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Managing Water Resources to Adapt to Climate Change: Facing Uncertainty and Scarcity in a Changing Context

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Abstract Some of the most significant future efforts in water resources management will be devoted to climate change adaptation. Climate change adaptation is of special concern in regions facing water scarcity where water management is already challenged by many problems. This paper is a review of current knowledge on approaches to address water issues under uncertainty in water-scarce regions, identifying specific policy actions for climate change adaptation. The focus is on regions, like the Mediterranean, California or Australia, where water resources are well developed and have become an essential part of socioeconomic activities but are currently facing significant challenges due to their dependence on water availability to maintain living standards. We provide an overview of the expected impacts of climate change on water resources and discuss management responses based on peer-reviewed studies published over the past three decades. The adaptation choices cover a wide range of options, from adaptive demand management to utilization of remaining marginal water sources. The intensification of successful measures already applied in the past is still viewed as a solution to reduce climate impacts. However, the emphasis is progressively being placed on sustainability, developing and extending the water management paradigm to include not only technical and economic criteria, but also ecological and social considerations.

Keywords Water resources · Water management · Climate change adaptation · Reservoir storage

1 Introduction

Recent decades have seen a dramatic development of water resources in many regions of the world, particularly in semiarid areas with scarce water resources but mild climate favouring population growth, irrigation and tourism. Southern Europe, California and Australia are good examples of areas with long tradition of adaptation to irregular water resources in a context of

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dynamic economic development and demographic changes. Water management in these regions covers many activities (water supply for urban and irrigation demands, hydropower, water quality, flood control, ecosystem protection) to the extent that regional economies are largely dependent on freshwater resources to sustain their living standards. Pressure on these resources due to withdrawals from different sectors has been steadily growing, raising justified concerns on the sustainability of traditional water management and calling for further efforts to cope with future challenges linked to climate change.

These challenges will be met through a combination of already successful methods and additional adaptation capacity. These regions are characterized by (Alcamo et al. 2003) institutional capabilities for water management from the basin to local scale; (Alcamo et al. 2007) well-developed infrastructure, including storage facilities and integrated transportation and distribution networks that interconnect multiple supply and demand nodes; (Anderson 2003) extensive planning and operational experience under uncertainty and hydrologic variability and (Andreu et al. 1996) long tradition of developing multiple strategies for water management, including water-use efficiency, optimal management, non-conventional resources, water transfers, water recycling and desalination. Overall they show strong institutional, engineering and economic ability to develop and operate complex water resources systems to adapt to climate and population changes. This ability was achieved after many decades of sustained effort to develop water resources under difficult technical and economic conditions, but with strong policy support. During the last century the water resources management paradigm evolved to incorporate new challenges, developing additional tools to address uncertainty, analyze water quality or optimize the management of complex systems including economic analyses.

Future challenges, however, will require further effort. The evidence of the effect of climate change on water resources has continued to accumulate. Future scenarios for these regions suggest a progressive decay of mean annual runoff and changes in seasonal and inter-annual variability which may threaten sustainability of current water uses. Pressure on water resources often results in conflicts among users who demand their share in the decision making process regarding water management. The raising environmental awareness calls for adequate protection of aquatic ecosystems further reducing water availability for consumptive uses. Achieving sustainability under climatic uncertainty poses novel challenges for water-scarce regions that require further expanding the paradigm to include not only ecosystem functions and services but also social considerations.

Considerable progress has been made during the past 30 years in understanding the causes of water scarcity, as well as in developing effective strategies to prevent or mitigate its adverse effects. Over this period, the journal *Water Resources Management* has taken a leading role in encouraging, promoting and disseminating research in the application of scientific knowledge to improve practical management of water resources. The evolution of the journal reflects the significant advances made in research and practice on adaptation to water scarcity and the increasingly wider focus of this discipline. The first editorial (Tsakiris 1987) already highlighted that water management decisions affect almost all aspects of life and placed the emphasis on policies and strategies, stressing the complementarity of economic, social and environmental analyses. Currently the journal demonstrates the added value of interdisciplinary approaches to addressing the adaptation of water systems to uncertain and changing conditions, covering a wide variety of themes and offering opportunities to engage with diverse social, political, and economic issues.

