities (Sen 1999). Water is a particularly important resource for creating such an enabling environment. While an ineffective water sector reinforces inequalities and has negative economic impacts, a strong water sector can foster equality while creating opportunities for the disadvantaged. For instance, securing water rights and availability helps disadvantaged people move away from conditions of poor sanitation, high mortality rates or environmental degradation while creating opportunities for furthering education and employment. This, in turn, promotes people's capacity to achieve higher levels of education, health, and employment.

Efficiently dealing with climate change impacts will imply choosing between conflicting water needs in a way that maximizes adaptive capacity. Choosing between the preservation of valuable ecosystems and the reduction poverty, for instance, is not an easy choice, but successfully managing both needs is of paramount importance. To navigate these difficulties it is necessary to understand how society and water are interconnected, including the synergistic ties that exist between adaptive capacity and development status. Thinking and acting strategically is the only way forward – this implies taking a holistic approach towards water in order to minimize the negative effects of variability and uncertainty. The objective of this chapter is to provide such a holistic approach in order to minimize the negative socio-economic effects that climate change's impacts on water may produce.

11.4.1 Determinants of Adaptive Capacity

Adaptive capacity is understood as the capacity of a system to cope with or recover from a potentially damaging change in climate conditions (Smit and Wandel 2005). In that sense, adaptive capacity is the combination of a number of social and economic components. (Yohe et al. 2006; Iglesias et al. 2010; IPCC 2007).In spite of the considerable associated uncertainties (Adger and Vincent 2005), a number of indices of adaptive capacity have been developed (Yohe and Tol 2002; Ionescu et al. 2009; Yohe et al. 2006; Iglesias et al. 2007a) to capture different elements of social and economic vulnerability to climate change. With this in mind the adaptive capacity index (ACI) presented in this section comprises five major components that characterize the social capacity, economic capacity, technological eco-efficiency, natural capital and climate capital of a country all of which determine a system's ability to adapt to climate change.

By establishing these five components the final objective of the adaptive capacity index is to evaluate how policy affects the magnitude of potential climate change impacts and to establish the differences in adaptive capacity between Mediterranean countries. The index presented in this section provides a measure of how able societies are to adapt to climate change impacts in the water sector; in doing so it provides insights for future policy developments.

The adaptive capacity index integrates determinants of policy in a country or region, based on the aggregate social, economic, technological, environmental, and climate components of adaptive capacity (described below). The value of the index for a system represents its potential adaptive capacity, understood as a modifier of climate impacts.

11.4.1.1 Social Capacity

As suggested by Brooks et al. (2005), in large part adaptive capacity is dependent on social and political characteristics. Social characteristics depend to a large extent on the type of policies implemented in the country or region and they determine the degree of social adaptive capacity to climate change. Social adaptive strategies can range from market-based, self-sufficiency strategies to protective policies for industrialized nations where agriculture plays a marginal role. The indicators selected for this component represent several aspect of social capacity that can support or limit a region's adaptation capacity.

Some indicators (i.e. human development, collective capacity, access to resources, institutional coordination, pressure on natural resource use, literacy rate, life expectancy or access to sanitized water) imply healthier and stronger societies that can develop and implement solutions to adapt to climate change in a more efficient manner. Other indicators, like agricultural employment, have a negative correlation to overall adaptive capacity because they imply a greater dependency on a highly variable sector.

11.4.1.2 Economic Capacity

The level of economic development is an indicator of the capacity of a country to invest in development technologies, food security and income stabilization. The indicators selected for this component are GDP and CO_2 emissions which represent a country's technological development. These two indicators exhibit a positive correlation to adaptive capacity, while the rate of agricultural GDP shows a higher dependence on agriculture and, again, a lower adaptive capacity.

11.4.1.3 Technological Eco-Efficiency

The efficiency in the use of resources for production and the adoption of new technologies significantly increases a system's adaptation potential (Godfray et al. 2010). The three aspects represented in this component are general eco-efficiency, technological development and the specific level of technology applied to agriculture. The indicators selected represent the technological advancements applied to agricultural production and include GDP per unit energy use, technology exports and CO_2 emissions per capita. The development of agriculture significantly decreases the sector's dependency on climatic variables and stabilizes production. Therefore these indicators have a positive correlation with the overall adaptive capacity index, as they indicate the level of independence from climatic variables.

11.4.1.4 Natural Capital

One of the most relevant threats imposed by climate change projections in the Mediterranean region is higher levels of water scarcity. Adequate climate change adaptation policies in the Mediterranean region depend on the reliability and vulnerability of water resource systems in future scenarios and the availability of adequate management policies. Water management depends on factors such as infrastructure for water storage or transport, excess of demands or their mutual incompatibility, and constraints for water management (determined by policies). Indicators of agricultural water use and irrigated area show a positive correlation with adaptive capacity because the more water is used for agriculture; the easier it is to stabilize agricultural production independently from annual precipitation or distribution.

11.4.1.5 Climate Capital

Climate capital represents the baseline state conditions that are not modified in the short term. Current temperature and precipitation are determinants of the potential climate policies developed in the region. This component incorporates information related to the variability of precipitation, which decreases a system's general adaptation capacity because it hampers the effectiveness of developed infrastructure. This component does not represent implemented policies but is essential as the representation of the external hazard that the regions are exposed to.

11.4.2 Computing an Adaptive Capacity Index

The methodology used to compute the ACI integrates both quantitative and qualitative characterizations of adaptive capacity. The index can be applied locally or spatially and with different aggregation levels of the input data. The intermediate

Table 11.3 Components of the adaptive capacity index, aspect of climate policy addressed and selected indicators

Components	Aspect relevant to climate policy	Indicators
Social capacity	Human development (individual level)	Adult literacy rate
		Life expectancy
	Collective capacity	Agricultural GDP
		Population without access to improved water
		Population below the poverty line
	Institutional coordination	Institutional relations
		Public participation
	Pressure on resources	Total population
Economic capacity	Economic welfare	GDP per capita
		Energy use
	Public intervention	Public expenditure
Technological eco-efficiency	Eco-efficiency	GDP per unit energy use
		High technology exports
		CO_2 emissions per capita
	Agricultural innovation	Agricultural machinery
		Fertilizer consumption
Natural capital	Water management	Total water use
		Agricultural water use
		Irrigated area
	Environmental damage	Area salinized by irrigation
Climate capital	Response to climate impacts	Precipitation
		Temperature

components can be evaluated independently, making for a comprehensive interpretation of the strengths and weaknesses of each system.

The sequential steps taken for the quantification of the adaptive capacity index are: (a) select indicators that are policy relevant; (b) normalize the indicators with respect to a common baseline; (c) combine the sub-component indicators within each policy category by weighted averages; and (d) quantify adaptive capacity index as the weighted average of the components. The scores of the adaptive capacity index range from 0 to 1, and are generated as the average of each component. The approach is flexible and can be applied to managed and natural ecosystems as well as to socio-economic systems. A similar approach has been taken in the context of drought.