A review of current knowledge on approaches to address water issues under uncertainty in water-scarce regions is presented in this paper. In these regions, water resources systems are highly developed and they have achieved a profound transformation of the natural characteristics of water flow to adapt to variability and uncertainty. The fact that streamflow series in arid regions present a large variability is well acknowledged by water managers. One of the manifestations of long-term variability is the well-known Hurst phenomenon, which has been linked to non-stationarity (Klemeš 1974), so the awareness-raising paper by Milly et al. 2008 on the death of stationarity did not come as a surprise to water managers, who have always acknowledged that overcoming uncertainty is needed to achieve the goals of water resource management and planning. The dominant technical strategy to fight variability and uncertainty is the use of storage. It is noteworthy that one of the papers published in the first volume of Water Resources Management was devoted to a review of the evolution of the deterministic and stochastic theories of reservoir storage (Klemeš 1987). The key question is whether storage-based management can keep pace with growing pressures in the face of climate change and other drivers. Uncertainties include not only how environmental change will affect the quantity of water, but also its quality and availability, which are largely dependent on future socio-economic scenarios. We discuss water resources management responses to future challenges and outline a portfolio of climate change adaptation measures that may contribute substantially to future sustainability.

2 Pressures and Impacts on Water Resources Systems

2.1 Climate Change and the Hydrologic Cycle

Many studies have been carried out to assess climate change impacts on the hydrologic cycle at global, regional and local scales over the past three decades. The most comprehensive summaries are the five successive Assessment Reports of the Intergovernmental Panel on Climate Change (IPCC) (IPCC 2014). These studies provide a coherent pattern of change in annual runoff, predicting with a high degree of confidence severe decreases (10–30%) of surface runoff in areas already affected by water scarcity, like the Mediterranean, Central Asia, Southwest Africa, Patagonia, Australia and Southwest North America. These projections are obtained by combining results of global climate models (GCMs) under different hypotheses. Databases of climate scenarios are available from different research projects (e.g.: Christensen and Christensen 2007; Collins et al. 2006) including surface runoff among their output variables. The representation of the water cycle in the models used in these projects is very simple, based on a crude representation of topography and parameterizations of hydrologic processes. Qualitative analysis of these results is often used for decision making, since they are the most comprehensive database of regional climate change scenarios that exists today. However, decision making regarding water scarcity requires results at a much finer temporal and spatial resolutions and a special focus on water availability. The task of assimilating GCM results into water resources impact-assessment studies has proven to be very difficult. At the end of the past century Xu (1999) presented a review of the gaps between GCMs and hydrological models and identified future challenges. These challenges have been addressed either by downscaling climate model results to a finer scale (Fowler et al. 2007) or by developing macroscale hydrological models that improve the representation of the hydrological cycle (Loaiciga et al. 1997). In both cases researchers have obtained significant bias with respect to observations and wide uncertainty range in results when different GCMs, downscaling techniques or hydrological models are combined. Usually, it is difficult to identify robust predictions because results from this type of analysis provide a low signal-to-noise ratio in arid and semiarid regions due to the strong natural variability of hydrologic series. This uncertainty has not been reduced with the progressive improvement of modelling tools; on the contrary, it seems to be increasing as a result of the evolving approach to generating emission scenarios.

2.2 Direct Impact on Water Resources

The long term changes in climate over timespans of several decades present a major challenge to water resources systems. There are several hundred studies on climate change impact assessment on already stressed water systems (EEA 2012). Patterns and trends show that effects of climate change will affect the water cycle (Seneviratne et al. 2010) and thus have an impact on water uses and ecosystems. A summary of the most relevant studies is presented on Table 1. These studies show that hydrological stress is expected to increase in many regions (Barnett et al. 2005; Henriques et al. 2008; Seager et al. 2013). A significant fraction of the world population is expected to be under threat of water security (Vörösmarty et al. 2010) due to the combined influence of climate drivers and human activities. A reduction of average natural water resources will produce increasingly more frequent and more intense episodes of water shortage and originate conflicts among water users (Iglesias et al. 2007; Mizyed 2009). It is also foreseen that climate change will produce alterations in the variability of water resources, intensifying the frequency and magnitude of extreme events, like floods and droughts, which will produce important impacts on the population (Easterling et al. 2000; Hoerling et al. 2012; Hirabayashi et al. 2008; Lehner et al. 2006; Feyen et al. 2012; Brown et al. 2011). Climate change is expected to modify water demand; higher temperatures are expected to lead to increased water demand for irrigation and urban supply (Gleick 2003; Döll 2002; Arnell and Delaney 2006; Wisser et al. 2008; Nkomozepi and Chung 2012). However, it is expected that future evolution in water use will be more dependent on social factors, like income and population growth than on climate drivers (Alcamo et al. 2007). Natural ecosystems will be altered by climate change (Walther et al. 2002). There are many possible routes of interaction, such as alteration of trophic interaction (Winder and Schindler 2004), temperature increase, with consequent changes in the activity of biological processes (Meyer et al. 1999), chemical modification of the flow of water through the soil (Rounsevell et al. 2005), with the alteration of the transport of nutrients and pollutants (Dunn et al. 2012; Nearing et al. 2004), among others. Although there are many processes involved, the results so far point to a likely deterioration of ecosystem health, especially in areas where the natural river regime has been significantly altered (Döll and Zhang 2010). In addition to natural alterations, the increase of pressures on consumptive water uses will induce an increased human intervention on the hydrological cycle, which will have additional impacts on the natural environment (Jackson et al. 2001).

The studies compiled it Table 1 have different emphasis over a wide range of spatial scales and time frames. Although the results are diverse, the consensus is that climatic zones are likely to migrate, leaving the climate of some regions dryer, other wetter, and all more variable and unpredictable. Certain regions already exposed to water scarcity will experience a further reduction of water availability and an accentuation of the extremes, with more pronounced floods and droughts. This will require a significant adaptation effort.

3 Water Availability

Water availability is a main concern in arid and semi-arid areas. The literature on water availability is extensive and the topic has been approached from diverse points of view. A vision dominant on global or regional studies considers changes in water availability directly linked to changes in average runoff, as the net difference between precipitation and evapotranspiration (Gardner 2009; García-Ruiz et al. 2011). This geophysical approach has proven

Table 1 Projected climate change impacts on water resources

Projected impacts	Potential negative effects and consequences for water resources	A sample of studies (1987–2016)
All	Review of all impacts	IPCC 2014
Changes in hydrologic cycle	Decreased water availability Risks of water quality loss Groundwater depletion Conflicts among water users	Arnell 1999; Barnett et al. 2005; Beniston 2003; Fronzek and Carter 2007; Gerten et al. 2011; Giannakopoulos et al. 2009; Giorgi and Lionello 2008; Henriques et al. 2008; Milly et al. 2005; Rosenzweig et al. 2004; Seager et al. 2013; Vorösmarty et al., 2010
Changes in extremes (floods and water scarcity)	Increased frequency and magnitude of extreme events Changes in seasonality Increased water shortages	Arnell et al. 2011; Beniston 2003; Beniston et al. 2007; Brown et al. 2011; Easterling et al. 2000; Feyen et l., 2012; Hirabayashi et al. 2008; Hoerling et al. 2012; Iglesias et al. 2007; Kundzewicz et al. 2010; Lehner et al. 2006; Mizyed 2009
Increased water requirements	Increased urban demand Increased demand for irrigation High in areas already vulnerable to water scarcity	Alcamo et al. 2007; Arnell and Delaney 2006; Arnell et al. 2011; Döll 2002; Gleick 2003; Mizyed 2009; Nkomozepi and Chung 2012; Rosenzweig et al. 2004; Wisser et al. 2008
Effect on water ecosystems	Decrease in water quality Increased risk of desertification High impact for water-scarce countries	Barnett et al. 2005; Döll and Zhang 2010; Dunn et al. 2012; Gleeson et al. 2012; Jackson et al. 2001; Nearing et al. 2004; Meyer et al. 1999; Rounsevell et al. 2005; Walther et al. 2002; Winder and Schindler 2004