11.4.2.1 Selection of the Indicators

Table 11.3 shows the components of the ACI that have already been defined and the indicator-relevant aspects of these components. The indicators included were selected according to the following eligibility criteria: (1) they are relevant to represent different aspects of the climate policy; (2) data were available and an example could be computed; and (3) the indicators are SRES scenario dependent and geographically explicit.

The described criteria for indicator selection allow for the computation of the index under current conditions or for each of the SRES storylines in the future.

11.4.2.2 Normalization to a Common Baseline

The indicators shown in Table 11.3 were normalized between the different countries in order to compare the results. The standardization has been made with respect to the maximum value of each indicator across the countries. This guarantees that the index can be expressed as a percentage rate. Sub-component indicators can be combined within each category by using either a geometric mean or a weighted mean with weights inversely proportional to the impact uncertainty level. This study considers the weights separately for each of the categories, as in Iglesias et al. (2007a, b), in order to evaluate them independently, underlining the strengths and weaknesses of each component in the total adaptive capacity index within each country. It should be noted that the climate policy components have an inverse interpretation compared to the indicators traditionally applied to vulnerability evaluations (Iglesias et al. 2009).

11.4.2.3 Quantification of the Adaptive Capacity Index

The adaptive capacity index here is calculated with a methodology similar to that of the Human Development Index (HDI). Each component of the index can be viewed as a dimension. Before calculating the overall adaptive capacity index, a value for each of the dimensions needs to be computed. To compute the dimension indices, minimum and maximum values are chosen for each underlying indicator. These minimum and maximum values are used to harmonize the index and refer to the minima and maxima of the nations which are in the scope of analysis. For all values, except literacy rate and life expectancy, the minima and maxima among the nations are used as a harmonization basis. For life expectancy and literacy rate, the goalposts from UNDP (2009) are applied.

Performance in each dimension is then calculated as the dimension index with (11.1) for proxies which exhibit a positive correlation to the overall adaptive capacity,

$$\frac{x_i - x_{min}}{x_{max} - x_{min}} \tag{11.1}$$

and with (11.2) for proxies which exhibit a negative correlation to the overall adaptive capacity.

$$1-\left(\frac{x_i - x_{min}}{x_{max} - x_{min}}\right) \tag{11.2}$$

Where: x_i = proxy value for country in question, $x_{\min}$ = minimum value of the indicator, and $x_{\max}$ = maximum value of the indicator. The overall adaptive capacity index is then calculated as a weighted arithmetic mean of the dimension indices and gives the relative level of adaptive capacity for a country or region in relation to the countries included in the study.

11.4.2.4 Adaptive Capacity Index Distribution

We apply the GINI index methodology in order to determine the distribution of climate policies among the Mediterranean countries. The adaptive capacity index distribution measure can be expressed as:

$$ACI_D = \frac{1}{2n^2\mu}\sum_{i=1}^{n}\sum_{j=1}^{n}\left|ACI_i - ACI_j\right|$$

Which is, a half of the absolute differences average of every pair of ACI, normalized by the average value of ACI (μ). If the policies are equally distributed, the index value will be 0 (since the concentration area will be 0), and in a theoretical situation of one country concentrating all the efforts, the index value will be 1. This index has some interesting advantages, such as the independence of the ACI value. This is important since we have explained that the ACI is an ordinal index that allows for monotonic transformations.

The index can be calculated for different components and time periods, including climate change scenarios.

11.4.2.5 Evaluation of Adaptive Capacity

The total adaptive capacity index has been quantified as the weighted average of each of the five components previously described. Figure 11.1 shows the global values of the ACI for seven Mediterranean countries. The scores of the adaptive capacity index range on a scale of 0–1, 0 being the situation where adaptive capacity is least developed and 1 where adaptive capacity is most developed. The total index is generated as the average of all components. The final value of the index depends on the valuation of each component. Here we present the results of the index under a single scenario, where all components are valued equally. Alternatively we can weight the components differently. For example, a plausible scenario may give the social component an additional weight reflecting the assumption that a society with institutional coordination and strengths for public participation is less vulnerable to climate change.

Figure 11.1 shows how the global value of ACI is higher for countries located in the North of the Mediterranean basin, being the highest one for France, then Italy and then

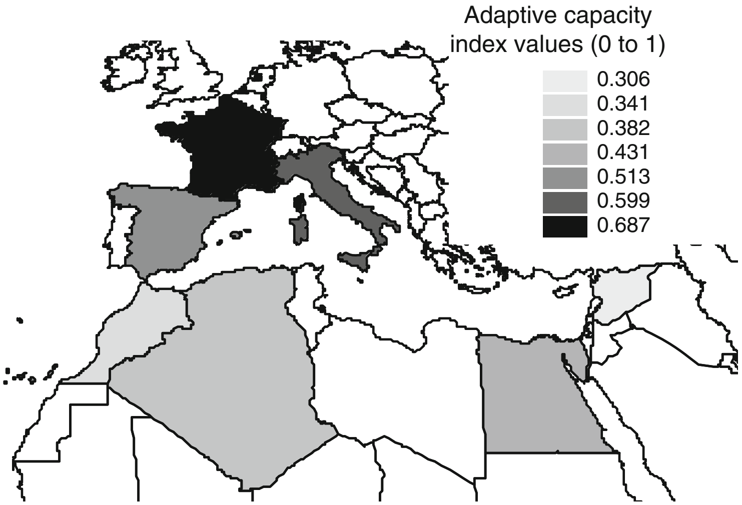

Fig. 11.1 Adaptive capacity index for selected Mediterranean countries

Spain. The lowest ACI value is for Syria, with a value lower than the half of the ACI for France. These values show the enormous difference existing in the Mediterranean basin in terms of adaptive capacity to climate change and the urgency of acting in certain areas to increase this capacity to face the future climate conditions.

The results of this evaluation lead to the identification of actions to minimize risk by increasing adaptive capacity. The results contribute to increase adaptive capacity and develop policy decisions to increase adaptation options. This assessment bridges the gap between impact assessment and policy formulation by directing policy attention to the underlying causes of adaptive capacity rather than to the potential impacts of triggering events such as climate change-driven water scarcity. This evaluation helps define a system's sensitivity to external shocks and identify the most relevant measures that decrease the level of risk under climate change.

Figure 11.2, on the other hand, shows the individual values for the components that integrate the global ACI. From this figure it is clear that for northern countries economic and social capacity are playing a major role in the maintenance of high ACI values, while the natural capital and the climate capital are quite similar or even lower than in southern countries. Technological eco-efficiency is also higher in France and Italy, but Spain shows levels quite similar to those of countries in the South.

This kind of information is useful for identifying priority aspects for the definition of adaptation strategies. According to the results from this study it would seem appropriate to develop strategies to improve the economic and social capacity of the countries in the south Mediterranean.