to be very useful for global comparative studies (Alcamo et al. 2003) because of its suitability to develop water stress indicators. In water scarce regions, however, spatial and temporal variability of flow are major determinants of water availability, to the extent that they may be even more important than average values.

In many cases water scarcity arises from streamflow variability. Main water uses in semiarid regions are linked to urban water supply and irrigation. In both cases a regularity of supply is required to sustain water use and it is evaluated with the help of suitable indicators (Hashimoto et al. 1982). In the absence of infrastructure, water availability would be either null or extremely low because it would be determined by long term minimum values of flow. This is the reason why massive investments in infrastructure have been made in these regions during the past century. Hydraulic infrastructure plays a critical role to make water available to users by overcoming the spatial and temporal irregularities of the natural regimes through the basic functions of regulation and transportation.

Three factors are at play in regulated water resources systems: streamflow variability, storage capacity and yield reliability. They are usually linked through storage-yield-performance characteristics, which describe how a system is able to supply its demands and with what reliability (Vogel et al. 2007). A wide range of techniques have been proposed to analyse these factors, from relatively simple stochastic processes relating these variables (Phatarfod 1989) to highly complex models solving the water allocation problem (Andreu et al. 1996; Wurbs et al. 2005; Yates et al. 2005) even including social and economic considerations (Harou et al. 2009). These techniques have been used for analysing the interaction among the three factors in areas prone to water scarcity, showing that, in addition to average streamflow, changes of seasonal or interannual variability may introduce major changes in the performance of the regulation system and determine water availability (McMahon et al. 2006; Garrote et al. 2015). Löf and Hardison (1966) presented an analysis of the storage requirements in the US to obtain different levels of water availability accounting for seasonal and internannual variability. Vogel et al. (1999) repeated the analysis and found that reservoir behaviour can be characterized in terms of the coefficient of variation of annual inflows and the standardized net inflow. A frequent approach is the application of generalized storage–yield-performance relationships, like the Gould-Dincer suite of models (McMahon et al. 2007). These relationships provide a method to analyse the storage–yield problem using simple input factors such as the coefficient of variation of streamflow and the required system reliability.

A parallelism could be established between the three factors that control water availability in a regulated system and the management approach adopted in semiarid countries. Streamflow variability is linked to natural conditions, storage is linked to infrastructure measures and yield is linked to socio-economic measures. Over the past century strategies adopted to increase water availability were linked to infrastructure. For instance, Fig. 1 shows the temporal evolution of the estimated water availability in Spain as a function of available storage. The investment in storage infrastructure during the decades of the 1950s and 1960s produced a dramatic increase in water availability with respect to natural conditions. However, further increases in storage produced comparatively less effect and per-capita water availability has remained approximately constant since the 1970s. The storage-based strategy, which proved very successful in the past, is currently limited in developed countries by financial constraints and by concerns about environmental impacts of dams (Nilsson et al. 2005) and therefore the emphasis is currently being placed on how to improve management of existing infrastructure and on socio-economic measures through demand management and water use efficiency. An overview of climate change adaptation measures in water scarce regions is presented in the following section.