Figure 11.3 presents the distribution of the adaptive capacity index and each of its components, following the methodology used to calculate the GINI index

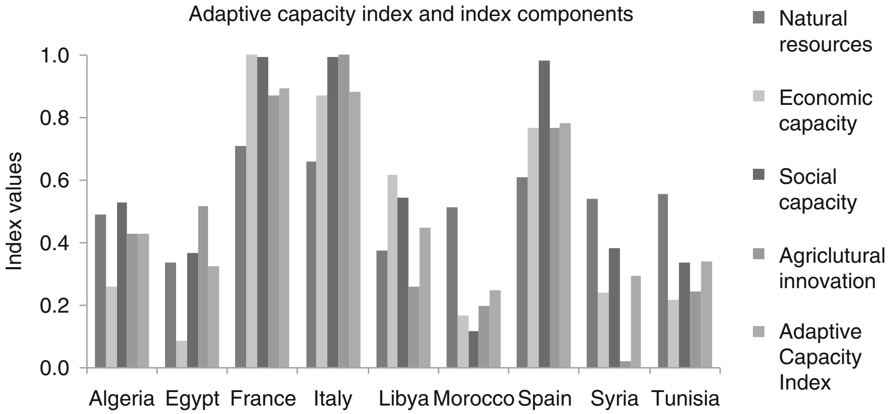

Fig. 11.2 Evaluation of the adaptive capacity index and components for selected Mediterranean countries

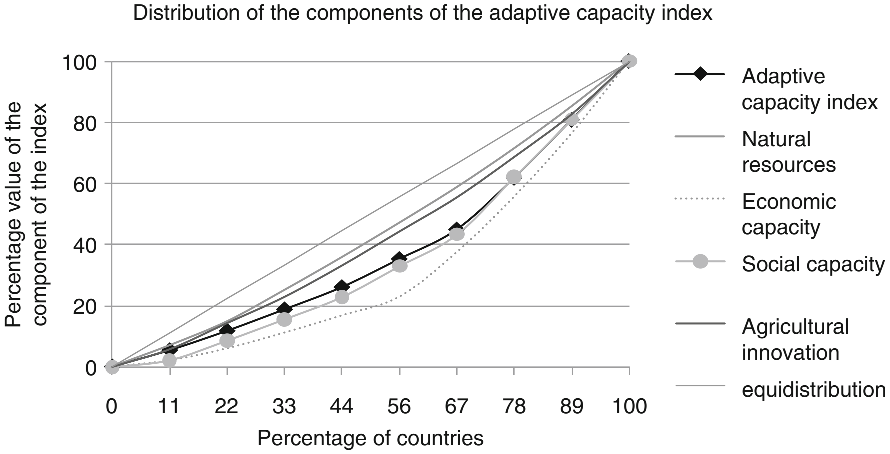

Fig. 11.3 Distribution of the components of the adaptive capacity Index

presented above. The Lorenz curve applied in the analysis helps identify the differential distribution and contribution of the different components to the global adaptation capacity level. The discontinuous line in Fig. 11.3 shows what would be a perfect distribution among the countries, where each country would contribute to the overall value in the same degree. However, all the components, including the adaptive capacity index itself, show distributions below that equity line indicating that countries have different levels of contribution. This difference is especially clear in the case of economic and social capacities. In the first case, nearly 60% of the countries contribute around 10% of the total economic capacity of the region, and in the case of social capacity, 40% of the countries contribute more than 65% to the total of the region. The distribution is quite even for the rest of the components, including the adaptive capacity index itself which underlines the importance of developing a partial analysis of the components.

Although, Mediterranean countries have similar adaptive capacity index distributions overall, countries differ greatly in their economic and social capacity. In contrast countries have similar technological and eco eco-efficiency capacity, natural capital and climate capital. As we shall see in the next section, this insight is extremely valuable for the development of policies that seek to redress low levels of adaptive capacity in order to cope with climate change impacts.

11.5 Estimating How People May Modify Water Availability

11.5.1 Water Supply and Demand Scenarios

All water-abstracting sectors require a reliable supply in order to provide sufficient water during periods of prolonged lack of rainfall. Over time, people have developed a number of ways to guarantee their water supply. As a result, the storage of surface water in reservoirs is commonplace and transfers of water between river basins also occur as is the artificial recharge of groundwater by river water. Recently, the production of freshwater via desalination or recycling is also playing an increasingly important role.

However, as we have seen, climate change jeopardizes the equilibrium of water resources systems and the impacts will vary as a result of local regulation capacity. Although there are many studies on the impacts of climate change in the natural hydrological regime, climate change impacts on regulated systems have not received as much attention. An analysis of climate change in regulated systems in the Mediterranean water basins would highlight the effects of adaptive regulation as management alternative.

Reservoir regulation has been one of the most important water resources management in Mediterranean countries and has generated significant impacts. A reservoir is a dynamic storage of water, which can be controlled, and is used to balance the irregularity of water resources. Existing reservoirs are being subjected to intense multi-objective demands on limited resources. Reservoir water uses include water supply, flood control, hydropower, navigation, fish and wild life conservation, and recreation. Water quality may also be considered a reservoir purpose when water is provided to assimilate waste effluents. It is not surprising then that defining optimal reservoir operation for reservoirs with multiple water uses is a challenge.

Reductions of water inflow and increased variability may result in significant decreases in the water availability. This clearly demands for adaptation measures with large impacts to society. In most Mediterranean basins the reductions in water availability will result in impositions of demand restrictions since regulatory capacity is already at a maximum.

This is particularly true in the case of irrigation water demand scenarios since it is reasonable to assume that, without changes in policy, land use or technology, projected irrigation demand in the basin will be higher than present irrigation demand even if farmers apply efficient management practices and adjust cropping systems to the new climate. Moreover, when policy and technology remain constant, it has been shown that agricultural water demand will increase in all scenarios in the region (Iglesias et al. 2007a, b; Iglesias 2009). The main drivers of this irrigation demand increase are the decrease in effective rainfall and increase in potential evapotranspiration (due to higher temperature and changes of other meteorological variables).

These scenarios demonstrate that in the Mediterranean, water availability is likely to be one of the great future challenges. Defining future water availability will therefore a basic step for water policy formulation

11.5.2 Defining Water Availability

The Water Availability and Policy Assessment model (Garrote et al. 2011; Fig. 11.4) links water supply, demand and management and is used to analyze policy options. The model computes water availability and reliability as result of implementing climate or policy scenarios. WAPA is used to compute water availability and demand-reliability curves, which provide a simple way to evaluate water availability under different policy and climate change scenarios. The model has been applied to evaluate economic decisions of drought policy and water policy in the Mediterranean (Iglesias et al. 2011).

11.5.2.1 Model Architecture

The WAPA model may be used to compute the water availability and demand-reliability curves, which provide a simple way to evaluate water availability under different policy and climate change scenarios. WAPA simulates the joint operation of all reservoirs in a basin to satisfy a unique set of demands. Basic inputs to the WAPA model are the river network topology, the reservoir characteristics (monthly maximum and minimum capacity, storage-area relationship and monthly evaporation rates), the naturalized stream flow series entering different points of the river network, the environmental flow conditions downstream of reservoirs and monthly values of urban and agricultural demands for the entire basin. The model is based on the mass conservation equation, and main assumptions refer to how reservoirs are managed in the system: to supply demands for any given month, water is preferentially taken from the most downstream reservoir available, since spills from upstream reservoirs can be stored in downstream ones.

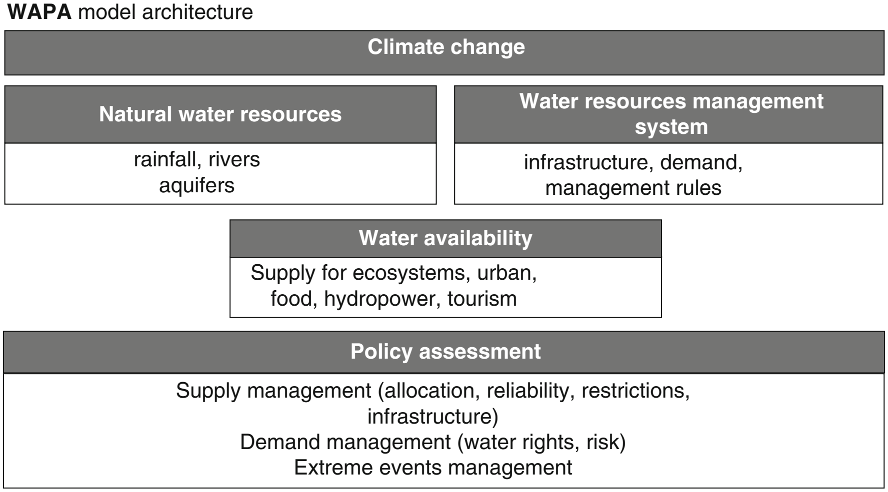

Fig. 11.4 Architecture of the Water Availability and Policy Assessment model (WAPA)

Model architecture is summarized in Fig. 11.4. The WAPA model is based on a basic reservoir operation model. The reservoir operation model takes as input the monthly inflows, the monthly required environmental flow, the monthly demand values sorted by priority with the corresponding return flow, the reservoir data (monthly maximum and minimum capacity, storage-area relationship and monthly evaporation rates) and the reservoir initial condition (initial storage). The result of the reservoir operation model is a set of time series of monthly volumes supplied to each demand, monthly storage values and monthly values of spills, environmental flows and evaporation losses. From this output, demand reliability can be computed applying any conventional procedure. Additionally WAPA can be operated as a joint reservoir operation model that combines all reservoirs in a basin to satisfy a unique set of demands. Reservoirs are ordered by priority (water is taken preferably from reservoirs with higher priority). In each time step, the model performs the following operations:

(a) Satisfaction of the environmental flow requirement in every reservoir with the available inflow. Environmental flows are passed to downstream reservoirs and added to their inflows.
(b) Computation of evaporation in every reservoir and reduction of available storage accordingly
(c) Increment of storage with the remaining inflow, if any. Computation of excess storage (storage above maximum capacity) in every reservoir.
(d) Satisfaction of demands ordered by priority, if possible. Use of excess storage first, then available storage starting from higher priority reservoirs.
(e) If excess storage remains in any reservoir, computation of uncontrolled spills.

11.5.2.2 Example of Model Results

WAPA model can be used to evaluate water availability for a set of specific demands under different conditions. As an example of model results, we present an analysis of water availability for irrigation demands, once urban demands are adequately satisfied. Runoff is estimated from the results of Regional Climate Models (RCMs). Monthly time series of runoff in every subbasin are generated from the results produced by RCMs for the "runoff" variable. Urban demands are estimated on the basis of population and per-capita water requirement. Subbasin population was obtained from the Global Rural-Urban Mapping Project (GRUMP), available at the Center for International Earth Science Information Network. An average value of 300 L/p.day was used as per capita water requirement.

WAPA computes water availability for irrigation demand with a loop that considers a fixed amount of urban demand and a variable amount of irrigation demand. For every value of irrigation demand, the model assigns available water in every month to urban demand first, and then to irrigation demand, computing demand reliability for both types of demands. Water availability for irrigation corresponds to the maximum irrigation demand that satisfies both urban reliability and irrigation reliability. Results are shown in Fig. 11.5, which corresponds to DMI to Regional Climate Model. The per-unit reduction in runoff in climate change scenario with respect to the control scenario is compared to reduction in water availability. In many European basins, the proportional reduction of water availability is larger than the reduction in mean annual runoff.

11.5.2.3 Trade-off Between Water Allocation and Supply Reliability

The regulatory effect is evaluated through water availability, i.e. the maximum demand that could be potentially attended in a certain point of the fluvial network for a pre-determined guarantee criteria. In order to facilitate the comparison, this variable is normalized using the average annual flow in a particular point of the system. Then it is possible to evaluate the effect of climate change scenarios.

Reliability is computed for every demand by comparing the actual supply values during the simulation with theoretical demand values. Figure 11.6 shows the supply reliability curve under current climate and climate change scenarios. In the current situation a defined volume of water is supplied to a sector with acceptable reliability. For example, reliability of urban supply is always 100% in European cities while reliability of agricultural supply may be as low as 50% in Mediterranean areas. Under climate change scenarios, the water allocation may remain the same (Management 1), but in this case reliability has to decrease significantly. This choice is not acceptable for urban supply. An alternative option (Management 2) is a reduction of the water allocation that is compatible with an acceptable reliability. For urban supply, a reduction of reliability is not an option. But for