4 Adaptation Choices

Adaptive management is not new in water-scarce regions. The acknowledgement that hydrologic forcing may no longer be considered stationary is relatively recent (Milly et al. 2008). However, socioeconomic conditions have always been perceived as a dynamic factor in water resources planning for these regions. A large number of projects developed in the past century were designed under larger uncertainty than is currently attributed to climate change. The critical infrastructure thus developed is still operational under conditions radically different from those that were assumed at planning stage, thanks to efficient adaptive management. In fact, the history of water resources development in semiarid regions is one of permanent adaptation. Unlike in other sectors, the challenge posed by climate change in water-scarce regions is not unique; it is only one among many long-standing pressures, like population dynamics, upgraded standard of living, economic and social development, among others (Iglesias et al. 2007). Most of the problems that are anticipated as a result of climate change are really an intensification of structural problems linked to water scarcity which have already emerged in various regions. This section presents an overview of successful adaptation measures which have been implemented in these regions and may be taken as a portfolio of measures for adaptation to climate change. The list of measures is far from complete; it rather reflects the kind of polices that may be appropriate to keep fighting water scarcity in an uncertain and changing context (Krysanova et al. 2010). These adaptation choices fall into two overlapping areas. The first area corresponds to the approach adopted in managing water resources and reflects the evolving socioeconomic context. The

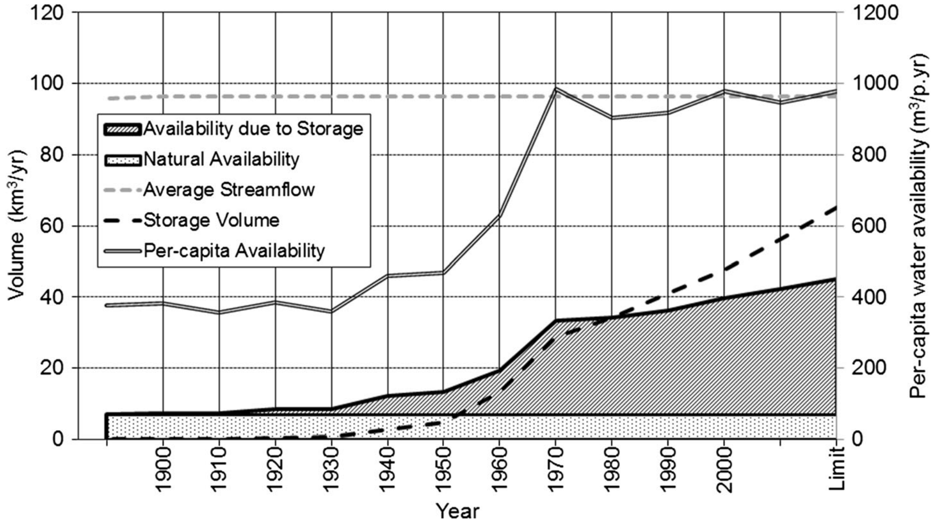

Fig. 1 Time evolution of storage volume, total water availability and per-capita water availability in Spain, according to the Spanish White Paper on Water (MIMAM 2000)

second area corresponds to the portfolio of technical solutions and reflects our improved understanding of the behaviour of complex hydrosystems.

4.1 Wider Scope in Water Management

Water resources management began mostly as an engineering discipline, as is reflected on the first textbooks on the topic (e. *g.* Major and Lenton 1979). During the past thirty years the scope has been progressively widening to include many other disciplines, from physical and biological to economic and social sciences. There is a growing consensus on the need to evolve from a paradigm for water management based on infrastructure development by public administrations to a model based on adaptive and integrated water resources management incorporating all stakeholders (Pahl-Wostl et al. 2011). Today water resources management is considered to be a multidisciplinary activity, which includes not only water, but also land and related resources with the final goal of social welfare and environmental sustainability. This vision grew from the acknowledgement that supply-side technology was not enough to address the increasingly complex problems linked to water management, which should be formulated in a wider scope than mere maximization of water supply. Although implementation of Integrated Water Resources Management (IRWM) is still in progress even in the most advanced regions, it remains essential for climate change adaptation (Biswas 2004).