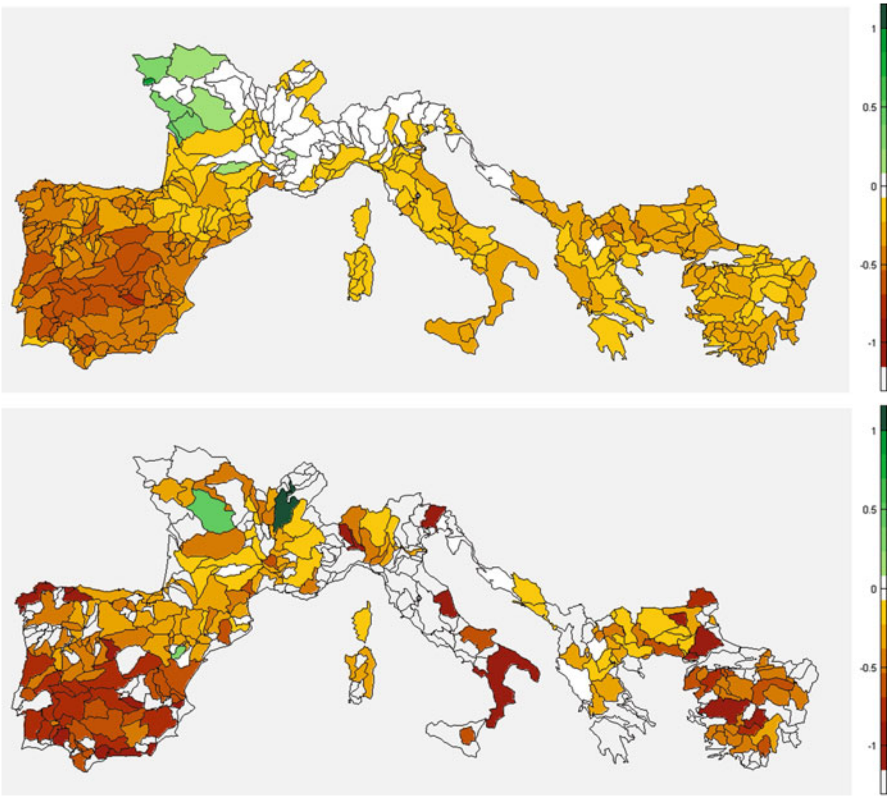

Fig. 11.5 Per unit reduction of runoff (*above*) and water availability for irrigation (*below*) in climate change scenario (2070–2100) with respect to control run (1960–1990) for DMI model in Mediterranean European basins

agricultural supply, a reduction of reliability may be acceptable if farmers have risk transfer mechanisms.

The choice between reduction of water allocation and reduction of reliability depend on the risk aversion that stakeholders (water managers and users) are willing to take (Quiroga et al. 2010). For example, reducing the water allocated for irrigation (Management 2 in Fig. 11.6) seems to be the optimal decision, independently of the risk aversion coefficient considered. On the other hand, when stakeholders accept a certain amount of risk, reducing water reliability (Management 1) is the optimal decision. Reducing water allocation has a lower associated risk level, and would therefore be preferred by managers that are more risk averse. Reducing water reliability has a higher associated risk level and would therefore be preferred by those less risk averse. The results show that there is no optimal policy response and that this is highly dependent on the scenario considered and the willingness to accept risk of the stakeholders.

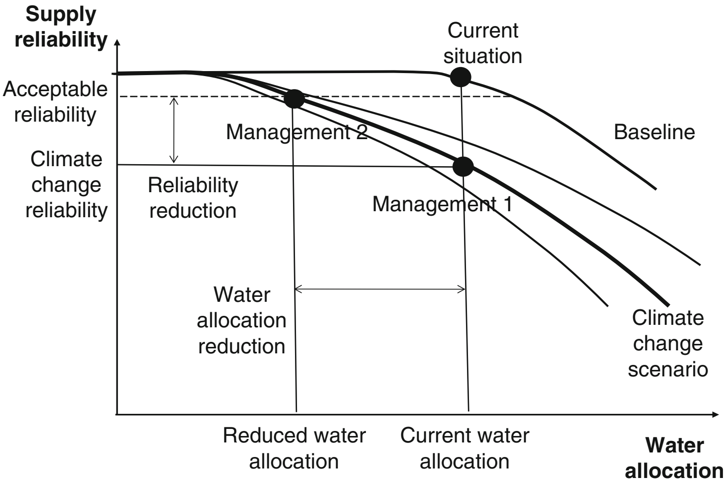

Fig. 11.6 Summary of the trade-off between water allocation and supply reliability under current climate and climate change scenarios

11.5.2.4 Management Policy Evaluation

Management policies may be evaluated in WAPA by modifying the different coefficients or parameters which affect system performance and create policy scenarios. Two broad management policy categories may be considered: supply management and demand management (Table 11.4).

11.5.3 Example of Application in the Ebro Basin

The Ebro basin is representative of a medium size water unit in the Mediterranean; the system is composed of 34 rivers, 27 major reservoirs totaling 7,13 km^3 of reservoir storage, an urban demand of 0,96 km^3/year and current irrigation demand of 6,35 km^3/year. Climate change scenarios were generated for every streamflow point in the Ebro basin by transforming the mean and coefficient of variation of the original series as suggested by the corresponding climate projection. Environmental flows were fixed at 10% of mean annual flow in every location.

Garrote et al. (2011) estimated change in water availability under climate change (Table 11.5). The study first estimated changes in runoff and runoff variation under a range of climate change scenarios, then applied the WAPA model to evaluate optimal management that represents the optimal policy options with the corresponding trade-off between supply and reliability as determined by the WAPA analysis. According to the results of the climate change simulations, runoff and water levels will change significantly during different seasons (Fig. 11.7). The results are in line with the results from previous studies in the Mediterranean regions (Iglesias et al.

Table 11.4 Types of polices and implementation in the WAPA model

Type of policy	Actions	Implementation in WAPA (example)
Supply management policies	Water allocation for environmental and consumptive uses	Selected quantile of the monthly marginal distribution to specify minimum environmental flow requirements
	Reuse of urban water	A coefficient for internal water reuse within cities that takes into account the population per-capita water requirement is and the return coefficient and a reuse coefficient
	Reduction of water allocation	Reduction of water allocation for a given use can be analyzed through its effect on demand reliability
	Increase water supply	Increase of the regulation volume available for water conservation or a densification of the water distribution networks
	Increase supply efficiency	Selected quantile of the monthly availability
Demand management policies	Reduction of per-capita or per-hectare water use	Reduction of per-capita water requirements in the model
	Water rights exchange programs	Changes in the required performance for urban demands
	Increase resource efficiency	Changes in the required performance for irrigation demands

Table 11.5 Simulation of water availability in the Ebro water unit under different management alternatives in the current climate

Type of management	Variable	Value
Current management	Annual streamflow mean (hm^3/year)	16,921.78
	Annual streamflow coefficient Var. (–)	0.27
	Storage volume (hm^3)	7,276.00
	Water availability (hm^3/year)	2,928.31
Simulated effect of management alternatives that imply no further expansion of infrastructure (effects of optimal reservoir management)	Water availability in the “Local management” alternative (hm^3/year)	9,401.56
	Water availability in the “Large distribution networks” management alternative (hm^3/year)	11,173.11
	Water availability in the “Global management” management alternative (hm^3/year)	11,464.45

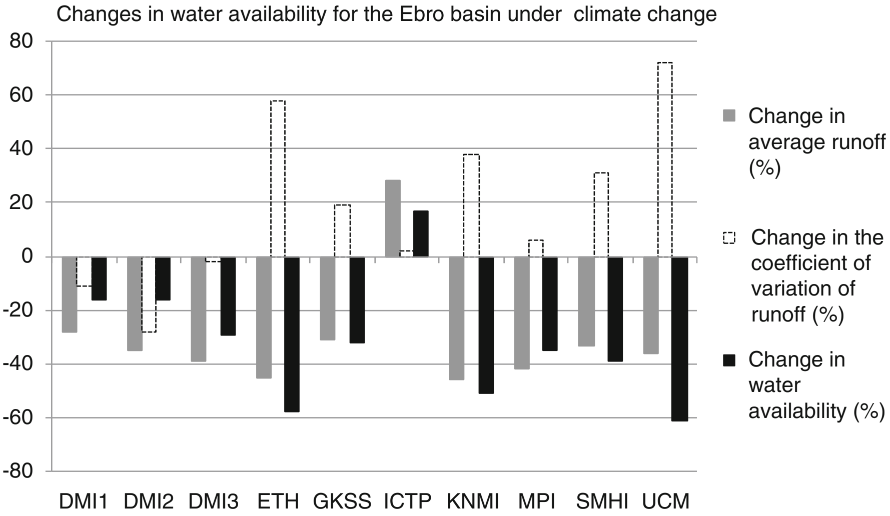

Fig. 11.7 Changes (difference between scenario climate change scenarios and baseline in percent values) of the average value and coefficient of variation of runoff and of water availability in natural regime for the Ebro basin