4.2 Emphasis on Adequate Governance and Strong Institutions

Adequate governance is increasingly being perceived as a critical component of adaptive capacity (Pahl-Wostl 2007). The roles to be played by the public administration in future scenarios in a climate change context are substantially different from those of the past. Traditionally, the role of the administration in areas exposed to water scarcity was to ensure and increase the availability of water resources through the implementation of hydraulic infrastructure and the control of water uses. Public administration is shifting its focus on managing water scarcity and many agencies have changed their mission statement from reclamation and infrastructure development to improved management and optimal water allocation (Moore 1991). This implies redesigning institutions with increased emphasis in governance, promoting participatory decision making to combine top-down with bottom-up approaches (Livingston 1995). New methods have been developed to support conflict resolution in the decision-making process, starting from traditional multicriteria analyses (Hajkowicz and Collins 2007) and moving into more novel approaches (Madani and Lund 2011; Tsakiris and Spiliotis 2011). In many cases these methods have been structured into model-based tools to support water management (Berger et al. 2007; Maia and Schumann 2007; Purkey et al. 2007), although their application to practical problems remains limited.

4.3 Intensification of Demand Management and Supply Enhancement

The preferred adaptation option to respond to water scarcity is demand management (White and Fane 2001). The greatest scope for action is in irrigation demands which usually account for the largest fraction of total demand in water-scarce regions. There are many alternative technologies that allow reducing the amount of water used in irrigated crops (Wallace 2000; Pereira et al. 2002). The application of these technologies has not always been easy due to the high economic cost of deployment and the training requirements of farmers. Special care should be taken to implement programs to increase the medium and long term adaptive capacity of farmers by providing adequate training and viable financial instruments. In the case of water use in urban areas, the adaptation measures include, among others, the information and education of citizens to promote domestic water savings with adequate pricing policy. Local authorities and water supply providers are also intensifying their programs for avoiding leakage in water distribution networks and reducing public demand through water recycling and water use efficiency.

In a scenario of potential reduction of natural resources, supply enhancement measures are also being used where feasible. Conventional measures of surface and ground water management may offset the expected reduction of natural resources due to climate chance in certain areas (Tanaka et al. 2006), although controls should be intensified to ensure the correction of social and environmental impacts. In some basins it is acknowledged that conventional measures alone cannot correct the decline of natural resources and should be combined with other activities, promoting non-conventional water resources, including wastewater reuse (Vargas-Amelin and Pindado 2014). Some demands can be satisfied with recycled water, like irrigation, recreational uses such as watering golf courses, municipal uses such as street cleaning and irrigation of parks and gardens, or aquifer recharge (Anderson 2003). In areas that are already facing serious problems of water scarcity, new technologies are being developed for improved energy efficiency of desalination of brackish or seawater as a costly alternative for the enhancement of resource availability.

4.4 System Interconnection and Optimal Operation

In a scenario of growing water scarcity, supply and demand are being optimally managed in increasingly larger and more complex systems. Effective operation of complex systems can reduce the impacts of climate change (Yao and Georgakakos 2001; Medellín-Azuara et al. 2008). The sources of water supply from different origin can have very different characteristics. Resources of different nature (e.g.: surface and groundwater) show highly significant differences in terms of variability and reliability. The integration of a large number of water sources in a unique management unit is a significant step to maximize water availability. Likewise, the integration of different kinds of water demands in conjunctive systems increases robustness. The reliability of the most important demands can be protected through the use of strategic reserves or the exchange of water rights. The tendency is to integrate a large number of supply sources and demands in complex systems that can best respond to situations of scarcity through optimal management, using every resource for the purposes that are more appropriate depending on its amount, regularity and reliability, as in the case of conjunctive use of surface and ground water (Pulido-Velazquez et al. 2011).