2007a, b; IPCC 2007; European Environment Agency 2008; Giorgi and Lionello 2008); climate change results in a moderate increase of flood risk throughout the year and a large increase in spring and summer drought. This implies the need to establish alternative options for water management for all sectors and highlight the importance of hydrological forecast to enhance the potential for improved regulation planning.

With the WAPA results for water availability under current climate and under climate change it is then possible to estimate the tradeoff between water allocation and supply reliability (Fig. 11.8). As we will see in the next section, understanding how supply reliability and water allocation are affected by climate change is a crucial part of determining water scarcity and hence establishing policy priorities.

11.6 Establishing Policy Priorities

Policy is deeply involved in the water sector. Usually, policy development is based on an historical analysis of water demand and supply. It is therefore a challenge to develop policies that respond to an uncertain future. Indeed, science-policy integration is one of the most complex challenges that the scientific and policy making communities face since it involves knowledge sharing and exchange among a wide range of disciplines and actors (Quevauviller et al. 2005). Despite these challenge, it is possible to achieve this goal and there are success stories throughout the world.

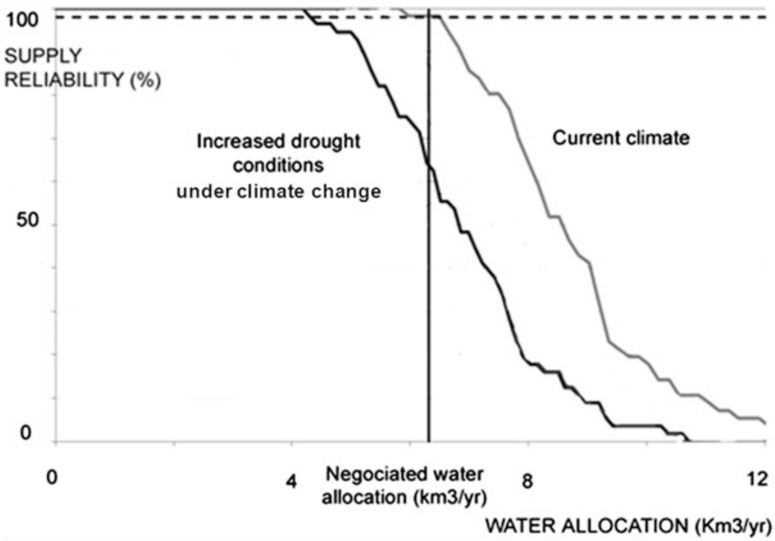

Fig. 11.8 Application of the WAPA model to estimate the trade-off between water allocation and supply reliability under current climate and climate change scenarios in the Ebro basin

In this chapter we have attempted to face part of this challenge by presenting an approach that assesses how people – society and policy – may influence water in the Mediterranean under climate change. We have also shown how an estimation of adaptive capacity evaluates the extent to which a system can respond to climate change. Together – the assessment of water risks and adaptive capacity – may be useful in singling out areas of potential water stress and conflict. This information may be used to implement and develop policy.

We recognize that the data needs for developing such a decision-making tool are complex and may be hard to satisfy; nevertheless, the conceptual steps that are presented remain valid and may be undertaken at a simplified level. Moreover, since the kinds of policy decisions being considered are at a national level it is likely that the availability of data will be greater. Building on the results of the WAPA model we characterize water scarcity to define policy thresholds, these are then combined with the results of the adaptive capacity index to establish policy priorities.

11.6.1 Policy Options and Thresholds

Here we summarize a diagnostic tool to identify and evaluate climate change adaptation policies in areas of water scarcity based on the indices of water scarcity developed by Martin-Carrasco et al. (2012). The methodological framework comprises a set of three indices, described below, that must be used jointly to

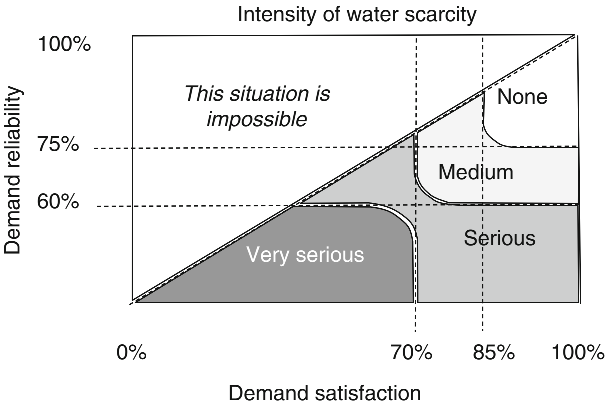

Fig. 11.9 Intensity of water scarcity problems and thresholds of demand reliability and satisfactions

quantify the severity of potential water scarcity problems in a system, its causes, and possible solutions. The indices are numerical index values that are classified in qualitative categories:

Water scarcity index (SI) evaluates the system's capacity to supply its demands.
Demand reliability index (RI) quantifies the system reliability to satisfy demands.
Potential for more infrastructure index (II) evaluates the natural resources available for development in the system.

Figure 11.9 shows a characterization of the intensity of water scarcity through a combination of the demand reliability index and the demand satisfaction index. This characterization is used to define thresholds of water scarcity based on their intensity – this is the first step in formulating water policy.

Next a combined analysis of the indices is used to diagnose water management problems and the reliability and vulnerability of systems under climate change scenarios this also helps identify public policies to recover equilibrium between water supply and demand. In general, systems with high water scarcity require actions that increase available resources while systems with low demand reliability generally require structural actions to consolidate water supply to demands or non-structural actions to mitigate drought impacts. When these problems coincide with low values of potential infrastructure development, actions should focus on the demand side, trying to improve water conservation by reducing losses, increasing water efficiency, encouraging water recycling, and making different demands compatible. Table 11.6 shows how the characterization of water scarcity problems can be combined with broad categories of policy solutions. Each category of policy solution proposes the utilization of different tools that target different user groups in order to tackle the problem of water scarcity flexibly.