4.5 Revisiting Water Rights and Water Allocation Procedures

Re-allocation of water rights in areas of water scarcity is one of the challenges of climate change adaptation. There are currently many areas where available water resources are fully or nearly fully allocated and a potential reduction of water availability will create conflicts (Jury and Vaux 2007) because water management would not be able to provide adequate reliability to legally acknowledged water uses. Progressive adaptation may be achieved through water reallocation arrangements that maximize the social and economic welfare. Economic instruments and water markets are favoured by economists as one of the most efficient ways to achieve this goal. However, their practical implementation has proven to be very difficult, due to social, economic and environmental barriers (Newlin et al. 2002). It is essential to incorporate the different stakeholders into the decision-making process to agree on the water uses to be maintained through a transparent process, based on scientific evidence and public participation. Water allocation during shortages is also of interest. A water shortage is a temporary situation where available water is insufficient to meet all demands in the system. The frequency of these situations is expected to increase as a result of climate change. Improving the water allocation process during shortages is a key adaptation measure to tackle water scarcity problems. The assignment may be done by operating rules of the systems (Spiliotis et al. 2016), setting priorities for the uses and allocation criteria (Garrote et al. 2007), by involving users in the bodies responsible for decision-making or by creating an environment where different users can negotiate with their water rights depending on their needs and their expectations of profit.

4.6 Early Warning and Risk Management

Droughts represent the most demanding conditions for the operation of complex water supply systems in semiarid regions. Drought risk management is a key factor for effective adaptation to water scarcity (Wilhite et al. 2000). This requires a coordinated series of actions in terms of awareness and education, investment in conservation, maintenance and improvement of facilities, establishment of rules for exchanging water rights and increasing the flexibility of the operation of the water resource system (Tsakiris et al. 2013). The increasing emphasis on proactive risk management rather than reactive crisis management has favoured the adoption of Drought Management Plans (DMPs) (Estrela and Vargas 2012). DMPs include a more controlled and planned management of droughts that has allowed prioritizing uses, ensuring public urban supply and minimizing environmental degradation. Long-term strategies for drought management include also reducing vulnerability and improving drought forecasting and early warning systems (Naumann et al. 2014), although they remain at very early stage because of the lack of means to predict climate conditions with sufficient skill and lead-time.

5 Conclusions and key Ideas

Areas exposed to drought and water scarcity are very sensitive to climate change, because of the current pressures on water resources, the imperative need to allocate more water for environmental uses and the narrow margin to improve water availability. Climate change in these regions is an intensification of existing pressures, which will imply strong reductions in water availability and further increases in water demand. This will lead to the intensification of water management conflicts, due to the competition for water among different social agents and the degradation of water quality through the alteration of the hydrological cycle. In some regions, current water uses cannot be maintained in the future. If climate predictions are right, reductions of water availability may lead to a deep crisis of the whole socioeconomic model of semiarid regions, based largely on highly productive agriculture and tourism.

The challenge of adaptation consists on anticipating these negative effects of climate change by means of the analysis possible scenarios and on adopting adaptive management strategies. Two basic principles are emerging: The first is to verify the effectiveness of proposed management strategies under different scenarios of change. The second is to select the strategy which responds correctly in all scenarios of change, or which can be adapted progressively as the situation evolves. Most adaptation measures discussed in this paper are already effective in addressing currently existing water scarcity problems and therefore their implementation will produce beneficial results in a wide range of climate change scenarios. In this sense, the social awareness of climate change may be an opportunity to address current challenges in the management of water resources and to correct major environmental problems.

Although the effects of climate change on water resources can be very significant, the effects of public policy for water resources management can be comparatively much greater, so there is potential to guide the rational long-term climate change adaptation in the sector in such a way that, in addition to offset its effects, it may even improve substantially the current reality. Climate change adaptation will originate profound social changes, progressive reduction of water demand and reallocation of water availability to those uses that are deemed socially as more appropriate. All these strategies will imply a high cost in terms of significant investment in infrastructure, environmental externalities, constraints on water consumption, loss of rights established by law, among others. In some cases, adaptation measures will have to be radical, introducing dramatic changes in the established paradigm for water management in these regions.

Since 1987 the journal *Water Resources Management* has contributed to the creation of an international community of scientists and engineers interested in the assessment and conservation of water resources and in planning, design and operation of water resource systems. Overall it has produced an important synthesis of our current understanding of the complex processes leading to water scarcity and has stimulated the development of effective adaptation strategies under a changing context. It can only be expected that the journal will continue to promote productive discussion of the means to address future water resources challenges in the decades to come.

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