Table 11.6 System characterization as a function of index values

		No water scarcity		Low water scarcity		High water scarcity	
		Problem	Solution	Problem	Solution	Problem	Solution
Reliable demand	Potential more infrastructure	n.a	n.a	1	B	1	B, C
	No new infrastructure	n.a	n.a	1	A, B	1, 3	A, B, C
Some unreliable demand	Potential more infrastructure	2	D	1, 2	B	1, 2	B, C
	No new infrastructure	2	A, D	1, 2	A, B	1, 2, 3	A, B, C
High unreliable demand	Potential more infrastructure	2	B, D	1, 2	B, C	1, 2	B, C
	No new infrastructure	2, 3	A, B, D	1, 2, 3	A, B, C	1, 2, 3	A, B, C

Problems

1: Vulnerable: water scarcity may produce important damages
2: Unreliable: low intensity droughts may lead to water scarcity
3: Excess of demand with respect to natural resources

Solutions

A: Demand management
B: Supply management: regulation
C: Supply management: water transfers or additional resources (i.e., water re-use)
D: Efficiency management: Communication and education

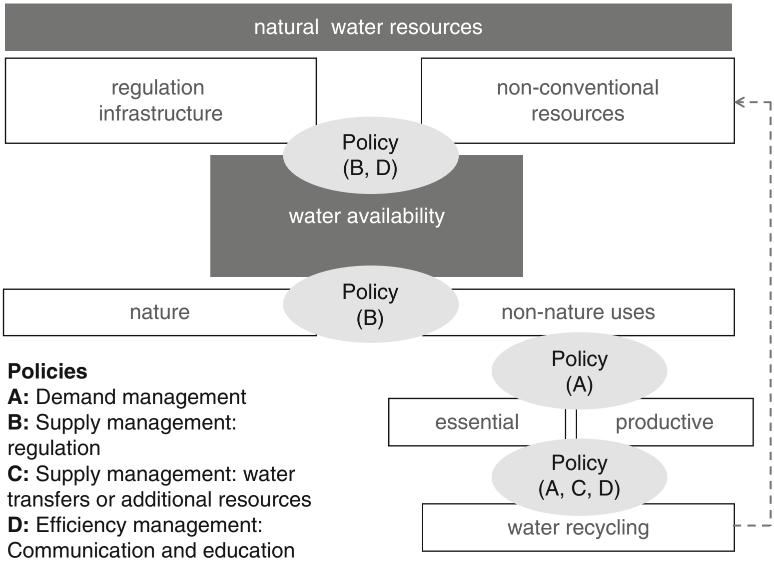

Fig. 11.10 Role of policy interventions on the water sector

11.6.2 From Index Thresholds to Policy Recommendations

The effect of water policy decisions may be evaluated by considering the resulting water availability for nature and non-nature use. Figure 11.10 outlines how policy interventions may modify water for nature and for non-nature uses. Water allocation for environmental and consumptive uses is an essential policy (type B in Fig. 11.10). Policy makers establish the criteria to authorize water abstractions from rivers based on the environmental conditions that should be respected for natural ecosystems. In the past, little attention was paid to environmental status of water bodies, and abstractions were usually approved even if there was no minimum environmental flow specified. Recently, the Water Framework Directive has placed emphasis on environmental status, and therefore strict control is placed on environmental flows before water abstractions are authorized.

The reuse of urban water may be included in a group of policies (type A, C and D in Fig. 11.10) that will need to become increasingly important since future scenarios project higher population and per-capita water requirement. Other demand side policies could make use of appropriate water pricing mechanisms, investments in technology to improve efficiency, upgraded distribution networks and making sure that agricultural subsidies are linked to efficient use (European Environment Agency 2009). Efficiency policies may play a major role for improving management (type D in Fig. 11.10). For example reduction of per-capita or per-hectare water use that always results in an increase of water availability and reliability.

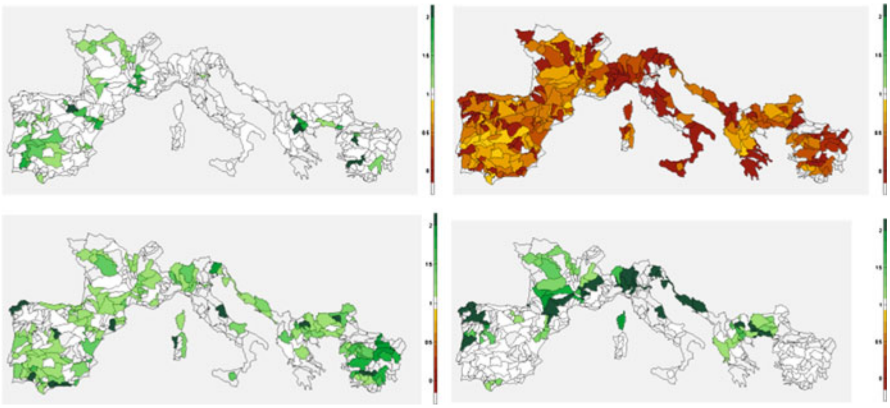

Fig. 11.11 Effect of policy options on water availability for irrigation: per unit change in water availability for irrigation in climate change scenario (2070–2100) with respect to control run (1960–1990) for DMI model in Mediterranean European basins under four policy options: (**a**) Improved water resources management (*top left*) (**b**) Water allocation for environmental uses (*top right*) (**c**) Improved water efficiency in urban use (*bottom left*) and (**d**) use of hydropower reservoirs for water conservation (*bottom right*)

A number of polices may be implemented to overcome temporary water deficits. Water rights exchange programs (type A in Fig. 11.10) may be implemented to overcome temporary deficits and to increase system performance. Proactive drought management measures to increase drought resilience may include improved performance for irrigation demands (type A and D in Fig. 11.10). Policies that foster communication and education are also since it has been shown that joint participative knowledge is an important factor in facilitating efficient water management (Huntjens et al. 2010).

Finally, polices may seek to increase water supply (type B and C in Fig. 11.10) by effectively increase of the regulation volume available for water conservation or a densification of the water distribution networks. Among other measures this may include water recycling and desalination (European Environment Agency 2009).

The quantitative assessment of the effect of policy options may be carried out with the help of WAPA model. Alternative policy options may be implemented in several ways. For instance, the effect of four policy alternatives for water availability analysis performed on European Mediterranean basins is presented on Fig. 11.11.

Adding the adaptive capacity evaluation to previous policy assessment we can formulate specific recommendations that respond to a range of water scarcity levels and address the weakest component of the adaptive capacity. The policy recommendations formulated in Table 11.7 vary according to the water scarcity level as described below and have a double aim: (1) to prioritize management strategies; (2) to evaluate synergies between environmental and development policies.

Table 11.7 Proposal of potential policy interventions based on water scarcity and adaptive capacity

Water scarcity levels	Weakest component of the adaptive capacity	Policy Recommendations
Low to medium	Social and economic factors	Promote pro-poor management Promote health and education Improve access to water for production and sanitation
	Technological eco-efficiency and natural capital	Focus on environmental mitigation Promote more efficient technologies Reduce water use
	Climate	Promote flexible water storage options Invest in physical infrastructure Develop safety net programs
Serious to very serious	Social and economic factors	Develop micro-irrigation technologies Integrate ground and surface water management
	Technological eco-efficiency and natural capital	Reform conflict prevention institutions. Promote information sharing and cooperative management
	Climate	Promote policies that help create a paradigm shift Design adaptation policies Develop new alternative sectors

11.6.2.1 Low to Medium Water Scarcity

In conditions of low to medium water scarcity where social and economic drivers of inequality prevail, policies should foment social and economic development policies that will improve policy formulation and implementation in the future, thus minimizing the risks of climate change impacts. In this case, basic needs such as education and health need to be taken care of. At the same time, in contexts of climate change, a longer term strategy that seeks to diversify a country's economy could also help mitigate the effects of climate change impacts.

Where water scarcity remains at low to medium levels and inequality is driven by technological eco-efficiency and natural capital, then environmental mitigation policies are recommended. Some policy options might include the development of more efficient technologies that would reduce water use in key economic activities.

When water scarcity is low or medium and climate drives inequality then current policies should be adjusted for adaptation. Policy options might include fostering greater flexibility in water storage options in order to choose those that will maximize sustainability and effectiveness. Other options could be building or improving physical infrastructure to prevent the risk of extreme events or developing safety net programs to strengthen livelihood asset availability for vulnerable populations.

11.6.2.2 High Water Scarcity

If water scarcity levels are serious or very serious and social and economic drivers of inequality prevail, then pro-poor water management policies are recommended. Effective policies might include the development of micro-irrigation technologies, or the promotion of mechanisms that allow an integrated management of groundwater and surface water.

If water scarcity is serious or very serious and technological eco-efficiency or natural capital drive inequality then the most appropriate policies would be those that reform institutions for the resolution of water conflicts. These reforms would imply developing a more holistic approach for the management of shared water resources that ensure that different user needs are taken care of. Increased cooperation and information-sharing at sub-national, national and even regional levels will be required in order to prevent water conflicts from aggravating.

Finally in conditions of serious to very serious water scarcity where climate drives inequalities than climate-driven policies that allow adaptation and a greater paradigm shift should be put in place. In this case, profound reforms aimed at transforming a country's economic activity should be emphasized. Particularly in agriculture-dependent countries the strengthening of other economic sectors such as industry or tourism would be in order.

The policies outlined above show that, for the water sector, planned interventions must consider both supply side and demand side solutions. On the supply side, adaptation options involve increases in storage capacity or abstraction from water courses; demand-side options, like increasing the allocative efficiency of water to ensure that economic and social benefit is maximized through use in higher-value sectors, aim to increase value per volume used and to ensure that quality is maintained. All in it becomes clear that the water sector's importance for numerous other productive and social arenas requires policies and management strategies to be well aware of water's widespread impacts.

11.7 Conclusions

This chapter shows that policies need to be successfully balanced to achieve a true integrated water resources management, which will require striking a balance between human resource use and ecosystem protection. This is no surprise (Vorosmarty et al. 2010) but has special relevance in the Mediterranean where water policies are often centuries old and socially embedded. The reality of climate changes renders it impossible to use the past as an indicator for the future. In this assessment we find reasons to be optimistic given the important role that science and technology will play in increasing adaptive capacity and improving water accessibility. There are however also reasons to be pessimistic. It remains to be seen whether the current inequalities that exist in the Mediterranean will be successfully redressed given the high costs associated with technology transfer for less advantaged regions and countries.

The recent past has demonstrated a high sensitivity of water resources to changes in climate and the resulting effects on the social system. Adaptation planning is inherently challenging and often, restricted by a number of factors, including limitations in the participatory processes with the stakeholders that will have to adapt in the future; the exhaustive data requirements for evaluating adaptive capacity; the problems related to selecting adequate evaluation methods and criteria; difficulties in forecasting water supply and demand; and challenges in predicting the future adaptive capacity of the water system. Uncertainties in climate change science and long planning horizons add to the complexity of adaptation decision-making. A further important complication is presented by the difficulties in identifying and linking adaptation and development policies in many areas in the Mediterranean where a large proportion of the population does not have access to clean water and sanitation. The uncertainty of the cost and benefits of the various policies suggested is not addressed here; this is a shortcoming of this assessment.

Knowledge transfer to water managers and users and to sectors linked to water use (technology, energy, health, agriculture, and tourism sectors) is essential to enable adaptive action. The indirect impacts of water resources change in these other areas will have additional cumulative affects. Knowledge transfer between scientists, political decision-makers and the people directly affected by climate change is currently weak, and existing information is poorly used. One of the difficulties is the number and range of stakeholders involved. Another challenge is the inherent uncertainty in climate science and impacts projections: uncertainty can lead to confused messages and inertia, if it is not communicated in the right way.

While there is a continuing need to strengthen the climate change knowledge base (through research), improved understanding of climate change science will be insufficient on its own for adaptation policy development and to drive adaptation action. There is a complementary need to engage stakeholders, by developing suitable methodologies for assessment of impacts, vulnerabilities and planning as a pre-requisite for cost-effective adaptation.

Wider influences on water users' behavior, such as changes in demand and tariffs, must be considered alongside climate change. It is important to consider whether adaptations are sustainable, or rendered irrelevant by other sectoral drivers. This holistic approach should also ensure that adaptation decisions and investments are both cost-effective and proportionate to the risks or benefits that may be incurred.

The development of adaptation measures must take into account future socio-economic scenarios as well as future climate change scenarios. Practitioners need to understand the relevance of a future climate to a future society, rather than to society today. Credible socio-economic scenarios are required to provide a framework for adaptation decision-making for practitioners.

With so many competing pressures and drivers, and so many contributing factors to consider, not only in understanding the impacts of climate change, but also in developing adaptation options, it is likely that the role of training and advice facilities for the users and suppliers of water could become more important. While there may be many simple adaptation measures that could theoretically be introduced to address a particular risk or opportunity, these may only be practically possible under certain circumstances. For example, improving efficiency of irrigation or introducing water metering may only be options for societies that already have an understanding of alternative technologies, and who know how to encourage implementation.

A final challenge for consideration is that of finance. Many potential adaptation options are low-cost and technically manageable by individual water managers. However there are also adaptations that require large scale and long-term effort, either water district management or in infrastructure development. In order for policy to be able to consider and take up such options, it may be necessary for financial support mechanisms to be made available.

The approach to impacts and adaptation developed in this study has provided options for wide-ranging problem. However adaptations often involve combined effort across many sectors. Water resources are sensitive to the responses in many sectors; particularly agriculture, tourism and biodiversity conservation, and so adaptation measures for water will be strongly influenced by policies in other sectors.

Adaptation is unlikely to be facilitated through the introduction of new and separate policies, but rather by the revision of existing policies that currently undermine adaptation and the strengthening of policies that currently promote it. If adaptation is to become "mainstreamed", it will be necessary for relevant polices, such as the CAP and the Water Framework Directive to address the issue more directly.

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